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Joseph S. Kostka
Sept. 30, 1964

CATECHISM

OF THE

LOCOMOTIVE.

SECOND EDITION,

REVISED AND ENLARGED.

BY

MATTHIAS N. FORNEY,

Mechanical Engineer.

THIRTY-SEVENTH THOUSAND.

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1892.

PREFACE

TO THE FIRST EDITION.

BOOKS, like individuals, have their histories, and it seems but proper that, in introducing them, somewhat of their ancestry should be detailed. The present book originated in this wise: the publishers of the RAILROAD GAZETTE procured a copy of the "Katechismus der Einrichtung und des Betriebes der Locomotive," by Georg Kosak. As no English translation of this excellent little book was known to be in existence, the editors of the above paper determined to translate it and adapt it to the American practice in the construction and management of locomotive steam engines, and republish it in their journal. The translation was therefore made and submitted to the writer for revision and adaptation, according to the original intention. Before the latter was entertained, however, he had commenced writing an elementary treatise on the locomotive. In revising the first part of the translation of Mr. Kosak's book, it was found that the latter occupied only to a very limited extent the ground which the writer had "staked out" in his own incomplete plan. He therefore concluded to abandon the original intention of "adapting" Mr. Kosak's work, and determined to rewrite it and make substantially a new book of it. For the "idea," however, and to some extent its plan, and for much valuable material, the author must acknowledge his indebtedness to Mr. Kosak. In some few cases the language of the translator has been employed, in part or in whole, without quotation marks, but with an acknowledgment in a foot-note. A similar plan has also been pursued in using some other books. This was done to avoid cutting up paragraphs and sentences into fragmentary parts with numerous quotation marks.

The following books have been consulted and used in writing the Catechism of the Locomotive: Heat considered as a Mode of Motion, by Prof. Tyndall; The Conservation of Energy, by Balfour Stewart; Railway Machinery, by D. K. Clark; Treatise on the Locomotive Engine, by Zerah Colburn; Treatise on the Steam Engine, by W. J. M. Rankine; Indicator Experiments on Locomotives, by Prof. Bauschinger; Richards' Steam Indicator, by Charles T. Porter; Die Schule des Locomotivfuhrers, by J. Brosius and R. Koch; Mechanics, by A. Morin; The New Chemistry, by J. P. Cooke, Jr.; Combustion of Coal and the Prevention of Smoke, by C. Wye Williams; A Treatise on Steam Boilers, by Robert Wilson; Reports of the American Railway Master Mechanics' Association; Link Valve Motion, by William S. Auchincloss, and Emergencies and How to Treat Them, by Dr. Joseph W. Howe.

For the title of the book an apology is perhaps needed, as the word Catechism is associated in nearly all persons' minds, we will trust, with early religious and theological instruction, and therefore a Catechism of the Locomotive is very apt to sound more ludicrous than scientific. The title of Mr. Kosak's book was adopted before it was determined to rewrite it, and it was afterwards deemed best not to change it. To those who are disposed to smile at it, the precedent of Mr. Bourne's excellent Catechism of the Steam Engine is quoted, and if they will refer to Webster's Dictionary for the definition of the word "catechism," they will find that it means "an elementary book containing a summary of principles in any science or art, but appropriately in religion, reduced to the form of questions and answers, and sometimes with notes, explanations and reference to authorities," which describes exactly what the present book is intended to be.

To persons accustomed to books and study, the catechetical form is very apt to seem cumbrous and awkward, but it has some very decided advantages in writing for those who have not acquired studious habits of thought. To such the question asked presents first a distinct image of the subject to be considered, so that the explanation or instruction which follows is much more apt to be understood than it would be if no such question had been asked.

The author is indebted to Mr. D. B. Grant for the use of drawings from which most of the engravings of details of locomotives with which this book is illustrated have been made, and to other locomotive builders, whose engines are illustrated in the full-page plates, for the drawings thereof. He has also received very valuable aid from Mr. Richard H. Buel, Mechanical Engineer; Mr. William Buchanan, Master Mechanic of the Hudson River Railroad; Mr. Frank D. Child, Superintendent of the Hinkley Locomotive Works; and Mr. E. T. Jeffrey, Assistant Superintendent of Machinery of the Illinois Central Railroad.

The object in writing the book was to furnish a clear and easily understood description of the principles, construction and operation of the locomotive engine of the present day, a subject which is not concisely or adequately treated in any one similar book. If the author has succeeded in making what he has written plain to plain people, his aim will be fully accomplished.

No. 73 Broadway, New York, 1873.

PREFACE

TO THE SECOND EDITION.

THE first edition of the Catechism of the Locomotive was written in 1878. Since then many changes and improvements have been made in the construction of locomotives, so that in preparing a second edition of the book the first one had to be thoroughly revised, and to a great extent rewritten, and a great deal of entirely new matter had to be added to bring it up to the present "state of the art" of locomotive engineering. Most of the illustrations are entirely new, and have been selected from the latest practice in this country. Additional chapters have been added on Force and Motion; Resolution of Motion and Forces; the Principles of the Lever; the Action of the Piston, Connecting-Rod and Crank; Action of the Pistons, Cranks and Driving-Wheels; the Westinghouse Air-Brake; the Care and Use of Air-Brakes; and the Eames Vacuum Driving Wheel Brake.

The difficulty has been to keep the book within the limits of size to which an elementary treatise should be confined. This limitation made it compulsory to omit much which ought to be discussed and described in any complete treatise. Among the omissions is a description of compound locomotives which are now attracting a great deal of attention in this country and in Europe. The development of compound locomotives is, however, to a great extent—especially in this country—still in an embryonic state, and no well established practice has yet been developed in their construction. Probably in a third edition of this book, this type of locomotive will demand distinct consideration and full description.

I must here acknowledge my indebtedness to Messrs. Burnham, Parry, Williams & Co., proprietors of the Baldwin Locomotive Works, for drawings, photographs and assistance in the work of revision; to the Schenectady Locomotive Works and other manufacturers of the locomotives of which engravings are given in the following pages; to the Westinghouse Air-Brake Company, the Eames Vacuum-Brake Company, and to other manufacturers whose machinery and appliances have been illustrated and described. I am also obliged to express anew my indebtedness to Mr. William Buchanan, Superintendent of Machinery of the New York Central & Hudson River Railroad for much valuable assistance.

The excellent little treatise on the Steam Engine, by George C. V. Holmes, and Arthur Riggs' Practical Treatise on the Steam Engine, were both frequently consulted and quoted from.

M. N. FORNEY.

No. 145 Broadway, New York,
Nov. 9, 1889.

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INTRODUCTION.

THE Catechism of the Locomotive is intended for a large class of readers, among whom are all kinds of railroad officers and employees, consisting of locomotive engineers, firemen, and the many different kinds of mechanics employed in railroad shops and in the construction of locomotive and other railroad machinery and material. Besides these there are many amateur engineers, students and persons interested directly or indirectly in railroads, and a not inconsiderable class who are always seeking information on all subjects whatsoever. It is evident, therefore, that the only way to adapt the book to all the classes for whom it is intended, was to make it so plain that the "wayfaring man" will have no difficulty in comprehending it. It has therefore been written in as simple and plain language as the writer could command, and the subjects presented are explained with the least possible employment of either scientific or practical technicalities. The only deviation from this plan will be found in the use of algebraic symbols to designate arithmetical calculations. This was done to save space, and because it was thought that such symbols could be explained so that even those without any knowledge whatsoever of algebra could easily comprehend them. To such as have no such knowledge the following explanation is given:

Suppose it is necessary to add two numbers, say 1,872 and 468. The calculation, if made arithmetically, would be thus:

$$\begin{array}{r} 1{,}872 \\ 468 \\ \hline 2{,}340 \end{array}$$

This it will be seen occupies the space of several lines of print. If we want to express this calculation algebraically, it can be done by simply writing the two numbers and placing the sign +, called *plus*, between the two, which indicates that they are to be added together, thus:

$$1,872+468$$

To indicate what the *sum* will be, or what the two added together will amount to, the sign =, called *equal to*, or the sign of equality, is placed after the two numbers and between them and the sum, thus:

$$1,872+468=2,840,$$

which can be read as follows:

1,872 *added to* 468 *is equal to* 2,840.

Now the only use of the algebraic signs + and = is that they save time in writing and room in printing, and when persons become accustomed to their use they make plain a number of operations at a single glance, as will be shown hereafter.

In the same way that the sign + means *added to*, the sign — means *less* or subtracted from, thus:

$$1,872-468=1,404,$$

which is the same as though it was printed as follows:

1,872 *less* 468 *is equal to* 1,404.

The sign × means *multiplied by*, or is the sign of multiplication. Thus:

$$1,872\times 468=876,096;$$

that is,

1,872 *multiplied by* 468 *is equal to* 876,096.

The sign ÷ means *divided by*, thus:

$$1,872\div 468=4,$$

which means:

1,872 *divided by* 468 *is equal to* 4.

The same thing is expressed by putting a line under the dividend and writing the divisor under the line, thus:

$$\frac{1,872}{468}=4$$

These signs are combined in various ways. Thus, supposing we wanted to add 1,872 to 468 and then divide the sum by 117, it would be necessary, in order to represent the arithmetical calculation, to do it as follows:

```
    1,872
      468
    -----
117)2,340(20
    234
    ---
      0
```

Algebraically it would be stated thus:

$$\frac{1,872+468}{117}=20.$$

If you wanted to add 124 to the quotient 20 above, the calculation would be as follows:

```
    1,872
      468
    -----
117)2,340( 20
     234  124
     ---  ---
       0  144
```

This operation could be expressed by writing it as follows:

$$\frac{1,872+468}{117}+124=144.$$

If we wanted to multiply the quotient 20 by 124 we would simply put the sign $\times$ instead of $+$ before 124, thus:

$$\frac{1,872\times 468}{117}\times 124=2,480.$$

The sign of subtraction or division can be used in the same way.

By carefully reading these explanations it is believed that any one, with nothing more than an ordinary knowledge of the four elementary rules of arithmetic, can understand all the mathematics contained in the following pages. A little explanation may also be needed of the method of representing machinery and other structures by mechanical drawings.

If we want to represent any object, say an apple, as it appears when looking at it from the side, we make a drawing of it as shown at fig. *B*, which is called a *side view*.

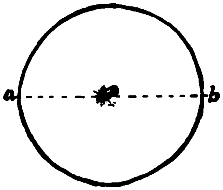


Fig. *A*. Plan.

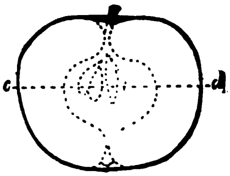


Fig. *B*. Side View.

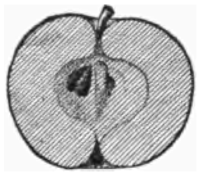


Fig. *D*. Vertical Section.

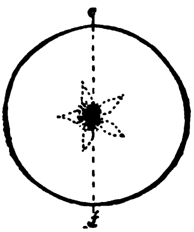


Fig. *C*. Inverted Plan.

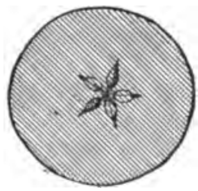


Fig. *E*. Sectional Plan.

If we represent it as it will appear if we are above it and looking down on it, as shown by fig. *A*, it is called a *top view* or *plan*, and if the object is turned upside down and is represented as in fig. *C*, it is called an *inverted plan*.

If we want to show the inside of the apple, say the seeds and core, we can cut it in half vertically and represent it as shown at fig. *D*, which is then called a *section* or *sectional view* of the apple. It is evident, too, that it might be desirable to show the arrangement of the seeds in the apple as they would appear if it was cut through in the other direction, say on the line *c d*, fig. *B*, and as is shown by fig. *E*. There are therefore two kinds of sections; one fig. *D*, in which the object is supposed to be cut through vertically, and therefore called a *vertical section*, the other when the object is supposed to be cut through horizontally, and therefore called a *horizontal section*, or *sectional plan*, as shown by fig. *E*. In order to distinguish the parts which are represented as though they were cut in two, from those whose surfaces only are shown, it is customary to shade sectional views with parallel lines, as shown in figs. *D* and *E*. Sections are also sometimes represented with solid black surfaces, as in Plate IV, and in the engraving of an injector, fig. 181.

It is often desirable in drawings to show some internal parts on an exterior view of a machine or other structure. In such cases the interior parts are represented by dotted lines. Thus, to show the position and form of the seeds of the apple in figs. *B* and *C*, they are represented by dotted lines.

The appearance of any object, whether it be an apple or a locomotive, of course depends upon our position in relation to it. Thus, fig. *B* is a side view of an apple, and Plate III a side view of a locomotive;* fig. *D* is a vertical section of an apple, and Plate IV a section of a locomotive. Fig. *A* and Plate V† are plans of these same objects.

It is obvious that a number of different sectional views can be made of any object, especially of a machine. Thus, we could suppose a locomotive cut through vertically and lengthwise, as is shown in Plate IV. It is of course possible to represent a transverse section of a machine like a locomotive at a great many different points; for example, it could be shown as though it was cut through the smoke-stack, as in fig. 98, or a section of the boiler farther back, as it is shown in fig. 122. Usually when a section is shown through a cylindrical object like a chimney or boiler, it is shown through its centre. If, however, this is not apparent from the drawing or engraving, it should be stated at what point it is supposed to be taken, thus the cross-section, fig. 122, of the boiler is through the firebox.

It is also customary, in drawings of machinery, to take great liberties with the objects represented and to show them with parts removed or broken away, if their construction can thus be made plainer. It should be remembered that the purpose of drawings of this kind is not to give a

* The cylinder, 1, is shown in section in this engraving.

† Part of the boiler is supposed to be removed in this view.

pictorial representation of the object as it appears to the eye, but to make its construction and mode of operation apparent to the mind. In such drawings, therefore, all perspective is disregarded. It would lead us too far were we to explain the reasons for this, and therefore readers must accept the assertion without the proof.

In reading the following pages for the first time, many persons, especially those who have had somewhat limited educational advantages or technical training, will perhaps find it best to omit chapters IX, XVI and XVII, which they may find are rather hard reading. These chapters can probably be taken up, by such persons, to better advantage after the others have been read.

CATECHISM OF THE LOCOMOTIVE

(REVISED AND ENLARGED).

By M. N. Forney.

CHAPTER I.

FORCE AND MOTION.

Question 1. *How do we get our first notion of the nature or of the effect of force?*

Answer. It is suggested to us by the so-called muscular sense; that is, we have a peculiar feeling of pressure when we try to move any object or piece of matter.

Question 2. *What is "force?"*

Answer. We know nothing about the absolute nature of force. All that we know is what we can learn through the senses of its effects. It has been defined as "that which *affects* the motion of matter;" and again as "any action between two bodies which changes, or tends to change, their relative condition as to rest or motion." In the plainer words of a distinguished author* "the word force is obviously to be applied to any pull, push, pressure, tension, attraction or repulsion, etc., whether applied by a stick or a string, a chain or a girder, or by means of an invisible medium such as the attraction of gravitation or electricity."

Question 3. *How is the motion of one body in relation to others produced?*

Answer. It is produced by the exertion on it of force.

Question 4. *Are bodies ever made to move in any other way excepting by the action of some force or forces on them?*

Answer. No. Part of what is called the first law of motion is that "*a body at rest remains at rest until some force acts upon it to set it in motion.*"

*P. G. Tait. "Recent Advances in Physical Science," p. 35.

QUESTION 5. *What is the other portion of the first law of motion?*

Answer. "*That a body in motion continues with its motion unchanged, either in direction or velocity, until acted upon by some external force.*" Thus, a top can be made to spin in the open air for a minute or more, but in a vacuum it will spin a much longer time, because there it has not the resistance of the atmosphere to overcome. If it be accurately balanced and revolves on a small steel point which bears on a glass plate, it can be made to spin in a vacuum for an hour or longer, because there the resistance, or force, which is opposed to its revolution is reduced to the lowest possible amount. Nevertheless, this force, however small, will check the speed of the revolutions of the top, and finally it will cease to spin altogether. As there is always some force which resists motion, there is a corresponding tendency which causes bodies about us, as we know them, to come to a state of rest.

QUESTION 6. *What is meant by "inertia?"*

Answer. Inertia has been defined as "that property of matter by which it tends when at rest to remain so, and when in motion to continue in motion." Thus, if a cannon-ball be suspended from a long string so that it can swing freely a force must be exerted against it to move it, or if it is moving a force must be exerted to resist its movement to stop it.

QUESTION 7. *When is motion said to be uniform?*

Answer. When a body passes over equal spaces in equal periods of time. Thus, the motion of the minute hand of a clock is uniform, because it passes over equal spaces on the clock face in each minute or hour. A railroad train is said to have a uniform velocity when it runs successive miles in the same number of minutes or seconds.

QUESTION 8. *What is meant by accelerated and retarded motion?*

Answer. Motion is *accelerated* when the spaces passed over in equal periods of time become greater and greater, and motion is *retarded* when these spaces become smaller and smaller. Thus, if a railroad train should run one mile in five minutes, the next one in four, and the following ones in three and two minutes each, its motion would be said to be *accelerated.* A stone falling from any height is another example of accelerated motion. On the other hand, a railroad train, when it is being stopped, and a stone thrown upward are examples of retarded motion.

QUESTION 9. *What is meant by uniformly accelerated or uniformly retarded motion?*

Answer. Motion is said to be uniformly accelerated or retarded when the increase or diminution of velocity in each interval of time is the same.

Thus, if a railroad train should have a velocity of two-tenths of a mile at the end of the first minute, three-tenths at the end of the second, four-tenths at the end of the third, and five-tenths at the end of the fourth, its motion would be said to be uniformly accelerated. A falling body is another example. Its velocity is 32.2 feet per second at the end of the first second, 64.4 at the end of the second, 96.6 at the end of the third, etc. In the case of the railroad train, the velocity is increased one-tenth of a mile for each minute, and that of the falling body is increased 32.2 feet for each second.

QUESTION 10. *How is the velocity of a moving body increased or diminished?*

Answer. By the action of force on it. If this force is exerted in the direction of the movement of the body, its velocity will be increased so long as the force, or the *motive power* as many call it, is greater than the resistance opposed to it. Whenever the motive power equals the resistance, then the moving body will have a uniform speed; and when the resistance becomes greater than the moving form, the velocity will be retarded.

QUESTION 11. *How is this illustrated in a railroad train and a locomotive?*

Answer. When the locomotive starts, the speed of the train is increased, until its resistance is equal to the force or power exerted by the engine. If the train reaches an up grade, and its resistance is consequently increased, its speed will be retarded. On a level, the speed will also be retarded if steam is shut off, either partially or wholly, so as to diminish the force or power which the engine exerts.

QUESTION 12. *What relation is there between the force exerted on a moving object and its velocity?*

Answer. With any object of a given weight, the greater the force exerted the quicker will the speed be increased or diminished. Every boy has learned this in drawing a wagon or sled or in trying to stop one in motion.

QUESTION 13. *Can we know how much the velocity of a moving body will be increased or diminished by a known force, if there is no other resistance to motion excepting the inertia of the moving body?*

Answer. Yes, this has been ascertained by the effect of the attraction of gravitation, which causes all objects to fall toward the centre of the earth if their movement is not resisted by some greater force.

QUESTION 14. *What is the rate of acceleration of falling bodies?*

Answer. It has been found by the most exact experiments, that at the surface of the earth all bodies falling in a vacuum, where the air offers no resistance, acquire a velocity of 32.2 feet per second at the end of the first second, 64.4 feet at the end of the second second and 96.6 feet at the end of the third, and so on with an increase of 32.2 feet for each successive second.

QUESTION 15. *Can this increase in motion be represented in any way by drawing?*

Answer. Yes, we can draw a diagram which will show to the eye the rate at which a body falls. To do this let us suppose that a stone is allowed to fall from 0, fig. 1, and that the distance 0 1 is drawn to any convenient scale to represent the distance, 16.1 feet, that it will fall in the first second; 1 2 the distance, 48.3 feet, that it will fall the second second; and 2 3, 3 4, 4 5 and 5 6 the distances it will fall in successive seconds. If now

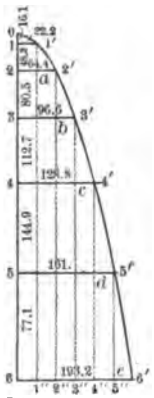


Fig. 1. Diagram of Falling Body.

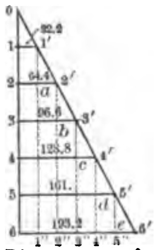


Fig. 2. Diagram of Falling Body.

from 1 a horizontal line, 1 1′, be drawn whose length represents 32.2 feet, the velocity the stone will acquire at the end of the first second, and 2 2′, 3 3′, etc., be drawn, each representing the velocity in feet per second that the stone has acquired at the end of the successive seconds, and a curve, 0 1′ 2′ 3′ 4′ 5′ 6′, be drawn through the extremities of the horizontal lines, then the horizontal distance of the curve from any point in the vertical line *o 6* will represent the velocity of the stone at that point.

QUESTION 16. *In what way may this diagram be modified?*

Answer. For some purposes, which will be explained in a future chapter, it is more convenient, as in fig. 2, to make the spaces 0 1, 1 2, 2 3, etc., between the horizontal lines, which represents seconds, equal to each other. The lines 1 1′, 2 2′, etc., can then be drawn as in the preceding diagram, to represent the velocity of the stone at the end of each second, and the line 0 1′ 2′ 3′, passing through their extremities, will then be a straight line if the fall of the stone is uniformly accelerated, as it would be if it fell in a vacuum.

QUESTION 17. *How is the law which governs the velocity of falling bodies still further illustrated by the diagram?*

Answer. Before this question is answered it will again be explained, and should be clearly understood by the reader, that in fig. 1 the spaces between the horizontal lines represent the *distances* through which the stone falls in successive seconds, whereas, in fig. 2 the spaces between the horizontal lines represent the *periods of time* or *seconds* occupied by the fall.

In both figures, the lines 1 1′ represent the velocity, 32.2 feet per second, that the stone has acquired at the end of the first second. If its fall was not still further accelerated then the horizontal distance of the dotted line, 1′ 1″ from 0 6 would represent its velocity. But in falling from 1 to 2 it again acquires an addition of 32.2 feet per second—represented by the line *a 2′*—to its velocity, so that at the end of the second second it is 64.4 feet. By examining the diagram, it will be seen that during each second of the fall the velocity previously acquired by the stone is increased by the amounts represented by the lines *b 3′, c 4′, d 5′ and e 6′*, each equal to 32.2 feet.

QUESTION 18. *How is the law which governs the distance through which a body will fall illustrated by the diagram?*

Answer. As shown in fig. 2 the stone starts from a state of rest at *o*, and at the end of the first second has acquired a velocity of 32.2 feet per second. Its average velocity during the first second is, therefore, one-half of 32.2 feet, so that it falls 16.1 feet in that time. As it has acquired a velocity of 32.2 feet at the end of the first second, it would fall that distance during the second second, but during that time it acquires an additional velocity of 32.2 feet which will cause its fall 16.1 further than it would if it was not accelerated during that period. The distance that it will fall in the second second is, therefore, $32.2+\frac{32.2}{2}=48.3$ feet. From the diagrams it will be seen that in each successive second the distance that the stone falls is 16.1 feet more than that through which it fell the preceding second.

QUESTION 19. *How can the velocity of a falling body be calculated?**

Answer. As shown by the diagrams the velocity which a stone acquires is equal to 32.2 feet per second at the end of the first second; at the end of the second second it is twice 32.2; at the end of the third second it is three times, and so on; so that if we *multiply 32.2 by the number of seconds that the body has fallen will give its velocity.*

QUESTION 20. *How is the distance through which a body will fall in a given time calculated?*

Answer. MULTIPLY THE SQUARE OF THE NUMBER OF SECONDS, THAT THE BODY HAS FALLEN, BY 16.1. THE PRODUCT WILL BE THE DISTANCE FALLEN.

QUESTION 21. *Do all bodies fall at the same velocity?*

Answer. In a vacuum, where the atmosphere offers no resistance, they all fall at the same velocity. A feather will fall as fast as a piece of lead, and a cannon-ball, weighing one pound, will fall as quickly as one weighing a hundred.

QUESTION 22. *What relation is there between the weight and the motion of a body?*

Answer. The heavier a body is, the greater will be the force required to move it and to accelerate or retard its motion. This we all learn by ordinary experience, as in drawing a wagon or moving a piece of furniture. We are apt to attribute it to the fact that the friction of heavy objects when rolling or sliding is greater than light ones, which is part of the reason why more force is required to move them; but if we suspend two cannon-balls, one weighing one pound and the other a hundred pounds, by long cords, so that they can swing freely like a pendulum, with little or no friction, we will find that it takes a much greater force to move the heavy ball than is needed to move the light one the same distance in the same time. In this case there is hardly any resistance excepting *inertia*, which opposes the swinging of the balls.

QUESTION 23. *What relation is there between the weight and the inertia of a body?*

Answer. They are proportional to each other. That is, a body weighing a hundred pounds has twice as much inertia as one weighing fifty. It will be found that the heavy suspended cannon-ball will take a hundred times as much force to cause it to swing a given distance in a given time as is needed for the light one. It is assumed that they are suspended by

* This rule is correct only for bodies falling in a vacuum, but is approximately correct for heavy bodies falling in the atmosphere.

very long cords so that the arc or path in which they swing does not differ appreciably from a straight line.

QUESTION 24. *If this is the case why is it that a heavy object will fall as quickly as a light one?*

Answer. It is because its *weight*, which is the force that causes the heavy body to fall, is proportional to its inertia. That is, each pound of inertia—if we may so express it—has one pound of weight or force to impel the body downward.

QUESTION 25. *Would a force acting upward, horizontally or in any other direction have the same effect?*

Answer. Yes, if it acted against the body which could move freely and without any other resistance excepting that of its own inertia.

QUESTION 26. *How can this be more clearly illustrated and explained?*

Answer. To make this clear, we will again suppose that we have a cannon-ball, *B*, fig. 3, suspended by a very long string, *A*, so that it can move freely, and that the arc in which it will swing will not differ appreciably from a straight line. We will also suppose that we have a long

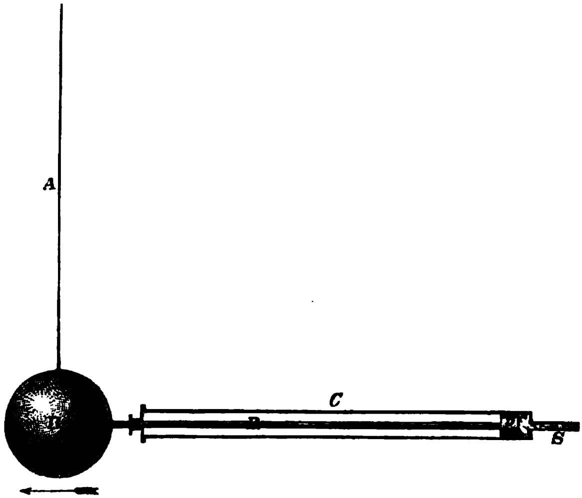


Fig. 3. Suspended Cannon-Ball.

cylinder, *C*, with a piston, *P*, and rod, *R*, fitted in it so that they can move freely in the cylinder—the rod, *R*, being attached to, or bearing against the cannon-ball, *B*. If, now, we were to admit steam or compressed air into the cylinder by the pipe *S*, of such a pressure that the force exerted on the cannon-ball is equal to its weight, then, assuming that there is no friction of the piston, the ball would be moved in the direction in which the force or pressure on it is exerted, and in a given time it would acquire the same velocity that it would if it were allowed to fall freely. In the one case, the pressure in the piston acting in a horizontal direction is the accelerating force, and in the other, the accelerating force

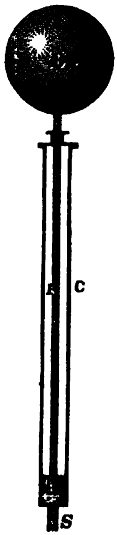


Fig. 4. Cannon Ball Moving Vertically.

is the attraction of gravitation or weight of the cannon-ball which acts downward. If these forces are equal to each other the velocity and acceleration of the suspended ball in a horizontal direction will be the same as if it was allowed to fall vertically an equal distance.

If we had a vertical cylinder, *C*, as shown in fig. 4, with a ball, *B*, piston, *P*, and rod, *R*, then if the pressure on the piston was equal to its own weight and that of the rod and ball, the two forces, that is, the pressure under the piston acting upward and the attraction of gravitation acting downward, would just balance each other, and there would be no motion. If, however, the pressure against the piston was double that of the weight on it, then there would be an upward force equal to twice the weight of the parts, which would be resisted by their inertia alone. What might be called the *net* upward force, or that which would be exerted to push the parts upward, after the attraction of gravitation had been overcome, would then be equal to the weight of the parts. Consequently, under these conditions the cannon-ball would fall upward—if such an expression may be used—at the same velocity that it would fall downward by its own weight.

QUESTION 27. *If the force acting on a moving body is increased or diminished what effect does it have on the velocity?*

Answer. The velocity is in exact proportion to the force acting on it. If you double the force, you double the velocity. Thus, if the cylinder shown in fig. 4 was turned upside down, and a pressure was then produced on top of the piston equal to the weight attached to it, then there would be two forces acting downward on the cannon-ball—its own weight and that due to the pressure on the piston. If the two are equal then the cannon-ball would fall at double the velocity that it would if acted upon by gravitation alone. This principle is applied to steam-hammers, which are so arranged that when a light blow is required the hammer-head is allowed to fall by its own weight alone, but when a harder blow is needed steam is admitted above the piston to force it and the hammer-head down faster than it would fall by its own weight.

CHAPTER II.

RESOLUTION OF MOTION AND FORCES.

QUESTION 28. *When one object is moved by two forces acting simultaneously in different directions but not opposite to each other, what occurs?*

Answer. It moves in the shortest path between the point from which it starts to that which it would reach in a given time if acted upon by each of the forces separately.

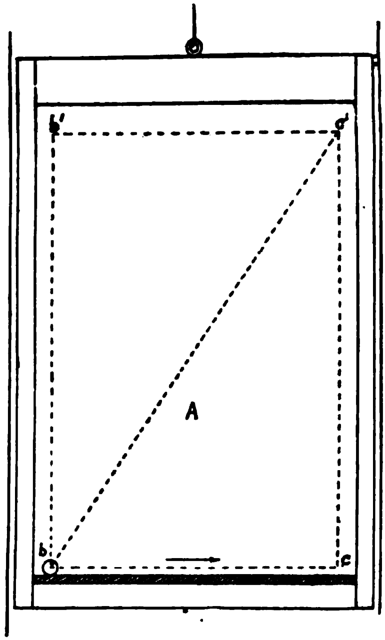


Fig. 5. Elevator and Billiard-Ball.

QUESTION 29. *How can this be shown?*

Answer. This will be made apparent if it be supposed that a billiard-ball or other object is rolled on the floor of an elevator—used for raising and lowering goods or passengers—while the elevator is ascending or descending. Thus, let *A*, fig. 5, represent a vertical section of the elevator, and *b* a billiard-ball. If the distance from *b* to *c* is equal to 4 feet, and that from *c* to c' equal to 6 feet, then if the ball is rolled from *b* to *c* at the rate of 4 feet per second while the elevator is standing still, the horizontal dotted line *b c* would represent its path. But if the ball is not rolled, and the elevator ascends at the rate of 6 feet per second, then the vertical dotted line $b\ b'$ would represent its path. If, however, the elevator is going up at the same time that the ball is rolling, then, while the latter is moving horizontally 4 feet, from *b* to *c*, it is also ascending 6 feet, so that its path would be represented by the diagonal line $b\ c'$.

The same principle is also illustrated if a boat is rowed across a river which flows at a rate of, say, 3 miles an hour. If the river is a mile

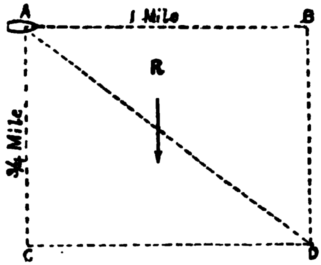


Fig. 6. Diagram of Movement of Boat.

wide, and the boat is rowed at a speed of 4 miles an hour, it will take a quarter of an hour to cross. But while the boat is being rowed across it also drifts three-quarters of a mile down stream with the current, as illustrated in fig. 6, in which *R* is the river and *A* the starting point of the boat. If there was no current in the river and the boat was rowed in the direction *A B* at the speed mentioned, it would cross and reach *B* in a quarter of an hour. On the other hand, if it were allowed to drift with the current and were not rowed, it would float down stream three-quarters of a mile to *C* in the same time. If, when the boat reached *C* there was then no current, and the boat was rowed across, it would reach *D* in 15 minutes after leaving *C*. If, however, the boat starts from *A* and is rowed in the direction *A B* while it is crossing, it will simultaneously drift down stream with the current, so that it will take the diagonal path *A D*, and will reach *D* in the same time that would be required to row from *A* to *B* or *C* to *D* if there was no current, or to float from *A* to *C* if the boat was not rowed.

QUESTION 30. *How can we determine graphically the direction and distance which an object like a boat will move if acted upon by two forces as described?*

Answer. If we will draw one line *A B*, fig. 6, whose direction and length represents to any convenient scale the direction and the distance that the body would be moved by one force in a given time, then draw another line, *B D*, representing in the same way the direction and distance that the object would be moved by the other force, and then draw a diagonal line from the starting point *A* to the terminal point *D*. Or we may proceed in the reverse order and draw *A C* first, and then make *C D* equal and parallel to *A B*, and then complete the diagram with the diagonal line *A D*. It should be noticed that *A B* must be equal and parallel to *C D*, and *A C* equal and parallel to *B D*, so that the line *A D* is a diagonal of a parallelogram whose sides are equal and parallel to the direction of the two forces which simultaneously act upon the body.

In fig. 5 the lines $b\ b'$ and $c\ c'$ are equal and parallel, and so are $b\ c$ and $b'\ c'$, so that $b\ c'$ is a diagonal of the parallelogram $b\ b'\ c'\ c$. Hence, we see that the motion which results from the action of two forces, is the diagonal of a parallelogram, the sides of which represent the extent and direction of the motion which would have been produced by each force acting separately.

QUESTION 31. *How is the general principle stated in scientific language?*

Answer. It is said by Rankine: "If two forces whose lines of action traverse one point be represented in direction and magnitude by the sides of a parallelogram, their *resultant* is represented by the diagonal."

QUESTION 32. *How can this be still further illustrated?*

Answer. Let it be supposed that a sail-boat *A*, fig. 7, is acted upon by the wind so that in a given time, say a half hour, it would be moved in the direction and a distance represented by the line *A B*, and that in the same time the tide would carry it from *A* to *C*. Now, lay down *A B* representing, to any convenient scale, the effect of the wind, and *A C* that of the tide, and draw *B D* equal and parallel to *A C*, and *D C* equal and parallel to *B A*, then the diagonal *A D* will represent the direction and the distance the boat will move under the combined effect of wind and tide.

QUESTION 33. *What is the movement which results from the combined* *action of two or more forces, and which in figs. 6 and 7 is represented by the diagonals of the parallelograms, named?*

Answer. It is named the "*resultant.*"

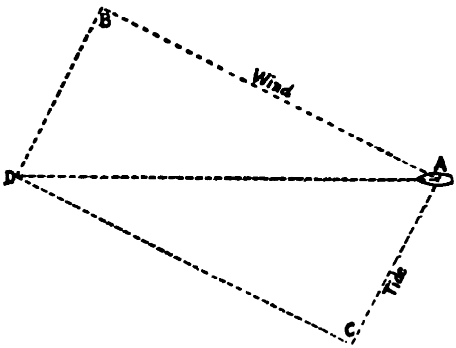


Fig. 7. Diagram of Movement of Boat.

QUESTION 34. *What are the forces represented by the sides of the parallelogram, and which act upon a body to produce the resultant, called?*

Answer. They are called the "*components.*"

QUESTION 35. *If we have a resultant and wish to ascertain two components acting in given directions which would produce the resultant, how can we do it?*

Answer. This can be done by drawing a line representing the resultant in direction and length; then from its extremities lines must be drawn representing the direction of the components. A parallelogram can thus be constructed of which the resultant is the diagonal, and the sides will represent the components. Thus, suppose *A B*, fig. 8, represents the direction and the distance which a boat is carried by the combined action of the wind blowing in the direction *A E*, and of the tide flowing from *A* toward *F;* if we want to find out how far the wind or how far the tide would carry the boat in the time that it moves from *A* to *B*, we draw the line *A E* through *A* in the direction of the wind, and *A F* also through *A* in the direction of the tide. We then complete the parallelogram by drawing *B E* through *B* and parallel to *A F*, and *F B* parallel to *A E*. Then the side *A E* represents the distance the tide would carry the boat, and *A F* that which the wind would move it while it is going from *A* to *B* under their combined influence.

QUESTION 36. *What is the process by which two motions are resolved into one, or one into two, which has been described, called?*

Answer. It is called the "*composition of motion.*"

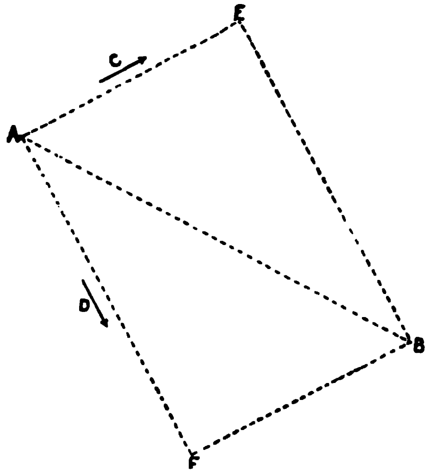


Fig. 8. Parallelogram of Motion and Forces.

QUESTION 37. *Can the effect of two forces or strains acting simultaneously on a body be represented in the same way?*

Answer. Yes.

QUESTION 38. *How is a force or strain represented by a line?*

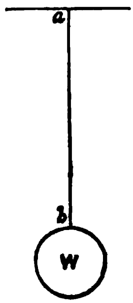


Fig. 9. Weight or Force Represented by a Line.

Answer. Forces are compared to or measured by the downward pressure which a 1-lb. weight exerts at the surface of the earth, so that it is easy to conceive that the magnitude of a pushing or pulling force may be described as equivalent to so many pounds. We may therefore take any length of line to represent one pound; that is, a line one inch long may represent a pound, one 2 inches would represent 2 lbs., and one 6 inches long 6 lbs., etc. Or we may take one-eighth of an inch to represent a pound, as in fig. 9, in which the weight *W* is supposed to be equal to 9 lbs., and the line *a b* is made equal to nine-eighths, or $1\frac{1}{8}$ inches, and it thus represents the magnitude of the force or weight *W*. In the same way, if a horse was pulling on a rope and exerted a strain of 100 lbs., we may make 1 lb. $=\frac{1}{100}$ of an inch, so that a line *c d*, fig. 10, 1 inch long will represent the force or

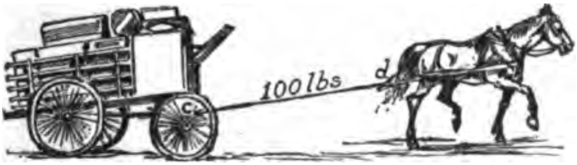


Fig. 10. Force Represented by a Line.

strain which the horse is exerting on the rope. Or, taking the illustration of the boat in fig. 6, it may be supposed that the person rowing it exerts a force of 24 lbs., while the current of the river is equal to 18 lbs. This diagram has been drawn so that one-sixteenth of an inch is equal to one pound. The line *A B* is therefore $1\frac{1}{2}$ inches long, and *A C* $1\frac{1}{8}$ inches long. If the parallelogram is completed the length of the diagonal *A D* will then represent the resultant of the two forces, or their combined effect on the boat in the direction *A D*.

From what has been said, it will be seen that a line may be made to represent the magnitude of a force, and also the direction in which it is exerted. Thus, in fig. 9 the line *a b* represents a force which is exerted downward; in fig. 10 the force represented by *c d* is exerted horizontally, or nearly so, and in fig. 8 *A B* acts diagonally. Therefore it is plain that the length and position of a line may be made to represent any magnitude and direction of a force.

QUESTION 39. *Does the principle of the composition of motion apply to forces or strains exerted by bodies at rest?*

Answer. Yes.

QUESTION 40. *How can we show this experimentally?*

Answer. If we will suspend a weight *W*, fig. 11, equal, say, to 10 lbs., by two inclined cords *b f* and *b g*, which pass over pulleys *f* and *g*, it will be found that the weights *A* and *B*, which will balance *W*, can be determined as follows: As the force exerted by the weight *W* acts downward, its di-

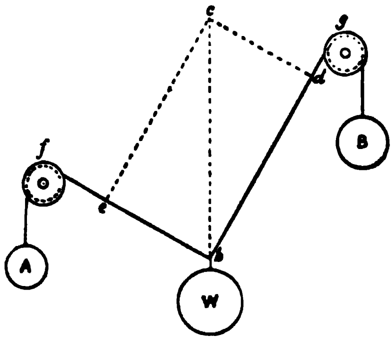


Fig. 11. Diagram of Composition of Forces.

rection is represented by the perpendicular line *b c*. If now we lay off the distance *b c* to any convenient scale, say ⅛ inch=1 lb., to represent the weight *W*, and then draw the lines *c d* and *c e* parallel to *b f* and *b g*, then *c d* or *e b* will represent the strain on the cord *b f* and *c e*, or *d b* will represent that on *b g*, and they will be equal to the weights *A* and *B*, which will balance *W*. Hence, we see again that the *resultant* of two forces is the diagonal of a parallelogram, the sides of which represent the direction and magnitude of those forces.

QUESTION 41. *What is this process of determining the direction and magnitude of three or more forces called?*

Answer. It is called the "*composition of forces*," and a figure like *c e b d*, fig. 11, is called a "*parallelogram of forces*."

QUESTION 42. *What other illustrations may be given of the application of this principle?*

Answer. The strain on the parts of a common crane, fig. 12, for lifting heavy objects can be deduced in this way. Thus, let *A* represent the post, *B* the jib, and *c* the tie rod of such a crane. If *W* equals 1,000 lbs., if we make *a b*=1,000, and draw *b c* parallel to *C*, then the length of the line *c b* will represent the strain on the rod *C* and *c a* that on the strut *B*. It will be plain from the figure and a little reflection that the effect of the weight *W* will be to compress *B* and pull *C* apart. Therefore *B* is said to be subjected to a *strain of compression* and *C* to one of *tension*. If the parallelogram of forces was completed the line *a d* would be drawn parallel to *C* and to *c b*, and *b d* parallel to *B* or *c a*. In most cases all that is needed

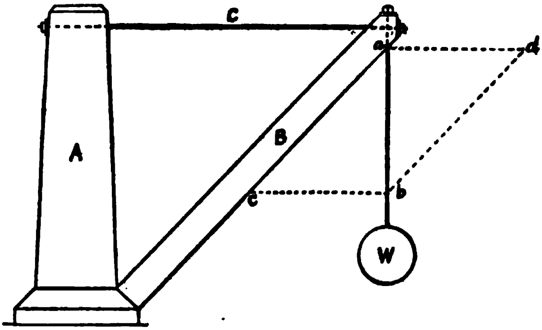


Fig. 12. Crane.

to determine a strain on a structure is to draw a triangle like *a b c*, which is one-half of the parallelogram *a c b d*.

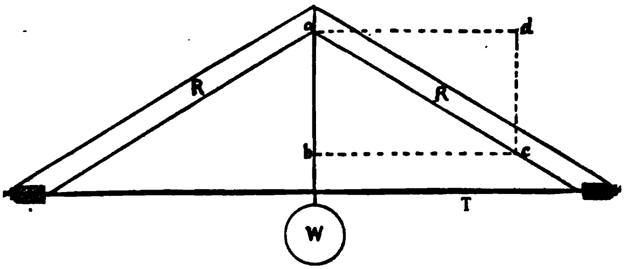


Fig. 13. Roof Truss.

A roof or bridge truss like that shown in fig. 13 is another illustration of this principle. In this *R R* are the timbers or rafters, and *T* a tie-rod, and *W* a weight resting on the rafters. One-half of this weight will be carried by each of the rafters *R*. If then *a b* is made equal to one-half of *W*, and *b c* is drawn parallel to *T*, then *a c* will represent the strain on *R* and *b c* that on *T*. If the inclination of the timbers *R R* is the same, they will each be subjected to an equal strain, and the foot of the one will push against the tie-rod with a force just equal to that exerted by the other timber at the opposite end.

QUESTION 48. *Can the velocity in different directions of a moving body also be represented by a parallelogram?*

Answer. Yes, this is shown in fig. 5 in the case of the billiard-ball and elevator. Here the ball *b* had a velocity of 4 feet per second in the direction of the horizontal line *b c*, and a vertical velocity of 6 feet per second, as shown by the line *b b'*. If it is moved simultaneously at these velocities and in the directions indicated by the lines, then, as was shown, it will move in a direction and a distance equal to the length of the line *b c'* in the same period of time; *b c'* will therefore represent the velocity of the ball under the combined action of the horizontal and vertical velocities.

On the other hand, if we know the velocity at which the ball moves in the direction *b c'*, and wish to ascertain the speeds at which it moves horizontally and vertically, all we need do is to draw a parallelogram whose sides represent the direction of the velocity which we want to ascertain.*

* The principle of the resolution of motion, forces and velocities has a direct application to the action of the piston, connecting-rod and crank, which is discussed in chapter IX.

CHAPTER III.

THE PRINCIPLES OF THE LEVER.*

QUESTION 44. *How may the principle of the lever be explained?*

Answer. Every boy has learned that if the middle of a board rests on a fence-rail or other support that two boys, of equal weight, will balance each other, if one of them sits on one end of the board and one on the other end. If it is 12 feet long, and is moved so that the support is 4 feet from one end and 8 feet from the other, then the boy who sits on the short end must be twice as heavy as the one on the long end to balance the other. If the support is 3 feet from one end and 9 feet from the other, as in fig. 14, then the heavy boy must be three times the weight of the small one. That is, if the small boy weighs 40 lbs. the big one must weigh 120 lbs. It is also obvious that the weight of both boys is sustained by the support *B*, and therefore the load on it is equal to 40+120=160, leaving out the weight of the board. It will also be noticed that the weight of both boys bears downward on the board, and if the edge of the support *B* was sharp and hard, and the board soft, that an indentation in it would be made where it rests on the support, showing that the pressure against the board at this point is in an upward direction.

The same principle would be illustrated if the board was used as a lever to lift a heavy stone or other object, as shown in fig. 15. In this case if the stone weighed 120 lbs. and the two arms of the lever were the same length as before, it would require a pressure of 40 lbs. at *A* to balance or raise the stone at *C*, and the support or *fulcrum*, as it is called, at *B* would sustain a pressure of 160 lbs. In this case, too, the forces at *A* and *C* both act downward and the force against the boards is upward, as indicated by the arrows.

If we place the support at *C*, as in fig. 16, and the stone at *B*, then an upward force of 40 lbs. exerted at *A* will raise a stone of 160 lbs. weight at *B*. In this case the two forces at *A* and *C* both act upward, and that at *B* downward, as indicated by the arrows.

* The principles explained in this chapter are applied in succeeding parts of the book, but especially in the chapters relating to brakes.

If the support or fulcrum against which the board bears is placed above it at *A*, and if the stone is at the end *C*, as show in fig. 17, and the person should take hold of the board at *B*, then it would require an upward pull of 160 lbs. at *B* to raise the stone, and the forces would act in the direction indicated by the arrows.

Fig. 14. Lever.

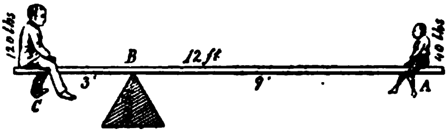


Fig. 15. Lever.

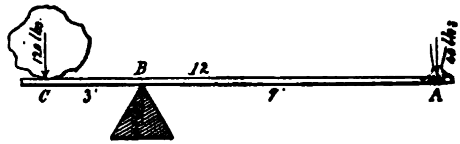


Fig. 16. Lever.

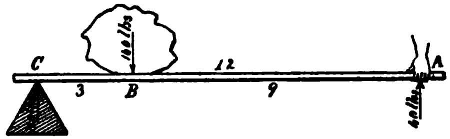
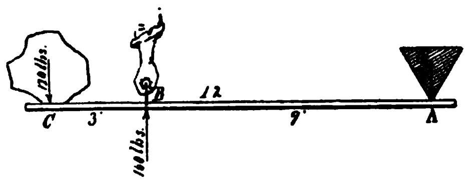


Fig. 17. Lever.



From these illustrations it will be seen that in each case when the levers are in equilibrium or are balanced, *there are two forces which act in one direction against the ends of the lever, and one force which acts in the opposite direction between them*, and that *the two end forces added together or their sum is equal to the third force acting in the opposite direction.* This is true not only of the cases illustrated, but it is true *of all levers* on which the forces act in directions parallel to each other, which are the only kind which need be considered here. The greater of the two forces which act in the same direction and is exerted on the short end of the lever will be called the *major-force*, the smaller one, which acts on the long end of the lever, the *minor-force*, and that acting in the opposite direction between the two ends the *counter-force*. The major-force is always at the short end of the lever, and the minor-force at the long end. If the two arms of the lever are of equal length, the major and minor-forces will also be

Fig. 18. Lever. Fig. 19. Lever. Fig. 20. Lever.

equal. If *the major-force is multiplied by the length of the short arm of the lever, the product will always be equal to that of the minor-force multiplied by the length of the long end of the lever.* That is, in fig. 14 the weight of the major boy, $C=120$ lbs., multiplied by 3 feet (the length of the short end $C\,B$)=360, and the weight of the minor boy, $A=40$ lbs. × 9 feet (the length of the long end, $A\,B$) also=360.

It does not make any difference, either, in what direction these forces act. The effect of their action will be the same, if instead of being horizontal the levers stood upright or vertical, as shown in figs. 18–20, in which the direction of the forces is indicated by darts and their magnitude by figures. These figures show, too, that the action of the forces in figs. 18 and 20 is exactly the same, and that the only difference between them and fig. 19 is that the forces in the two cases act in opposite directions.

QUESTION 45. *How can we know which is the major, which the minor, and which the counter-force acting on a lever?*

Answer. This can always be known with certainty if it is remembered that the major and minor-forces always act on the ends of the lever and in an opposite direction to the counter-force* which is between them, and that the major-force is always at the short end of the lever and the minor one at the long end.

QUESTION 46. *If we have the length of the two ends of a lever and either the major or the minor-force, how can we calculate the other?*

Answer. MULTIPLY THE KNOWN FORCE BY THE LENGTH OF ITS END OF THE LEVER AND DIVIDE THE PRODUCT BY THE LENGTH OF THE OPPOSITE END. The quotent will be the required force. Thus, supposing that in fig. 14 we have the weight of the small boy, 40 lbs., and the length of the two ends of the lever as 9 and 3 feet respectively, then $40 \times 9 \div 3 = 120$ $=$ the major force at *C*.

QUESTION 47. *If we have the length of the two ends of a lever and either the major or the minor-force, how can we calculate the counter-force?*

Answer. ADD THE LENGTH OF THE TWO ENDS OF THE LEVER TOGETHER TO GET ITS WHOLE LENGTH; THEN MULTIPLY THE KNOWN FORCE BY THE WHOLE LENGTH AND DIVIDE BY THE LENGTH OF THE END OF THE LEVER OPPOSITE TO THE KNOWN FORCE. Thus, in fig. 14, knowing the weight of the small boy at *A*, and the length of the two ends of the lever being 3 and 9 feet, then $3 + 9 = 12 \times 40 \div 3 = 160 =$ counter-force at *B*.

QUESTION 48. *If we have the counter-force and the length of the two ends of the lever, how can we calculate the major and minor-forces?*

Answer. TO GET THE MAJOR-FORCE, MULTIPLY THE COUNTER-FORCE BY THE LENGTH OF THE LONG END OF THE LEVER AND DIVIDE BY ITS WHOLE LENGTH; TO GET THE MINOR-FORCE, MULTIPLY THE COUNTER-FORCE BY THE LENGTH OF THE SHORT END OF THE LEVER AND DIVIDE BY ITS WHOLE LENGTH. Thus, if in fig. 16 we have *B*, the counter-force equal to 160 lbs., and the two arms of the lever 3 and 9 feet respectively, then $160 \times 9 \div 12 = 120 =$ major-force, or $160 \times 3 \div 12 = 40 =$ minor-force.

QUESTION 49. *Having the major and minor-forces which are exerted*

* The direction in which a force acts on a lever can always be known by observing which side of the lever would be indented if it was made of soft material and the force was exerted against it by a sharp object.

at the ends of a lever, and its whole length, how can we calculate the length of its two ends?

Answer. FIRST, ADD THE MAJOR AND MINOR-FORCES TOGETHER, WHICH WILL GIVE THE COUNTER-FORCE; THEN TO GET THE LENGTH OF THE LONG END OF THE LEVER MULTIPLY THE MAJOR-FORCE BY THE WHOLE LENGTH AND DIVIDE BY THE COUNTER-FORCE. TO GET THE LENGTH OF THE SHORT END, MULTIPLY THE MINOR-FORCE BY THE WHOLE LENGTH AND DIVIDE BY THE COUNTER-FORCE. OR IF WE HAVE THE LENGTH OF ONE END WE CAN GET THAT OF THE OTHER BY DEDUCTING THE LENGTH OF THE ONE FROM THE WHOLE LENGTH.

Thus, supposing that in fig. 16 the major and minor-forces, A and C, are equal to 120 and 40 lbs. respectively, and the whole length of the lever 12 feet, then $120+40=160=$counter-force, and $120 \times 12 \div 160=9=$length of long end of lever, and $40 \times 12 \div 160=3=$length of short end of lever.

CHAPTER IV.

THE FORCES OF AIR AND STEAM.

QUESTION 50. *What is meant by the pressure of the air?*

Answer. It is the force exerted by the weight of the air on every point with which it is in contact. The globe of the earth is surrounded by a layer of air about 50 miles thick, and, like every other substance, the air possesses weight, and hence, presses upon every object with which it is in contact.

QUESTION 51. *How can it be shown that air possesses weight?*

Answer. By weighing a glass flask when it is filled with air, and again when the air is exhausted from it. In the latter condition the weight of the flask will be found to be sensibly less than it was when full of air, showing that the air which the flask contained when it was first weighed increased its weight.

QUESTION 52. *Why do we not feel this pressure on our bodies?*

Answer. Because the air surrounds us on all sides, and presses just as much in one direction as it does in another, so that the pressures in different directions just balance each other, or are *in equilibrium;* but if the air presses on one side only of an object as it does when you suck the air from a tube closed at one end and you cover the open end with your tongue, the air then presses your tongue against the tube, and the one appears to adhere to the other; or if the air be sucked out of a tube one end of which is inserted in a liquid, the latter will be forced up the tube. A piece of thick leather under ordinary conditions will not adhere to anything, but if it be thoroughly wet and pressed hard against the surface of a smooth stone, so as to force out the air from under it, the stone, as nearly all school-boys know, can be lifted up if a string is attached to the leather. These phenomena are due to the pressure of the atmosphere; in the first case on one side of the person's tongue, pressing it against the mouth of the tube; in the second, to the weight of the air pressing on the surface of the liquid, forcing it into the vacuum in the tube, and in the last, to the same pressure on the top of the leather, causing it to adhere to the stone.

QUESTION 53. *What is the amount of the pressure of the atmosphere, and how is it measured?*

Answer. It is usually measured by the pressure on one square inch of surface, which, at the earth's surface, is 15 pounds.* If, for example, we have a cylinder, *A*, fig. 21, with an air-tight piston, *B*, fitted to it, whose area is just one square inch, and through the tube, *C*, we exhaust the air from the cylinder above the piston, the air will press against the under side of the piston so that, if no power is required to overcome its friction in the cylinder, the pressure of the air will raise a weight of 15 pounds. The pressure of air varies, however, as you ascend or descend from the surface of the earth, because as you go up on a mountain or in a balloon the layer of air above you becomes thinner, and, therefore, its weight and consequent pressure are diminished; and as you descend, as in a deep mine, the layer is thicker, and its pressure is consequently greater.

Fig. 21. Weight Raised by Pressure of Air below Piston. Scale 3 in.—1 ft.

QUESTION 54. *What is steam?*

Answer. In the dictionary, steam is defined as "the elastic, aëriform fluid into which water is converted, when heated to the boiling-point," or, in other words, steam is water changed by means of heat into a gas. It is the transparent fluid which escapes from the mouth of a tea-kettle when

* In common practice it is generally taken at 15 lbs. per square inch, but the average atmospheric pressure at the level of the sea is, more accurately, 14.7 pounds.

the water in it is boiling. The visible cloud which escapes from boiling water and is seen in the form of mist at the mouth of the exhaust-pipe of a steam engine is not true steam. It is rather small particles of water. into which the steam has condensed through contact with the cold air. True steam is invisible, as we may observe near the mouth of a kettle or the exhaust-pipe of an engine from which we know it is escaping. At every temperature there is formed from water, on its surface, vapor of which the clouds are formed at all seasons of the year. This change of water into vapor, or evaporation of water, take splace at low temperatures only on its surface, however. But if we heat water in a vessel to a temperature of 212 degrees Fahrenheit, then the inner particles of the mass of water (lying on the heating surface of the vessel) are changed into steam, and rise to the surface in bubbles, which is the phenomenon we call *boiling*.

QUESTION 55. *If water is heated in an open vessel, what occurs?*

Answer. It continues for some time to increase in temperature, and the evaporation becomes more and more rapid. At length bubbles of vapor break out and reach the surface, and the process of boiling or ebullition has begun. When this takes place, the temperature of the water ceases to rise, and it remains stationary until all the water has boiled away, the only difference being that if the supply of heat be very great the process is very rapid, and if the supply of heat be small the process is very slow. The point at which ebullition commences is called the *boiling point*.

QUESTION 56. *On what does the boiling point depend?*

Answer. Chiefly on the pressure on the surface of the water, but to some extent upon the purity of the water. Thus, boiling, which takes place at 212 degrees under the ordinary atmospheric pressure, in lighter air, as on high mountains, takes place at a much lower temperature than on lowlands, and water will boil in a glass tube from which the air has been exhausted by the warmth of the hand, that is, at 92 degrees.

QUESTION 57. *What is the pressure of steam which escapes from boiling water in an open vessel?*

Answer. It is exactly equal to the pressure of the atmosphere in which it is boiled. Ordinarily, this is about 15 lbs., and the boiling-point 212 degrees; but if we go up on a mountain where the atmospheric pressure is only 10 lbs. per square inch, the water will then boil at a temperature of 193.3 degrees, and the steam which escapes will have the same pressure as the atmosphere, or 10 lbs. per square inch. On the other hand, if we could go down into a mine where the atmospheric pressure was 20 lbs. per square inch, the water would not boil until it was heated to 228 degrees, and the pressure of the escaping steam would then be 20 lbs. per square inch.

QUESTION 58. *If water is boiled in an enclosed vessel, like a covered tea-kettle or a steam-boiler, what occurs?*

Answer. The steam rises and fills the space above the water, and, if it cannot escape, increases in pressure. The temperature of both the water and the steam rises with the pressure, and will continue to do so as long as the heat is increased, or until the steam can escape, or the vessel is exploded. The boiling-point also rises as the steam pressure increases.

QUESTION 59. *How can this effect be illustrated?*

Answer. It can be shown if we take a glass tube, *T*, fig. 22, closed at its lower end, and put a small quantity of water in it, and then force a cork, *C*, which fits the tube, or a wad of cotton saturated with tallow, down on top of the water, and then hold the lower end of the tube over a spirit lamp or gas flame, and heat it slowly, so as not to crack the glass

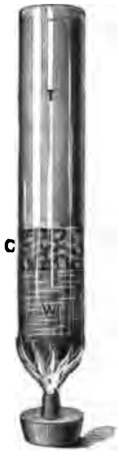


Fig. 22.

Fig. 23.

Generation of Steam in Glass Tube.

tube. Bubbles of steam will then form at the bottom of the water, as shown in fig. 23. These will rise to the top, and will soon force the cork or wad of cotton upward with more or less violence, in proportion to the tightness with which it fits the tube, and the rate at which the water is boiled.

QUESTION 60. *Is there any pressure which corresponds to the temperature of steam and water?*

Answer. Yes. There is a fixed pressure for every temperature, when steam is in contact with water, and its pressure cannot be increased or diminished without at the same time heating or cooling the water, and the higher the temperature of the water the greater will be the corresponding steam pressure. Thus water at 212 degrees produces steam with a pressure equal to that of the atmosphere; at 240 degrees, the steam will have a pressure of 25 lbs. per square inch, or 10 lbs. more than the atmospheric pressure; at 281 degrees, a pressure of 50 lbs.; and at 328 degrees, 100 lbs. As this relation of pressure to temperature is fixed, if we know the one we can tell the other. This is true, however, only where the steam is in contact with water, when it is called *saturated steam.* If it is separated from water, it may be heated to a higher temperature without increasing its pressure in the same proportion, and it is then called *superheated steam.* The temperature of steam at different pressures is given in a table in an appendix.

QUESTION 61. *How is the pressure of steam measured?*

Answer. In the same way as that of the atmosphere—that is, by the force exerted on one square inch of surface. Thus, if steam is admitted into the cylinder, *A*, fig. 24, under the piston, *B*, whose area is equal to one square inch of surface—supposing, as we did before, that no power is required to overcome its friction in the cylinder—then, if the pressure of the steam thus admitted below the piston would just balance the pressure of the atmosphere above it, the steam pressure would be equal to 15 lbs. If, besides overcoming the pressure of the atmosphere, the steam below the piston would raise a weight, *W*, of 15 lbs., then its pressure per square inch would in reality be equal to 30 lbs. per square inch. If the pressure of the atmosphere is *included* or *added to* that of steam *above* it, it is called its *absolute pressure.* In ordinary high-pressure steam engines, however, the steam must always overcome the pressure of the atmosphere, and therefore the only part of the pressure which is effective is that above, or by which it exceeds, the atmospheric pressure. This is therefore called the *effective* or *working pressure.* For example, although the steam admitted under the piston in fig. 24 has an absolute pressure of 30 lbs. per square inch, yet it will only raise a weight of 15 lbs., because it must first overcome the pressure of the air on the other side of the piston. The pressure of the steam used in most stationary and in locomotive engines is, therefore, measured by its pressure above the atmosphere. That is, if steam introduced under the piston in fig. 24 will raise a weight of only 15

Fig. 24. Weight Raised by Pressure of Steam below Piston. Scale 3 in.—1 ft.

lbs., we say it has a pressure of 15 lbs. per square inch; if it will raise 50 lbs., its pressure is said to be 50 lbs. per square inch, and so on. The pressure of the atmosphere is disregarded, and all steam-gauges used on locomotives are graduated in that way. In speaking of steam pressure in future, therefore, unless otherwise specified, we shall mean *effective* or *working* and not *absolute* pressure.

QUESTION 62. *What is meant by the expansion of steam?*

Answer. In all gases a repulsion is exerted between the various particles, so that any gas, however small in quantity, will always fill the vessel in which it is held. Steam possesses this same property, and, if placed in any vessel, the particles in endeavoring to separate from each other will exert a force on all its sides. This force we call the steam pressure. To illustrate this we will suppose that the cylinder, *A*, in fig. 24, is half filled with steam of 30 lbs. pressure. If, now, the supply of steam is shut off, the steam in the cylinder if the weight, *W*, is reduced, will expand so as to push the piston upward, but with a somewhat diminishing force, the nature of which will be explained hereafter.

QUESTION 63. *What is meant by the "volume" of air or steam?*

Answer. It means the space which it fills or occupies.

QUESTION 64. *What is the proportion which exists between the volume and the pressure of air, steam or other gas?*

Answer. As long ago as 1662, Robert Boyle, from experiments "touching the spring of air," discovered the law which has since been called "*Boyle's law,*" that "*the pressure of a portion of gas at a constant temperature varies inversely as the space it occupies;*" that is, the one increases in the same proportion as the other diminishes. If we admit steam of 30 lbs. absolute pressure per square inch into the cylinder, *A*, fig. 24, and then cut off the supply by closing the cock, *C*, and allow the steam in the cylinder to expand to double its volume by pushing the piston to the end of the cylinder, the steam pressure will then be only 15 lbs.; if it should expand to three times its volume its pressure would be only one-third, or 10 lbs. per square inch. This method for calculating the pressure of steam after it has expanded, is correct only for the *absolute* and not for the *effective* pressures of steam. In order to ascertain the effective pressures of steam after expansion, it is only necessary to make the calculation with the absolute pressure and deduct the atmospheric pressure from the result. If, after being thus expanded, the piston be pushed down again so as to compress the steam into its original space, its pressure will again be 30 lbs., providing no heat has been lost in any way.

QUESTION 65. *How can we determine approximately the pressure of steam, air or gas after it has been compressed or expanded?*

Answer. BY MULTIPLYING ITS ABSOLUTE PRESSURE PER SQUARE INCH BY ITS VOLUME BEFORE IT IS COMPRESSED OR EXPANDED, AND THEN DIVIDING THE PRODUCT BY ITS VOLUME* AFTER IT IS EXPANDED OR COMPRESSED. Thus, if we had a cylinder whose piston moves 24 inches, if 8 inches of its length was filled with steam of an ABSOLUTE pressure of 90 lbs., and it was expanded so as to fill the whole cylinder, the calculation to ascertain its pressure after expansion would be as follows:

$$\frac{90 \times 8}{24} = 30 \text{ lbs. final pressure.}$$

If 10, 12 and 15 inches of the cylinder was filled with steam and ex-

* The volume may be taken in cubic inches, cubic feet or in the number of inches in the length of a cylinder which is occupied by the steam, air or gas; but the same unit of measurement must be used for both the multiplier and the divisor.

panded to its full volume, the final pressures would be 37½, 45 and 56¼ lbs., respectively. To get the effective pressures, deduct the atmospheric pressure from these figures.

QUESTION 66. *What is the proportion between the volume of steam and that of the water from which it is formed?*

Answer. At the pressure of the atmosphere (15 lbs. per square inch) each cubic inch of water will make 1,610 cubic inches of steam. At double that pressure, or 30 lbs. absolute pressure, it will make a little more than half as much, or 838 cubic inches; at four times, or 60 lbs. absolute pressure, 437 cubic inches, or a little more than a fourth as much as at the pressure of the atmosphere.

QUESTION 67. *Why is it that the quantity of steam at high pressure is somewhat greater than in inverse proportion to the pressure?*

Answer. Because the boiling-point of water, as has already been explained, is higher as the pressure increases, and therefore the temperature of the steam produced at such pressure is also higher than at lower pressures; and, as all gases are expanded by heat, therefore the volume of steam at the higher pressures is somewhat greater than in inverse proportion to its pressure, on account of being somewhat expanded by its high temperature. To make this plain, if we take a cubic inch of water and convert it into steam of atmospheric pressure, its volume will be 1,610 times that of the water and its temperature 212 degrees.* If we convert this quantity of water into steam with a pressure double that of the atmosphere, the volume of the steam will be 838 times that of the water and its temperature will be 250.4 degrees. If the volume of the steam were exactly *inversely proportional* to the pressure, the cubic inch of water at double the atmospheric pressure would make only 805 cubic inches of steam; but, as the boiling-point at that pressure is 38.4 degrees higher. the steam is expanded 33 cubic inches by the increase of its heat due to the higher boiling-point.

QUESTION 68. *What is meant by the condensation of steam?*

Answer. It is the reconversion of steam into water by cooling it, or depriving it of part of its heat. It has been shown that the temperature of water must be raised to a certain point to generate steam of a given pressure. If the process is reversed, and we deprive the steam of a part of its heat, some of the steam is then at once reconverted into water, or *condensed*, and the pressure of that which remains will be reduced just in proportion as the heat is lost. When the temperature gets below 212

* More accurately, 213.1 degrees, if we call the atmospheric pressure 15 lbs.

degrees under atmospheric pressure, all the steam will be condensed. As the useful work which steam can do in an engine is due to its pressure, which, in turn, depends on its temperature, any loss of heat will diminish its effective power. For this reason, all waste of heat from a steam engine should, as far as possible, be prevented.

QUESTION 69. *How is the heat of the steam wasted or lost in an ordinary steam engine?*

Answer. It is wasted in three ways: First, by *conduction;* second, by *convection;* and third, by *radiation.*

QUESTION 70. *What is meant by these three terms?*

Answer. (1.) By *conduction* is meant that phenomenon which is manifested when we put one end of a metal bar, two or three feet long, into the fire and heat it. The heat is then gradually conveyed from one particle of the metal to that next to it until finally the end of the bar farthest from the fire may become so hot that it cannot be touched. The heat is then said to be *conducted* through the bar. In the same way the metal of the boiler, pipes, cylinders and other parts of the engine becomes heated on one side, and the heat is thus conveyed to the outside of these parts.

(2.) The air with which they are surrounded then becomes heated, and, being then lighter than the cold air, it rises and is again replaced with air which is not heated. In this way the heat is *conveyed* away by the air, and this phenomenon is therefore called *convection.*

(3.) If an iron plate be placed in front of an ordinary grate fire, three or four feet from it and exposed to the rays of heat from the fire, it will soon become so hot that you cannot bear your hand on it. If you place your hand between the iron plate and the fire you will find that only the side of your hand which is exposed to the fire will become hot; showing that the air between the plate and the fire is not nearly so hot as the plate soon becomes, and therefore that the heat is not conveyed to the plate by the air between it and the fire, but by the heat rays from the fire. This phenomenon is called *radiation.* The same thing occurs from any hot body, as, for example, a coil of steam pipe for heating a room, a steam boiler, or cylinder of an engine.

QUESTION 71. *Is there any difference in the conducting and radiating power of different substances?*

Answer. Yes, very great. The difference in the *conducting* power of wood and iron is shown if we place one end of a bar of each in the fire. The wood will be consumed without warming the bar more than a few inches from the fire, whereas the iron will soon become hot two or three feet from the fire. Owing to the difference in the conducting power of cotton and wool, we wear cotton clothing in summer and woolen in winter, because cotton allows the heat of the body to be conducted away from it, whereas woolen cloth prevents to a great degree this loss of heat. For the same reason, the venders of roasted chestnuts on our streets wrap them in a piece of blanket to keep them hot, that is, to keep the heat in; and in summer we wrap ice in the same way to keep it cold, that is, keep the warmth of the air out. The wool, being a very bad conductor of heat, simply prevents the heat from being transferred from the inside to the outside, and *vice versa*. It is for this reason that steam boilers, pipes and cylinders are nearly always covered with some non-conducting material, such as wood, and sometimes with felt.

The difference in the *radiating* power of various substances can be shown if we take a large thermometer and heat it up to the temperature of boiling water. If this thermometer is hung up in a room having the temperature of melting ice, it will loose in two ways—first, by heating the air which surrounds it, that is, by *convection*, and also by *radiation*. In order to confine ourselves to the latter process, we will suppose that the chamber is a vacuum. If we first cover the bulb of the thermometer with a thin coating of polished silver, and then ascertain how much heat it radiates in a minute, and then coat it with lamp black and repeat the same experiment—that is to say, allow the thermometer at the boiling-point to cool for one minute in a vacuum chamber at the freezing point—it will be found that the thermometer loses much more in a minute when coated with lamp black than it did when coated with silver, showing that much more heat is radiated from a surface covered with lamp black than from polished silver. Generally, it may be stated that polished metals radiate much less heat than surfaces which are not polished.* For this reason, as well as for ornament, locomotive and other boilers and cylinders are usually covered with Russia iron.

* The account of the above experiment is copied from Balfour Stewart's very excellent little book, "Lessons in Elementary Physics," of which, and the same author's "Elementary Treatise on Heat," the writer nas made frequent use.

CHAPTER V.

ON WORK, ENERGY AND THE MECHANICAL EQUIVALENT OF HEAT.

QUESTION 72. *For what purpose are all steam engines used?*

Answer. They are used to produce *motion*, which is opposed by some *resistance*. Thus, if an engine is employed to raise grain from a railroad car to the top of a warehouse, it must produce motion, which is resisted by the weight of the grain; if it is used to saw wood, it must give motion to the saw, which is resisted by the fibers of the wood; a locomotive engine must produce motion of a train of cars, which is resisted by the air, the friction of the journals, and the rolling of the wheels on the track; if the locomotive is employed on a grade or incline, besides the frictional resistance referred to, it must overcome that due to its own weight and that of the train, which is gradually lifted as it ascends the incline. In producing motion opposed by some resistance an engine is said to be doing "*work*."

QUESTION 73. *Can this work be accurately measured?*

Answer. Yes; but in order to measure anything we must first establish some accurate standard or unit of measurement. Thus, we say a bar of iron is so many inches long, or a road is so many miles long. In like manner we speak of so many seconds, or minutes, or hours, or days, or years, when we speak of time. So it is necessary, in order to estimate or measure "*work*" in a strictly scientific manner, for us to fix upon some accurate standard or unit. In this country and in Great Britain the unit agreed upon for this purpose is the amount of power required to raise ONE POUND ONE FOOT, and is called a *foot-pound*. If we raise one pound two feet we do two foot-pounds of work; if three feet, three foot-pounds, and so on. Again, if we raise a weight of two pounds one foot high, we likewise do two foot-pounds of work; or if we raise it two feet high, we do four foot-pounds, and so on. In order to determine the amount of work done, we must MULTIPLY THE MOTION PRODUCED (*in feet*) BY THE RESISTANCE (*in pounds*), AND THE RESULT WILL BE THE WORK DONE IN FOOT-POUNDS.

QUESTION 74. *How many foot-pounds of work are performed in a pile-driving machine in raising a weight of 1,200 lbs. 24 feet?*

Answer. 1,200 × 24 = 28,800 foot-pounds.

QUESTION 75. *When this weight is raised, is the force which was exerted in raising it annihilated or lost?*

Answer. No; because the force with which it is attracted towards the earth—which has been overcome in raising the weight—gives it the capacity of doing an equal amount of work when it falls. Now, although the weight has no motion-producing power when it is raised to the top of the machine, yet, obviously, such action is then *possible* which, when it rested on the earth, was not possible. If the weight is allowed to fall, it acquires a greater velocity the farther it falls, and it can then do work, as in driving piles. This capacity for doing work is called *energy*. It has no energy as it hangs there dead and motionless; but energy is possible to it, and we might fairly use the term *possible energy* to express this power of motion which the weight possesses* after it is raised up, and which is therefore called *potential energy*. As soon as the weight is allowed to fall and acquires velocity its potential energy then becomes, and is called, *actual energy*.

QUESTION 76. *How can such phenomena as the heating of a car-axle while turning under a car, the heating of brake-blocks when the brakes are applied to car-wheels, the heating of an iron rod by hammering, and of a turning tool when cutting a piece of metal be explained?*

Answer. All of these phenomena are due to the fact that the *actual energy* of motion is converted into heat, as has been repeatedly proved by many able and ingenious investigators and experiments.

QUESTION 77. *When the weight of the pile-driver falls, is its energy also converted into heat?*

Answer. A part is expended in compressing the material into which the pile is driven, and in overcoming the friction of the earth against the pile, each of which efforts develops heat, and another portion is converted into heat by the impact or blow of the falling weight on the head of the pile.

QUESTION 78. *Is all energy convertible into heat and heat into energy?*

Answer. Yes. Science has demonstrated very clearly that they are mutually convertible.

QUESTION 79. *Has it been ascertained how much heat is equivalent to one foot-pound of work?*

Answer. Yes. It has been found from carefully-made experiments that

* Tyndall's "Heat Considered as a Mode of Motion."

the amount of heat which is required to raise the temperature of one pound of liquid water by one degree of Fahrenheit* is equivalent to 772 foot-pounds of work.† It must be remembered that this is the theoretical equivalent of heat, and that only a very small proportion of this amount of work is ever realized from the heat developed by the combustion of fuel.

QUESTION 80. *If, then, heat is convertible into work and work into heat, can the transmutation of the heat of the steam in the cylinder of an engine into work and the reverse process be explained?*

Answer. Take a cylinder, fig. 25, and, in order to make the conditions of the experiment as simple as possible, imagine it to be placed in a

Fig 25. Cylinder and Piston. Scale 3/8 in.=1 foot.

vacuum. Now let saturated steam be admitted under the piston, *B*, so as to fill the cylinder half full at an absolute pressure of 100 lbs. If we will allow this steam to expand to double its volume and raise the piston *without doing any work*, and then repeat the experiment with a load of 50 lbs. on the piston, whose area is one square inch, it will be found that the temperature of the steam is sensibly less, after lifting the weight, than in the previous experiment, in which it expanded without doing work, showing that part of the heat was abstracted from the steam by doing work, or, in other words, was converted into work. If then, after the steam has expanded and lifted the weight, we press the piston down so that the steam under

* Thermometers are divided into different scales. The one called the Fahrenheit scale, after its originator, is the one ordinarily used in this country.

† More recent experiments, made by Prof. Rowland in Baltimore, show that the mechanical equivalent of heat is 778 foot-pounds of work.

the piston is compressed to its original volume, we shall find that its temperature is the same as before, as the work done in compressing it is converted into heat. In these experiments it is assumed that there is no friction of the piston, nor loss of heat from radiation or conduction. The same phenomena can be observed in machines used for compressing air. In these, the air is heated to so high a temperature, when it is compressed, that it is sometimes necessary to cool the cylinders by circulating a current of cold water around them.

QUESTION 81. *What practical relation is there between the convertibility of heat into work and the conducting and radiating properties of different substances explained in answer to Question 71?*

Answer. The fact that heat is only another form of energy, or "the power of doing work," indicates that its loss by conduction or radiation lessens that power just as much as or more than the loss or waste of coal would, and therefore every effort should be made to protect the different parts of engines from loss of heat by covering them with substances which conduct or radiate very little heat. Care should also be taken to exclude cold air from circulating in contact with those parts, and, excepting for supporting combustion, the nature of which will be explained hereafter, it should be excluded from the heating surface of boilers.

QUESTION 82. *What is meant by the term* LATENT HEAT OF EVAPORATION?

Answer. By *latent heat* is meant that heat which *apparently* disappears when water or other liquids are vaporized. Thus, it is found that if any quantity of water is converted into steam at any pressure, it is necessary not only to heat the water to a temperature equivalent to that of the steam, or to the boiling-point, but after the water has reached that temperature an additional amount of heat must be added in order to keep up the process of boiling. Notwithstanding this addition of heat to the water, the temperature of the steam produced will not be higher than that of the boiling water, thus showing that a considerable quantity of heat is absorbed, the effect of which is to change the water into a gas or steam. This apparent disappearance of heat can be shown if we take a pound of boiling water whose temperature is 212 degrees and mix it with a pound of ice-cold water at 32 degrees temperature. The result will be a mixture of two pounds of water of a mean temperature of 122 degrees. If now we convert a pound of water into steam at atmospheric pressure, its temperature will also be 212 degrees, but it will heat 6.37 lbs. of ice-cold water up to 122 degrees, showing that a pound of steam at atmospheric pressure contains over six times as much heat as a pound of water of the same temperature as indicated by a thermometer. A similar apparent disappearance of heat occurs when other liquids are evaporated, and when ice or any other solid is converted into a liquid.

QUESTION 83. *What is the explanation of these phenomena?*

Answer. The exact reasons which will explain them fully are probably not yet clearly understood, but it is at least extremely probable that when any substance is changed from a solid to a liquid, "a large portion of the heat is spent *in doing work* against the force of cohesion."* The particles of solid bodies, as we know, are so united that it requires more or less force, according to the nature of the substance, to tear them apart. Now, we can conceive that when the heat is applied to some solid substances, such as ice and metals, that it is changed into a form of energy, and in that condition resists this attraction of the particles to each other and they then melt. Further application of heat imparts more energy to the substances and they then assume a gaseous form, and their particles *repel* each other. When the heat is thus transformed it has lost the capacity of expanding the mercury in the thermometer. In a liquid condition the particles of the substance move freely about each other and have little or no attraction for each other, but when it becomes a gas they have a *repulsion from* each other. The heat is thus converted into the energy of repulsion, and therefore is in reality no longer in the condition of heat and consequently does not affect the thermometer. We can illustrate this by supposing that, by using steam, heat is converted into work by raising the weight, or drop as it is called, of a pile-driving machine. When the weight is raised to the top of the guides from which it falls, although, as already explained, the heat is converted into *potential energy*, yet if we attached a thermometer to the drop we would not find that it was any warmer than before the drop was raised. If it were possible to make an instrument sufficiently sensitive to indicate an instantaneous change of temperature in the weight while falling, we would not find any increase of its temperature at the instant it had acquired its greatest momentum and just before it struck the object under it, although its potential energy would at that instant be converted into *actual energy* of motion. If, however, the weight should strike an unyielding object, its actual energy would at once be reconverted into heat, which our thermometer would indicate. The phenomenon of what is called latent heat of evaporation, or "heat of gasification," seems to be very similar to that

* Balfour Stewart on the Conservation of Energy.

described—the heat when the water is changed from a liquid to a gaseous condition is transformed into energy, which, as already stated, has no effect upon the mercury of the thermometer.

QUESTION 84. *What is meant by the* TOTAL HEAT *of steam?*

Answer. The "total heat of steam" is a phrase used to denote the sum of the heat required to raise the temperature of water from some given point up to the boiling-point due to a given pressure, and of the heat which disappears in evaporating one pound of water under a given pressure (or *latent heat of evaporation*). Thus, the latent heat of one pound of steam at atmospheric pressure (14.7 lbs.) is 966.1 units; and 212 units of heat are necessary to raise water from zero to the boiling-point; therefore, the total heat counted from zero of steam of atmospheric pressure is 1,178.1 units.* At 100 lbs. absolute pressure the latent heat is 885.5 and the sensible heat 327.9 degrees; therefore the total heat measured from zero is 1,213.4 units. The table, in Appendix I, gives the temperature, total heat in degrees from zero of Fahrenheit's thermometer, weight of a cubic-foot, and the volume of steam of pressure from 1 to 300 lbs. per square inch.

* The total heat is sometimes measured from the freezing-point, 32 degrees.

CHAPTER VI.

THE STEAM ENGINE.

QUESTION 85. *What is the motive power employed in ordinary steam engines?*

Answer. The expansive force of steam.

QUESTION 86. *How is this expansive force of steam applied?*

Answer. It is applied by admitting it into a *cylinder*, *A*, fig. 26, in which

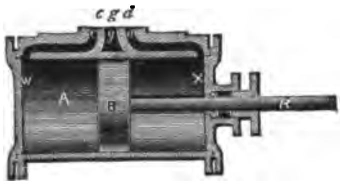


Fig. 26. Cylinder and Piston. Scale ⅜ in. = 1 ft.

a *piston*, *B*, is fitted so as to move air-tight from one end of the cylinder to the other. The steam, if admitted at *c*, will force the piston, *B*, to the opposite end* of the cylinder. When it has reached that end, if the steam is allowed to escape, and a fresh supply is admitted to the other end of the cylinder through the opening, *d*, it will move the piston back again. In this way, by alternately admitting steam at one end and exhausting it from the other, the piston receives a *reciprocating motion*, which is communicated to the outside of the cylinder by a rod, *R*, which is called the *piston-rod*, which works air-tight through an opening in one of the *cylinder-covers*, or *cylinder-heads*, as they are usually called.

QUESTION 87. *How is this reciprocating motion of the piston converted into rotary motion?*

Answer. By connecting the end of the piston-rod, *R*, fig. *A*, Plate I (in the back part of the book), by another rod, *E* (called a *connecting-roa*), with a crank, *P*, which is attached to a revolving shaft, *S*. It is apparent

* In all ordinary locomotives, the cylinders are so placed that the head, *X*, through which the piston-rod works, is behind, and the other head, *W*, in front. The two ends of the cylinder are therefore designated the *front* and *back ends*, respectively.

that if the piston, *B*, is moved in the direction shown by the dart, *R*, a rotary motion will be given to the crank in the direction of the dart, *n*. When, however, the crank reaches the position shown by the dotted lines at *N'*, it is plain that a force applied to move the piston in either direction will no longer produce a rotary movement of the crank and shaft. The same thing will occur when the crank is in the opposite position. These two positions are called the *dead-points* of the crank.

QUESTION 88. *How is the crank of an ordinary steam engine carried past the dead-points?*

Answer. A stationary engine usually has a large and heavy wheel, called a *fly-wheel, F*, Plate I, which is attached to the shaft, *S*. This wheel receives a sufficient amount of momentum from the crank, while the latter is moving from one dead-point to the other, to carry it past those points.

QUESTION 89. *How is the steam admitted to and exhausted from the cylinder?*

Answer. It is admitted through two channels, *cc'* and *dd'*, called *steam-passages*, cast in the cylinder. These passages terminate in a smooth, flat surface, *ff'*, called the *valve-seat*. The openings, *c* and *d*, fig. *C*, Plate I., of the steam-ports in the valve-seat, are called *steam-ports*. Between them is another port or cavity, *g*, called the *exhaust-port*, which communicates with the open air. The form of these ports is long and narrow, as shown in fig. *C*, which represents a plan of the engine, or a view looking down from above it, with the top of the steam-chest and valve removed. Over these ports a valve, *V*, figs. *A* and *B*, called a *slide-valve*, which is usually made of cast-iron, with a cavity, *H*, in its under side—is fitted so that by moving it backward or forward it will alternately cover and uncover the two steam-ports. The valve and valve-seat are inclosed in a sort of box, *I I*, made of cast-iron, called a *steam-chest*, into which steam is admitted from the boiler by a pipe, *J*. When the valve is in the position represented in fig. *A*, the front steam-port, *c*, is uncovered, and the steam is admitted to the front end of the cylinder, as indicated by the darts *c* and *c'*, and it thus forces the piston toward the back end, or in the direction of the dart, *R*. If, when the piston reaches the back end, as shown in fig. *B*, the valve has been moved into the position shown, the back steam-port, *d*, will be uncovered, and steam will be admitted to the back end of the cylinder, as indicated by the darts *d* and *d'*. At the same time it will be observed that the front steam-port, *c*, and the exhaust-port, *g*, are both covered by the cavity, *H*, in the slide-valve, so that the steam which was admitted to the front end of the cylinder can now escape as indicated by the arrows, c' c, through the steam-port into the exhaust-port, *g*, and thus into the open air. By moving the valve alternately back and forth, steam is simultaneously admitted first to one end of the cylinder, and exhausted from the other, and *vice versa*.

QUESTION 90. *How is the slide-valve moved so as to admit and exhaust the steam at the right time?*

Answer. This is done by means of what is called an *eccentric*, *G* (shown

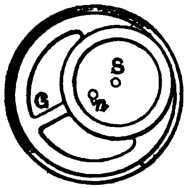


Fig. 27. Eccentric. Scale ¾ in.—1 ft.

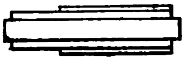


Fig. 28.

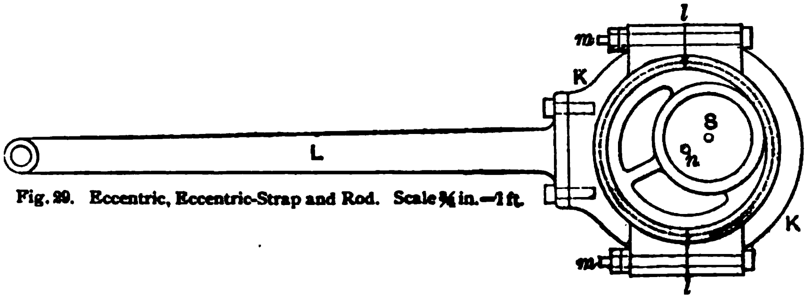


Fig. 29. Eccentric, Eccentric-Strap and Rod. Scale ¾ in.—1 ft.

separately in figs. 27 and 28), which is a circular disc or wheel, whose centre, *n*, is some distance from that of the shaft, *S*, to which it is fastened with keys or screws, and with which it revolves. The outside of the eccentric is embraced by a metal ring, *K K*, called an *eccentric-strap*, shown in fig. 29, and also in fig. *A* of Plate I. This strap is made in two halves, which separate in the line, *l l*, fig. 29. The two parts are fastened together by bolts, *m m*, which pass through lugs or projections cast on the straps, as shown. The outside, or the periphery, of the eccentric, is accurately turned, and the inside of the strap is bored to fit it, so that the one can revolve inside of the other.

QUESTION 91. *How does an eccentric work?*

Answer. Its action is precisely like that of a crank, in fact it may be defined to be a crank with a crank-pin large enough to embrace the shaft.

QUESTION 92. *How is the motion of the eccentric imparted to the valve?*

Answer. A rod, *L*, called an *eccentric-rod*, is attached to the eccentric-straps, as shown in fig. 29. It is obvious that, if the eccentric revolves inside of the strap, it will impart a reciprocating motion to the rod, *L*. The eccentric, *G*, strap, *K*, and rod, *L*, are represented in fig. *A*, Plate I. Before describing their operation, or rather their connection with the valve, *V*, it is necessary to understand that in this country the slide-valves of locomotives are usually placed on top of the cylinders, in which position it is difficult to connect the eccentric-rod directly with the valve. For convenience, therefore, what is called a *rocker*, *R R'*, is placed between the cylinder and the main shaft of the engine. This rocker has two arms attached to a shaft, *s*, and the two arms have a vibratory motion about it, as indicated by the dotted lines, *r R* and *R' r'*. The eccentric-rod, *L*, is attached by a pin, *R'*, to the lower arm of the rocker, and the slide-valve, *V*, is connected by the rod, *C*, called the *valve-rod*, or *valve-stem*, to a pin, *R*, on the upper end of the rocker. It is obvious that, as the eccentric, *G*, revolves, a reciprocating or vibratory motion will be given to the rocker, which will be communicated to the valve by the valve-stem; and it is only necessary to fix the eccentric in the proper position on the shaft, in relation to the crank and piston, to give the valve the required motion for admitting and exhausting the steam to and from the cylinder at the right time.

QUESTION 93. *How can the action of the eccentric and the movement of the valve and piston during a complete revolution of the crank be shown?*

Answer. It can be illustrated and explained by the aid of a series of diagrams—figs. 30–43. In these diagrams most of the parts are represented by their centre-lines and centre points only, so as to make them as simple as possible. The dimensions selected for these illustrations are, for the cylinder, 16 inches diameter and 24 inches stroke. The steam-ports are 1¼ inches, the exhaust-port, 2½ inches, and the metal or bars between them, which are called *bridges*, are 1⅛ inches wide. The eccentric produces a lateral movement of 4 inches, which is called its *throw*.* In fig. 30, the piston is at the beginning of the backward stroke.

* There is some ambiguity in the use of the term *throw*. In Webster's dictionary it is defined as "the extreme movement of a slide-valve, also of a crank or eccentric, measured on a straight line passing through the centre of motion." The definition of mechanical terms, in the edition of the dictionary quoted from, were prepared by the late Alexander L. Holley, so that no more eminent authority could be quoted for the usuage of the term with this meaning. Nevertheless, the word *throw* is sometimes used to designate the distance from the centre of a shaft to the centre of a crank-pin or eccentric, which, of course, would be only one-half the extreme movement of a valve or piston.

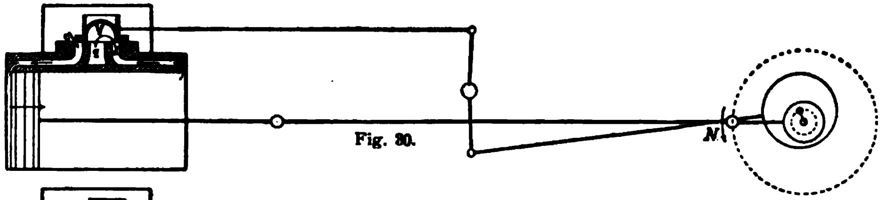


Fig. 30.

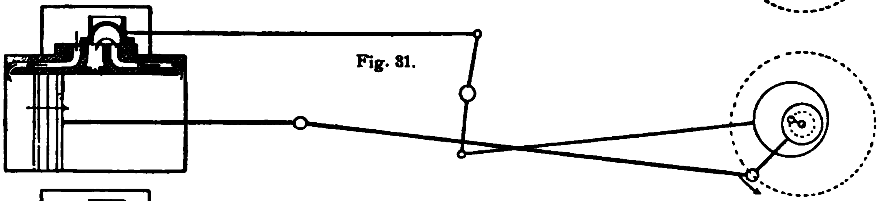


Fig. 31.

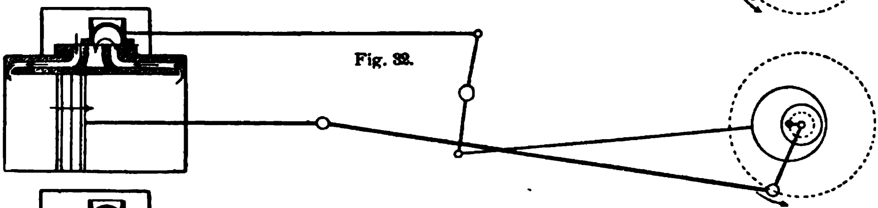


Fig. 32.

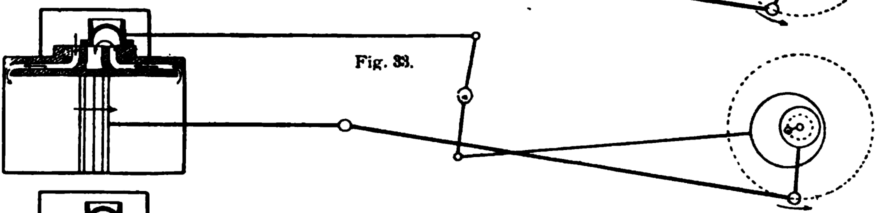


Fig. 33.

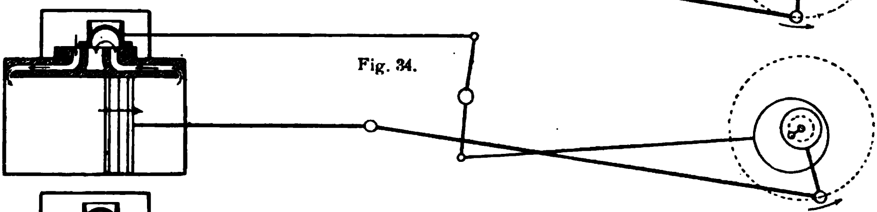


Fig. 34.

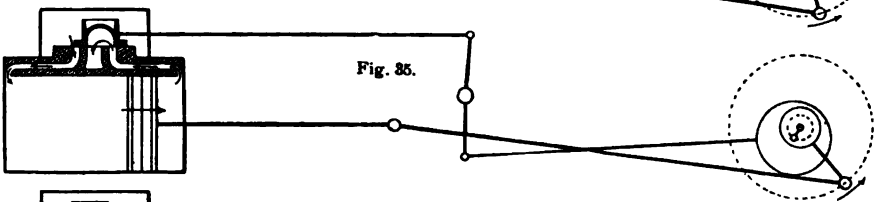


Fig. 35.

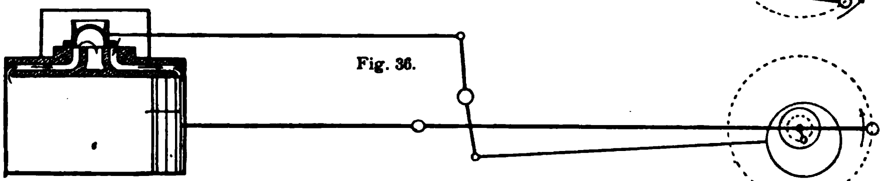


Fig. 36.

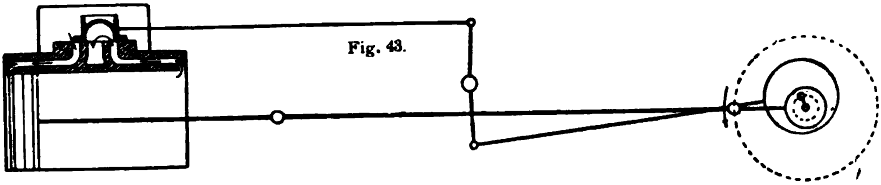


Fig. 43.

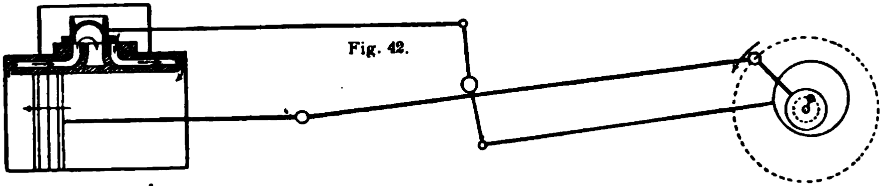


Fig. 42.

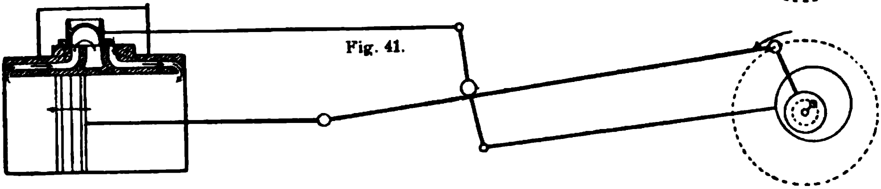


Fig. 41.

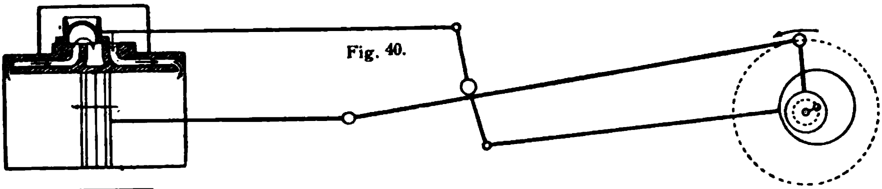


Fig. 40.

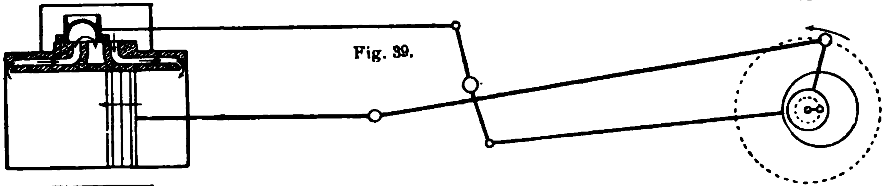


Fig. 39.

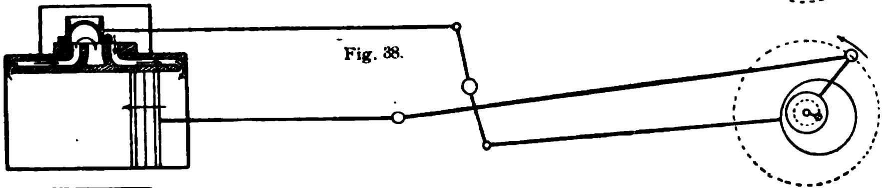


Fig. 38.

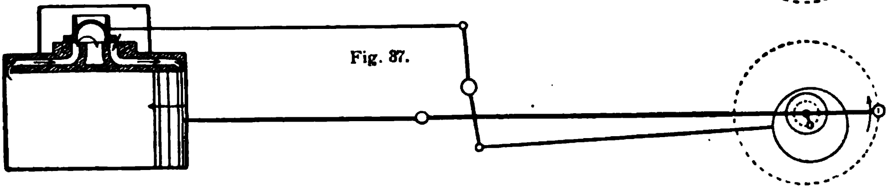


Fig. 37.

It will be seen that the valve, *V*, has then uncovered the first steam-port at *c*, and that steam can therefore enter the front end of the cylinder as indicated by the darts. At the same time, the exhaust-cavity, *V*, in the valve covers the exhaust-port, *g*, and the front steam-port, *d*, so that the steam in the back end of the cylinder can escape as shown by the arrows.

In fig. 31, the piston is represented as having moved 4 inches of its stroke; the valve has then opened both of the steam-ports wider. In fig. 32, the piston has moved 8 inches of its stroke, and the ports are now wide open, the front one to the steam and the back one to the exhaust. In fig. 33, the piston has moved 12 inches, or is at half-stroke, and the valve has then moved to its extreme throw. In fig. 34, the piston has moved 16 inches, and the valve has begun to return. In fig. 35, the piston has moved 20 inches, and the valve has nearly closed the front port to the steam. In fig. 36, the forward stroke is completed, and the back steam-port is then slightly opened to admit steam into the back end of the cylinder for the return stroke. The front steam-port has also been made to communicate with the exhaust-port so that the steam in the front end of the cylinder will be exhausted before the piston begins to return.

Figs. 37 to 43* represent the positions of the piston and valve during the forward stroke, corresponding with those described for the backward stroke. The darts in the steam-ports in the figures represent the movement of the steam in each position of the piston and crank. Other darts, on the piston and at the crank-pin, show the direction in which they are moving. By following the successive positions of the piston, crank and valve, as shown in these figures, the reader can get a very clear idea of the action of an engine of the kind illustrated.

QUESTION 94. *How is the piston of a steam engine made to work steam-tight in the cylinder?*

Answer. The cylinder is first accurately bored out, and the piston has two metal rings around its periphery. Each of these rings is cut apart, as shown at *B*, in fig. *A*, Plate I, so that they can be expanded by springs or other means to fit the cylinder. The open places are placed at different points on the circumference of the piston, so that the one opening is covered by the other ring, which prevents the steam from leaking through the openings. The construction of pistons is fully described in Chapter XV.

QUESTION 95. *How is the piston-rod made to work steam-tight through the cylinder-head?*

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* These are arranged in the reverse order to those on page 44 to represent the forward stroke of the piston.

Answer. By what is called a *stuffing-box.* This consists of a cylindrical chamber, *A A'*, figs. 44 and 45, the inside of which is made about 1¼ inches

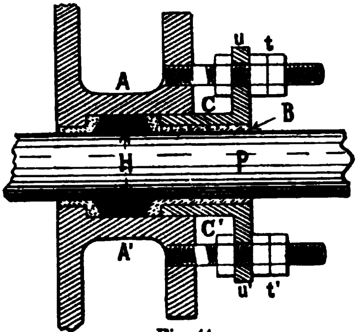


Fig. 44.

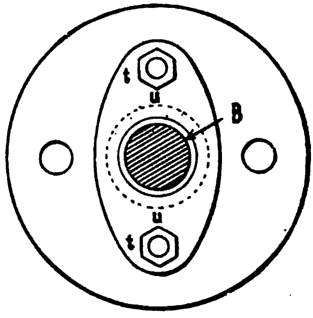


Fig. 45.

Stuffing-Box. Scale 1⅛ in.—1 ft.

larger in diameter than the piston-rod. This leaves an annular space ⅝ of an inch wide all around the rod. This space is filled with hemp, *H*, or some other fibrous material, called *packing*, saturated with oil or melted tallow. This packing is compressed by a hollow cylinder, *C C'*, called a *gland*, the inside of which fits the piston-rod, *P*, and the outside the stuffing-box. This gland is forced into the stuffing-box by nuts, *t t'*, which are screwed down on a flange, *u u'*, attached to the gland. The packing is thus compressed in the stuffing-box and forced against the piston-rod, which is made smooth and perfectly round and straight, and against the side of the stuffing-box, so that no steam can escape around the piston-rod. A brass ring or "*bushing*," *B*, is often put into the gland, and another in the cylinder-head, where it touches the piston-rod, because brass will bear the friction of the rod better than cast-iron, and, when it is worn out, it can be removed, and a new one substituted in its place. Packing made of metal is now often used for piston-rods instead of fibrous material. The construction of metal packing is described in Chapter XV.

QUESTION 96. *How must the piston and piston-rod move in order to keep steam-tight?*

Answer. The centre line of the piston and piston-rod must always be coincident with the axis or centre line of the cylinder.

QUESTION 97. *How is the movement of the piston-rod affected by the connecting-rod?*

Answer. Excepting when the crank is at one of the dead-points, the centre line of the connecting-rod is inclined to that of the piston-rod and axis of cylinder. Consequently, at all other points of the revolution, the connecting-rod has a tendency to either pull or push the end of the piston-rod downward, when the crank is turning in one direction, or upward if the crank turns the opposite way.

QUESTION 98. *How is this action of the connecting-rod resisted?*

Answer. The back end of the piston-rod and the front, or *small end*, as it is called, of the connecting-rod are attached to what is called a cross-head, *D*, shown in figs. *A* and *B*, Plate I. This moves between bars, *O O*, *O′ O′*, called guide-bars, which are set so that the motion of the cross-head is coincident with, or parallel to, the axis or centre line of the cylinder. As the end of the piston-rod is attached to the cross-head, they must both move in a path parallel to the faces of the guide-bars on which the cross-head slides. In this way, the pressure exerted by the connecting-rod bears on the guide-bars and is resisted by them.

QUESTION 99. *How is the connecting-rod attached to the crank-pin?*

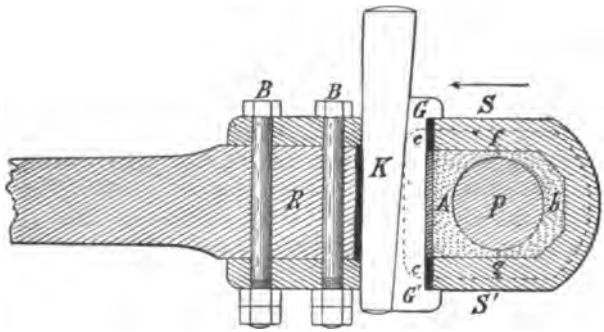


Fig. 46.

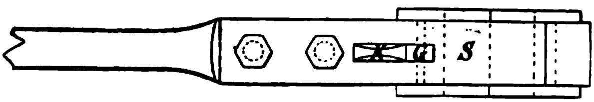


Fig. 47. Stub-End. Scale 1½ in.=1 ft.

Answer. By what is called a *stub-end* or *strap-head*, shown in fig. 46, which shows a section through the crank-pin, *P*, and fig. 47, which is a plan or view looking down from above. A stub-end consists of two brass "journal-bearings," or "brasses," *A* and *b*, which embrace the crank-pin and bear against it. These bearings are attached to the rod by the strap, or ⊃-shaped bar, *S S'*. The strap is fastened to the end of the connecting-rod, *R*, by the bolts, *B B*, and also by a key, *K*, and "gib" or "cotter," *G G'*. A little space, or "clearance," *c c'*, is allowed between the gib, *G*, and the strap, *S S'*, and also between the key, *K*, and rod, *R*. When the journal-bearings, *A b*, wear by reason of their friction on the crank-pin, they are taken out and filed away at *f g*, on their surfaces of contact with each other. The key, *K*, is then driven down, which moves the strap in the direction of dart, *S*—the clearance, at *c c'*, permitting such movement—which draws the journal-bearings together and takes up the "lost motion," as the wear of the journals is called.

QUESTION 100. *Why are the journal-bearings made of brass?*

Answer. Because brass resists the wear of a journal, when the pressure on it is very great, better than iron or steel. That is, brass bearings are less liable to get hot or be abraded than either iron or steel.

QUESTION 101. *Are the engines—that is, the cylinders and other mechanism—which are used in locomotives, similar in principle and construction to the stationary engines that have been described?*

Answer. Yes; the chief difference is that in locomotives two cylinders and cranks are used so as to overcome the difficulty there would be in starting from the dead-points if only one was used, and the valve gear is also arranged so that the motion of the engine can easily be reversed.

CHAPTER VII.

THE EXPANSIVE ACTION OF STEAM.

QUESTION 102. *How is the expansive action of steam, referred to in the answer to question 62, utilized in a steam engine?*

Answer. The valve and its movement are so arranged that the steam-ports, through which steam is admitted to the cylinder, are each open during a portion only of the stroke of the piston. When the piston has moved through a part of its stroke, the port through which steam is entering the cylinder is closed, without allowing the steam which has been

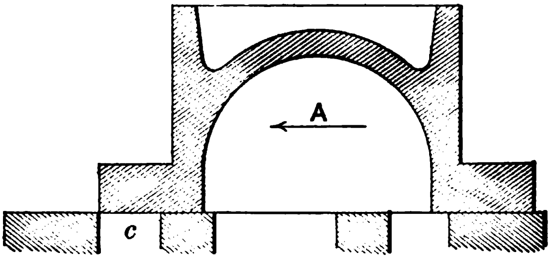


Fig. 48.

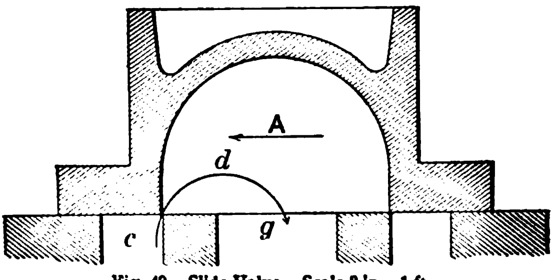


Fig. 49. Slide-Valve. Scale 3 in.—1 ft.

admitted to the cylinder to escape, until the piston has nearly reached the end of its stroke. Consequently, when the steam is thus enclosed, or "cut-off"* as it is termed, its expansive action continues to exert a diminishing pressure against the piston until the exhaust-port is opened. Thus, in fig. 35, it will be seen that the valve has nearly closed the steam-port, although the piston has not yet reached the end of its stroke. Fig. 48 shows the valve on an enlarged scale in the position it occupies when the steam-port, *c*, is first closed; and in fig. 49 the valve is represented after it has moved far enough to begin to open communication from the steam-port, *c*, to the exhaust-port, *g*, as indicated by the dart, *d*. While the valve is moving from the position in which it is shown in fig. 48 to that represented in fig. 49, it is evident that the steam-port, *c*, will be covered by the valve, and therefore during that period the steam is confined in the front end of the cylinder and expands as the piston advances. It thus exerts a pressure on the piston after the steam-port is closed. As the piston advances, and the space or volume occupied by the steam in the cylinder is increased, the pressure of the steam is reduced as was explained in answer to question 64.

QUESTION 103. *How can we know how much pressure is exerted by the steam during expansion?*

Answer. As explained in answer to question 64, the pressure of air or steam *is inversely proportional* to its volume. This can be shown if we have a cylinder, *A*, which is shown in section in fig. 50, with a piston, *P*, fitted so as to work air-tight in the cylinder. If the space in front † of the piston is filled with air of 15 lbs. absolute pressure per square inch, which is equal to the ordinary atmospheric pressure. Let it be supposed that a tube, *T*, is screwed into the cylinder just in front of the piston, *P*, and that this tube also has a small piston, *P*, whose area is just one square inch, fitted in it, so as to work air-tight from one end to the other, and that a spiral spring, *s*, inside of the tube, bears on top of the piston, *p*. The tension of this spring is such that for every 10 lbs. of pressure exerted below the piston it will be moved upward a distance equal to the spaces between the horizontal lines drawn behind the tube.

The spring is also proportioned so that if there was no pressure or a vacuum below the piston, *P*, the air above it would extend the spring and force the piston downward so that it would then rest on the bottom of the tube, but as there is supposed to be atmospheric pressure both above

* The steam is said to be "*cut-off*" when the steam-port or opening by which steam is admitted to the cylinder is closed by the valve.

† The piston-rods of locomotives almost always pass through the back cylinder-heads. Therefore the opposite end becomes the *front* of the cylinder and it will be so designated hereafter.

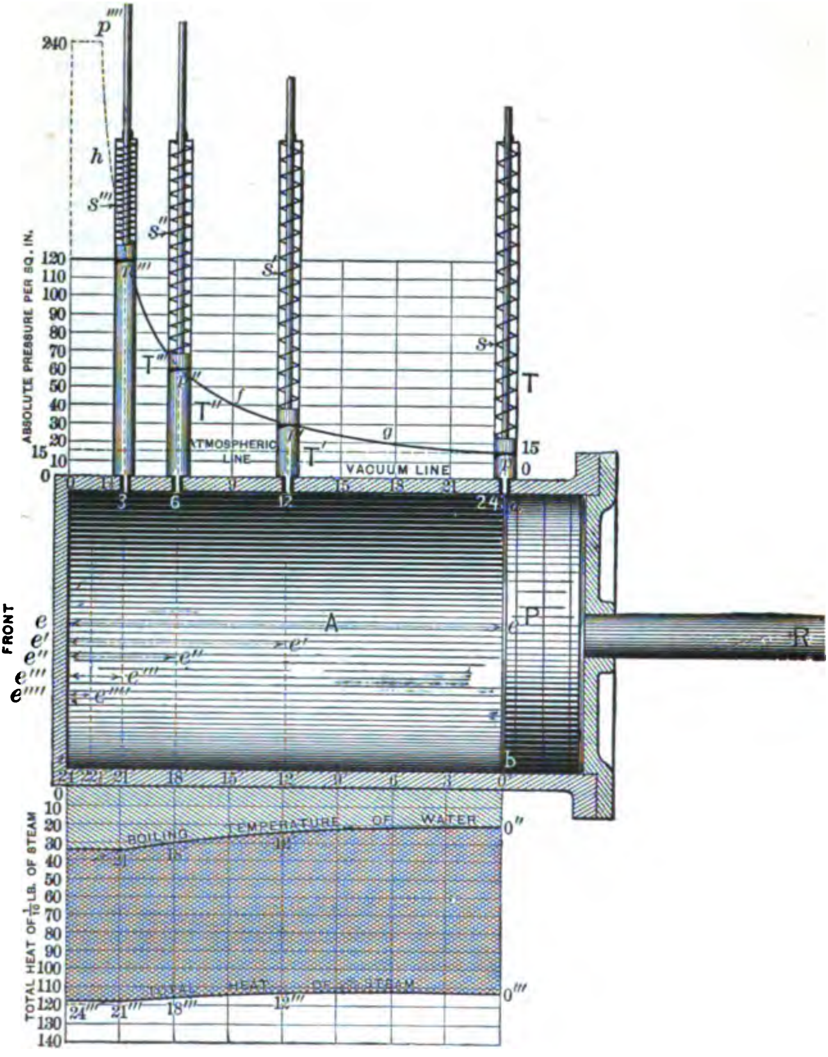


Fig. 50. Cylinder, Piston and Diagrams, to show the effect of Compression and Expansion of Air and the Properties of Steam.

and below the piston, its lower side, *p*, stands at a distance equal to 1½ times the spaces between the horizontal lines above the bottom of the tube. If there was a vacuum below the piston it would be forced down to the bottom by the air above it, therefore, a horizontal line, *o o*, corresponding with that position is called the "*Vacuum Line*," and as the piston would stand at a distance of 1½, the spaces between the lines above *o o*, when there is atmospheric pressure both above and below it, a dotted horizontal line, 15 15, is drawn through this position and is called the "*Atmospheric Line*." As explained before, the horizontal lines are drawn and the spring, *T*, is so proportioned that for every 10 lbs. of pressure exerted below the piston it is pushed up a distance equal to the spaces between the lines. Consequently the pressures corresponding to the position of these lines, above the vacuum line, *o o*, are marked on the left-hand side of the engraving, and the position of the piston in relation to these lines will thus indicate the pressure below it. Its position, at *p*, shows that there is an absolute pressure of 15 lbs., equal to atmospheric pressure, under it.

If, now, we should push the piston-rod, *R*, forward so as to move the piston, *P*, towards the front end of the cylinder, the air enclosed in it would be compressed. Let it be supposed that it is moved so that the face, *a b*, of the piston corresponds with the dotted line, 12 12′, and that the distance, *e′ e′*, of the face from the front head is only half of *e e*. The air in front of the piston would then be compressed into half the space it occupied before, and, as explained in answer to Question 64, its pressure will then be doubled. If, now, the cylinder, *A*, had another tube, *T′*, like *T*, located above the line, 12 12′, then when the piston, *P*, reached the line, 12 12′, the air which is compressed in the front end of the cylinder, *A*, would force the piston, *p′*, upward, in *T′*, until its lower side corresponds with the horizontal line, marked 30, thus indicating that the pressure, in *A*, is equal to 30 lbs. per square inch. If the piston, *P*, is pushed still further forward, to 6 18′, so that its distance, *e″ e″*, from the front end of the cylinder, is only half of *e′e′*, the pressure of the air will again be doubled, or would be equal to 60 lbs. per square inch, as would be indicated by the piston, *p″*, in the tube, *T″*. If the piston, *P*, was moved to 3 21′, the distance, *e‴ e‴*, would be only ⅛ the distance, *e e*, so that the air which originally had a pressure of 15 lbs. would now have 120 lbs., which would be indicated by the piston, *p‴*. The positions of the pistons, *p p′ p″* and *p‴*, will thus show the pressure when the piston, *P*, is in the positions 24 0′, 12 12′, 6 18′ and 3 21′.

If the piston, *P*, was pushed still nearer to the front end of the cylinder so that *e'''' e''''* was equal to ½ of *e''' e'''*, or only 1½ inches, then the pressure of the air would again be doubled, and be 240 lbs., and if there was another tube and piston similar to *T''*, but of sufficient length, its piston would be forced up to *p''''*, and would then indicate the pressure after the air, which filled the whole cylinder, was compressed sixteen times.

If we draw a curve, *p'''' p''' p'' p' p*, through the positions of the pistons which indicate the pressure, then the distance of this curve above the vacuum line, *o o*, will show the pressure in the cylinder, *A*, during the whole period while the piston, *P*, is moving from 24 0′ to 1½ 22½′. Thus, when it has moved from 0′ to 6′, or 6 inches of its stroke, the pressure is then measured by the vertical distance, *18 g*, of the curve above the vacuum line, and when it has moved from 0′ to 15′, or 15 inches, the pressure is measured by *9 f*.

If, on the other hand, air of a higher pressure is allowed to expand in a cylinder so as to have a lower pressure, just the reverse action takes place. Thus, if the piston, *P*, occupied the position, 3 21′, so that the distance, *e''' e'''*, of its face was 3 inches from the front end of the cylinder, and the space, 0 3 21′ 24′, was filled with air of 120 lbs. pressure, and it was then allowed to expand and push the piston to 6 18′, so that the space, 0 6 18′ 24′, occupied, or the volume of the air was double what it was before, then the pressure would be ½ of 120, or 60 lbs. per square inch, which would be indicated by the piston, *p''*. If the piston, *P*, moved to 12 12′, so that the volume of the air was four times what it was at first, its pressure would be ¼ of 120, or 30 lbs., and would be indicated by the piston, *p'*, or if it was expanded to fill the whole cylinder, or to occupy eight times its original volume, its pressure would then be only 15 lbs. If a curve, *p''' p'' p' p*, is drawn through the successive positions of the pistons, *p''' p'' p' p*, this curve will represent the pressure of the air during the whole movement of the piston. Such a curve is called an "expansive curve."

QUESTION 104. *Do all gases act in conformity with Boyle's law as explained in answer to Question 64?*

Answer. All of what are known as fixed gases—that is, those which cannot be readily liquefied by cold or pressure—with slight variations, act in accordance with this law, but steam and some other gases, which can be condensed easily, vary somewhat from it, as was explained in answer to Question 67. Some of the reasons for this variation are not yet thoroughly understood, and the explanation of those which are would require the use of mathematics, and the explanation of abstruse scientific principles, which would be out of place in an elementary book like this. For the present these variations may be disregarded, as all that is now aimed at is to give a general idea of the nature of the law which governs the volume and pressure of gases.

In calculating the pressure of steam before and after compression or expansion, it must always be kept in mind that the absolute pressure must be taken in making the calculations. The working pressure can then be ascertained by deducting the atmospheric pressure, or 15 lbs. per square inch, from the results of the calculations.

QUESTION 105. *How may an expansive curve be most easily drawn?*

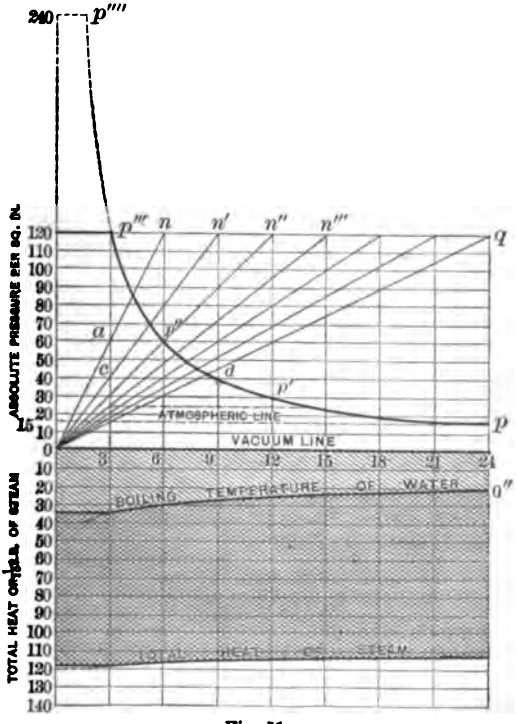


Fig. 51.

Answer. As such curves nearly always represent the expansion of steam in a cylinder, a horizontal line, 0 24, fig. 51, should be first laid down to any convenient scale to represent the "*stroke*"* of the piston, and this line should then be subdivided into any convenient number of divisions, and vertical lines drawn through these subdivisions. The line, 0 24, may then be regarded as the vacuum line. Supposing now that it is desired to lay down an expansion curve for steam of 120 lbs. absolute pressure, which fills 3 inches in length of the cylinder, shown in fig. 50. On the left hand vertical line of fig. 51 lay off to any convenient scale, a distance, 0 120 above 0 24, representing the steam pressure. As the steam fills 3 inches of the cylinder, draw a horizontal line, 120 p''', equal to 3 inches. The rectangle, 120 p''' 3 0, will then represent the volume of the steam before expansion, which is supposed to begin at p'''. By the rule given in answer to Question 65, calculate the pressure of the steam from any degree of expansion, say to double its volume, which would give a pressure of 60 lbs. On the vertical line, *6 n*—which is twice as far from *o*, the beginning of the stroke, as *3* p''' is—lay off, *6* p'', equal to the pressure, 60 lbs., after expansion has taken place. In a similar way calculate for a four-fold expansion, and lay off on *12* n'', *12* p'=to 30, and for eight-fold lay off *24* p=to 15, on *24 q*. Now, through the points thus laid off, draw the curve, p''' p'' p' p, which will be the expansion-curve. In practice it is well to calculate the pressure for more points of the stroke in order to be able to lay down the curve accurately.

Another method of drawing such a curve without calculations is to lay down the rectangle, 120 p''' 3 0, to represent the volume and pressure of the steam. Extend the line, 120 p''', parallel to 0 24, to *q*. To find the pressure at any point of the stroke, 6, for example, corresponding to the volume, 0 6, draw the vertical *6 n*, and draw a line, *o n*, through 0, the extremity of 0 24, and *n* the intersection of *6 n*, with 120 *q*. Then draw a horizontal line, *a* p'', through *a*, the intersection of *o n* with *3* p''', and the intersection of *a* p'' with the vertical, *6 n*, will then represent the pressure at 6 inches of the stroke and it will be one point in the curve. Any number of other points may be obtained in the same way—as *d*, by drawing *9* n', *o* n' and *c d*—and the curve can then be drawn through these points.†

QUESTION 106. *How can the relation existing between the heat, pressure and volume of steam be shown?*

Answer. The table which is published in Appendix I, gives the pres-

* The "*stroke*" of the piston is the distance it moves in the cylinder, and in ordinary engines is always twice the length of the crank, measured from centre to centre of the shaft and crank-pin.

† From Steam, by William Ripper.

sure, the temperature, the total heat, the weight and the relative volume of steam compared with the water from which it was raised, and a study of this table will give an idea of the relation referred to. But as it is difficult to get a clear conception of a general law from so many figures, this relation is illustrated by a diagram in fig. 50. The cylinder, *A*, is supposed to hold just $\frac{1}{10}$ of a pound of steam, at atmospheric pressure, or 15 lbs. absolute per square inch. If now the piston, *P*, was in the position represented in fig. 50, and $\frac{1}{10}$ of a pound of water was put into the cylinder, and heat was applied to it, it would be necessary to heat the water to 212 degrees before it will boil. To represent this heat, the vertical line, 24 0′, is extended below the horizontal line, 24′ 0′. To heat $\frac{1}{10}$ of a pound of water to 212 degrees takes 21.2 units of heat, which is laid off from *o*′ to *o*″ to the scale represented by the horizontal lines. But, as shown in the table in the appendix, after the water begins to boil, 96.6 more units of heat must be added to it to convert it all into steam of atmospheric pressure. This number of units of heat is, therefore, laid off from *o*″ to *o*‴. If the piston is moved to 12 12′, the middle of the cylinder, and $\frac{1}{10}$ of a pound of water is again put into it, and it is all converted into steam, it will have a pressure of 30 lbs. per square inch, as it occupies only half the volume that the same quantity of steam did before. To make water boil under a pressure of 30 lbs., it must be heated to a temperature of 250.4 degrees, which in this case will require 25 units of heat, which is laid down from 12′ to 12″. To convert the water into steam, after it begins to boil, will require 93.9 more units of heat, which is also laid down from 12″ to 12‴. In the same way the total heat to boil and convert $\frac{1}{10}$ of a pound of water into steam of 60 and 120 lbs. pressure, is taken from the table in the Appendix, and laid down on 18′ 18‴ and 21′ 21‴, and the two curves, 21″ 18″ 12″ 0″ and 21‴ 18‴ 12‴ 0‴, are drawn through the points which have been laid down. The vertical distance of the one curve, from 24′ 0′, represents the heat required to boil $\frac{1}{10}$ of a pound of water at the pressures indicated by the curve, *p*‴ *p*″ *p*′ *p*, above, and the vertical distance of the curve, 21‴ 18‴ 12‴ 0‴, from 24′ 0′, represents the *total units of heat* required to convert $\frac{1}{10}$ of a pound of water into steam of a volume indicated by the horizontal distance of any point of the curve from 24′ 24‴, and when pressure is indicated by the expansion curve above. This curve, and the heat diagram, may be very conveniently combined, by adding the latter below the vacuum line, as shown in fig. 51. The relation of the volume pressure and total heat is thus shown very clearly.

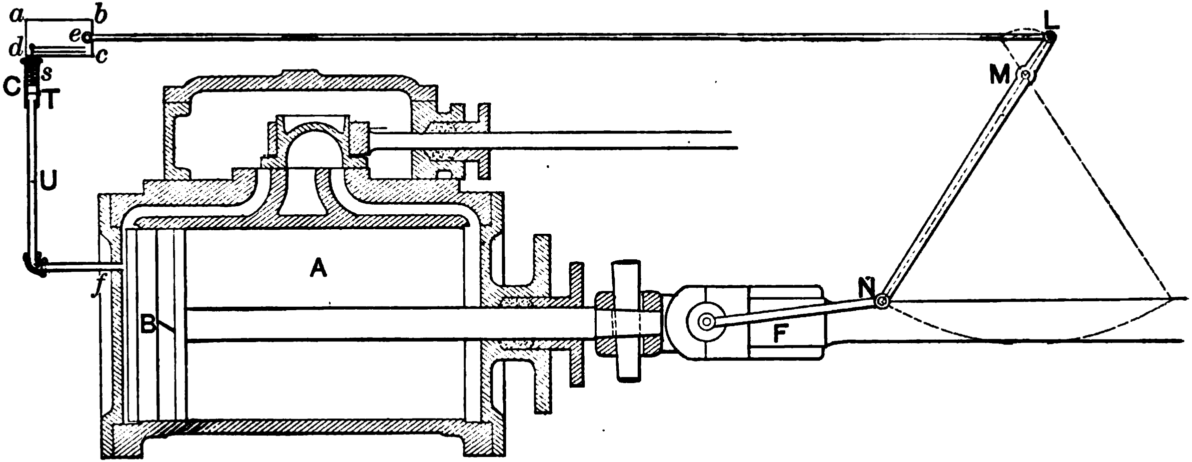


Fig. 52. Cylinder, Piston and Steam Indicator. Scale ¾ in.—1 ft.

QUESTION 107. *What is the relative quantity of heat required to convert a given weight of water into steam of different pressures?*

Answer. As has been stated the total quantity of heat required to convert 1 lb. of water under different pressures into steam is given in the table in Appendix I. From this table it may be learned that it takes 1,178.1 units of heat to convert 1 lb. of water into steam of atmospheric pressure, and only 39 units more is required to increase the pressure to 120 lbs. absolute, while an addition of 17.2 units would then double the pressure, or make it 240 lbs. The slight addition to the temperature required to generate steam of high pressure, is also shown in the heat diagram in figs. 50 and 51. The relative quantity of heat required to generate steam of different pressures is a fact of very great importance in relation to the economical use of steam, and which will be more fully explained farther on.

QUESTION 108. *How can we determine by experiment the pressure of the steam in the cylinder of a steam engine at all points of the stroke of the piston?*

Answer. By the use of an instrument made for that purpose, called an *indicator.* Its action can be best explained by supposing that we have a small cylinder, *C,* with a piston, *T,* fig. 52 (shown on an enlarged scale in

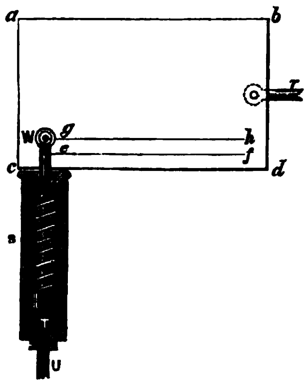


Fig. 53. Steam Indicator. Scale ¼ in.=1 in.

fig. 53), and that the cylinder is connected by a pipe, *U,* to the front end, *f,* of the cylinder, *A,* so that when steam is admitted to that end, it will be conducted to *C,* through the pipe, *U.* Over the small piston, *T,* and attached to it is a spiral spring, *s*, which is compressed when the piston rises, and extended when it falls. To the top of the piston-rod, *V*, fig. 53, a pencil, *W*, is attached. Behind this pencil we will suppose there is a card, *a b d c*, and that this card is so arranged that it can slide horizontally and in contact with the pencil point. With only the pressure of the atmosphere above and below the piston, *T*, the spring would be neither compressed or extended, and the piston would then stand in the position shown in fig. 53. If, now, we move the card horizontally, the pencil will draw the atmospheric line, *g h*. We will now suppose that the tension of the spring is such that a pressure of 10 lbs. per square inch above or below the piston will either extend or compress the spring ¼ inch. In other words, every pound of pressure per square inch in the piston will move it $\frac{1}{40}$ of an inch. If we could produce a vacuum under the piston, it would be pressed down by the atmosphere above it $\frac{15}{40}$, or ⅜ of an inch. If, when it is thus depressed, we again slide the card along in contact with the pencil point, it will draw the vacuum line, *e f*. Assuming that we have drawn these two lines, and that the piston and card are in the position shown in figs. 52 and 53, we will then suppose that a reciprocating motion can be given to the card by the lever, *L M N*, fig. 52, which is pivoted, at *M*, and attached, at *N*, to the cross-head by a short connecting-rod, *F*. It is obvious that by connecting the upper end, *L*, of the lever, by a rod, *L e*, to the card, *a b c d*, the latter will be moved backwards and forwards by the motion of the piston, *B*, and cross-head, *F*, and that the motion of the card will be simultaneous with that of the piston, but of shorter stroke. We will assume that the stroke of the card is equal to the length of the atmospheric and vacuum lines, *g h* and *e f*, fig. 53. If, now, the piston being at the beginning of the stroke, as shown in fig. 52, steam of 85 lbs. effective pressure per square inch (which is equal to 100 lbs, absolute pressure) is admitted into the cylinder, *A*, it will be conveyed through the pipe, *f U*, to the cylinder, *C*, and will force up the piston $\frac{85}{40}$ or 2⅛ inches above the atmospheric line, or $\frac{100}{40}$ or 2½ inches above the vacuum line, as shown in fig. 54, and the pencil will draw a vertical line, *g i*, on the card (represented by a dotted line in fig. 54). We will suppose further that steam is admitted during 8 inches of the stroke and is then cut off. When the piston, *B*, fig. 52, has moved that distance, which is ⅓ of its stroke, the card will also have moved ⅓ of its stroke, and will stand in relation to the pencil in the position represented in fig. 55, and as the absolute steam pressure in the cylinder was maintained at 100 lbs. while the card was moving that distance, the pencil will have drawn a

Fig. 54.

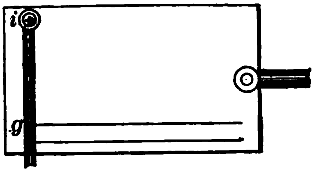


Fig. 55.

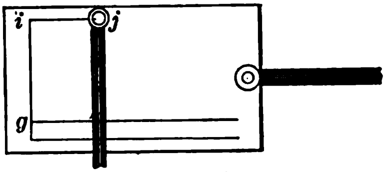


Fig. 56.

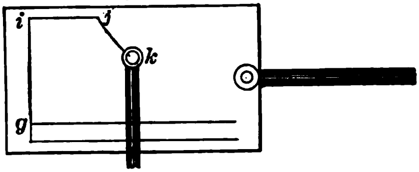
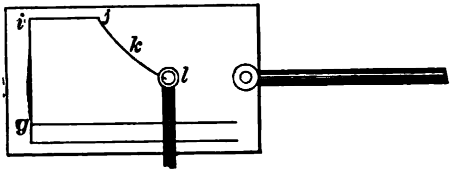


Fig. 57.



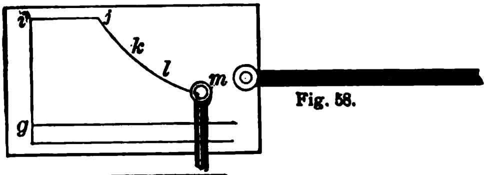


Fig. 58.

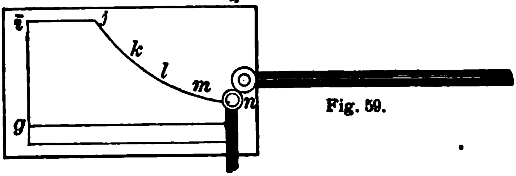


Fig. 59.

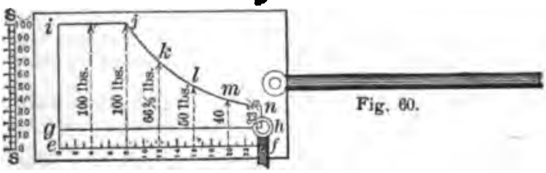


Fig. 60.

Steam Indicator Cards. Scale ¼ in.—1 in.

horizontal line, *i j*. The steam is now cut off and begins to expand, and its pressure is thereby reduced. When the piston of the engine is at half-stroke, the card will also be at half-stroke, and the steam will be expanded from 8 to 12 inches of the stroke. By the rule given in the answer to question 65, its absolute pressure would then be $66\frac{2}{3}$ lbs., and the indicator-piston will then be pressed down by the spring, so that the pencil will stand in the position shown in fig. 56, or $\frac{66\frac{2}{3}}{40}$ of an inch above the atmospheric line. The pencil meanwhile will have drawn the curved line, *j k*. When the piston has moved 16 inches, the steam will be expanded to double its volume, and its absolute pressure will therefore be 50 lbs., and consequently the pencil will stand $\frac{50}{40}$, or $1\frac{1}{4}$ inches above the atmospheric line, as shown in fig. 57, and the pencil will have continued the curve, *j k* to *l*. At 20 inches the steam will have 40 lbs., and at the completion of the stroke $33\frac{1}{3}$ lbs. absolute pressure, and the pencil will have completed the curve, *j k l m n*, as shown in figs. 58 and 59. This is the *expansion curve*, which has already been described, and its form approximates to what mathematicians call a hyperbolic curve. If the steam is exhausted, the indicator-piston will descend and carry the pencil down to the atmospheric line, and the vertical line, *n h*, fig. 60, will be drawn. On the return stroke, after the steam is exhausted from the engine cylinder, *A*, fig. 52, the pencil would draw the atmospheric line, *h g*, fig. 60, thus showing that there is no steam pressure under the piston.

Such a diagram is called an *indicator diagram*.* In practice there are a great many influences which modify it, such as condensation, performance of work, imperfection of valve gear, etc., but for the present these are disregarded.

QUESTION 109. *How can we ascertain the pressure of the steam for any point of the stroke from such a diagram?*

Answer. By measuring the vertical distance of the expansion curve (fig. 60) from the vacuum or the atmospheric line, as for example 8 *j*, 12 *k*, 16 *l*, 20 *m*. As the indicator spring is extended or compressed $\frac{1}{40}$ of an inch † for every pound of pressure per square inch, either above or below the indicator-piston, if we construct a scale, *S S*, fig. 60, divided into divisions of $\frac{1}{40}$ of an inch each, one of them will represent 1 lb.

* The indicator used in practice, to show the action of the steam in the cylinders of steam engines, differs essentially in its construction from that which we have described. The principles of operation are, however, the same in both. The construction of indicators is explained in another chapter.

† Indicator springs are used of various degrees of tension, in proportion to the steam pressure to be indicated.

of pressure per square inch if measured vertically from the atmospheric or vacuum line. If we sub-divide the vacuum line with the same number of parts as there are inches in the stroke of the piston (see fig. 61) we can draw vertical lines from these points and thus determine the pressure by comparing the length of such lines with the scale, *S S*, fig. 60. Thus, the line, 8 *j*, measures $\frac{100}{40}$ of an inch, thus showing that the absolute steam pressure at 8 inches of the stroke was 100 lbs. per square inch; the line 12 *k* measures $\frac{66\frac{2}{3}}{40}$ of an inch, thus showing that at 12 inches of the stroke the steam pressure was 66⅔ lbs. At 16, 20 and 24 inches of the stroke the vertical lines measure $\frac{50}{40}$, $\frac{40}{40}$ and $\frac{33\frac{1}{3}}{40}$; and, therefore, the number of fortieths represents the pounds of steam pressure when the piston was at the points of the stroke named. Similar measurements could be made from other points, such as 2, 6, 10 or any other number of inches of the stroke. Of course, if we measure from the vacuum line we will have the absolute steam pressure, or the pressure *above a vacuum*, as it is sometimes called; if we measure from the atmospheric line we will have the effective pressure, or the *pressure above the atmosphere.*

QUESTION 110. *How can we determine the average pressure during the whole stroke of steam which works expansively?*

Answer. This can be determined approximately by the following method: In the first place, divide the vacuum line (fig. 61) into any number of equal divisions, say six. From the points of division, 4, 8, 12, 16 and 20, which in this case correspond with the points which represent inches of the stroke, draw perpendicular lines, which will divide the indicator diagram into six divisions. It is obvious that during the time the steam is working full stroke the pressure is uniformly 100 lbs. absolute. While the piston is moving from 8 to 12 inches, the pressure falls from 100 to 66⅔ lbs., so that at 10 inches we have very nearly the average pressure

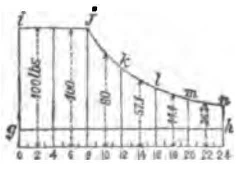


Fig. 61. Steam Indicator Diagram.

during the period named. So from 12 to 16, 16 to 20 and 20 to 24 the average is nearly 57.1, 44.4 and 36.3 lbs., respectively. BY ADDING TOGETHER THE PRESSURES IN THE MIDDLE OF EACH ONE OF A NUMBER OF

EQUAL DIVISIONS OF THE STROKE AND DIVIDING BY THE NUMBER OF DIVISIONS, WE WILL OBTAIN APPROXIMATELY THE AVERAGE ABSOLUTE PRESSURE DURING THE WHOLE STROKE. TO GET THE AVERAGE EFFECTIVE PRESSURE, DEDUCT THE ATMOSPHERIC PRESSURE FROM THE RESULT. The calculation would, in the above case, be as follows:

100	lbs.
100	"
80	"
57.1	
44.4	
36.3	
6)417.8	
69.6	=average absolute pressure.
15	
54.6	=average effective pressure.

A more accurate way of calculating the average or mean pressure, as it is called, when steam is used expansively, and the one which is usually employed, is to DIVIDE THE LENGTH OF THE PISTON'S STROKE IN INCHES BY THE NUMBER OF INCHES AT WHICH THE STEAM IS CUT OFF: THE QUOTENT IS THE RATIO OF EXPANSION. GET THE HYPERBOLIC LOGARITHM OF THE RATIO OF EXPANSION FROM THE TABLE OF LOGARITHMS (in Appendix II.), ADD 1 TO IT, AND DIVIDE THE SUM BY THE RATIO OF EXPANSION AND MULTIPLY THE QUOTENT BY THE MEAN ABSOLUTE STEAM PRESSURE IN THE CYLINDER DURING ITS ADMISSION. THE RESULT WILL BE THE MEAN ABSOLUTE PRESSURE DURING THE STROKE. TO GET THE MEAN EFFECTIVE PRESSURE, DEDUCT THE ATMOSPHERIC PRESSURE.

The calculation for the above example would be as follows:

$$\frac{24}{8}=3=\text{ratio of expansion.}$$

$$\frac{1.0986+1}{3}\times 100=69.95=\text{mean absolute pressure.}$$

$$69.95-15=54.95=\text{mean effective pressure.}$$

QUESTION 111. *How can the power which a locomotive will exert be increased or diminished in proportion to the work to be done?*

Answer. It can be done either by "throttling" the steam, that is by opening the throttle-valve only a short distance, so that the pressure in the cylinders will be less than that in the boiler; or, the steam can be worked expansively by allowing it to enter the cylinders during a portion only of the stroke, and the flow can then be "cut off," as it is called, that is, the steam passages through which the steam enters the cylinders are closed when the piston has moved through a part, say a half, a third or a quarter of the stroke, and the steam then expands during the rest of the stroke. As the work which a locomotive must do is constantly varying, it is important to know whether it is more advantageous to throttle the steam or work it expansively.

QUESTION 112. *What advantages result from using steam expansively?*

Answer. The most important one is that considerably more work can be done with a given amount of steam and fuel if the steam generated thereby is worked expansively than if it is not.

Next, the pressure exerted on the crank is equalized by expansive action, and lastly, the strain and shocks to the mechanism which are produced by the rapid motion of the piston and other reciprocating and revolving parts of the engine are very much diminished by allowing the steam to expand, and thus become reduced in pressure during the latter part of the stroke.

The expansive force of steam represents energy or capacity of doing work, and, therefore, if we allow it to escape with a comparatively high pressure without doing work, it is a waste of energy.

QUESTION 113. *What question must usually be considered in operating locomotives?*

Answer. It must be determined whether it is more economical to use steam of a comparatively high pressure in the boiler and a high degree of expansion in the cylinders, or, whether the pressure of the steam should be reduced before it enters the cylinders, by partially closing the throttle-valve, and then expanding it less in the cylinders.

QUESTION 114. *How can the advantages of high boiler pressure and high degrees of expansion over lower pressure and less expansion be shown?*

Answer. By comparing the work done by a given weight of steam of different volumes and pressures. Thus, in fig. 62, the shaded area represents the volume of $\frac{1}{10}$ of a pound of steam of 120 lbs. pressure per square inch, which is supposed to be admitted into the cylinder, shown in fig. 50, which is 15.4 inches in diameter, and the piston has 24 inch stroke. The quantity of steam represented in fig. 62 would occupy $\frac{1}{8}$ of the

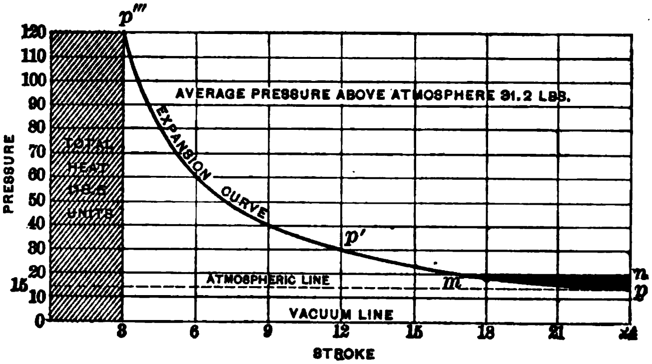


Fig. 62.

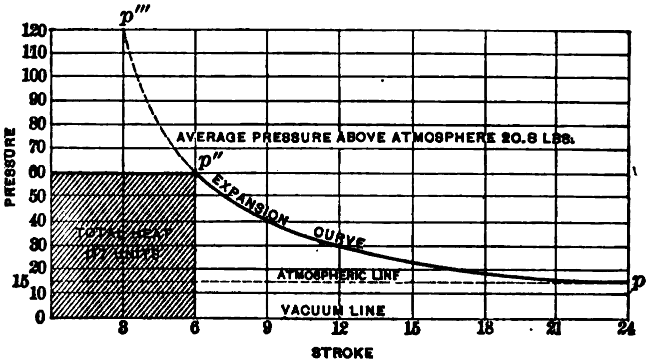


Fig 63.

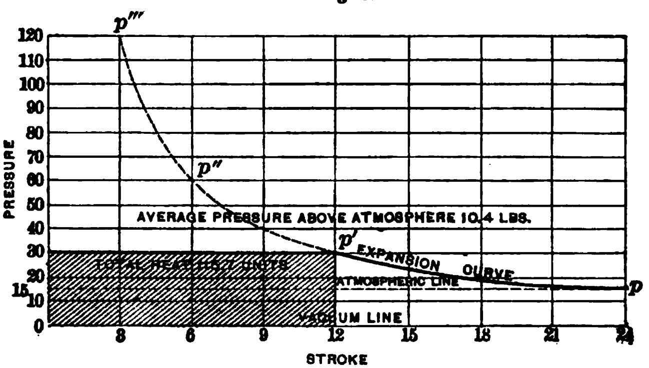


Fig. 64.

cylinder or 3 inches of its length* and can therefore expand eight times. By the rule given in answer to Question 110, we find that under these conditions the average pressure above the atmosphere during the whole stroke will be 31.2 lbs. The same weight of steam of 60 lbs. pressure will fill $\frac{1}{4}$ of the cylinder, as shown by the shaded area in fig. 63, and if expanded four times, will have an average pressure of 20.8 lbs. At 30 lbs. pressure, $\frac{1}{10}$ of a pound of steam will fill half the cylinder, as shown in fig. 64, and if expanded twice, will have an average pressure of 10.4 lbs. The total heat of $\frac{1}{10}$ of a pound of steam at the different pressures assumed would be as follows:

At 120 lbs. pressure per square inch........118.5 units.
" 60 " " " " ....117.0 "
" 30 " " " " ....115.7 "

The area of a piston 15.4 inches diameter is 186.2 square inches, and its stroke in this instance is 2 feet. By multiplying the average pressure in pounds per square inch into the area of the piston in square inches, will give the total average pressure on the piston, and by multiplying this by the stroke in feet, will give the number of foot-pounds of work done during each stroke, as follows:

$31.2 \times 186.2 \times 2 = 11{,}618.8$ foot pounds.
$20.8 \times 186.2 \times 2 = 7{,}745.9$ " "
$10.4 \times 186.2 \times 2 = 3{,}872.9$ " "

If we now divide the amount of work done in foot-pounds by the units of heat in the steam, it will show the amount of work done per unit of heat, and show the theoretical difference there is in working steam of a high pressure and a high degree of expansion, compared with the use of steam of low pressure and corresponding expansion. Such a calculation has been made and is given in the following table:

* In making these calculations the volume of one-tenth of a pound of steam of atmospheric pressure has been taken at 4,466.8 cubic inches, which is the capacity of a cylinder of the dimensions given. The volume of steam has then been assumed to be inversely proportional to its pressure. This is not exactly correct as the volume of steam of greater pressure, owing to its higher temperature, is more than has been given. The data have been assumed only to illustrate a principle and not to reach precise results.

PRESSURE, TOTAL HEAT AND WORK DONE DURING 1 STROKE BY $\frac{1}{16}$ OF A POUND OF STEAM WITH DIFFERENT RATIOS OF EXPANSION IN A CYLINDER 15.4 INCHES DIAMETER AND 2 FEET STROKE OF PISTON.

ABSOLUTE INITIAL PRESSURE.	AVERAGE PRESSURE.	RATIO OF EXPANSION.	TOTAL HEAT.	WORK DONE.	WORK DONE PER UNIT OF HEAT.
Lbs. per sq. inch.	Lbs. per sq. inch.		Units.	Foot-pounds.	Foot-pounds.
120	31.2	8	118.5	11,681.8	98.5
60	20.8	4	117.0	7,745.9	65.8
30	10.4	2	115.7	3,872.9	33.4

From the calculations—the results of which are given in the last column of the table—it will be seen that with steam of 120 lbs. pressure expanded eight times, a given quantity of heat should do nearly three times as much work as the same quantity of heat will, if steam of 30 lbs. pressure is used and expanded to twice its volume.

QUESTION 115. *Can the principle of the increased efficiency of steam with increased pressures be shown graphically?*

Answer. Yes; this can be shown by a comparison of figs. 62, 63 and 64. In fig. 64 the shaded area, *30 p' 12 o*, represents the volume and pressure of $\frac{1}{16}$ of a pound of steam of 30 lbs. absolute pressure, and the area, *30 p' p 15*, represents the useful work which it will do; its total heat is 115.7 units. In fig. 63, *60 p'' 6 o*, represents the volume and pressure of $\frac{1}{16}$ of a pound of steam of 60 lbs. pressure. The total heat of this is 117 units, and the area, *60 p'' p 15*, represents the work done by it. It will be seen, then, that by the addition of 1.3 units of heat to the steam represented in fig. 64, that the work done by it would have been increased by an amount equal to the area, *60 p'' p' 30*, in fig. 64. By comparing fig. 62 with 64 it will be seen that the shaded area, *120 p''' 3 o*, represents the volume and pressure of $\frac{1}{16}$ lb. of steam of 120 lbs. pressure, and the area, *120 p''' p' p 15*, the work done by it, and that its total heat is 118.5 units. Therefore, if 2.8 units of heat had been added to the steam represented in fig. 64, its energy would have been increased by the area, *120 p''' p'' p' 30*.

QUESTION 116. *Can it be shown in any other way why it is economical to work steam expansively?*

Answer. Yes; it can be shown from the "total heat" contained in a given quantity of steam used expansively and that in steam which has been used without expansion, and then comparing the two quantities with the amount of work done under the two different conditions.

For the basis of the calculation, a cylinder of 16 inches diameter, and piston with 24 inch stroke, and steam of 100 lbs. absolute pressure cut off at 8 inches of the stroke, will be taken. It will be supposed, further, that the steam used is generated from water of a temperature of 60 degrees, and the total number of units of heat in the steam used for each stroke of the piston will then be calculated. The area of a piston 16 inches in diameter is 201 square inches; and as the steam is admitted until the piston moves 8 inches of its stroke, therefore, the quantity of steam would be 8 times 201 cubic inches, or

$$201 \times 8 = 1{,}608 \text{ cubic inches} = \frac{1{,}608}{1{,}728} \text{ cubic feet.}$$

From the table it will be seen that 1 cubic foot of steam of 100 lbs. pressure weighs 0.2307 lbs.; therefore, the weight of the fraction of a cubic foot given above would be calculated as follows:

$$\frac{.2307 \times 1{,}608}{1{,}728} = .2146 \text{ lbs.} = \text{weight of 1608 cubic inches of steam of 100 lbs.}$$

absolute pressure.

From the table it will be seen that the total heat above zero of steam of 100 lbs. absolute pressure is 1,213.4 degrees. It was explained in the answer to Question 79, that 1 lb. of water heated 1 degree is the standard of measurement or *unit of heat*. Now, if we have 1 lb. of water with a temperature of zero, evidently it will take 1,213.4 *units of heat* to convert it into steam of 100 lbs. absolute pressure. But as the water from which our steam was generated had a temperature of 60 degrees, we must deduct that much from 1,213.4: 1,213.4—60.=1,153.4=units of heat in 1 lb. of steam of 100 lbs. absolute pressure generated from water of 60 degrees temperature.

If then 1 lb. of steam has 1,153.4 units of heat, the following calculation will give the units of heat in .2146 lbs,: 1,153.4 × .2146=247.51 =units of heat in .2146 lbs., or 1,608 cubic inches of steam of 100 lbs. absolute pressure. It was shown in answer to Question 110 that the average pressure of steam of 100 lbs. cut off at 8 inches of the stroke was 69.95 lbs. per square inch. So that if steam of 100 lbs. absolute pressure is used expansively it requires 247.51 units of heat to produce an average absolute pressure of 69.95 lbs. per square inch during the whole stroke. Disregard-ing the small fraction, we will call it 70 lbs. Now, if we admit steam of this pressure through the *whole stroke* of the piston, we will use 4,824 cubic inches. It will be found by a calculation similar to the above, that to generate this quantity of steam of 70 lbs. absolute pressure from water of a temperature of 60 degrees would require 527 units of heat, or more than twice as many as were required to do the same work with steam of 100 lbs. pressure cut off at 8 inches when using it expansively during the rest of the stroke.

There is also an incidental advantage in working steam expansively, because low-pressure steam can be exhausted more quickly from a cylinder than steam of a high pressure, and consequently there is less resistance or *back pressure*, as it is called, in the exhausted end of the cylinder to the movement of the piston.

QUESTION 117. *Does the theoretical economy in using steam increase with the pressure and the degrees of expansion?*

Answer. Yes; this is shown in the following table, in the first column of which the number of inches of the piston stroke is given during which steam is admitted to a cylinder 16 inches in diameter and 24 inch stroke. In the second column is given the pressure of the steam or *initial pressure*, as it is called, which must be admitted into the cylinder in order to produce a mean absolute pressure of 70 lbs. per square inch when it is cut off at the point indicated in the first column. In the third column is given the total heat which is required to generate the steam required in each case, and in the last column the percentage of saving is given, which results from the different degrees of expansion and a mean pressure of 70 lbs. per square inch in each case.

RESULTS OF USING STEAM EXPANSIVELY.

PERIOD OF ADMISSION OR POINT OF CUT-OFF.	INITIAL ABSOLUTE PRESSURE OF STEAM, IN POUNDS PER SQUARE INCH.	TOTAL HEAT OF STEAM USED, IN UNITS.	PERCENTAGE OF SAVING COMPARED WITH FULL STROKE.
Full stroke..	70.	527.	
18 in. — Three-quarters of the stroke........	72.5	408.7	22½
12 in. — One-half " "	82.7	302.8	42½
8 in. — One-third " "	100.	247.5	53
6 in. — One-quarter " "	117.4	216.6	58
4 in. — One-sixth " "	150.5	183.8	65
3 in. — One-eighth " "	181.8	165.8	68½
2 in. — One-twelfth " "	241.4	144.8	72½

From this table it will be seen that if we could get the full advantage of using steam expansively, 22½ per cent. of heat would be saved by cutting off at ¾ of the stroke and using steam of 72.5 lbs. pressure instead of steam of 70 lbs. worked full stroke. Cutting off at ½-stroke and using steam of 82.7 lbs., 42½ per cent. of heat would be saved, and cutting off at ¼-stroke with steam of 117.4 lbs., should save 58 per cent. of heat; and at $\frac{1}{12}$ of the stroke, or expanding steam of 241.4 lbs. pressure to twelve times its volume would save 72½ per cent. of heat.

QUESTION 118. *In practice can we get as much advantage from working steam expansively as the above calculations seem to show is possible?*

Answer. No; it is not possible in steam engines, as they are at present constructed, to convert all the potential energy in steam into actual work. There is more or less loss in all engines from back pressure, clearance in the cylinders and the loss of heat from radiation, and condensation, and other causes is greater when steam of a high pressure is expanded much than when lower pressure steam is admitted through a greater part of the stroke.

QUESTION 119. *What effect does back pressure have when steam is worked expansively?*

Answer. Its effect is to reduce the effective pressure. Thus, in fig. 62, the effective pressure, instead of being 46.2 lbs. per square inch, is only 31.2, owing to the pressure of the atmosphere on the back of the piston. If the area of the piston is 186.2 square inches and the stroke 2 feet, the work done in one stroke will be equal to $186.2 \times 31.2 \times 2 = 11{,}618.8$ foot-pounds. If there was a vacuum behind the piston so that the effective pressure was 46.2 lbs. instead of 31.2, then the work done would be equal to 17,204.8 foot-pounds. In locomotives the back pressure nearly always exceeds the atmospheric pressure, and at high speeds is sometimes twice as great. If the back pressure was 20 lbs. above a vacuum or 5 lbs. above the atmosphere then under the conditions shown in the diagram, fig. 62, the steam pressure in front of the piston from the point, *m* to *p*, would be less than the back pressure behind it, as is indicated by the black area, *m n p*. It is obviously a disadvantage to expand the steam below the back pressure, as the retarding effort of the latter is then greater than the propelling pressure on the opposite side of the piston.

There are also other practical difficulties in the way of using high degrees of expansion. It has been explained that, if steam is cut off early in the stroke and the degree of expansion increased, the pressure and consequently the temperature of the steam must also be increased to do the same amount of work. The danger of explosion is greater with the higher pressures, and stronger and more expensive boilers and machinery are therefore needed. With steam of very high temperature the metal of the cylinders, pistons, and valves becomes so much heated that they soften, and then the friction of the one on the other is liable to cause them to cut or scratch each other. The high temperature at the same time destroys the oil or other lubricant used in contact with the steam. It is also impossible to admit and cut off steam very early in the stroke with the ordinary mechanical appliances used for moving slide-valves of locomotives. This latter difficulty and the effect of expansion in equalizing the pressure on the crank and lessening the strains and shocks on the mechanism of the engine will be more fully explained hereafter.

QUESTION 120. *How may the amount of expansion that can be made practically useful be illustrated and explained?*

Answer. It was shown in answer to Question 110, that if steam of 100 lbs. pressure is admitted into the cylinder during one-third of the stroke, and it is allowed to expand during the rest of the stroke, the mean effective pressure represented by the indicator card shown in fig. 61 will be 54.95 lbs. per square inch. As the stroke of the piston is 2 feet, the number of foot-pounds of work which would be exerted for each square inch of area of the piston during each stroke would be 54.95 x 2=109.9. Let *i j n o p*, fig. 65, represent this card, and let it be supposed that the cylinder is lengthened so that the piston will have 4 feet stroke instead of 2 feet, and that the steam is expanded six times instead of three times. The indicator diagram which the steam would then make would be represented by *i j n k p*. By calculating the mean effective pressure for the whole stroke of 4 feet, in the manner already described, it will be found to be 31.53 lbs. As the pressure is exerted through 4 feet of stroke, the work done per square inch of piston will be 31.53 x 4=126.12 foot-pounds or a gain of nearly 15 per cent. It should be observed that to secure this economy the cylinder and a number of other parts of the engine must be doubled in size. If, as indicated by the black area, fig. 65, the back pressure was double the atmospheric pressure, as it sometimes is in locomotives, then the steam pressure would fall below the back pressure from *c* to *k*. The loss by expansion would therefore be greater than the gain. It will thus be seen that with a given amount of back pressure there is no advantage in carrying expansion beyond a certain point, unless there is a corresponding increase in initial pressure.*

* The pressure of the steam when it is first admitted to the cylinder and before it is cut off is called the *initial pressure*.

QUESTION 121. *What will be the result, if, instead of increasing the size of the cylinder and rate of expansion, we double the "initial pressure" of the steam which is introduced into the cylinder, and then cut it off at $\frac{1}{6}$ of the stroke instead of $\frac{1}{3}$?*

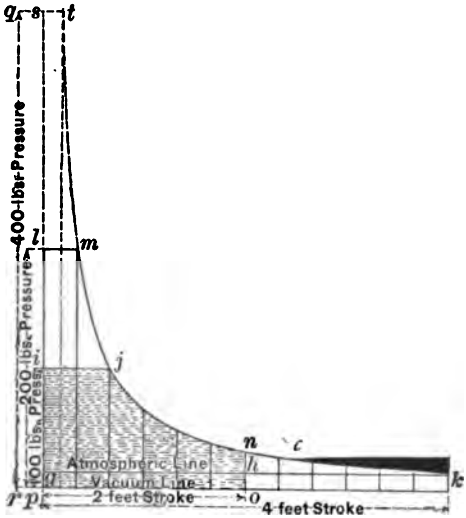


Fig. 65. Steam Indicator Diagram.

Answer. The effect of this can be shown if we draw a diagram, *l m j n o p*, fig. 65, in which the initial pressure represented by the height, *l p*, is 200 lbs. absolute, instead of 100, and the steam is supposed to be cut off at *m*, or at 4 inches of the stroke, instead of 8, and the piston to have a stroke, *p o*, of 2 feet. If the average effective pressure is then calculated as before, it will be found to be 78.06 lbs. per square inch, so that the work done per square inch of area of the piston during each stroke will be 156.12 foot-pounds instead of 109.9, or a gain of over 42 per cent., with steam of 100 lbs. pressure expanded three times. By referring to the table of the properties of steam it will be seen that with 100 lbs. pressure the total heat is 1,213.4, and with 200 it is 1,229.8, a difference of 16.4 degrees or units, or only a little over $1\frac{1}{3}$ per cent. more. That is, theoretically, by adding $1\frac{1}{3}$ per cent. more heat to the steam and expanding it twice as much, there is a gain of 42 per cent. in the amount of work done. To do this, though, the boiler and engine must be made twice as strong to resist these high pressures.

We may assume, still further, that the stroke is lengthened, and the steam of 200 lbs. pressure is expanded twelve times, as indicated by the diagram, *l m j n k p*, and also that the pressure is increased to 400 lbs. with the same degree of expansion as shown by the diagram, *s t m j n o p*, or twenty-four times as represented by *s t k p*. In the following table the calculated results from these high pressures and rates of expansion are given:

1	2	3	4	5	6	7	8	9	10
	Initial Pressure in lbs. per square inch.	Rate of Expansion.	Stroke of Piston.	Average cylinder pressure.	Foot-lbs. of work done per stroke for each inch in area of cylinder.	Percentage of gain.	Boiler, strength of.	Cylinder. Size of	Cylinder. Strength of
			Feet.						
a	100	3	2	54.95	109.09	..	1	1	1
b	100	6	4	31.53	126.12	15	1	2	1
c	200	6	2	78.06	156.12	42	2	1	2
d	200	12	4	43.08	172.32	57·	2	2	2
e	400	12	2	101.00	202.00	83	4	4	2
f	400	24	4	54.6	218.4	100	4	4	4

Column 6 shows the gain in foot-pounds of work done per square inch of piston, and from the increased steam pressure and higher rates of expansion. Column 7 gives the percentage of gain in the work done when compared with the results with steam of an initial pressure of 100 lbs. expanded three times. Column 8 gives the relative strength of the boiler for pressures of 100, 200 and 400 lbs. Columns 9 and 10 give the relative sizes and the strength of cylinders required for the pressures and rates of expansion given in columns 2 and 3. From the horizontal line, *b*, of the table, it will be seen that, by doubling the rate of expansion, there is a gain of 15 per cent., but the cylinder must then be twice as large as before. This means an increase in size and strength of other parts. To gain 42 per cent., by doubling the pressure and rate of expansion, as shown in the line marked *c*, the boiler and cylinder must both be doubled in strength. A gain of 57 per cent., by doubling the pressure and quadrupling the rate of expansion, requires the strength of boiler, and size and strength of engine, all to be doubled, and the gain of 100 per cent. in the last line compels the strength of boiler, and strength and size of cylinder all to be quadrupled. From this table it is obvious that we soon reach a point at which increasing the steam pressure and rate of expansion involves so much expense for the larger size and strength of boiler and engine, that the gain in the work done will not pay for the increased cost.

An inspection of the diagram will also show that it requires a comparatively small increase of back pressure above the atmosphere to neutralize the advantages of the high degrees of expansion. As there always is a considerable amount of back pressure in locomotives, especially at high speeds, it will be seen that there is no economy in carrying expansion beyond certain limits. It should also be explained that there are other causes which have an effect in the economy of expansion. In every engine there is always a very considerable loss of heat from radiation, conduction, and from the conversion of heat into work, and probably from causes not yet perfectly understood.

QUESTION 122. *What is meant by the "clearance" of a piston and cylinder?*

Answer. When the piston of an engine is at the end of its stroke there is always some space left between it and the cylinder-head so that there will be no danger of the one striking the other. The distance between the piston and cylinder-head at the end of the stroke is called the "*clearance.*" Besides this space, the passages between the valve-face and the end of the cylinder must also be filled with steam before the piston begins its stroke. The whole of the spaces between the piston and valve-face is called the *clearance space.*

QUESTION 123. *What effect does the steam which is required to fill the clearance spaces have on the piston?*

Answer. To explain this it will be supposed that the clearance space at each end of the cylinder is equal to $\frac{1}{12}$ of its cubical contents. If steam was used at full pressure during the whole stroke of the piston, it would take $\frac{1}{12}$ more steam for each stroke to move the piston, and this steam would be wasted. But if the steam was allowed to expand in the cylinder, then that which fills the clearance spaces would expand as well as that in the cylinder, and would thus exert pressure on the piston. To illustrate this, let *a b* 24 0, fig. 66, represent a diagram to show the action of steam in a cylinder. It will also be supposed that *a d e* 0 represents the clearance space $= \frac{1}{12}$ the contents of the cylinder. It may now be supposed that while the steam is flowing in to fill this space the piston is standing still, and the steam, therefore, does no work during this period. When the clearance space is filled with steam of initial pressure, the piston begins to move until it reaches p''', where the steam is cut off and begins to act expansively. If now only that part of the cylinder, represented by the area $a\ p'''\ 3\ 0$, was filled with steam, an expansion curve, $p'''\ p''\ p'\ p$, like that represented by the dotted line in fig. 62, would represent the pressure of the steam. But the steam which expands, after it is cut off, is not only that which fills

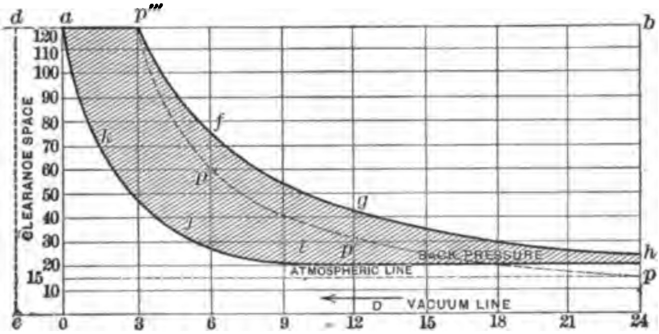


Fig. 66. Diagram showing Effect of Clearance.

the space, $a\ p'''\ 3\ 0$, but that which fills the space, $d\ p'''\ 3\ e$. Consequently, its expansive action is the same as though the cylinder had been lengthened 2 inches, and its contents were equal to $d\ b\ 24\ e$, and 5 instead of 3 inches was filled with steam of initial pressure. Therefore, the curve, $p'''\ f\ g\ h$, represents the pressure of the steam during expansion. The space between the two curves shows the effect of the expansive action of the steam contained in the clearance space.

QUESTION 124. *Is there any waste of steam on account of the clearance spaces?*

Answer. Yes; if live steam must be admitted to fill these spaces it does no useful work while it is being admitted.

QUESTION 125. *Can the loss caused by the clearance spaces be reduced in any way?*

Answer. Yes; by closing the exhaust passage in the cylinder before the end of the stroke of the piston, so that the steam thus enclosed in front of the piston will be compressed and fill the clearance spaces at a pressure and temperature equal to, or nearly equal to that of the steam which enters the cylinder. This is illustrated in fig. 66, in which it is supposed that there is a back pressure of 20 lbs. per square inch, and when the piston is moving in the direction of the dart, *D*, the exhaust-port is closed at *i*, while the piston must still move 10 inches before reaching the end of its stroke. The steam of 20 lbs. pressure in front of it must, therefore, be forced into the clearance space, and will be compressed six times, as indicated by the curve, *i j k a*, so that at the beginning of the stroke its pressure will be 120 lbs., or equal to that of the entering steam. At the beginning of the stroke the clearance space will thus be filled, so that no live steam will be wasted, with the exception of the loss due to escape of heat, leakage and friction, the steam will give out as much power by expansion, as was required to compress it, so that there will be little waste due to compression, if the clearance space, the compression, and the back pressure, are properly proportioned to each other.

QUESTION 126. *What other reasons are there why very high pressures and high degrees of expansion are not economical nor practicable?*

Answer. If steam of high pressure is admitted into a cylinder, the difference between its temperature and that of the cylinder during the period when the steam is exhausted is so great as to condense a considerable portion of the steam. This loss from condensation increases with the difference between the temperature of the steam admitted and that of the cylinder during the time that it is exhausted. This loss finally equals or exceeds what is gained. There is also the difficulty that the valve-gear which is now generally used will not admit steam freely to the cylinders and cut it off short; and next, high rates of expansion require either large cylinders or high initial pressure. In either case, it means that the propelling force, exerted to turn the wheels, will be excessive during some portions of each revolution of the wheels, and will thus cause them to slip. This will be explained in a future chapter.

QUESTION 127. *In what way may steam of higher pressure, and higher degrees of expansion be used, than are practicable with the ordinary means employed?*

Answer. This may be done by compounding the engines—that is by working steam of a high tension and reducing its pressure by expansion in small cylinders, and then allowing it to escape into larger cylinders when it is worked over and expanded again. This method is now very generally employed in marine and stationary engines and results in great economy. Compound locomotives are also largely used in Europe, and at present, 1890, to some extent, experimentally, in this country.

CHAPTER VIII.

THE SLIDE-VALVE.

QUESTION 128. *How is an ordinary slide-valve constructed?*

Answer. The general construction of a slide-valve was explained in answer to Question 89. Such a valve is represented by figs. 67 and 68; fig. 67 being a longitudinal section and fig. 68 a plan.

QUESTION 129. *What is meant by the lap of a valve?*

Answer. The "*lap*" of a valve is that portion of it which overlaps the steam-ports, when it stands midway over the valve-face. Thus, in fig. 67, the parts, *L L'*, shaded with cross-lines, and which overlap the outside edges of the steam-ports, *c* and *d*, form the "*outside lap*" of the valve; and the parts, *l l'*, shown in black, which overlap the inside edges of the steam-ports, form the "*inside lap*." Ordinarily, in speaking of a "lap" of a valve it means the outside lap.

QUESTION 130. *What is meant by the "lead" of a valve?*

Answer. "*Lead*" means the width of the opening of the steam-port when the piston is at the beginning of its stroke. Thus, if the valve, *H*, fig. 69, stood in the position shown, when the piston is at the end of the cylinder, and the piston is at the beginning of its stroke, the opening, *a*, of the steam-port, *c*, would be the lead. The opening of the port on the outside of the valve is called *outside lead;* on the inner or exhaust side, as shown at *b*, it is called *inside lead.*

QUESTION 131. *What is meant by the "travel" of a valve?*

Answer. By the "*travel*" we mean the distance that the valve is moved back and forth, or, in other words, its stroke. In an engine like that shown in Plate III, if the rocker-arms are both of the same length, the travel of the valve will be equal to the throw of the eccentrics.

QUESTION 132. *What are the essential conditions which a slide-valve must fulfil in governing the admission and exhaust of steam to and from the cylinder of an ordinary engine?*

Answer. 1. It must admit steam to one end only of the cylinder at one time, so that the pressure, which moves the piston, will not be exerted on both sides of it at the same time.

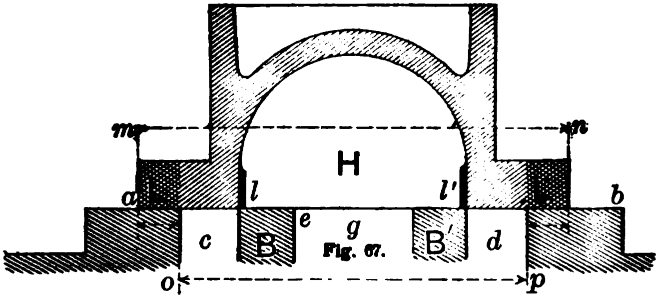


Fig. 67.

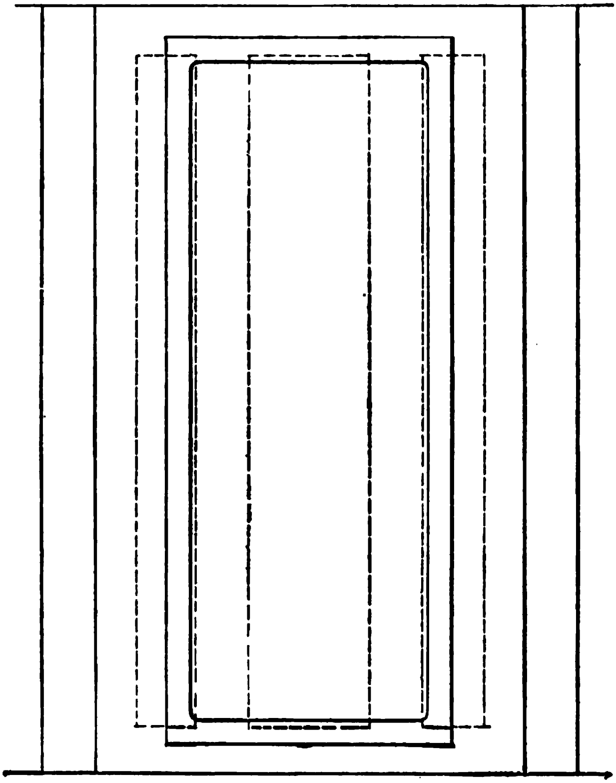


Fig. 68. Slide-Valve. Scale ¼ in.—1 in.

2. It must cover the steam-ports so as not to permit steam to escape from both steam-ports at once.

3. It must allow the steam to escape from one end of the cylinder *before* it is admitted at the other end, so as to give the steam, which is to be exhausted, time to escape before the piston begins its return stroke.

4. It must not allow "live steam"* to enter the exhaust-port from the steam-chest.

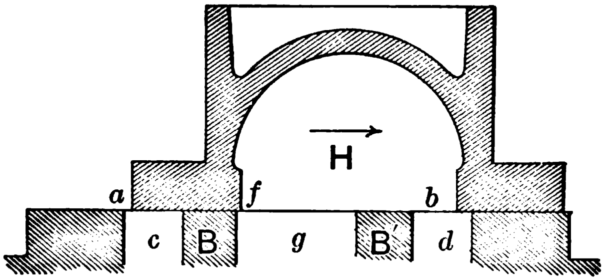


Fig. 69.

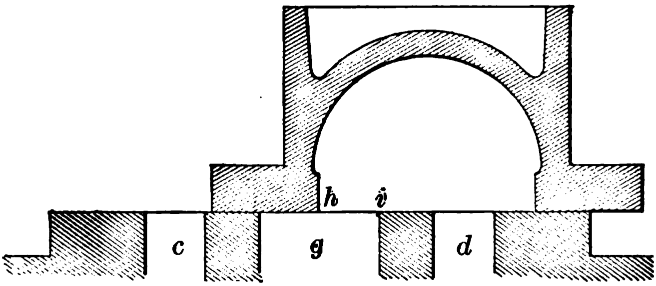


Fig. 70. Slide-Valve. Scale ¼ in.—1 in.

5. In order to utilize the expansive force of the steam, the valve must close each steam-port on the outer or steam side before it is opened on the exhaust side.

QUESTION 133. *How does the valve shown by figs. 67–70 fulfil these conditions?*†

* By *live steam* is meant steam which has been taken direct from the boiler, and which has not been expanded in the cylinder. The term is used in contradistinction to steam which has been admitted to the cylinder, and by the exertion of its expansive force has done work on the piston.

† The reader is recommended to draw a valve, like that shown in fig. 67, on a card, letting the lower edge, *a b*, correspond with the lower edge of the card. This card can then be moved on the line, *a b*, and will show the action of the valve more clearly than any drawings or description can.

Answer. 1. The lap on the outside of this valve being greater than that inside, makes it impossible to open either one of the steam-ports for the admission of steam, until *after* the other port is opened to the exhaust. Thus the valve cannot be moved from the position shown in fig. 67, to that shown in fig. 69, so as to open the port, *c*, at *a*, without first opening the port, *d*, at *b*, which allows the steam in *d* to escape into *g*. The outside width of the valve, as indicated by the dotted line, *m n*, fig. 67, is greater than the distance over the outside edges of the steam-ports—shown by the dotted line, *o p*—so that it is manifestly impossible for the valve to uncover both steam-ports, and thus admit steam into each at once.

2. The width of the exhaust cavity, *H*, in the valve, measured from *l* to *l'*, is less than the distance over the inner edges of the steam-ports, *c* and *d*—consequently, these ports cannot both communicate with the exhaust cavity simultaneously.

3. If the valve shown in fig. 69 is moving in the direction indicated by the dart, at *H*, it is obvious that the steam-port, *d*, will be opened to the exhaust, at *b*, before the port, *c*, will be uncovered, at *a*, for the admission of steam. The same action will occur when the valve moves in the opposite direction, and, as already pointed out, is due to the fact that the outside lap is greater than that inside.

4. Live steam cannot enter the exhaust-port unless it should be uncovered by the valve. This cannot occur unless the valve, fig. 67, should move far enough so that its edge, *a*, will pass beyond the edge, *e*, of the exhaust-port. For this reason half the travel of the valve must always be less than the widths of the lap, *L*, the steam-port, *c*, and the bridge, *B*,* added together.

5. It will be plain that if the valve shown in fig. 69 is moving from right to left, or in the reverse direction to that indicated by the dart, *H*, that the opening, *a*, will be closed before the port, *c*, is opened on the exhaust side, as the width, *a f*, of the valve is greater than the width of the steam-port.

QUESTION 134. *What other point must be observed in proportioning a slide-valve and the steam-ports for it?*

Answer. The exhaust-port must be made of such a width that when the valve is at the end of its travel, the opening of the port will be wide enough so as not to choke or "*throttle*" the exhaust steam. Thus, in fig. 70, the valve is represented in the position it occupies at one end of its

* The metal, *B*, between the steam and exhaust-port, is called a *bridge*.

travel. The point which must be observed is, that when it is in this position, the opening, *h i*, must be sufficiently wide for the free escape of the exhaust steam from the port, *d* into *g*.

QUESTION 135. *How does the lap of a valve cause the steam to act expansively?*

Answer. When a valve has outside lap, as was explained in answer to Question 102, those portions of its face which cover the steam-ports, being wider than the ports, occupy some time in moving over them, during which time the steam is enclosed in the cylinder, as there is then no communication either with the steam-chest or the exhaust-port. This action of the valve is due to its lap.

QUESTION 136. *What other good effect results from the outside lap of a slide-valve?*

Answer. If the outside lap of a valve is greater than that inside—as it always is in well-proportioned slide-valves—it causes the exhaust-port at one end of the cylinder to be opened before the steam-port at the other end is uncovered to admit steam. This is shown in fig. 49, from which it will be seen that if the valve is moved in either direction, one of the steam-ports will always be opened on the exhaust side of the valve before the other one is opened to admit steam to the cylinder.

QUESTION 137. *What is the object in giving a slide-valve lead?*

Answer. It is done so that the steam-port will be opened for the admission of steam a little before the piston reaches the end of its stroke, so that there will be a cushion of steam to receive the piston and reverse its motion at the end of the stroke. Another advantage which lead gives is that it results in the steam-port being wider open, for the admission of steam when the piston begins its return stroke, than it would be if there were no lead.

QUESTION 138. *What effect do lap and lead have on the release or exhaust of the steam?*

Answer. They cause the steam to be exhausted earlier in the stroke than it would be if there were no lap or lead. They also cause the steam-port to be closed on the exhaust side before the piston completes its stroke, the advantage of which will be explained hereafter.

QUESTION 139. *How is the motion, which will make a slide-valve fulfil the conditions, which have been explained, imparted to it?*

Answer. In the answers to Questions 90, 91 and 92, the general construction and action of an eccentric was described, but to make these still plainer, figs. 71 and 72 have been drawn, showing an eccentric in two

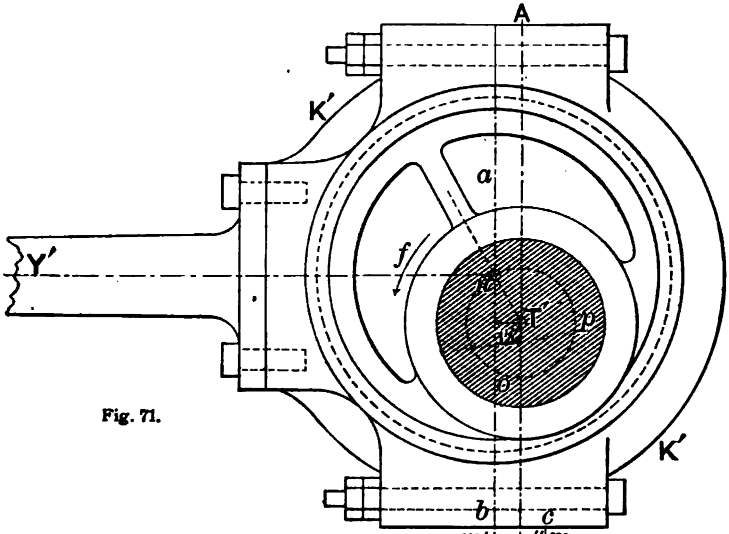


Fig. 71.

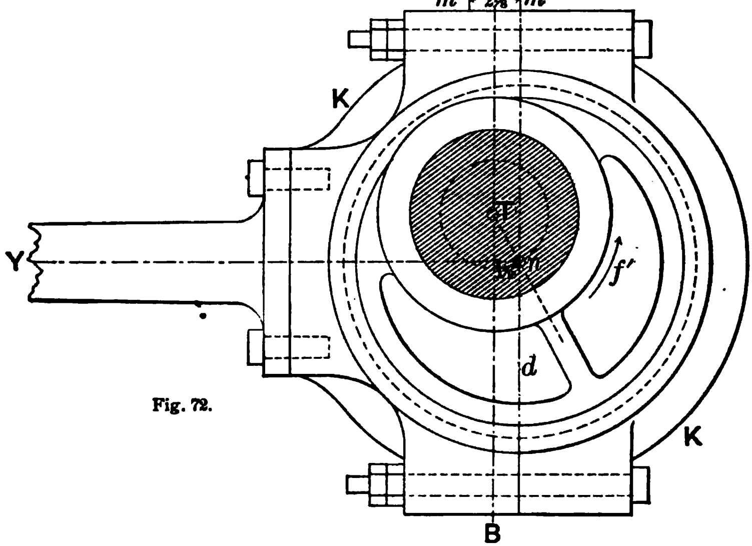


Fig. 72.

Eccentric and Strap. Scale ⅛ in.=1 in.

opposite positions, or as it would appear before and after the shaft has made half of a revolution.* In fig. 71 it is represented in the same position that it occupies in fig. 30—when the piston is at the beginning of its stroke, and the valve is in the position shown in fig. 69, and has $\frac{3}{16}$ inch lead at *a*. In fig. 67 the valve is shown in the middle of the valve-face, and, as already explained, in fig. 69 it has moved from its middle position a distance equal to the lap, $\frac{7}{8}$ inch, and lead, $\frac{3}{16}$ inch, or $\frac{7}{8}+\frac{3}{16}=1\frac{1}{16}$ inches. Consequently, when the piston is at the beginning of its stroke, and the valve is in the position described and shown in fig. 30, the eccentric must be in a corresponding position—that is, it must be $1\frac{1}{16}$ inches from the middle of its throw. In figs. 71 and 72, *T'* and *T* are the centres of the axles or shafts, *A B* is a vertical centre line drawn through these centres, and *n'* and *n* are the centres of the eccentrics. The valve, it will be seen from figs. 30 and 69, is on the *right* side of its middle position, therefore, as the motion of the eccentric is reversed by the rocker, the centre of the eccentric must be on the *left* side of the middle of its throw, as shown in fig. 71. As the centre *n'* of the eccentric revolves around *T'*, the centre of the shaft, obviously *n'* moves an equal distance on each side of the vertical line, *A B*. It has been explained in another place that the eccentrics and their straps, *K' K'*, are always turned so as to fit each other accurately. Consequently, the centre, *n'*, of the eccentric, always coincides exactly with that of the strap, and, as the distance from the centre *n* of the strap, fig. 29, to the centre of the pin at the other end of the rod, *L*, always remains the same, if we know the position of the centre of the eccentric, we can always know that of the pin, which will show the movement imparted to the rocker and by it to the valve. Therefore, in studying the action of an eccentric all that we need concern ourselves about is the movement of its centre in relation to that of the shaft.

It has been explained that, in the example given, the valve, at the beginning of the stroke of the piston, must be $1\frac{1}{16}$ inches from its middle position on the valve-face. The centre of the eccentric must therefore be the same distance from the middle of its throw. Consequently, if we draw a vertical line, *a b*, fig. 71, $1\frac{1}{16}$ inches from *A B*, the centre of the eccentric must be on the line, *a b*, and, as the eccentric has $4\frac{1}{2}$ inches throw, if we draw a circle, *n' o p*, $4\frac{1}{2}$ inches diameter, with *T'* as a centre, the centre of the eccentric will also be on this circle, and therefore it must be at the point where the line, *a b*, and the circle, *n' o p*, intersect each other. As

* Figs. 71 and 72 are drawn to a scale just $\frac{1}{8}$ that of figs. 67 to 70—that is, figs. 67 to 70 show the valve $\frac{1}{4}$ its full size, whereas the eccentric is represented only $\frac{1}{8}$ of its full size.

a b has two points of intersection, *n'* and *o*, we must take that one which will move the valve in the right direction.

QUESTION 140. *How can we know in which position the centre of the eccentric should be placed?*

Answer. This can easily be determined if we know which way the crank is turning and the position of the piston. Thus in fig. 30 the dart, *N*, indicates the direction that the crank is turning, and the piston is represented at the front end of the cylinder. Obviously the front steam-port must then be opened to admit steam in front of the piston to force it backward, and the valve must, therefore, be moved toward the right-hand side. As the motion of the eccentric is reversed by the rocker, the centre of the eccentric must move toward the left-hand side. In fig. 71, the dart, *f*, shows the direction of revolution of the shaft—the same as *N*, in fig. 30. It will be evident from the engraving, fig. 71, that if the centre of the eccentric is located at *n'*, that it will move toward the left-hand side, whereas if it was at *o*, it would move toward the right-hand side when the shaft turns in the direction shown by the arrow, *f*.

QUESTION 141. *What does fig. 72 show?*

Answer. In fig. 72 the shaft and eccentric are represented as having made a half revolution from the position shown in fig. 71. Consequently the centre *n* is on the right-hand side of the line, *A B*, and the same distance from it as it was in fig. 71.

QUESTION 142. *How can the action of an eccentric be shown in the most simple way?*

Answer. As explained in answer to Question 139, the movement of the centre of an eccentric shows the motion imparted to the strap and rod. All that is needed, therefore, is to draw a circle which will represent the path in which the centre of the eccentric revolves, and then lay out positions on that circle that the centre would occupy during a whole revolution of the crank. But before describing how this is done, it will be necessary to give an answer to the following question:

QUESTION 143. *How can the position of the crank and eccentric be determined for any position of the piston?*

Answer. This can be done by the aid of the diagram, fig. 73. Before describing the method of doing this, it should be explained first that the cross-head and piston, being rigidly connected together, their motion coincides exactly. We may therefore disregard the piston for the present, and simply observe the movement of the pin of the cross-head in relation to the crank. The large circle shown by a full line in fig. 73, represents

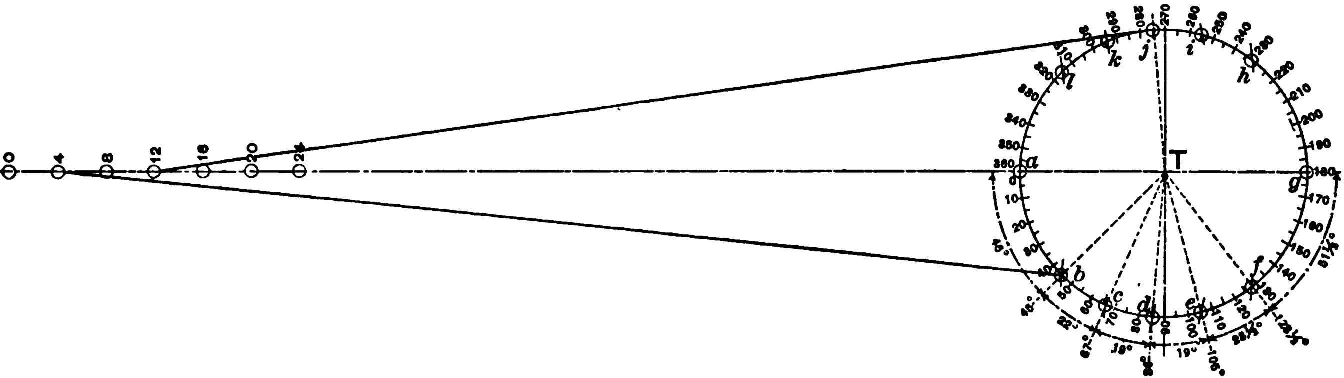


Fig. 78. Diagram of Movement of Piston and Crank. Scale ¾ in. = 1 ft.

the path of the centre of the crank-pin, and is divided into degrees. The small circles, 0 4 8 12 16 20 and 24, on the left-hand side, represent the successive positions of the cross-head pin corresponding to those shown in figs. 30 to 36. The length of the connecting-rod, 7 feet, is the distance from 0 to *a*, or from 12 to the centre *T*. By taking this length in a pair of compasses, and with 4 as a centre, if we intersect the circle with a small arc at *b*, it will give the position of the crank-pin when the piston has moved a distance equal to that from 0 to 4, or 4 inches of the stroke. With a connecting-rod of the length given, 7 feet, and 24 inch stroke of piston, it will be found that while the latter has moved 4 inches, the crank has turned through 45 degrees of a complete revolution. In other words, a line *b T*, drawn through the centre *b* of the crank-pin, and the centre *T* of the shaft, will form an angle of 45 degrees with the centre-line *a T*. As the crank, shaft, and eccentric are all rigidly connected together, if the one turns 45 degrees of a revolution, the others must turn equally as much. We will now draw a circle, *n o p*, fig. 74, representing the path of the centre or the throw of the eccentric, and its centre *n* will be laid down in the position it occupies when the piston is at the beginning of its stroke, as shown in figs. 30 and again in 71, and we will draw a line, *a T*, through the centre, *n*, of the eccentric and *T* of the shaft. A similar line will also be drawn in fig. 75. From what has been said it is obvious that while the crank is turning from the position shown in fig. 30, to that shown in fig. 31, or from *a* to *b* in fig. 73=45 degrees, that the eccentric must also have turned an equal amount. Therefore, if from the line *a T*, in fig. 75, we lay off an angle *a T b*=45 degrees, the intersection of the line *b T* with the circle will represent the position of the centre of the eccentric when the piston has moved 4 inches, or is in the position shown in fig. 31, and the crank is in the position shown at *b* in fig. 73.

Returning again to fig. 73, let it be supposed that the piston has moved 8 inches. We will take the centre of the small circle 8 as a centre and the length of the connecting-rod as a radius, and intersect the large circle with a small arc at *c*. It will then be found that in moving from *b* to *c* that the crank has turned 22 degrees. Proceeding as before, the line *b T* will be laid down in fig. 76 in the same position as in fig. 75, and an angle *b T c*, equal to 22 degrees, will be laid off from *b T*. Then the intersection of *c T* with the circle at *n*, will be the position of the centre of the eccentric when the piston has moved 8 inches of its stroke.

In this way we may proceed and lay out the position of the eccentric for each position of the piston shown in figs. 30 to 37, or for the corres-

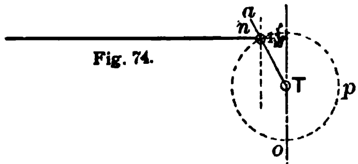


Fig. 74.

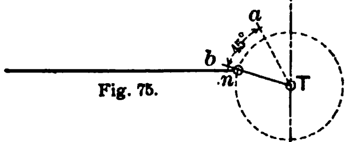


Fig. 75.

Fig. 76.

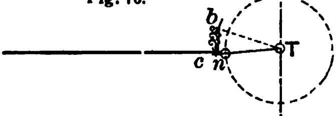


Fig. 77.

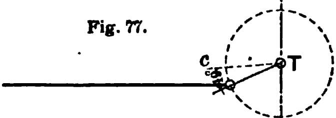


Fig. 78.

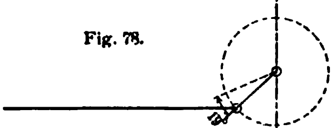


Fig. 79.

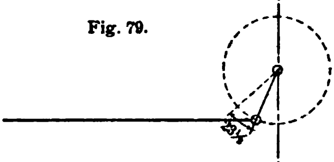
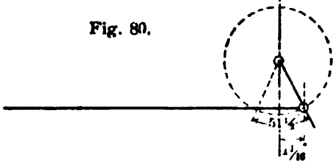


Fig. 80.



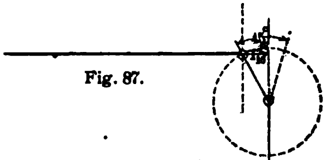


Fig. 87.

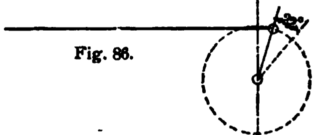


Fig. 86.

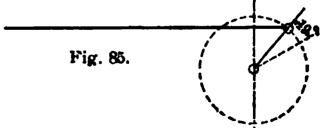


Fig. 85.

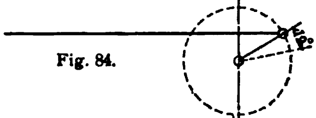


Fig. 84.

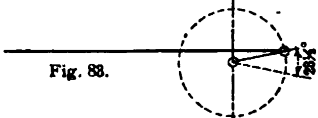


Fig. 83.

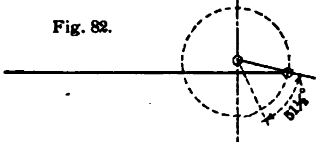


Fig. 82.

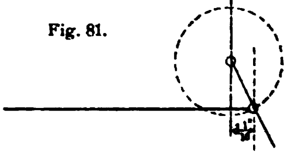


Fig. 81.

Diagrams showing Movements of Eccentric. Scale ⅛ in.—1 in ponding positions of the crank represented by *a b c d e f g h i j k* and *l* in fig. 73. This has been done in figs. 74 to 87, and if the reader will draw a similar series of diagrams it will probably give him a clearer idea of the action of an eccentric than he can get in any other way.*

QUESTION 144. *How can the movement and the action of a valve be shown most perfectly on paper?*

Answer. By drawing a diagram—that is, by representing the valve in a number of the positions it occupies in relation to the steam-ports during a complete stroke of the piston, and then drawing what are called "*motion curves*" through the inner and outer edges of the valve in each one of the positions in which it is represented. As such curves are in a sense purely imaginary, and do not represent any object on an engine, it is difficult to explain clearly their nature and purpose, and perhaps it will be still harder for those with little or no knowledge of drawing to understand an explanation, no matter how clearly it may be written. The reader must, therefore, expect to give close attention and perhaps some hard study to the following description of this method of showing the movement of a slide-valve, in relation to that of the piston and crank, and to the steam and exhaust-ports:

It will be supposed, in the first place, that the horizontal line *f f'*, Plate II, represents the valve-face, and *H* a valve with $\frac{7}{8}$ inch outside lap; *c* and *e* are the steam-ports, $1\frac{1}{4}$ inches wide, and *g* the exhaust-port, $2\frac{1}{2}$ inches wide, the bridges between being $1\frac{1}{8}$ inches thick. The valve, *H*, is represented in the position it would occupy when the piston is at the front end of the cylinder, and at the beginning of its stroke, the valve having $\frac{3}{16}$ inch lead at *M*. *B E* is a vertical centre line through the valve-face and exhaust-port *g*; *h i* is the vertical centre line of the valve. As the lap is $\frac{7}{8}$ and the lead $\frac{3}{16}$, the distance, *j k*, between the centre line of the valve and that of the face must be $\frac{7}{8}+\frac{3}{16}=1\frac{1}{16}$ inches.† Let *X Y* represent a rocker, *T*, the centre of the main shaft, and the dotted circle around it the path of the centre, *m*, of the eccentric, which has $4\frac{1}{2}$ inches throw. The rocker and eccentric, to save room in the engraving, are both represented nearer to the valve-face than they would be on an engine. The position of the piston, crank, etc., are supposed to be the same as shown in fig. 30. The dart, *H*, shows the direction in which the valve is moving, and the

* In drawing such a series of diagrams, it will be best to make them to a larger scale than they are represented in the engravings.

† The reader is recommended to use a valve drawn on card-board, as explained in the note to Question 133 in reading the following description.

one at *m*, the way the eccentric is revolving. As the valve should be $1\frac{1}{16}$ inches from its central position at the beginning of the stroke, and the rocker arms being of equal length, obviously the centre, *m*, of the eccentric must also have moved the same distance, *m m'*, from the vertical line, *m' r'*, drawn through the centre of the shaft. Therefore, if we draw a vertical line, *m t*, parallel with *m' r'*, and $1\frac{1}{16}$ inches from it, as already explained, its intersection, *m*, with the dotted circle will be the location of the centre of the eccentric, when the piston is at the beginning of the backward stroke, and the valve is in the position shown at *H*.

It will now be supposed that the piston has moved 4 inches, or into the position shown by fig. 31. In doing so it will be seen that the crank has turned a certain distance from the dead point, shown in fig. 30, to the position represented in fig. 31. It has been explained that this angle —with a connecting-rod and stroke of piston of the dimensions given— will be 45 degrees. Therefore, if in Plate II, we draw a line, *m T*, through the first position of the centre of the eccentric and the centre of the shaft, and draw another line, *n T*, through *T*, and at an angle of 45 degrees to *m T*, its intersection, *n*, with the dotted circle will represent the position of the centre of the eccentric, when the piston has moved 4 inches from the dead point.

The effect of this movement on the valve can easily be followed if the reader will observe the direction of the motion indicated by the darts at *m Y X* and *H*. It will be noticed that when the centre of the eccentric is at *n*, its distance, *n n'*, from the vertical centre line is greater than when it was at *m*. The horizontal line, *m m'*, is equal to the distance, $j\,k = 1\frac{1}{16}$ inches between the centre line of the valve and that of the valve-face, *n n'* shows the distance between these centre lines when the piston has moved 4 inches of its stroke. If, therefore, we draw the valve, with its centre line, a distance equal to *n n'* from the middle of the valve-face, it will be in the position it occupies when the piston is in the position shown in fig. 31. If we drew it in this position on the line, *f f'*, of Plate II the drawing would be liable to be confused with the valve already represented there. To avoid such confusion another horizontal line, 4 20', has been drawn a distance, 0 4, equal to the movement of the piston, or 4 inches, below *f f'*, and on this line a perpendicular, *h' i'*, has been laid down at a distance, *j' h'*—equal to *n n'*—from the centre of the valve-face; *h' i'* will then represent the middle of the valve in its new position. The edges of the ports, *c g* and *e*, have been extended downward, and the lower part of the valve has been drawn on the line, 4 20′,* with *h′ i′* as its centre line, which shows it in the position it will occupy in relation to the steam and exhaust-ports when the piston has moved 4 inches of its stroke, as shown in fig. 31.

We can now proceed in the same way to show the position of the valve on the line, 8 16′, when the piston has moved 8 inches of its stroke, as represented in fig. 32. It has been shown from fig. 73 that when the cross-head pin has moved 8 inches, that the crank has turned through 22 degrees of a revolution from *b*, or 67 degrees from the dead point, *a*. If, then, we draw a line, *o T*, on Plate II, at an angle of 67 degrees with *m T*, its intersection with the dotted circle will be the position of the centre of the eccentric when the piston is in its new position. The centre of the eccentric is therefore a distance, *o o′*, from the centrè line, *m′ r′*, which indicates the movement of the valve. For the reason already explained—that is, to avoid confusion in the diagram, the valve will be represented in its third position on the line, 8 16′, and it will be laid off as before.

Proceeding in the same way, the positions, *p q r* and *s*, of the centre of the eccentric, when the piston has moved 12, 16, 20 and 24 inches of its stroke, may be laid down in Plate II. The edges of the steam and exhaust-ports and the centre-line, *g E*, are extended downward, and the distance, *C E*, is made equal to the stroke of the piston. Horizontal lines, 8 16′, 12 12′, 16 8′, etc., are drawn at distances from *f f′* equal to the movement of the piston. The different positions of the valve indicated in figs. 30 to 36 are then laid down on these lines.

We now have a graphical representation of the movement of the valve in seven successive positions of a stroke. The position of the outer edge of the valve, which controls the admission of steam, is shown, in its relation to the port, *e*, at *M N O P Q R* and *S*, and the inner edge which controls the exhaust is shown at *M′ N′ O′ P′ Q′ R′* and *S′*. It will be seen that at *N* the steam-port is wide open, and remains so until the valve gets into the position shown at *P*, when it begins to close the port. At *R* it is almost entirely closed. If now we draw a curve, *M N O P Q R S*, through the edge of the valve in its successive positions, that curve will show the movement of the valve in relation to the steam-port during the whole stroke. Horizontal lines 1 23′, 2 22′, 3 21′, etc., have been drawn between *f f′* and 4 20′ to represent each inch of the stroke, and the spaces between these lines have been subdivided by other lines which represent

* To avoid too much confusion, in the diagram only the edges of the valve, which control the admission and exhaust of steam, are represented in its successive positions.

eighths of an inch, and the whole distance from *C* to *E* has been subdivided in the same way. The relation of the curve, *M N O–S*, to these horizontal lines will show exactly the position of the outer or steam admission edge, *M*, of the valve at all points of the stroke of the piston. Thus, the distance of the curve on the line 1 23′ from the outer edge of the port, *c*, as indicated by the line at *w*, shows how wide the port was open when the piston had moved 1 inch of its stroke. A similar line at *x* shows the width of opening at 14 inches of the stroke, and the intersection of the curve with the outer edge of the port at 20⅝ inch of the stroke shows that the port was then closed and the steam cut off.

A similar curve, *M′ N′ O′ P′ Q′ R′ S′*, shows the position of the inner or exhaust edge, *M′*, of the valve in relation to the port, *e*. Other curves, *S U M*, and *S′ U′ M′*, have also been drawn which represent the movement of the valve during the return stroke of the piston. The dotted line, below *R′*, shows the width of the opening of the port, *e*, to the exhaust when the piston has moved 20½ inches, and the intersection at *y* shows that the port was closed to the exhaust at $22\frac{1}{16}$ inches of the stroke.

The slight intersection of the curve, *S U M*, with the outer edge of the port, *c*, just below *M*, shows that the port was slightly opened before the piston had reached the end of its stroke, and the intersection at *z* shows that the port, *e*, was open to the exhaust when the piston still had to move 1 inch to complete its stroke.

It will thus be seen that such diagrams show very plainly the movement of a valve, and they present to the eye a diagram which shows its different positions during a whole revolution of the crank. A clearer idea may thus be formed of its action than it would be possible to have without some such a graphical representation.

QUESTION 145. *Can the drawing of such a diagram be simplified in any way?*

Answer. Yes, if it is observed that the only way in which the rocker effects the movement of the eccentric and valve is to reverse their motions in relation to each other. We may, for simplicity, suppose the rocker is removed and that the shaft and eccentric are located at *T′* above *T* and opposite to the valve, and that the eccentric is connected by a rod, *m″ D*, directly with the valve. In that case, in order to move the valve in the same direction that it was moved with the rocker, it will be essential that the centre, *m″*, of the eccentric be in the opposite position in its path from that in which it is shown at *m* below. This will be plain if the reader will follow the motions indicated by the darts at *m Y X* and *H*, and then observe the direction that m'' and the valve, *H*, are supposed to be moving. It should be observed that the centre, m'', must be on the right side of the centre line, T' T, instead of the left, and that the distance, m''' m'', from the centre line must be the same as m m' equal to j k or $1\frac{1}{16}$ inches.

On the middle of *C E*, the vertical centre line of the valve-face, we will now take *A* as a centre, and draw a circle, C' *F E D*, to represent the path of the centre of the crank-pin. It will also be imagined that the centre, *T*, of the shaft is located at *A*, and that the circle, m'''' n''–s'', represents the path of the centre of the eccentric, and that its centre, m'''', occupies the same relation to the vertical centre line, *C E*, that m'' does to T' T—that is, it is $1\frac{1}{16}$ inches to the right of *C E*. If now we draw a vertical line, m'''' i, through the centre, m'''', of the eccentric upward it will coincide with i h, the centre line of the valve. By drawing a line, A m'''' u, through the centre, m'''', of the eccentric to the circumference of the large circle, which represents the path of the centre of the crank-pin, and then from u, the intersection of this line with the large circle, laying off a space, u v, equal to 45 degrees, and drawing a line, v A, its intersection at n'' with the path of the centre of the eccentric will give the position of its centre when the piston has moved 4 inches. The successive positions, o'' p'' q'', etc., of the curve of the eccentric can then be laid out in the way described, and by drawing perpendicular lines through these centres they will give the corresponding positions of the middle of the valve.

QUESTION 146. *What is the effect of increasing the lap of a valve if the travel remains the same?*

Answer. It shortens the period for the admission of steam—that is, it cuts the steam off earlier in the stroke. It also closes and opens the ports to the exhaust earlier. Thus, in fig. 88, motion curves have been drawn for a valve with $1\frac{1}{4}$ inch lap and $4\frac{1}{2}$ inch travel. From the steam curve, *M N–S*, it will be seen that the steam-port is closed at *q*, or at $16\frac{1}{2}$ inches of the stroke instead of $20\frac{1}{4}$, as it is when the valve has $\frac{7}{8}$ inch lap, as shown in Plate II. The exhaust curve, M' N'–S', shows that the port, *e*, is closed on the exhaust side at $21\frac{1}{4}$ inches instead of $22\frac{5}{8}$ inches, and that on the return stroke it opens the port to the exhaust at $21\frac{5}{8}$ inches instead of 23, as shown in Plate II.

It will also be seen that with the proportions of the valve and the travel represented in fig. 88, that the steam-port, *c*, is not opened wide at any period of the stroke.

QUESTION 147. *If the lap remains the same, what is the effect of reducing the travel?*

Answer. 1. Whenever the travel is less than twice the lap added to twice the width of one of the steam-ports, the latter will not be opened wide. This is shown in fig. 88, in which the valve has 1¼ inches lap and the steam-port is 1¼ wide, so that $1\frac{1}{4}+1\frac{1}{4}\times 2=5$ inches. As the travel is only 4½, the valve does not move far enough to uncover the steam-port completely. It is also shown in fig. 89 with a valve having ⅞ inch lap and a travel of 3½—represented by the motion curves drawn in full lines. It will be seen at w' that the greatest width of opening of the port is only ⅞ inch. The dotted curves show the motion of the valve with 2¾ inches travel. They show at w that the maximum opening of steam-port is only ½ inch.

2. The period of admission is reduced or the steam is cut off shorter. At q and q', in fig, 89, the motion curves show that with ⅞ inch lap and 3½ and 2¾ inches travel, the valve closes the steam-port at 13¼ and 17¼ inches of the stroke instead of 20¼ inches with 4½ inches travel, as shown in Plate II.

3. The steam-port is closed and opened to the exhaust earlier. Thus, at y and y', fig. 89, the curves show that the steam-port, e, is closed at 19⅝ and 21½ inches of the stroke instead of 22½, as shown in Plate II, with 4½ inches travel. At z and z' the curves show that the port is opened on the exhaust side at 21⅝ and 19⅝ inches of the stroke instead of 23 inches.

4. The valve opens the steam-port for the admission of steam earlier with a short travel than with a long one. This is indicated by the two curves just below M, fig. 89. The full line shows that the port is opened when the piston still has $\frac{3}{16}$ inch to move before completing its stroke. The dotted curve, which shows the movement of the valve with a shorter travel, indicates that the valve opens the port, while the piston still has $\frac{7}{16}$ inch to move before it reaches the end of its stroke.

QUESTION 148. *What occurs when the valve closes communication between the exhaust-port and the steam-port ahead of the piston?*

Answer. The steam which has not been exhausted from the cylinder is enclosed in it and is compressed by the advancing piston, and it thus acts like the pre-admission of steam before the piston has completed its stroke—that is, as a cushion to resist the momentum of the piston and bring it to a state of rest at the end of the stroke.

QUESTION 149. *Does this compression result in loss of energy?*

Answer. No, because the power required to compress the confined steam is again given out by its expansion behind the piston on its return stroke. In fact, it results, as explained in answer to Question 125, in a

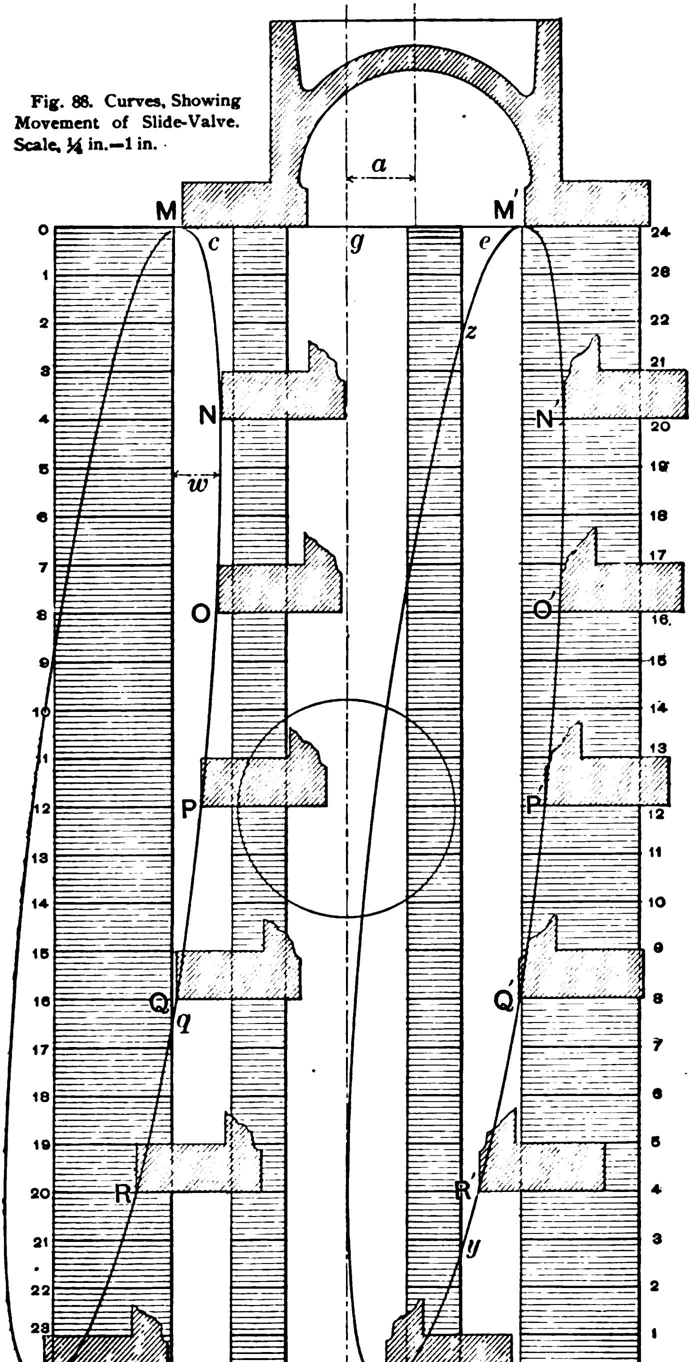


Fig. 88. Curves, Showing Movement of Slide-Valve. Scale, ¼ in.—1 in.

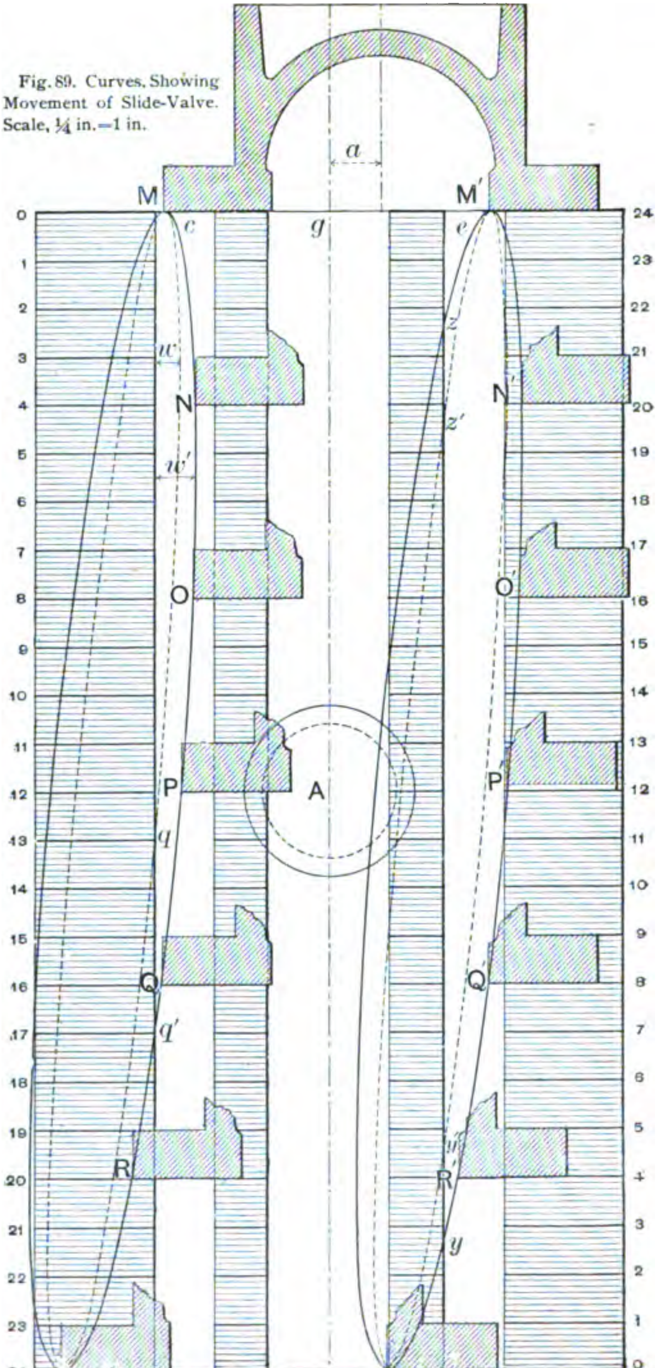


Fig. 89. Curves, Showing Movement of Slide-Valve. Scale, ¼ in.=1 in.

direct economy, because by the compression of confined steam the clearance spaces and steam-ways are filled with steam of a high pressure. Without such compression it would be necessary to fill them with live steam when the steam-port is opened.

If the steam thus compressed is exhausted before it is expanded to the pressure it had before compression, there is a loss due to the escape of steam at this higher pressure.

QUESTION 150. *What is the effect of inside lap?*

Answer. It delays the release or exhaust of steam and increases the compression. For this reason no inside lap is usually given to valves for engines which rnn at a high rate of speed, as with it the exhaust steam has not time enough to escape freely. In fact, in some cases what is called *inside clearance* is given to valves—that is, the width of the exhaust cavity of the valve is made somewhat wider than the distance over the inner edges of the steam-ports, so that it does not entirely cover them when it is in the middle of the valve-face. The effect of inside clearance is just the reverse of that produced by inside lap—that is, it causes the release to occur earlier in the stroke and compression later.

CHAPTER IX.

THE ACTION OF THE PISTON, CONNECTING-ROD AND CRANK.*

QUESTION 151. *What effect does the connecting-rod have on the relative movements of the piston and crank?*

Answer. The inclination of the rod to the centre line, *A B C*, of the cylinder, as shown by *E F*, in fig. 90, causes the piston to move somewhat more than half its stroke while the crank is passing from the dead-point, *B* to *F*, or during the first quarter of its revolution, and somewhat less than half its stroke during the second and third quarter, and again somewhat more during the last quarter of the revolution, or while the crank-pin is passing from *G* to *B*.

QUESTION 152. *How can this effect of the inclination—or "angularity," as it is called—of the connecting-rod be shown?*

Answer. It will be made apparent if we draw a circle, *B F C G*, fig. 90, representing the path of the centre of the crank-pin, and then divide it into 16 equal parts, 1 2, 2 3, 3 4, etc. From 1, which is the front dead-point of the crank, a distance 1 1′ will be laid off equal to the length from centre to centre of the journals of the connecting-rod, and from 9, the back dead-point of the crank, a distance of 9 9′ is laid off also equal to the length of the connecting-rod; 1′ and 9′ then represent the positions of the centre of the cross-head pin when the crank is at its dead-points and when the piston is at the ends of its stroke. As explained before, the cross-head and the piston are rigidly connected together, so that the motion of the one represents that of the other. The movement of the centre of the cross-head pin may therefore be regarded as the same as that of the piston. If now, with a pair of compasses, we take a distance equal to 1′ 1, or the length of the connecting-rod, and from 5 as a centre a short arc, *E*, is described so as to intersect the centre-line, *A* 9′ *B C*, the point of intersection will represent the position of the centre of the cross-head pin when the crank is at 5, or when it has turned $\frac{1}{4}$ of a whole revolution. If we subdivide the distance, 1′ 9′, which represents the stroke of the piston, into two equal parts, 1′ *a* and *a* 9′, then it will be found that the distance

* This chapter should be read in connection with Chapters I and II.

from 1′ to E is somewhat more than 1′ a, or half the stroke of the piston. That is, while the crank-pin has moved from 1 to 5, or turned ¼ of a revolution, the piston has traveled a little *more* than half its stroke. When the

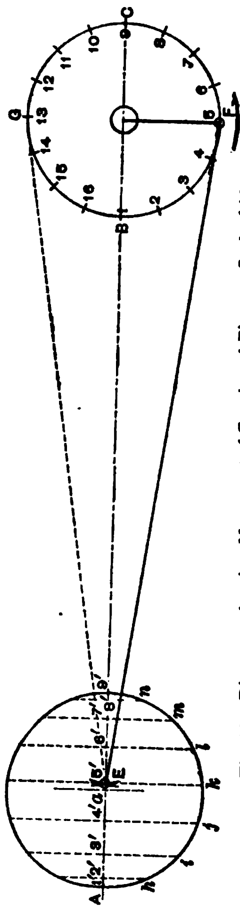


Fig. 90. Diagram, showing Movement of Crank and Piston. Scale, ⅛ in.—1 ft.

crank-pin reaches the dead-point at 9, then the cross-head pin will be at 9′, so that while the crank has moved through the second quarter of its revolution the cross-head pin and piston have traveled a distance, E 9′, somewhat *less* than half the stroke, a 9′.

Again, when the crank has reached 13, and has passed through the third quarter of its revolution, if we take the length of the connecting-rod, and from 13 as a centre, with 13 E as a radius, describe another short arc, it will intersect A B again at E, so that while the crank-pin has revolved through the third quarter the piston has moved from 9′ to E, or *less* than half its stroke. When the crank again reaches 1 the cross-head pin will be at 1′, so that it and the piston have moved *more* than half a stroke while the crank passed from 13 to 1, the fourth quarter of its revolution. Owing to this action of the connecting-rod which is due to its *angularity*, as it is called, the crank-pin is behind the piston during its backward stroke and ahead of it during the forward stroke.

QUESTION 153. *How does the action of the connecting-rod influence the motion of the piston and valve in relation to each other?*

Answer. As the crank moves slower than the piston during the first and last quarter of the revolution, and as the valve is moved by the eccentric, and it in turn by the shaft and crank, consequently the movement of the valve is delayed in relation to that of the piston during these periods. As the crank moves faster than the piston during the second and third quarters, the points of cut-off and release occur earlier in the stroke during these periods than they do during the first and fourth quarters of the crank's revolution.

This is not, however, a matter of very great practical importance with stationary engines which run at comparatively slow speeds; but if it is thought desirable, the period of admission and the point of release for both stokes can be equalized, either by giving the valve more lead or lap at one end than the other, or by making the one steam-port wider than the other. The mechanism employed for moving locomotive slide-valves, however, furnishes us with the means of modifying their motion in relation to that of the piston, and of thus equalizing the periods of admission and release for the front and back strokes. The methods of doing this will be more fully explained hereafter.

QUESTION 154. *What effect does the angularity of the connecting-rod have on the cross-head and slides?*

Answer. When the crank is revolving in the direction represented by the dart, F, in fig. 90, the piston *pushes* the connecting-rod and it is then plainly subjected to a compressive strain while the piston is moving backward or toward the shaft, and during the first half of the revolution of the crank. The pressure on the cross-head and guides due to the angle of the rod is therefore upward. When the piston is moving from the shaft, or making its forward stroke, and the crank is passing from *C* to *B*, the piston then *pulls* the connecting-rod, and it is then in tension, and the pressure on the cross-head and guides is again upward. If, however, the crank should revolve in the opposite direction from that represented by the dart, the pressure on the cross-head and guides would be downward—that is, the direction of the pressure on the guides is reversed, when the direction of the revolution of the crank is reversed, or when the engine runs backward.

QUESTION 155. *What is the nature of the motion of a piston of a steam-engine during each stroke?*

Answer. When it is at the end of the cylinder, and the crank is at one of the dead-points, the piston is momentarily at rest or stationary. After it starts its speed is increased up to a point near the middle of the stroke, where it reaches its maximum velocity. From that point the speed is diminished to the end of the stroke, when it again comes to a momentary state of rest before beginning the return stroke. During the return stroke its motion is almost exactly the same, excepting that the direction of its movement is reversed.

QUESTION 156. *How can the motion of the piston be represented graphically?*

Answer. This can be done by constructing a diagram as shown in fig. 90. In this the circle, *B C*, as already explained, represents the path in which the centre of the crank-pin revolves and is divided into sixteen equal parts, 1 2, 2 3, 3 4, etc. Let it be supposed that the crank is turning in the direction indicated by the arrow, *F*—which is the way a locomotive driving-wheel would move in running forward. If the crank is revolving at a uniform speed the crank-pin will move through each of the spaces 1 2, 2 3, 3 4, etc., in equal times. If we take a pair of compasses, with a distance between the points equal to the length of the connecting-rod, and then with 2 as a centre we describe a small arc to intersect the centre line, *A B*, at 2′, the point of intersection will be the position of the centre of the cross-head pin when the crank-pin is at 2. The distance from 1′ to 2′ will then represent the movement of the cross-head and piston while the crank-pin was passing from 1 to 2. If we place the point of the compasses at 3 and describe another arc, 3′, intersecting the centre line, *A B*, then the distance, 2′ 3′, will be that which the cross-head has moved while the crank-pin was passing from 2 to 3. If, in a similar way, we draw successive arcs, 4′ 5′ 6′, etc., from 4 5 6, etc., as centres, then the spaces, 3′ 4′, 4′ 5′, 5′ 6′, etc., will represent the movement of the cross-head and piston while the crank-pin is passing over the successive spaces laid out in the circle, *B C*. An inspection of the spaces 1′ 2′, 2′ 3′, 3′ 4′, etc., will show

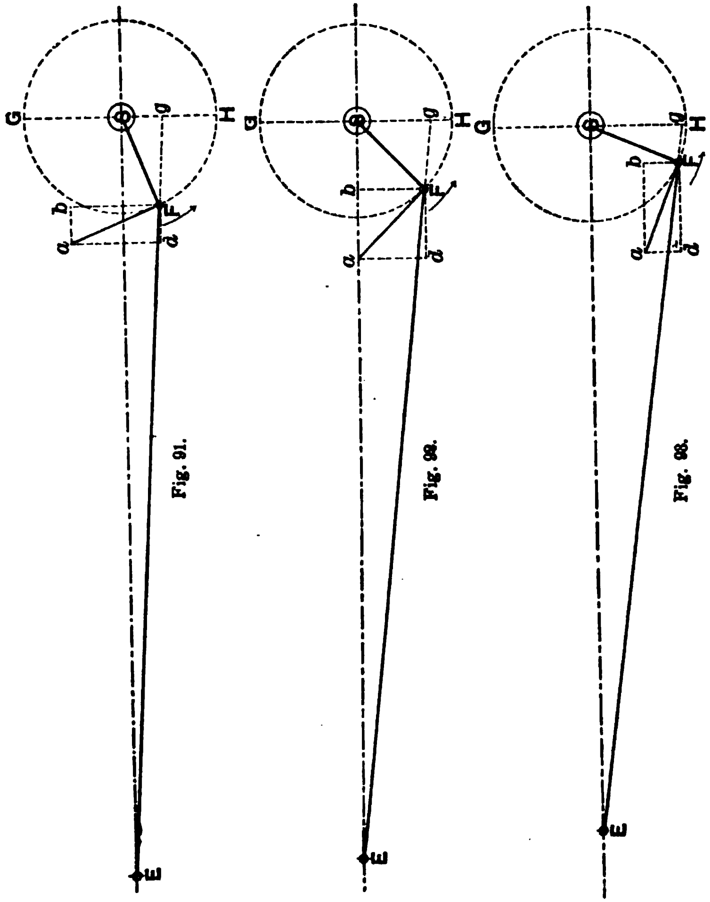


Fig. 91. Fig. 92. Fig. 93.

Diagrams, showing Movement of Crank and Piston. Scale, ⅛ in. = 1 ft.

that they successively increase from the beginning to near the middle of the stroke of the piston, and they then diminish from near the middle to the end of the stroke. The movement of the piston during its forward stroke is the same as that represented in the diagram, but in a reversed direction.

QUESTION 157. *How can the velocity of the piston during any portion of its stroke be ascertained?*

Answer. In explaining this, it will first be assumed that the stroke of the piston is 2 feet, and that the crank is moving in its path, *B C*, at a velocity of 30 feet per second.

It should be noticed that a point like the centre of a crank-pin which is moving in a circle is constantly changing the direction of its motion. At any one instant of time, however, it moves at right angles to the centre line of the crank. Thus, when the crank, *F S*, fig. 91, is in the position shown, the line, *a F*, drawn at right angles to *F S* represents the instantaneous direction in which *F* is moving when in the position represented. If the length of *a F* represents the velocity=30 feet per second—of the crank-pin, then by the principles of the composition of motion, if this line is made the diagonal of a parallelogram, *a b F d*, of which the two sides, *a b* and *d F*, are horizontal and *a d* and *b F* vertical, then these sides will represent the horizontal and vertical velocity of the centre of the crank-pin. As the horizontal movement of the crank-pin is nearly coincident with that of the cross-head and piston, the motion of these latter parts being communicated to the crank-pin by the connecting-rod, therefore the line, *d F* or *a b*, which represents the horizontal velocity of the crank-pin, will also represent very nearly the velocity of the cross-head and piston. Similar diagrams for other positions of the crank are given in figs. 92 and 93, in which the horizontal lines, *d F*, represent approximately the horizontal velocity of the crank-pin and piston.

QUESTION 158. *What effect has the connecting-rod on the velocity of the piston?*

Answer. As already explained, the velocity of the piston is accelerated by the connecting-rod while the former is moving from the front end of the cylinder to the middle of the stroke, and again when it moves from the middle to the front end. It is correspondingly retarded at the other end of the cylinder.

QUESTION 159. *Do the diagrams in figs. 91, 92, and 93 represent the velocity of the piston precisely?*

Answer. No; they do not show the effect of the angularity of the connecting-rod.

QUESTION 160. *How can a diagram be drawn which will show the velocity of the piston correctly?*

Answer. This can be done if the line, *a F*, figs. 91. 92, and 93, which represents the circumferential velocity of the crank-pin is made equal to the radius, *F S*, of the crank. Then if the line, *E F*, which represents the centre line of the connecting-rod is prolonged so as to intersect the vertical line, *G H*, drawn through the centre of the shaft, *S*, at *g*, then the line, *g S*, will represent correctly the velocity of the piston. If the crank-pin is in a position on the right side of *G H*, then the distance of *g*, the point of intersection of *E F* with the vertical line from the centre, *S*, of the shaft will represent the velocity of the piston.*

QUESTION 161. *How can the velocity of the piston be shown during its whole stroke?*

Answer. It has been explained how the velocity at any one point may be ascertained. We may determine the velocity for each of a number of successive points of the stroke, and then construct a diagram which will represent graphically the rate of speed or velocity of the piston during the whole stroke of the piston or revolution of the crank. Thus, fig. 91 represents the crank in the position marked 2, in fig. 90. The centre line, *E F*, of the connecting-rod is extended to *g*, so that *g S* represents the velocity of the piston at the instant that the crank-pin is at 2, fig. 90. A perpendicular line, *2′ h*, equal to *S g*, of fig. 91, is then drawn, in fig. 90, from *2′*, the position of the cross-head pin corresponding to that of the crank at *F*, in fig. 91. In fig. 92, the crank-pin, *F*, is in the position 3, of fig. 90. The centre line, *E F*, of the connecting-rod is again extended to *g*, and the distance, *S g*, is laid off from 3′, in fig. 90—which is the corresponding position of the cross-head pin—to *i*. In the same way the velocity of the cross-head pin is plotted for each of its positions, 4′, 5′, 6′, 7′ and 8′, and a curve, *A h i j k l m n* 9′, fig. 90, is drawn through the extremities of the perpendicular lines. The perpendicular distance of this curve *below* the centre line, *A* 9′, represents the velocity of the cross-head pin and piston for each point of the backward stroke. A similar curve has been drawn above the line *A B*, and shows the velocity of the piston during the forward stroke.

QUESTION 162. *What is shown by the form of these curves?*

Answer. It will be seen from the engraving that the curves do not form a true circle, but the figure is somewhat egg-shaped—

* The demonstration of this theorem would require the introduction of mathematical principles which would be out of place in an elementary book like this. The reader will find the whole subject very fully discussed in "A Practical Treatise on the Steam-Engine," by Arthur Rigg, and in George C. V. Holmes's excellent little book on the Steam-Engine.

that is, the left-hand or front portion of each of them is fuller than at the other end, showing, as has already been pointed out, that the

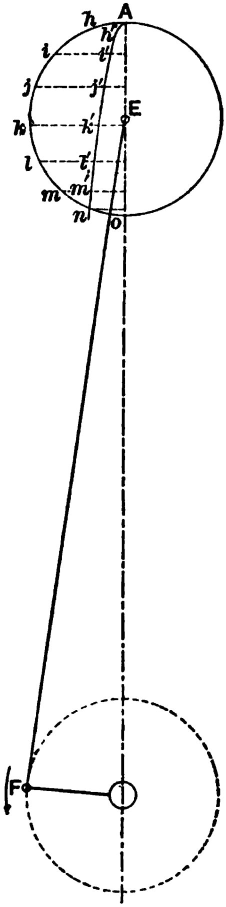


Fig. 94. Diagram showing Velocity of Piston. Scale ⅛ in.=1 ft.

velocity of the piston, owing to the influence of the angularity of the connecting-rod, is somewhat greater during the first and last quarters of the revolution than it is during the second and third.

QUESTION 163. *Is any considerable amount of power required to accelerate the piston and other reciprocating parts of an engine during the first half of the stroke?*

Answer. Yes. In fast-running engines much more power is required to accelerate the reciprocating parts during the first half of each stroke than is usually supposed.

QUESTION 164. *How can this be shown?*

Answer. This will be apparent if we will compare the velocity of these parts with those of a falling body. To do this, it will be supposed that the cylinder of the engine is placed vertically above the crank, as shown in fig. 94, and that the cross-head starts from *A*. The curve *A h i j k l m n o* shows the velocity of the piston when the crank-pin is moving with a circumferential velocity of 30 feet per second, which is equivalent to a speed of about 50 miles per hour for a locomotive having driving-wheels 5 feet in diameter and 2 feet stroke of piston. Another curve, *A h' i' j' k' l' m' n*, has been constructed to show the velocity which a body falling freely from *A*, would acquire in a distance, *A o*, equal to the stroke of the piston. It should be observed that the horizontal distance of the two curves from the vertical line, *A o*, represents the velocities of the piston and of the falling body. They can therefore be compared with each other, and it will be seen that at the middle of the stroke of the piston its velocity is about four times that of the falling body. It must be remembered, as was explained in Chapter I, that the force which moves and gives velocity to a falling body is its own weight, or the attraction of gravitation, and that the velocity which a body acquires is proportional to the force acting on it. If, then, the reciprocating parts of an engine in moving a given distance have a velocity imparted to them four times as great as that which a falling body would acquire in the same distance, the force which acts on the reciprocating parts to produce this motion must be equal to over four times their own weight. As these parts of a passenger locomotive, with 18 x 24-inch cylinders, weigh about 550 lbs., the pressure on the pistons required to give them the required velocity in moving from the beginniug to the middle of the stroke at a speed of 50 miles an hour, must be equal to that produced by a weight of not less than 550 x 4=2,200 lbs. acting through a distance of 1 foot.

QUESTION 165. *Is the rate of the acceleration of the velocity of a piston the same as that of a falling body?*

Answer. No. A falling body can move freely under the action of the force which attracts or impels it downward, whereas the movement of the reciprocating parts of a steam-engine are restrained by the crank, which moves in its path at a nearly uniform rate of speed. The relative velocity of a piston and a falling body are shown by the form of the curves, *A h i j k l m n o* and *A h' i' j' k' l' m' n' o*, in fig. 94, from which it will be seen that in moving from *A* to *h* and *i* the rate of acceleration, or the increase in the speed of the piston is very great, whereas from *i* to *j*, and *j* to *k*, it is very slight, and the motion begins to be retarded at *k*. A falling body, as was explained in answer to Questions 13 to 20, has a uniform increase of its velocity for every second that it falls.

QUESTION 166. *In what way can we determine how much force is required to move the reciprocating parts of an engine at the beginning of the stroke?*

Answer. To make this plain let it be supposed that the weight of the piston and other reciprocating parts is concentrated at *A*, fig. 90, and that the crank is at the dead-point, *B*. It has been explained, that if a crank-pin, *F*, is in the position shown in fig. 95, and is revolving about the

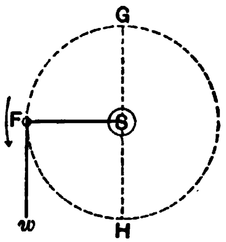


Fig. 95.

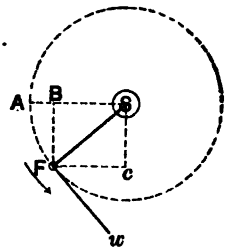


Fig. 96.

Diagrams showing Movement of Crank. Scale ⅛ in.=1 ft.

centre of the shaft, *S*, its tendency would be to move in the direction of the line, *F w*, at right angles to the crank, but this movement is resisted by the crank which draws the pin towards the shaft, *S*. Referring again to fig. 90, and supposing as before that the weight of the reciprocating parts is concentrated at *A*, and that *A* is connected to the crank-pin at *B*, by a connecting-rod, *A B*, and it will be obvious that while the crank-pin is revolving any distance, say from *1* to *2*, that—excepting so far as their movement is effected by the angularity of the connecting-rod—the *horizontal* movement of the reciprocating parts from *A*, will be coincident with or be the same as that of the crank-pin from *B*. As the crank-pin and the reciprocating parts are connected together by the connecting-rod, if their weight was concentrated in the centre of the crank-pin at *B*, the *horizontal* movement of the weight would then be the same as it is from *A*, and the force required to move it *horizontally* from *B*, would be equal to that needed to move it from *A*. We may, therefore, assume that the weight of the reciprocating parts is concentrated at the centre of the crank-pin, and, as shown in fig. 95, that the latter is at *F*, one of the dead-points. In this case the crank, *F S*, is supposed to be horizontal, and the crank-pin, *F*, to be moving in the direction indicated by the dart. As already remarked, the tendency of the weight concentrated about the centre of the pin, *F*, will be to move in a straight line, *F w*, at right angles to the centre line, *F S*, of the crank, as is shown by the way that water flies from a rapidly revolving grindstone, or sand from a carriage-wheel. This tendency of the weight to continue moving in a straight line, causes it to exert a force upon the crank—the same as that exerted on a string when a stone or other heavy object attached to it is whirled around—and this is called the *centrifugal force*. The resistance of the crank tending to pull the weight towards the centre of the shaft is called the *centripetal force*. As explained above, if the weight is concentrated at the centre of the cross-head pin at *A*, fig. 90, and it was connected to the crank-pin, at *B*, by a rod, as it is in a steam-engine, just as much force would be required to pull the weight toward the path of the crank-pin as would be needed if their weight was concentrated at *B*. Consequently, if we ascertain the centrifugal force which a weight equal to that of the reciprocating parts of an engine would exert on the crank when it is at a dead-point, we will know the force required to move those parts in a horizontal direction at the beginning of the stroke.

QUESTION 167. *How can the centrifugal force of a revolving body be calculated?*

Answer. MULTIPLY THE WEIGHT OF THE REVOLVING BODY IN POUNDS, THE SQUARE OF THE NUMBER OF REVOLUTIONS PER MINUTE, THE RADIUS OR DISTANCE IN FEET FROM THE CENTRE OF MOTION, AND .00034 TOGETHER, AND THE PRODUCT WILL BE THE CENTRIFUGAL FORCE IN POUNDS.

QUESTION 168. *How can we ascertain how much force is required to accelerate the piston at any point after the crank has passed beyond the dead-point?*

Answer. To explain this it will be supposed that the crank is in the position, *F S*, shown in fig. 96. The mass, whose weight it will again be supposed is concentrated at the centre, *F*, of the crank-pin, would then, if left to itself, move in a direction, indicated by *F w*, at right angles to the crank, *F S*. The centrifugal force again pulls *F* away from the centre, *S*, and acts in the direction of *S F*. It will be plain that when the crank is in this position, that it is only that portion of the centrifugal force which acts horizontally that accelerates or pulls the reciprocating parts in that direction. Therefore, if *F S* is equal to the centrifugal force by drawing a parallelogram of forces, *B S c F*, with *F S* for the diagonal, and the sides, *B S* and *F c*, horizontal, and *B F* and *S c* perpendicular, then by the principles already explained, *B S* and *F c* will represent the horizontal component or the horizontal pull exerted by the centrifugal force acting on the crank when it is in the position shown in fig. 96. Similar diagrams will show the horizontal pull of the centrifugal force for any position of the crank.*

QUESTION 169. *What would be the centrifugal force of the reciprocating parts of a locomotive which weigh 550 lbs., if it has driving-wheels 5 feet in diameter, cylinders with 2 feet stroke, and is running 50 miles an hour?*

Answer. By a simple calculation it will be found that at 50 miles an hour wheels 5 feet in diameter would make 280 turns in a minute. By the rule given in answer to Question 158 we would have:

$$550 \times 280 \times 280 \times 1 \times .00034 = 14{,}660 \text{ lbs.}$$

QUESTION 170. *How can the pressure required to accelerate the piston, during a whole stroke, be shown by a diagram?*

Answer. It has been explained that the pressure required at the beginning of the stroke will be equal to the centrifugal force of the weight of the reciprocating parts, if it was concentrated at the centre of the crank-pin. Horizontal components of the centrifugal force for different positions of the crank can be ascertained by diagrams similar to fig. 96. Having done this, a line, *A E*, fig. 97, may be laid off equal to the stroke of the piston, and a perpendicular, *A c*, can be drawn from the extremity, *A*, whose length is equal to the centrifugal force. From *B* at a distance *A B*=to *A B*, of fig. 96, a perpendicular, *B d*, is drawn equal to the horizontal component, *F c*, of the centrifugal force, as shown in fig. 96. Other lines, as *C e*, may be drawn representing the action of the centrifugal force when the crank and piston are in other positions. If now, a line, *c d e D*, is drawn through the extremities of the perpendiculars, it will be found to be a straight line, which will intersect the centre, *D*, of the line, *A E*,

* In this explanation no account has been taken of the effect of the angularity of the connecting-rod, which has some, although not a very great influence on the centrifugal action at the crank-pin.

representing the stroke; so that to make a diagram of this kind, all we need do is to calculate the centrifugal force and represent it by a perpendicular, *A c*. at the end of a line representing the stroke, and then draw a straight line through its extremity, *c*, and a point, *D*, in the middle of the line, *A E*.

QUESTION 171. *Is the power required to accelerate the piston in moving from the beginning to the middle of the stroke lost?*

Answer. No. The power represented by the momentum of the reciprocating parts is communicated by the connecting-rod to the crank-pin after the piston has passed the middle of its stroke. It has been explained that the *horizontal* movement of the crank-pin is accelerated during the first quarter of its revolution, and is retarded during the second. Consequently, during the latter period the crank-pin resists the accelerated motion or momentum of the reciprocating parts, which, therefore, press against it, and thus do work.

QUESTION 172. *How may the effect of this momentum of the reciprocating parts be shown in the diagram?*

Answer. During the first half of the stroke, as has been explained, pressure must be exerted against the piston to start the reciprocating parts from a state of rest, and then accelerate their motion up to a point about the middle of the stroke. After that the momentum of these parts exerts a pressure against the crank-pin.

QUESTION 173. *How does the diagram show the momentum of the reciprocating parts?*

Answer. In fig. 97 the vertical distance of the diagonal line, *c D*, below

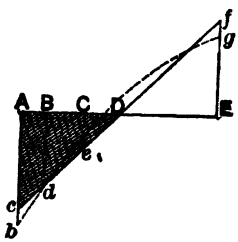


Fig. 97. Diagram showing Inertia and Momentum of Piston. Scale ⅛ in.—1 ft.

the horizontal line, *A E*, represents the pressure which must be exerted to start and accelerate the reciprocating parts. After the piston has reached its maximum velocity near the middle of the stroke the motion of these parts is retarded by the crank-pin, and they consequently press against it. During the first half of the stroke these parts resist acceleration, and during the latter part they resist retardation. Or, in plainer language, in the one case they hold back, and in the other they push the crank ahead. The forces exerted during the two portions of the stroke are, therefore, of opposite kinds. For that reason the force of momentum of the reciprocating parts is laid off on the opposite side of the line, *A E*. As the momentum of a moving body is just equal to the force required to produce the motion, if there has been no loss of energy from friction or other causes, the unshaded portion, *D f E*, of the diagram *above* the line, *A E*, would represent the pressure which the reciprocating parts exert against the crank-pin, and is just equal to *c A D*. This can be proved by constructing parallelograms of force for the last half in the same way as was explained for the first half. It would thus be found that the horizontal components of the centrifugal force of the reciprocating parts in the different positions of the crank are the same for the last half as they are for the first half of the stroke, if the effect of the angularity of the connecting-rod is not taken into consideration.

QUESTION 174. *What influence does the angularity of the connecting-rod have on the pressure required to accelerate and retard the reciprocating parts?*

Answer. It has been shown from fig. 90 that the rate of acceleration of the piston during the backward stroke is greater than it is for the forward stroke, and the rate of retardation is greater for the forward stroke than for its backward movement. Consequently, if the effect of the connecting-rod is taken into account the pressure represented by *A c*, in fig. 97, would be somewhat increased, and that shown by *f E* would be diminished.

The effect of the connecting-rod in thus increasing and diminishing the pressure required to accelerate and retard the reciprocating parts at the two ends of the stroke is equal to the proportion which the length of the crank bears to the connecting-rod. That is, in fig. 90, the crank is ¼ the length of the rod, so that ¼ must be added to the centrifugal force, which is equal to the pressure required to accelerate the parts when the piston is at the front end of the cylinder, and ¼ must be deducted when the piston is at the back end. The line, *b D g*, fig. 97, will then be curved as shown by the dotted line.*

* The proof of this is given in a note to the answer to Question 485. The subject is fully discussed in Arthur Riggs's "Practical Treatise on the Steam-Engine," in George V. Holmes's book on the same subject, and in "A Treatise on the Richards's Steam-Engine Indicator," by Charles T. Porter.

CHAPTER X.

GENERAL DESCRIPTION OF A LOCOMOTIVE ENGINE.

QUESTION 175. *What are the principal parts of an ordinary locomotive engine?*

Answer. A boiler for generating steam and a pair of high-pressure steam-engines, which are all mounted on suitable frames and wheels adapted for running on a track consisting of two iron or steel rails.

QUESTION 176. *How is the power of high-pressure engines applied to locomotives?*

Answer. By connecting the engines with the wheels so as to give the the latter a rotary motion.

QUESTION 177. *When the wheels revolve what will occur?*

Answer. Either they will slip on the track, or the locomotive will move backward or forward according to the direction the wheels are turning.

QUESTION 178. *What will determine whether the wheels will slip or the locomotive move?*

Answer. The friction or *adhesion*, as it is called, between the wheels and the track. If this adhesion is greater than the resistance opposed to the movement of the locomotive, the latter will overcome the resistance; but if the latter is greater than the friction, the wheels will slip.

QUESTION 179. *Upon what does the amount of friction or adhesion of the wheels depend?*

Answer. Chiefly on the weight which they bear, but to some extent upon the condition of the rails. Under ordinary circumstances, the adhesion of the wheels of a locomotive is in direct proportion to the weight they carry.

QUESTION 180. *Why are two cylinders employed on locomotives?*

Answer. Because if only one was used, it would be impossible or very difficult to start the engine, if it should stop on one of the dead-points.

QUESTION 181. *How is this difficulty overcome by the use of two cylinders?*

Answer. By attaching the two cranks to the same shaft or axle, and placing them at right angles to each other, so that when the one is at a dead point the other is in a position where the steam can exert the maximum power on the crank.

QUESTION 182. *How are the cranks of an ordinary locomotive made?*

Answer They are cast in one piece with the wheels that drive the locomotive, which are therefore called *driving-wheels*. In this country the centre portion of such wheels, or *wheel-centres* as they are called, are always made of cast-iron. They are bored out accurately so as to fit the axles, which are forced into the holes bored to receive them. The centres are keyed fast to the axles, so as to prevent them from turning. The wheel-centres have steel tires around the outside which are accurately turned inside, and are made a little smaller than the wheel-centres. Before they are put on the wheels the tires are expanded by heating them, and are then put on the wheel-centres, and as they cool they contract, which causes them to fit tight. The axle of a locomotive engine to which the pistons are connected is called the *main driving-axle*, and the wheels attached to it the *main driving-wheels*.

QUESTION 183. *What is the general construction and arrangement of the parts of a locomotive?*

Answer. The construction and arrangement of parts of an ordinary locomotive is shown by Plates III, IV and V, which represent a side view, a longitudinal section, and a plan of an 8-wheeled passenger engine built at the Baldwin Locomotive Works in Philadelphia, and by fig. 98, which is a transverse section through the cylinders, and fig. 99, which is an end view looking at the back end of the engine.*

QUESTION 184. *How are the cylinders and driving-wheels of a locomotive usually placed?*

Answer. The cylinders, 1, of 8-wheeled American passenger engines, Plates III, IV and V, and figs. 98 and 99, are placed at the front end of the locomotive, and the main driving-axle, 2, far enough behind them to permit the connecting rods, 3, to be attached to pins, 5, called *crank-pins*, in cranks, in the wheels. In this country the wheels and cranks are now universally placed on the outside of the frames, and therefore the cylinders must be placed far enough apart (as shown in fig. 98 and Plate V) to permit the connecting-rods to be attached to the crank-pins. For this reason the cylinders are also placed outside of the frames, 32 32 32. The frames, it will be seen, are inside of the wheels, and the cylinders now nearly always have their axes or centre-lines horizontal, although in old engines they are sometimes inclined. The cranks on the one side of the

* The same figures indicate the same parts in all these engravings.

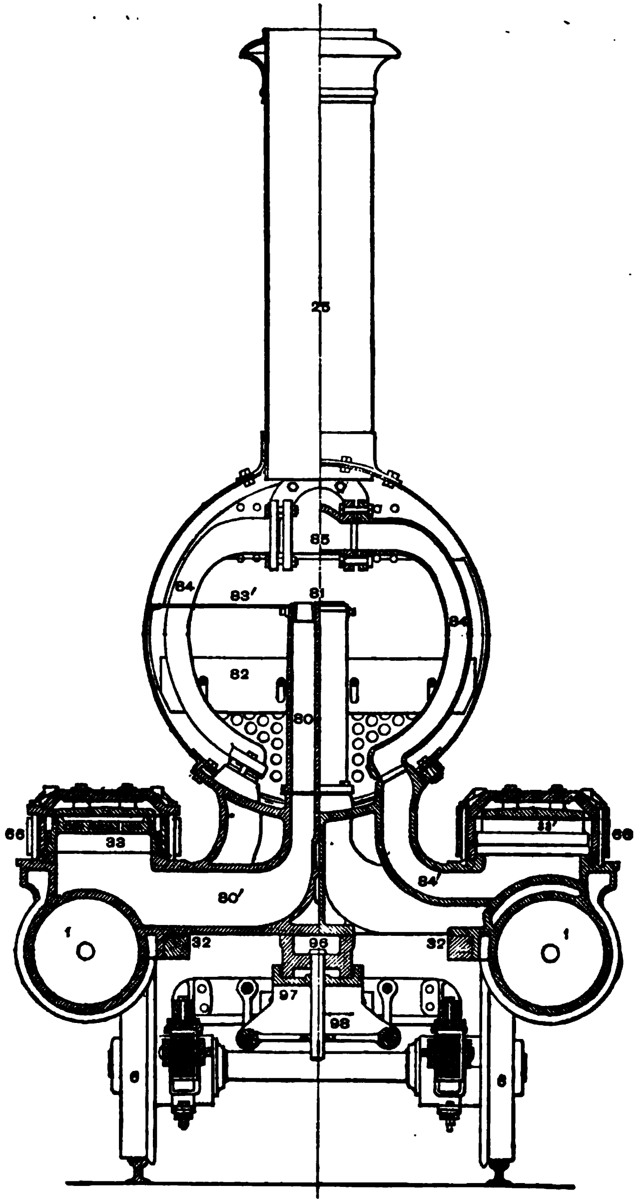


Fig. 98. Transverse Sections through Smoke Box of Locomotive. Scale ⅜ in. = 1 ft.

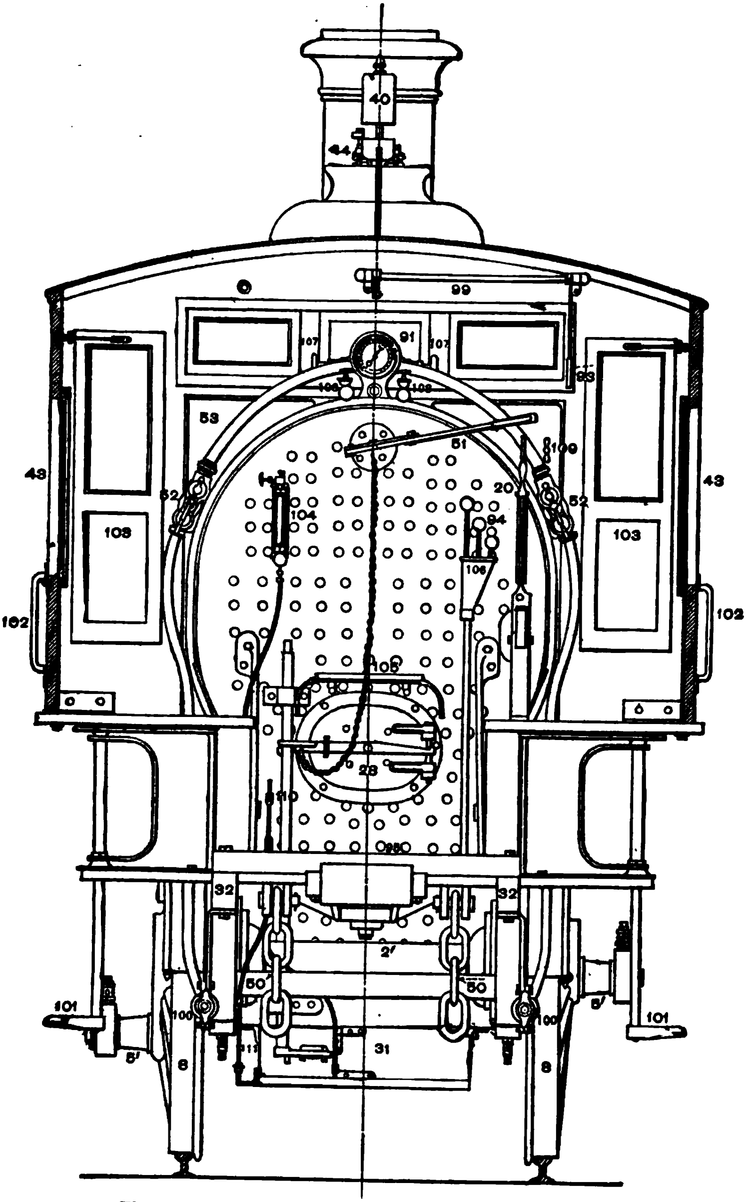


Fig. 99. Back End View of Locomotive. Scale ¾ in. = 1 ft.

locomotive, as has been explained, are placed at right angles to those on the other, so that when those on one side are at their dead-points, those on the other are half way between the dead-points. They are arranged in this way so that the piston on one side can exert its maximum power when the cranks on the other side are at their dead-points.

QUESTION 185. *Why are more than one pair of driving-wheels necessary for locomotives?*

Answer. Because if all the weight which is needed to create the requisite adhesion of the wheels of locomotives to pull heavy loads was placed on one pair of wheels the weight would be so excessive as to partly crush and injure the rails. It is therefore distributed, usually on two pairs, but sometimes on three or four or even more pairs. The cranks in the wheels on each side of the engine are connected together by rods or bars, 4, called *coupling* or *parallel-rods*, which are attached to the crank-pins, so that all the driving-wheels will revolve together.

QUESTION 186. *Where is the second pair of driving-wheels usually placed?*

Answer. These wheels, 8 8—called the *back driving* or *trailing driving-wheels*—are, in the ordinary type of locomotives used in this country, situated behind the main driving-wheels, far enough back to give the room necessary for the fire-box between the two axles.

QUESTION 187. *How are the axles, cylinders, etc., held in the right position in relation to each other?*

Answer. By the longitudinal frames, 32 32, which hold the axles in the proper place, and are bolted to the cylinders, and are also fastened to the boiler at 10 10.

QUESTION 188. *What are the smaller wheels, 6 6, called, and what are they for?*

Answer. They are called *truck-wheels*, and carry the weight of the cylinders and other parts of the front end of the locomotive, and serve to guide and steady the machine in a manner which will be more fully explained hereafter.

QUESTION 189. *How is a locomotive engine made to run either backward or forward?*

Answer. By having two eccentrics, 11 11′, Plates IV and V, for each cylinder. One of these is fixed or *set* on the shaft in such a position as to move the valve so that the engine will run in one direction; the other eccentric is set so that the engine will run the reverse way. The ends of each pair of eccentric rods are attached by rods, 12 12′, to what is called a *link*, 13, the object of which is to furnish the means of quickly engaging and disengaging either eccentric rod to or from the rocker, 14, 14. The rockers are connected to the main valves, 33, by rods, 34, called *valve-stems*. The links are suspended by bars, 15, called *link-hangers*, to the ends of arms, 16, attached to a shaft, 17, called a *lifting-shaft*. This shaft has another upright arm, 18, attached to it on the right-hand side of the engine, the upper end of which is connected by a rod, 19 21, called the *reversing-rod*, to a lever, 20 21 and 22, called the *reversing-lever*, in the cab. The principles and operation of this mechanism will be fully explained in another chapter.

QUESTION 190. *What are the principal parts or "organs" of a locomotive boiler?*

Answer. 1. A fireplace, or, as it is called, a *fire-box*, 9.

2. A cylindrical part, 23, attached to the fire-box at one end and to a chamber, 24, called the *smoke-box*, at the other.

3. The *tubes* or *flues*, 25 25′, Plate IV, which connect the fire-box with the smoke-box, and pass through the cylindrical part of the boiler and are surrounded with water.

4. The *chimney* or *smoke-stack*, 25.

QUESTION 191. *What is each of those parts or organs for and of what do they consist?*

Answer. The fire-box, 9, furnishes the room for burning the fuel, and consists of an inner and outer shell made of boiler plate, as shown in Plates IV and V, with the spaces, 26 26, between the two shells filled with water; a grate, 27 27, formed of cast-iron bars, with spaces between them for admitting air for the combustion of the fuel, which is placed on top of them; a door, 28, called the *furnace-door*, for supplying the grate with fuel; a receptacle, 29, below the grate, to collect ashes, and therefore called the *ash-pan*, which is supplied with suitable dampers, 30 and 31, for admitting or excluding the air from the fire.

The cylindrical part, 23, or *waist* of the boiler, as it is sometimes called, contains the greater part of the water to be heated.

The *flues* or *tubes*, as they are generally called, are usually 2 inches in diameter and from 10 to 12 feet long. The number of tubes in a locomotive boiler varies with its size. A boiler of the size represented in the illustration has about 250 tubes, as shown in fig. 91. They conduct the smoke and products of combustion from the fire-box to the smoke-box. The tubes are made of small diameter so as to subdivide the smoke into many small streams and thus expose it to a large radiating surface through which the heat is conducted to the water.

The chimney or smoke-stack serves partly for removing into the open air the smoke which passes through the flues, and partly for producing a strong draft of air, which is indispensably necessary for the rapid combustion of the fuel. Smoke-stacks are also often provided with arrangements for arresting the sparks and cinders which escape from the fire.

QUESTION 192. *What is a locomotive head-light, and what is it for?*

Answer. A *head-light* is a large lamp, 35, Plate III, which is placed on the front end of a locomotive to light up the track in front of it and give warning of its approach.

QUESTION 193. *What is a cow-catcher, and what is it for?*

Answer. A *cow-catcher*, 38, sometimes called a "*pilot*," as its name implies, is intended to "catch cows" or other obstructions on the track and throw them off, thus preventing them from getting under the wheels while the engine is running. It is a triangular-shaped structure made of wooden or iron bars and attached to the front of the engine.

QUESTION 194. *What is a sand-box on a locomotive for?*

Answer. The sand-box, 39, is usually placed on top of the boiler, and has pipes, 40, on each side of the engine by which sand is conducted to the rails in front of the driving-wheels, to prevent them from slipping when the engine is working hard.

QUESTION 195. *What is the cab of a locomotive for?*

Answer. A cab, 43, is for the protection of the men who run the engine from rain, cold and sunshine.

QUESTION 196. *How is the locomotive connected to the train behind it?*

Answer. By an iron bar, 48, called a draw-bar, which is attached by a pin, 49, Plate IV, to a casting on the back end of the engine. The draw-bar is coupled to the tender behind the engine by another pin similar to the one on the engine. The engine and tender are also coupled together by chains, 50, called safety-chains. These are used as a safeguard to prevent the engine and tender from separating in case the draw-bar should break.

QUESTION 197. *How are the water and fuel carried which must be supplied to a locomotive while it is running?*

Answer. The water is carried in a tank, which is usually constructed in the form of a letter U, so as to give room for the stowage of fuel between its two branches or sides, and is carried on a set of wheels, which forms a separate vehicle, independent of the locomotive, called a *tender*, the construction of which will be explained in a future chapter. In another class of engines, called *tank-engines*, the water-tank and fuel are carried on the engine.

THE FOLLOWING IS A

LIST OF PARTS DESIGNATED BY THE NUMBERS ON PLATES III, IV, V, AND FIGS. 98 AND 99.

1. Cylinders.
2. Main driving-axle.
3. Connecting-rod.
4. Coupling-rod.
5. Main crank-pin.
6. Truck wheels.
7. Main driving-wheels.
8. Back driving or trailing wheels.
9. Fire-box.
10. Expansion clamps.
11. Eccentrics.
12. Eccentric-rods.
13. Link.
14. Rocker.
15. Link-hanger.
16. Horizontal arm of lifting-shaft.
17. Lifting-shaft.
18. Upright arm of lifting-shaft.
19. Reversing-rod.
20. } Reversing-lever.
21. }
22. }
23. Cylinder, or waist of boiler.
24. Smoke-box.
25. Chimney or smoke-stack.
26. Water spaces.
27. Grate.
28. Furnace-door.
29. Ash-pan.
30. Front ash-pan damper.
31. Back ash-pan damper.
32. Frames.
33. Main-valve.
34. Valve-stem.
35. Head-light.
36. Head-light reflector.
37. Head-light lamp.
38. Cow-catcher.
39. Sand-box.
40. Sand-pipes.
41. Bell.
42. Dome.
43. Cab.
44. Safety-valve.
45. Safety-valve lever.
46. Whistle.
47. Whistle-lever.
48. Draw-bar.
49. Coupling-pin.
50. Safety-chains.
51. Throttle-lever.
52. Injector.
53. Injector steam-pipe.
54. Injector feed-pipe.
55. Injector check-valve.
56. Running-board.
57. Hand-rail.
58. Equalizing-lever.
59. Driving-springs.
60. Counter-balance weights.
61. Driving-wheel guard.
62. Guide-bar.

63. Cross-head.
64. Piston.
65. Piston-rod.
66. Steam-chest.
67. Spark ejector valve.
68. Relief-valve for steam-chest.
69. Spark ejector.
70. Smoke-box door.
71. Cylinder-cocks.
72. Cylinder-cock lever.
73. Cylinder-cock shaft.
74. Truck-spring.
75. Truck-frame.
76. Truck equalizing-lever.
77. Truck wheel-guard.
78. Truck check-chain.
79. Push-bar.
80. Exhaust-pipes
81. Exhaust-nozzle.
82. Deflector.
83. Wire-netting.
84. Steam-pipe.
85. T-pipe.
86. Dry-pipe.
87. Throttle-pipe.
88. Throttle-valve.
89. Throttle-stem.
90. Throttle bell-crank.
91. Steam-gauge.
92. Steam-gauge lamp.
93. Whistle lever.
94. Gauge-cocks.
95. Foot-board.
96. Truck centre-bearing.
97. Truck centre-plate.
98. Truck centre-pin.
99. Whistle-shaft.
100. Suction-pipes.
101. Foot-steps of cab.
102. Hand-holes of cab.
103. Front door of cab.
104. Water-gauge.
105. Stand for oil-cans.
106. Drip for gauge-cocks.
107. Injector-valve.
108. Oil-cup for oiling main valves.
109. Handle for opening valves in sand-box
110. Handle for opening front damper.
111. Bell-crank for opening front damper
112. Rod for opening front damper.
113. Mud-plugs.

CHAPTER XI.

DIFFERENT KINDS OF LOCOMOTIVES.

QUESTION 198. *Into what classes may locomotives be divided conveniently?*

Answer. 1. Locomotives for "switching," "shunting," or "drilling" service—that is, for transferring cars from one place to another at stations; 2, for freight traffic; 3, for ordinary passenger traffic; and 4, for metropolitan or suburban railroads, where a great many light trains are run.

QUESTION 199. *What kinds of locomotives are used in this country for switching cars at stations?*

Answer. Four and six-wheeled locomotives similar to those represented by figs. 100 and 101. Such engines are now usually made with separate tenders, but they are sometimes made so as to carry the water-tank and fuel on the locomotive itself, as shown by fig. 117, and are then called *tank locomotives.*

QUESTION 200. *Why are four and six-wheeled locomotives used for switching?*

Answer. Because in such service it is necessary to start trains often, many of which are very heavy, and therefore a great deal of adhesion is needed. For this reason the whole weight of the locomotive, and, in the case of some tank locomotives, that of the water and fuel, is placed on the driving-wheels. It is also necessary for such locomotives to run over curves of very short radius and into switches whose angle with the main track is very great; and therefore, in order that they may do this and remain on the track, their wheel-bases must be very short, and consequently the wheels are all placed near together and are usually between the smoke-box and fire-box.

QUESTION 201. *Why are such locomotives not suited for general traffic?*

Answer. Owing to the shortness of their wheel-bases they become very unsteady at high speeds, and acquire a pitching motion, similar to that of a horse-car when running rapidly over a rough track. This unsteadiness not only becomes very uncomfortable to the men who run the locomotive, but when it occurs there is danger of the engine running off the track.

As nearly all switching is done at very slow speeds, it is not so objectionable for that service as it would be on the "open road"* at high speeds.

QUESTION 202. *How can such engines be made to run steadier?*

Answer. By putting a pair of truck-wheels under the front or rear end of the engine, as shown in figs. 102, 103, 104 and 105.

QUESTION 203. *What kinds of locomotives are used for passenger service?*

Answer. The greater part of the passenger service of this country is performed by locomotives like that selected for the illustrations of these articles, and represented in Plates III, IV and V. Such locomotives have been called "American" locomotives, because they first originated in this country, and are now more generally used here than anywhere else. Perspective views of similar engines are also shown in figs. 110 and 111.

QUESTION 204. *How are such engines constructed?*

Answer. One pair of driving-wheels is usually placed behind the fire-box and one in front, and the front end of the engine is carried on a four-wheeled truck. In some cases the fire-box is extended back over the top of the rear axle. Usually the fire-box is placed between the frames, but they are sometimes put on top, in order that it can be made wider than is possible if it is placed between.

QUESTION 205. *What are the dimensions of such engines?*

Answer. The principal dimensions of the engines illustrated by figs. 110 and 111 are given opposite the engravings, but locomotives of this plan are built of much smaller and also of larger sizes than those represented by the engravings. In some cases they do not weigh more than 35 or 36,000 lbs., with cylinders from 8 to 12 inches in diameter. In other cases they weigh over 100,000 lbs., with cylinders 18 or 20 inches in diameter. The wheels vary from 4 to 6 feet in diameter, but the most common sizes are 4½ to 5½ feet.

QUESTION 206. *What kinds of locomotives are used for freight service?*

Answer. Much of the freight service in this country is performed by "American" locomotives, similar to those described for passenger traffic. Usually engines used for freight service have smaller driving-wheels than those designed for passenger trains.

QUESTION 207. *When it is desirable to pull heavier loads than is possible with the adhesive weight that can be placed on four driving-wheels, what is done?*

* The term "*open road*" is a literal translation from the German, for which there is no corresponding English term, and means the road between stations where trains run fast.

Answer. One or more pairs of driving-wheels are added, as in the ten-wheeled and "Mogul" locomotives represented by figs. 112 and 113, and the "Consolidation" and twelve-wheeled engines by figs. 114 and 115, and the "Decapod" locomotive by fig. 116. The ten-wheeled locomotive is similar in construction to an ordinary "American" locomotive, excepting that it has another pair of driving-wheels in front of the main driving-wheels. It will be seen, however, that it is necessary to keep these close to the latter, because if they are brought further forward they will be too near the back truck wheels. For this reason a truck consisting of a single pair of wheels is often in place of the four-wheeled truck and is placed in front of the cylinders, as represented in the engraving of the Mogul engine, fig. 112, and the front pair of driving-wheels can then be placed further forward, and they thus bear a larger proportion of the weight than they do if located as they are under the ten-wheeled engine. There is a similar difference between the construction of the twelve-wheeled and "Consolidation" engines, shown by figs. 114 and 115.

QUESTION 208. *Under what circumstances are the different classes of freight locomotives which have been described employed?*

Answer. On comparatively level roads, or those having a light business, "American" locomotives are generally used for freight as well as passenger business. On lines which have moderately heavy grades or heavy traffic, ten-wheeled and Mogul engines are used; and where the grades and traffic are both heavy, Consolidation or twelve-wheeled engines are employed. For excessively heavy mountain grades, Decapod locomotives are employed.

QUESTION 209. *What is meant by metropolitan and suburban railroads? What is the nature of their traffic?*

Answer. By metropolitan railroads are meant railroads in large cities. They may be divided into two classes: one for carrying freight cars from the outskirts of cities to the warehouses and stores at their business centres, and also from the terminus of one road to that of another. Metropolitan railroads of this kind are usually branches of lines which extend from the city. Locomotives for such traffic must have great tractive power, in order to pull heavy trains; and as the speed is usually slow, the wheels and the boiler capacity may be small. They must generally be capable of running through curves of very short radius; and as the traffic is usually carried through the streets in close proximity to buildings, the locomotives should be as nearly as possible noiseless. The other class of metropolitan roads is for carrying passengers. The traffic of the latter is similar to that usually carried on horse railroads, and consists almost exclusively of passengers. Many light trains must be run at short intervals and at comparatively slow speeds, and therefore very light locomotives are required.

The traffic of suburban railroads consists chiefly of the transportation of passengers to a large town or city in the morning and to their homes in the evening. As the largest number of passengers must be carried during a few hours in the morning and evening, it is necessary to run very heavy trains at those times. As the passengers must be distributed at many stations which are near together, it is necessary to stop often; and in order that the average speed may be reasonably fast, the trains must run very rapidly between these stations. It is, therefore, essential to have heavy locomotives, with more than the usual proportion of adhesive weight, so that the trains can be started quickly without slipping the wheels. The main valves should also have a liberal amount of travel, so that the steam will be admitted to and exhausted from the cylinders quickly. In some cases it is thought desirable to have locomotives which will run equally well either way, so that it will not be necessary to turn them around at each end of the "run."

QUESTION 210. *What kinds of locomotives are used on metropolitan railroads?*

Answer. For freight traffic ordinary switching locomotives, like those shown by figs. 100 and 101, are often employed. In some cases these have the water tanks on the locomotives. It often happens, though, that such traffic must be conducted in the streets of a city, and that the noise, especially of the exhausting steam, is thus liable to frighten horses and disturb the occupants of the houses. It is, then, necessary either to condense the exhaust steam or render its escape noiseless, which is done by allowing it to escape into the water-tanks. Street locomotives which have a condenser similar to the surface condensers used on marine engines are used on the New York Central and Hudson River Railroad in New York City. The exhaust steam passes through the condensers and then escapes into the tanks. The latter are long and narrow, so as to expose a great deal of surface to radiation, and in this way the water which becomes heated by the steam is cooled. The engines have four driving-wheels and vertical boilers. The cylinders are connected to a crank-shaft with a pinion on it, which gears with another wheel of larger size on the driving-axle. In this way the speed is reduced, and great tractive power can be exerted. The whole of the engine is enclosed so as to hide the machinery, the sight of which is supposed to frighten horses. The engines were designed and patented by the late A. F. Smith, formerly Master Mechanic of that road.

For roads in cities on which passengers almost exclusively are carried, an entirely different class of locomotive is needed. To suit passengers it is, of course, necessary to run a great many trains at very short intervals. When this is done the trains are necessarily very light, and therefore only light locomotives are needed. Fig. 105 represents one of the engines used on the New York Elevated Railroad. These run both ways, and through curves of only 90 feet radius. Engines similar to that shown by fig. 103 are also used on this road.

QUESTION 211. *What kind of locomotives are used for metropolitan and suburban railroads?*

Answer. The ordinary American eight-wheeled locomotive is used, perhaps, more than any other kind; but a number of locomotives, like that represented by fig. 102, have been built and are used for this traffic. These have one pair of driving-wheels in front of the main pair, and a Bissell truck in front of the cylinder. With this arrangement the driving-wheels bear a larger proportion of weight than they do if arranged on the ordinary American plan with a four-wheeled truck. Another plan is that shown by fig. 109. Such engines, it will be seen, have a Bissell truck at each end, and therefore they run equally well either way. The water and fuel is carried in separate tenders. In some cases the tanks of such engines are carried on the top and sides of the boiler, as shown in fig. 117. When they are obliged to run only a short distance, and a small supply of water is needed, this arrangement answers very well; but it is impossible to carry a large supply of water in this way without overloading the wheels of the locomotive, and at the same time increasing the evils of a varying load on the driving-wheels.

To get over this difficulty, and at the same time dispense with a tender, the frames are extended behind the fire-box, as shown by fig. 103, and the water-tank is placed on top of this extension of the frames, and its weight is carried on a pony-truck below the frames and behind the fire-box. With this arrangement the whole weight of the boiler and the machinery is kept on the driving-wheels, and the water and fuel is carried by the truck. The load on the driving-wheels is therefore constant.

When larger engines are required and more water must be carried, a four-wheeled truck is placed under the back end of the engine, as shown by figs. 104 and 105. This form of engine was first designed and patented by the Author, which must account for the name being coupled with it.

The late William S. Hudson designed and built a number of engines like that shown by fig. 108. These each had a four-wheeled truck at the back end and a pony-truck at the front. A similar engine, with three pairs of driving-wheels, and another with a six-wheeled truck in front are shown by figs. 106 and 107.

QUESTION 212. *What kinds of locomotives are used on street railroads?*

Answer. Fig. 118 represents a locomotive which is used on street and suburban railroads. Its construction is similar to that of the engine shown by fig. 103, but it is enclosed with a large cab, so that the working parts are not exposed. This is done to prevent horses from being frightened.

Fig. 119 represents a steam car for street railroads, and fig, 120 shows the running gear and engine without the car body. In this passengers are carried in the same vehicle that contains the engine. As shown in fig. 120, the engine has a vertical boiler, and the working parts of the engine are placed below the floor of the car.

QUESTION 213. *What is a compound locomotive?*

Answer. It is a locomotive in which the steam, after it has acted on the piston of one cylinder, escapes into another and larger cylinder, in which it acts on another piston, and thus expands more than it would if confined to one cylinder. Some engines of this kind have two cylinders, one large and one small one, or a high and a low-pressure cylinder. In other cases there are two high and one low-pressure cylinder, and in still others two high and two low-pressure.

QUESTION 214. *What advantage is claimed for the compound system?*

Answer. A saving of about 15 to 20 per cent. of the fuel is claimed, owing to the greater degree of expansion of the steam. Thus far such engines have been used in this country only in an experimental way, but they are now (1890) extensively used in Europe.

QUESTION 215. *What is the difference between inside and outside cylinder engines?*

Answer. In this country it is the universal practice to put the cylinders of locomotives outside of the wheels and frames, and connect the pistons to crank-pins on the outside of the wheels. In Europe, especially in England, it is more common to put the cylinders between the frames and wheels, and connect the pistons to cranks on the main driving-axle.

QUESTION 216. *What are the relative advantages and disadvantages of these methods of construction?*

Answer. It is claimed that engines with inside cylinders run steadier than those with cylinders outside, owing to the greater leverage which the pistons of the outside cylinders exert, owing to their being further from the centre line of the engine. This is undoubtedly true; but if locomotives are made with a long wheel-base, as they may be if one or two trucks are used, this leverage has very little influence on the steadiness of running of the engine. It is also claimed that when inside cylinders are used they are better protected from radiation and loss of heat, as they can be placed inside of the smoke-box. On the other hand, the great objection to inside cylinders is the crank-axles, which are expensive in the first place, and are subject to frequent breakage. The inside cylinders are also more or less inaccessible for making repairs, and there are limitations to their size, if they are put between the frames. Experience in this country has led to the entire disuse of inside cylinders on locomotives.

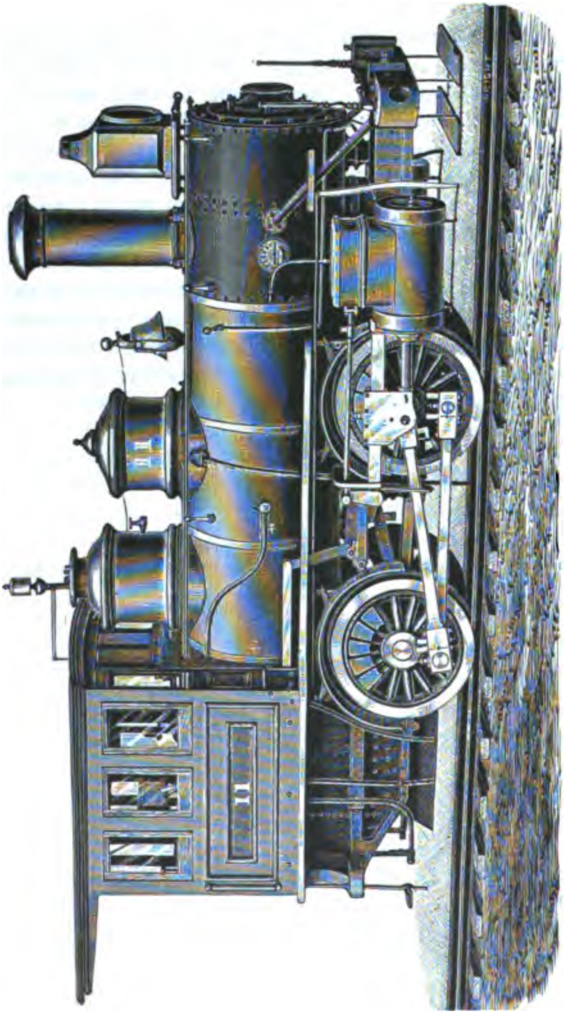


Fig. 100.

FOUR-WHEELED SWITCHING LOCOMOTIVE.

BY THE COOKE LOCOMOTIVE AND MACHINE WORKS, PATERSON N. J.

FIG. 100.

DIMENSIONS, WEIGHT, ETC.,

OF

FOUR-WHEELED SWITCHING LOCOMOTIVE,

BY THE

COOKE LOCOMOTIVE AND MACHINE WORKS, PATERSON, N. J.

Total weight in working order	59,000 lbs.
Total weight on driving-wheels	59,000 "
Diameter of driving-wheels	4 ft. 0 in.
Diameter of main driving-axle journal	7 "
Distance from centre of front to centre of back driving-wheels,	6 ft. 10½ "
Total wheel-base of engine	6 " 10½ "
Total wheel-base of engine and tender	31 " 5½ "
Diameter of cylinders	16 "
Stroke of cylinders	24 "
Outside diameter of smallest boiler ring	48 "
Length of fire-box, inside	4 ft. 0 "
Width of fire-box, inside	2 " 10 "
Depth of fire-box, crown-sheet to top of grate	4 " 3 "
Number of tubes	150
Outside diameter of tubes	2 in.
Length of tubes	10 ft. 5½ "
Grate surface	11½ sq. ft.
Heating surface, fire-box	73 " "
Heating surface, tubes	711 " "
Heating surface, total	784 " "
Exhaust nozzles	Single.
Size of steam-ports	15½ × 1¼ in.
Size of exhaust-ports	15½ × 2¼ "
Throw of eccentrics	5½ "
Greatest travel of valve	5 "
Outside lap of valve	0¾ "
Smallest inside diameter of chimney	1 ft. 4 "
Height, top of rail to top of chimney	12 " 9 "
Height, top of rail to centre of boiler	5 " 8½ "
Water capacity of tank	2,000 gals.

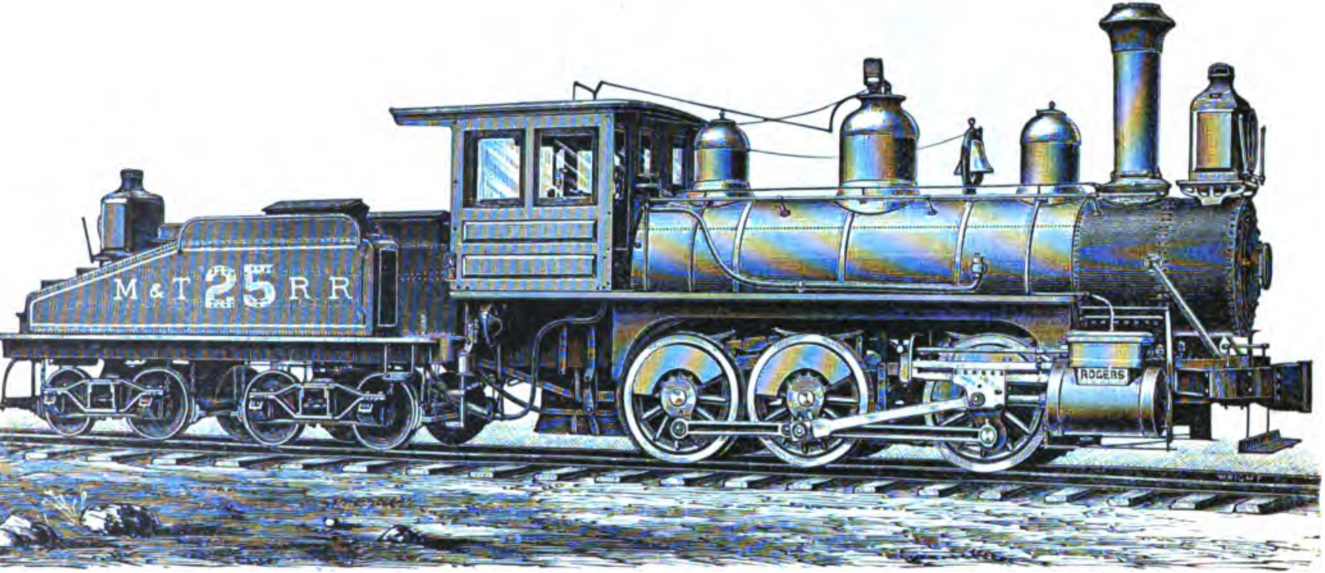


Fig. 101.

SIX-WHEELED SWITCHING LOCOMOTIVE.

BY THE ROGERS LOCOMOTIVE AND MACHINE WORKS, PATERSON, N. J.

FIG. 101.

DIMENSIONS, WEIGHT, ETC.,

OF

SIX-WHEELED SWITCHING LOCOMOTIVE,

BY THE

ROGERS LOCOMOTIVE AND MACHINE WORKS, PATERSON, N. J.

Total weight in working order	85,000 lbs.
Total weight on driving-wheels	85,000 "
Diameter of driving-wheels	4 ft. 2 in.
Diameter of main driving-axle journal	7 "
Distance from centre of front to centre of back driving-wheels	10 " 6 "
Total wheel-base of engine	10 " 6 "
Total wheel-base of engine and tender	37 " 1 "
Diameter of cylinders	17 "
Stroke of cylinders	24 "
Outside diameter of smallest boiler ring	51 "
Length of fire-box, inside	4 " 6 "
Width of fire-box, inside	2 " 9¼ "
Depth of fire-box, crown-sheet to top of grate	5 " 0 "
Number of tubes	123
Outside diameter of tubes	2¼ in.
Length of tubes	13 " 10⅛ "
Grate surface	12⅜ sq. ft.
Heating surface, fire-box	83 " "
Heating surface, tubes	1,005 " "
Heating surface, total	1,088 " "
Exhaust nozzles	Double.
Size of steam-ports	14⅛ × 1¼ in.
Size of exhaust-ports	14⅛ × 2½ "
Throw of eccentric	5 "
Greatest travel of valve	5 "
Outside lap of valve	0 11/16 "
Smallest inside diameter of chimney	1 ft. 3 "
Height, top of rail to top of chimney	14 " 6 "
Height, top of rail to centre of boiler	6 " 3¾ "
Diameter of tender truck-wheels	2 " 9 "
Water capacity of tank	2,000 gals.

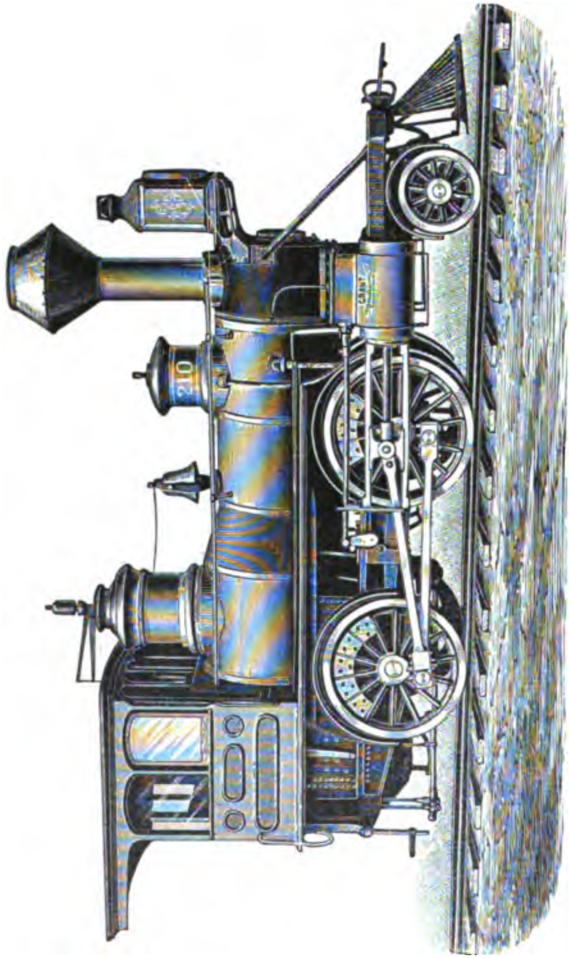


Fig. 102.

GRANT PONY LOCOMOTIVE.

BY THE GRANT LOCOMOTIVE WORKS, PATERSON, N. J.

FIG. 102.

DIMENSIONS, WEIGHT, ETC.,

OF

GRANT PONY LOCOMOTIVE,

BY THE

GRANT LOCOMOTIVE WORKS, PATERSON, N. J.

Diameter of driving-wheels	4 ft. 2 in.
Diameter of truck-wheels	2 " 4 "
Number of driving-wheels	4
Number of truck-wheels	2
Diameter of cylinders	14 in.
Stroke of cylinders	22 "
Length of fire-box, inside	6 ft. $1\frac{1}{8}$ in.
Width of fire-box, inside	2 " $9\frac{7}{8}$ "
Number of tubes	126
Outside diameter of tubes	2 in.
Length of tubes	7 ft. $10\frac{5}{16}$ "
Water capacity of tank	1,498 gals.

NOTE. The original drawings of this engine were destroyed by the fire at the works, in September, 1887, so that full specifications could not be obtained.

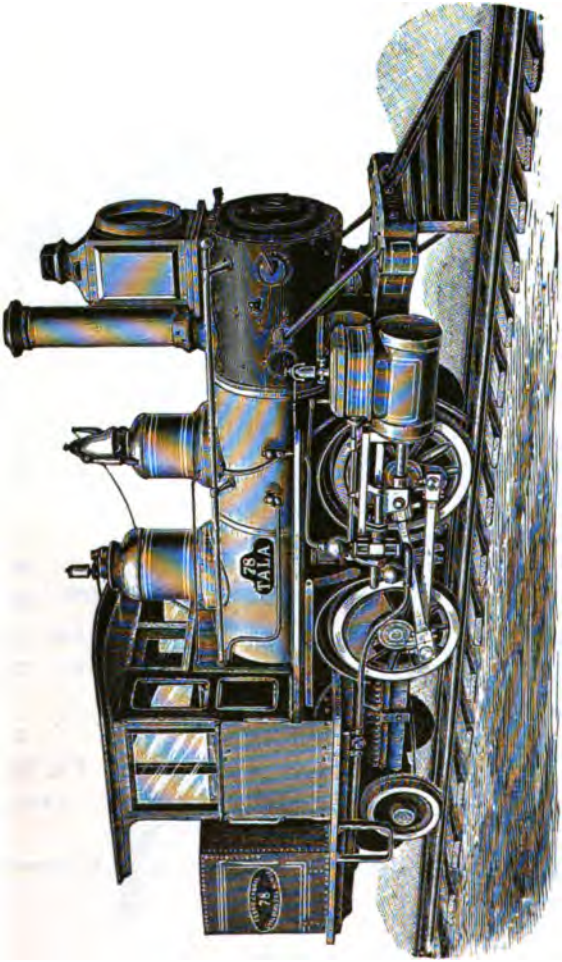


Fig. 108.

FORNEY PONY LOCOMOTIVE.

BY THE BALDWIN LOCOMOTIVE WORKS, PHILADELPHIA, PA.

FIG. 108.

DIMENSIONS, WEIGHT, ETC.,
OF

FORNEY PONY LOCOMOTIVE,

BY THE

BALDWIN LOCOMOTIVE WORKS, PHILADELPHIA, PA.

Total weight in working order		36,840 lbs.
Total weight on driving-wheels		28,500 "
Diameter of driving-wheels	3 ft.	1 in.
Diameter of truck-wheels	2 "	0 "
Diameter of main driving-axle journal		$4\frac{1}{2}$ "
Distance from centre of front to centre of back driving-wheels	4 "	6 "
Total wheel-base of engine	10 "	9 "
Diameter of cylinders		10 in.
Stroke of cylinders		16 "
Outside diameter of smallest boiler ring		34 "
Length of fire-box, inside	2 "	4 "
Width of fire-box, inside	3 "	$3\frac{1}{2}$ "
Depth of fire-box, crown-sheet to top of grate	2 "	10 "
Number of tubes		97
Outside diameter of tubes		$1\frac{1}{2}$ in.
Length of tubes	8 ft.	$0\frac{1}{4}$ "
Grate surface		7 sq. ft.
Heating surface, fire-box		33 " "
Heating surface, tubes		300 " "
Heating surface, total		333 " "
Exhaust nozzles		Double.
Size of steam-ports		9×1 in.
Size of exhaust-ports		$9 \times 1\frac{3}{4}$ "
Throw of eccentric		$3\frac{1}{2}$ "
Greatest travel of valve		$4\frac{3}{8}$ "
Outside lap of valve		$0\frac{1}{16}$ "
Smallest inside diameter of chimney		10 "
Height, top of rail to top of chimney	11 "	6 "
Height, top of rail to centre of boiler	4 "	6 "
Water capacity of tank		450 gals.

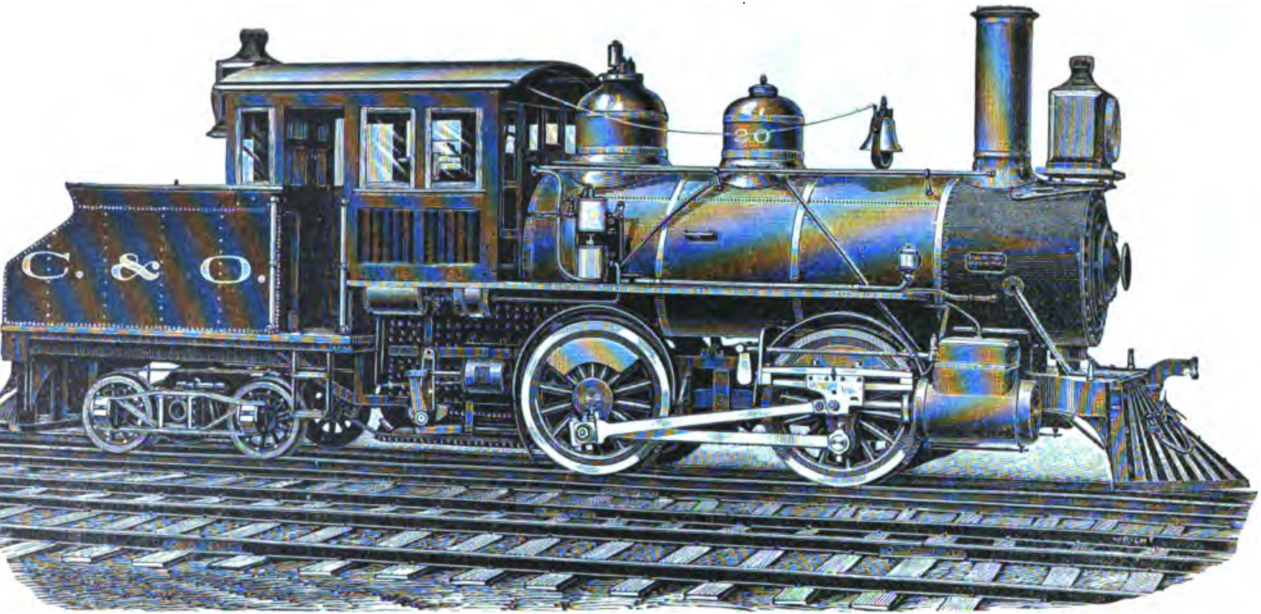


Fig 104.

FORNEY LOCOMOTIVE FOR SUBURBAN TRAFFIC.

BY THE SCHENECTADY LOCOMOTIVE WORKS, SCHENECTADY, N, Y.

FIG. 104.

DIMENSIONS, WEIGHT, ETC.,

OF

FORNEY LOCOMOTIVE FOR SUBURBAN TRAFFIC,

BY THE

SCHENECTADY LOCOMOTIVE WORKS, SCHENECTADY, N. Y.

Total weight in working order	110,000 lbs.
Total weight on driving-wheels	75,000 "
Diameter of driving-wheels	4 ft. 9 in.
Diameter of truck-wheels	2 " 6 "
Diameter of main driving-axle journal	7½ "
Distance from centre of front to centre of back driving-wheels,	7 " 6 "
Total wheel-base of engine	23 " 7 "
Diameter of cylinders	17 "
Stroke of cylinders	24 "
Outside diameter of smallest boiler ring	54 "
Length of fire-box, inside	5 ft. 0 3/16 "
Width of fire-box, inside	2 " 10⅝ "
Depth of fire-box, crown-sheet to top of grate	5 " 6 "
Number of tubes	187
Outside diameter of tubes	2 in.
Length of tubes	11 ft. 6 "
Grate surface	14.3 sq. ft.
Heating surface, fire-box	127.8 " "
Heating surface, tubes	1,116.9 " "
Heating surface, total	1,244.7 " "
Exhaust nozzles	Single.
Size of steam-ports	16 × 1¼ in.
Size of exhaust-ports	16 × 2¾ "
Throw of eccentrics	5¼ "
Greatest travel of valve	5½ "
Outside lap of valve	0¾ "
Smallest inside diameter of chimney	1 ft. 6 "
Height, top of rail to top of chimney	14 " 4 "
Height, top of rail to centre of boiler	6 " 8 "
Water capacity of tank	1,500 gals.
Coal capacity	6,000 lbs.

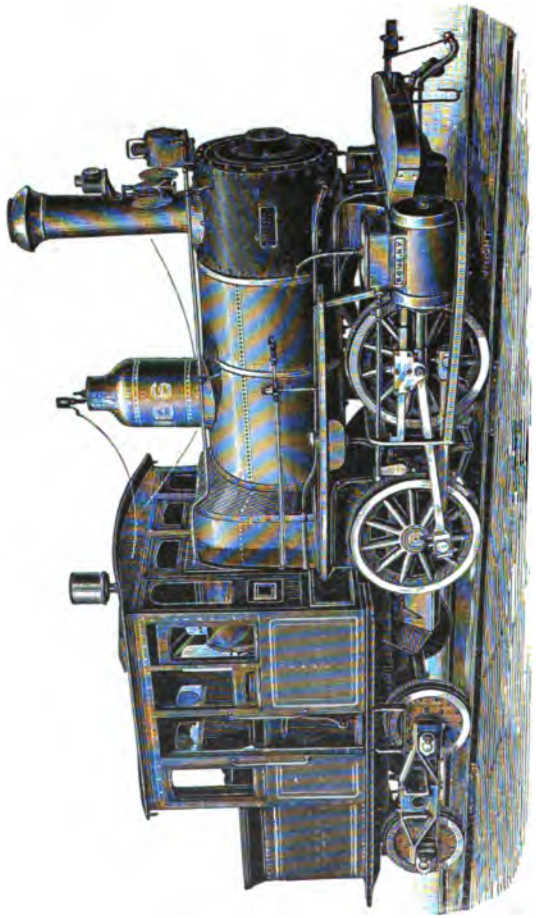


Fig. 105.

FORNEY LOCOMOTIVE, FOR THE NEW YORK ELEVATED RAILROAD,

BY THE ROME LOCOMOTIVE WORKS, ROME, N. Y.

FIG. 105.

DIMENSIONS, WEIGHT, ETC.,

OF

FORNEY LOCOMOTIVE FOR THE NEW YORK ELEVATED RAILROAD,

BY THE

ROME LOCOMOTIVE WORKS, ROME, N, Y.

Total weight in working order	44,350 lbs.
Total weight on driving-wheels	29,700 "
Diameter of driving-wheels	3 ft. 6 in.
Diameter of main driving-axle journal	$5\frac{1}{2}$ "
Length of main driving-axle journal	$6\frac{5}{8}$ "
Diameter of truck-wheels	2 " 6 "
Distance between centre of driving-wheels	5 " 0 "
Distance between centres of truck-wheels	4 " 8 "
Total wheel-base of engine	16 " 0 "
Diameter of cylinders	12 "
Stroke of cylinders	16 "
Outside diameter of smallest boiler ring	3 " 6 "
Length of fire-box, inside	4 " $7\frac{5}{16}$ "
Width of fire-box, inside	3 " 7 "
Depth of fire-box, crown-sheet to top of grate	2 " $11\frac{3}{4}$ "
Number of tubes	154
Outside diameter of tubes	$1\frac{1}{2}$ in.
Length of tubes	6 ft. $3\frac{1}{4}$ "
Grate surface	16.43 sq. ft.
Heating surface, fire-box	55.77 " "
Heating surface, tubes	375.15 " "
Heating surface, total	430.92 " "
Size of steam-ports	$8\frac{3}{4} \times 0\frac{7}{8}$ in.
Size of exhaust-ports	$8\frac{3}{4} \times 1\frac{3}{4}$ "
Throw of eccentrics	$3\frac{1}{4}$ "
Greatest travel of valve	$3\frac{3}{4}$ "
Outside lap of valve	$0\frac{5}{8}$ "
Smallest inside diameter of chimney	$10\frac{1}{2}$ "
Height, top of rail to top of chimney	12 " 1 "
Height, top of rail to centre of boiler	5 " $5\frac{3}{4}$ "
Water capacity of tank	600 gals.

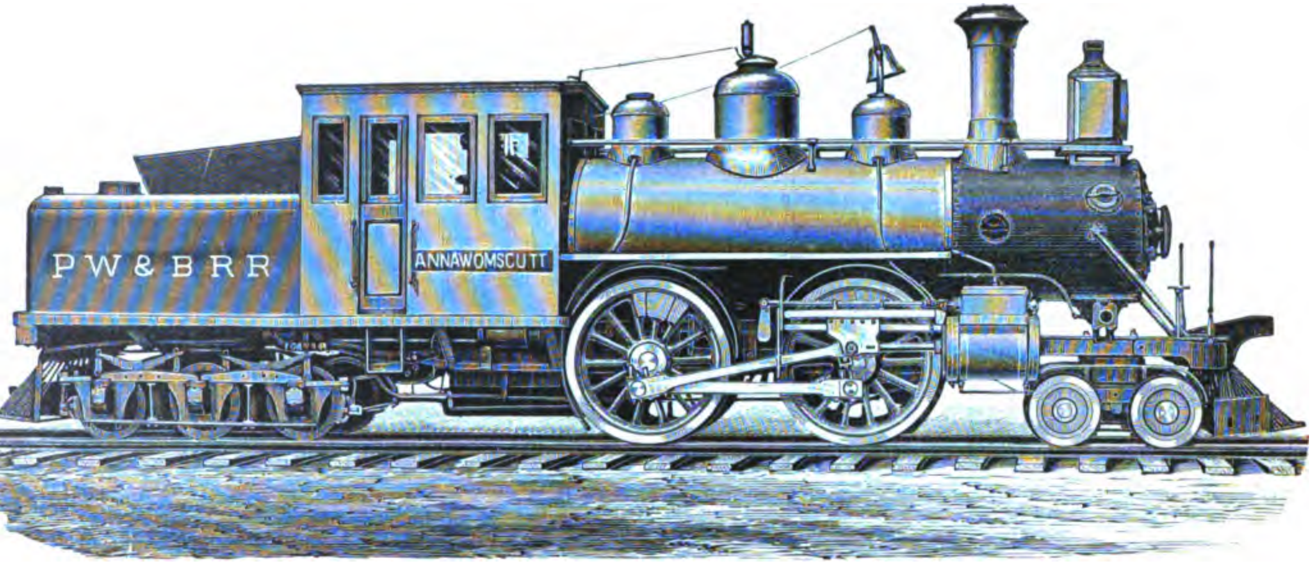


Fig 106.

LOCOMOTIVE FOR LOCAL PASSENGER SERVICE.

BY THE TAUNTON LOCOMOTIVE MANUFACTURING COMPANY, TAUNTON, MASS.

FIG. 106.

DIMENSIONS, WEIGHT, ETC.,

OF

LOCOMOTIVE FOR LOCAL PASSENGER SERVICE,

BY THE

TAUNTON LOCOMOTIVE MANUFACTURING COMPANY, TAUNTON, MASS.

Total weight in working order	118,700 lbs.
Total weight on driving-wheels	56,300 "
Diameter of driving-wheels	5 ft. 3 in.
Diameter of truck-wheels	2 " 2 "
Diameter of main driving-axle journal	7½ "
Distance from centre of front to centre of back driving-wheels	6 " 8 "
Total wheel-base of engine	16 " 4 "
Total wheel-base of engine and tender	34 " 5 "
Diameter of cylinders	17 "
Stroke of cylinders	20 "
Outside diameter of smallest boiler ring	54 "
Length of fire-box, inside	5 " 0 "
Width of fire-box, inside	2 " 10½ "
Depth of fire-box, crown-sheet to top of grate	5 " 4 "
Number of tubes	170
Outside diameter of tubes	2 in.
Length of tubes	10 " 10½ "
Grate surface	14 sq. ft.
Heating surface, fire-box	96½ " "
Heating surface, tubes	1,097 " "
Heating surface, total	1,193½ " "
Exhaust nozzles	Single.
Size of steam-ports	17 x 1 in.
Size of exhaust-ports	17 x 2½ "
Throw of eccentric	4½ "
Greatest travel of valve	5 "
Outside lap of valve	0¾ "
Smallest inside diameter of chimney	1 ft. 4 "
Height, top of rail to top of chimney	13 " 6 "
Height, top of rail to centre of boiler	6 " 8 "
Water capacity of tank	2,200 gals.

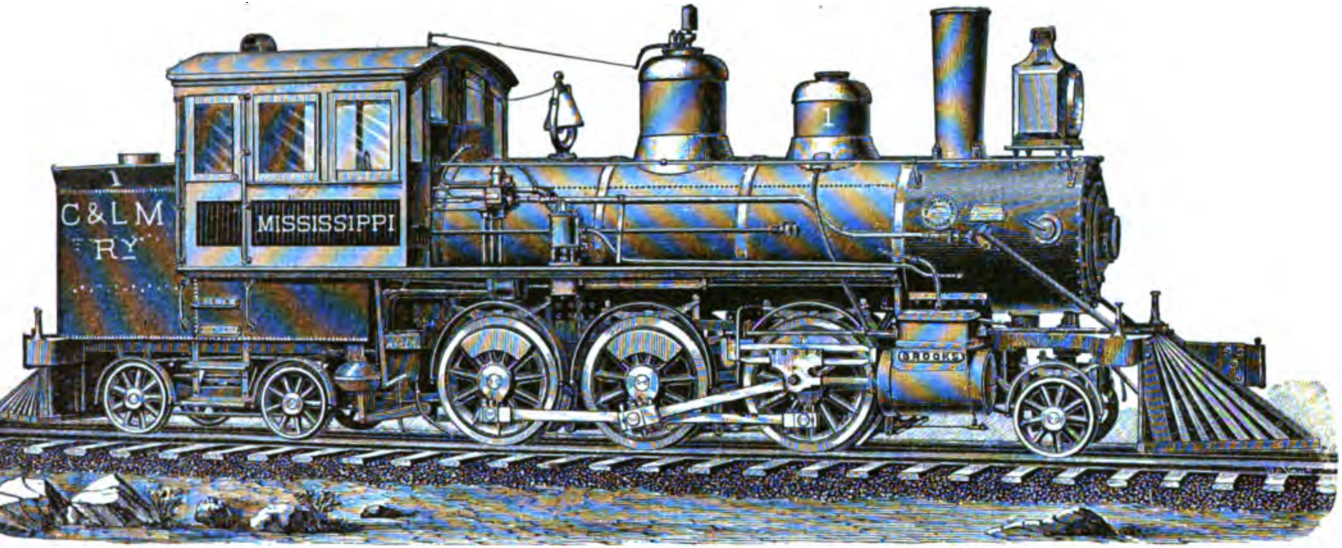


Fig. 107.

SIX-COUPLED RAPID TRANSIT LOCOMOTIVE.

BY THE BROOKS LOCOMOTIVE WORKS, DUNKIRK, N. Y.

FIG. 107.

DIMENSIONS, WEIGHT, ETC.,

OF

SIX-COUPLED RAPID TRANSIT LOCOMOTIVE,

BY THE

BROOKS LOCOMOTIVE WORKS, DUNKIRK, N Y.

Total weight in working order	112,000 lbs.
Total weight on driving-wheels	70,000 "
Diameter of driving-wheels	4 ft. 0 in.
Diameter of truck-wheels	2 " 4 "
Diameter of main driving-axle journal	7 "
Distance from centre of front to centre of back driving-wheels	10 " 0 "
Total wheel-base of engine	30 " 0 "
Diameter of cylinders	16 in.
Stroke of cylinders	24 "
Outside diameter of smallest boiler ring	54 "
Length of fire-box, inside	6 " 6 "
Width of fire-box, inside	2 " 10 "
Depth of fire-box, crown-sheet to hand-ring	5 " 1¼ "
Number of tubes	186
Outside diameter of tubes	2 in.
Length of tubes	9 ft. 0 "
Grate surface	18¾ sq. ft.
Heating surface, fire-box	97 " "
Heating surface, tubes	870 " "
Heating surface, total	967 " "
Exhaust nozzles	Single or Double.
Size of steam-ports	15 × 1¼ in.
Size of exhaust-ports	15 × 2¼ "
Throw of eccentrics	5 "
Greatest travel of valve	5¼ "
Outside lap of valve	0¾ "
Smallest inside diameter of chimney	1 ft. 1 "
Height, top of rail to top of chimney	13 " 2 "
Height, top of rail to centre of boiler	6 " 4¼ "
Water capacity of tank	2,000 gals.

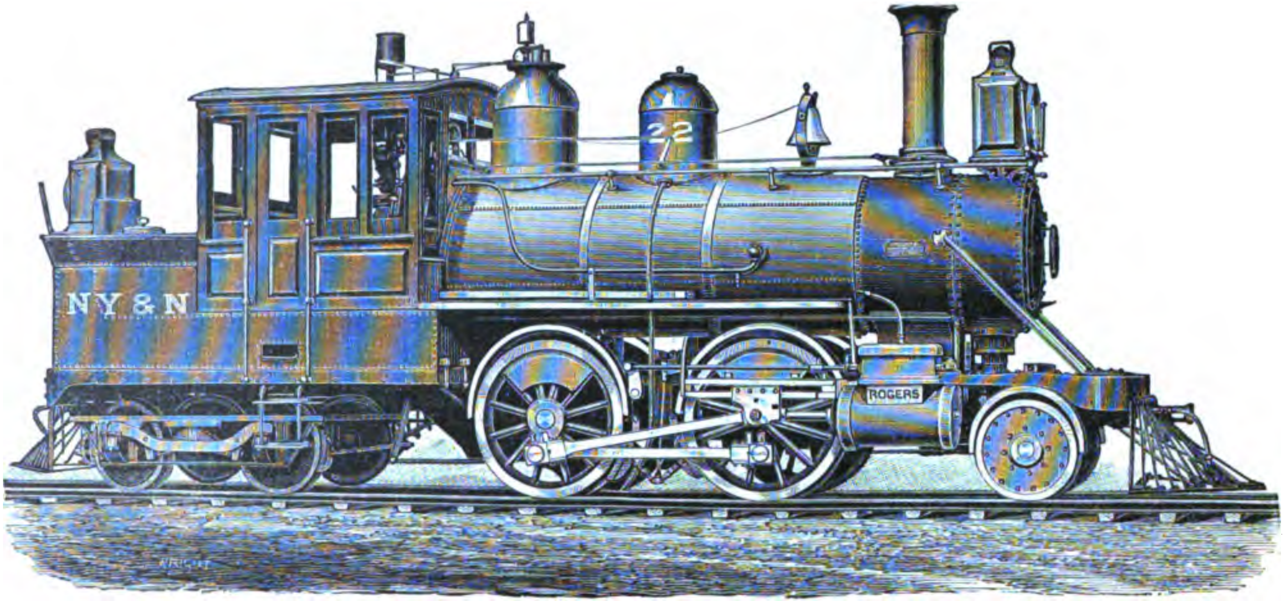


Fig. 108.

LOCOMOTIVE FOR SUBURBAN PASSENGER SERVICE.

BY THE ROGERS LOCOMOTIVE AND MACHINE WORKS, PATERSON, N. J.

FIG. 108.

DIMENSIONS, WEIGHT, ETC.,

OF

LOCOMOTIVE FOR SUBURBAN PASSENGER SERVICE,

BY THE

ROGERS LOCOMOTIVE AND MACHINE WORKS, PATERSON, N. J.

Total weight in working order	98,500	lbs.
Total weight on driving-wheels	50,000	"
Diameter of driving-wheels	4 ft. 6	in.
Diameter of truck-wheels	2 " 9	"
Diameter of main driving-axle journal	6½	"
Distance from centre of front to centre of back driving-wheels	6 " 3	"
Total wheel-base of engine	27 " 0	"
Diameter of cylinders	14	"
Stroke of cylinders	22	"
Outside diameter of smallest boiler ring	52	"
Length of fire-box, inside	5 ft. 11½	"
Width of fire-box, inside	3 " 5	"
Depth of fire-box, crown-sheet to top of grate	{ 3 " 0 3 " 5¾	" "
Number of tubes		186
Outside diameter of tubes	1¾	in.
Length of tubes	7 " 10¾	"
Grate surface	20½	sq. ft.
Heating surface, fire-box	77¾	" "
Heating surface, tubes	667¾	" "
Heating surface, total	745½	" "
Exhaust nozzles		Double.
Size of steam-ports	14 × 1⅛	in.
Size of exhaust-ports	14 × 2½	"
Throw of eccentrics	5	"
Greatest travel of valve	5	"
Outside lap of valve	0¾	"
Smallest inside diameter of chimney	11½	"
Height, top of rail to top of chimney	14 ft. 0	"
Height, top of rail to centre of boiler	6 " 10½	"
Water capacity of tank	1,000	gals.

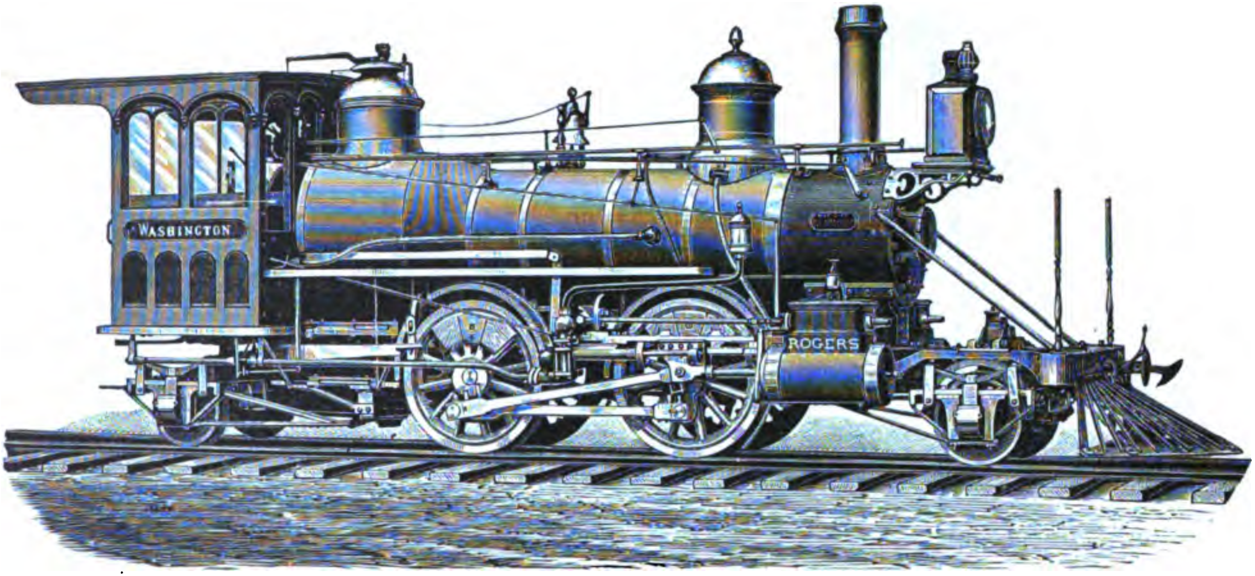


Fig. 109.

HUDSON DOUBLE-ENDER LOCOMOTIVE.

BY THE ROGERS LOCOMOTIVE AND MACHINE WORKS, PATERSON, N. J.

FIG. 109.

DIMENSIONS, WEIGHT, ETC.,

OF

HUDSON DOUBLE-ENDER LOCOMOTIVE,

BY THE

ROGERS LOCOMOTIVE AND MACHINE WORKS, PATERSON, N. J.

Total weight in working order	51,100			lbs.
Total weight on driving-wheels	30,500			"
Diameter of driving-wheels	4	ft.	$0\frac{3}{4}$	in.
Diameter of truck-wheels	2	"	2	"
Diameter of main driving-axle journal			$5\frac{1}{2}$	"
Distance from centre of front to centre of back driving-wheels,	6	"	0	"
Total wheel-base of engine	22	"	1	"
Total wheel-base of engine and tender	39	"	$2\frac{1}{2}$	"
Diameter of cylinders			12	"
Stroke of cylinders			20	"
Outside diameter of smallest boiler ring			$39\frac{3}{4}$	"
Length of fire-box, inside	4	ft.	3	"
Width of fire-box, inside	2	"	1	"
Depth of fire-box, crown-sheet to top of grate	4	"	$0\frac{3}{4}$	"
Number of tubes				100
Outside diameter of tubes			2	in.
Length of tubes	10	ft.	$2\frac{1}{2}$	"
Grate surface	$8\frac{7}{8}$			sq. ft.
Heating surface, fire-box	61		"	"
Heating surface, tubes	$534\frac{1}{2}$		"	"
Heating surface, total	$595\frac{1}{2}$		"	"
Exhaust nozzles				Double.
Size of steam-ports	$10\frac{1}{2} \times 1\frac{3}{16}$			in.
Size of exhaust-ports	$10\frac{1}{2} \times 2\frac{1}{2}$			"
Throw of eccentrics			$4\frac{1}{2}$	"
Greatest travel of valve			$4\frac{1}{4}$	"
Outside lap of valve			$0\frac{13}{16}$	"
Smallest inside diameter of chimney			$10\frac{3}{4}$	"
Height, top of rail to top of chimney	11	ft.	$4\frac{1}{2}$	"
Height, top of rail to centre of boiler	5	"	7	"
Water capacity of tank	1,250			gals.

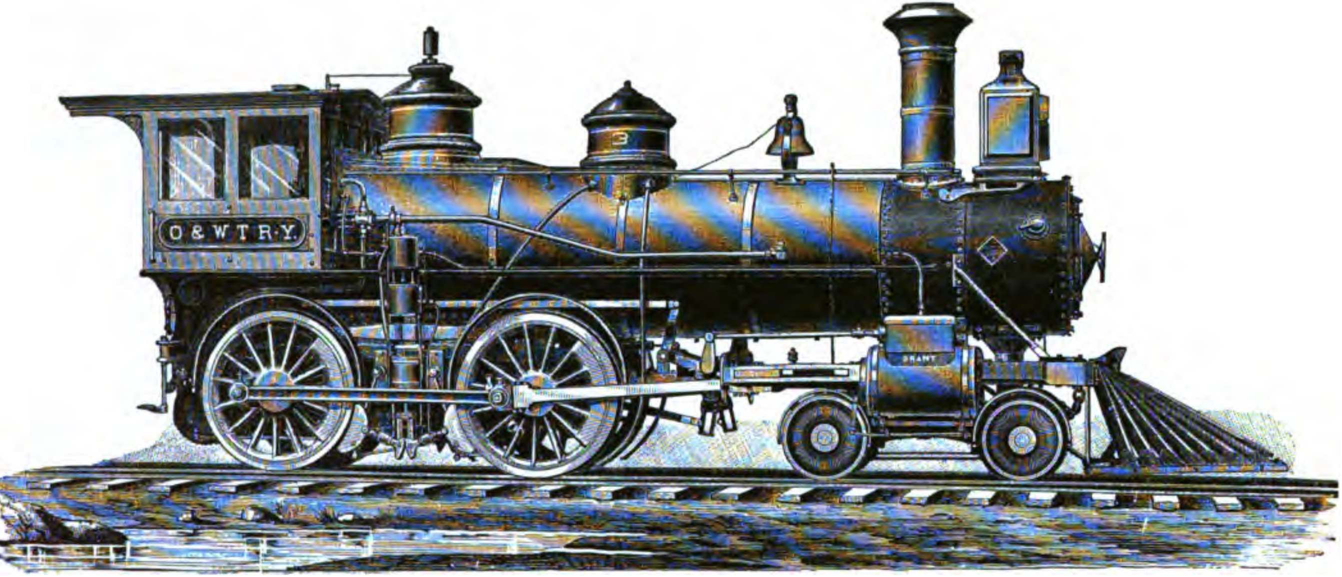


Fig. 111.

EIGHT-WHEELED "AMERICAN" LOCOMOTIVE.

BY THE GRANT LOCOMOTIVE WORKS, PATERSON, N. J.

FIG. 110.

DIMENSIONS, WEIGHT, ETC.,

OF

EIGHT-WHEELED "AMERICAN" LOCOMOTIVE,

BY THE

HINKLEY LOCOMOTIVE COMPANY, BOSTON, MASS.

Total weight in working order	96,000 lbs.
Total weight on driving-wheels	64,000 "
Diameter of driving-wheels	5 ft. 2 in.
Diameter of truck-wheels	2 " 6 "
Diameter of main driving-axle journal	7½ "
Distance from centre of front to centre of back driving-wheels,	8 " 6 "
Total wheel-base of engine	23 " 0½ "
Total wheel-base of engine and tender	46 " 2¼ "
Diameter of cylinders	17 "
Stroke of cylinders	24 "
Outside diameter of smallest boiler ring	53⅞ "
Length of fire-box, inside	6 ft. 0 "
Width of fire-box, inside	2 " 11 "
Depth of fire-box, crown-sheet to top of grate	5 " 8 "
Number of tubes	218
Outside diameter of tubes	2 in.
Length of tubes	11 ft. 6 "
Grate surface	17.5 sq. ft.
Heating surface, fire-box	125 " "
Heating surface, tubes	1,230 " "
Heating surface, total	1,355 " "
Exhaust nozzles	Single.
Size of steam-ports	18 × 1¼ in.
Size of exhaust-ports	18 × 3 "
Throw of eccentrics	5 "
Greatest travel of valve	5½ "
Outside lap of valve	0⅞ "
Smallest inside diameter of chimney	1 ft. 2 "
Height, top of rail to top of chimney	14 " 1¾ "
Height, top of rail to centre of boiler	6 " 8½ "
Water capacity of tank	3,000 gals.

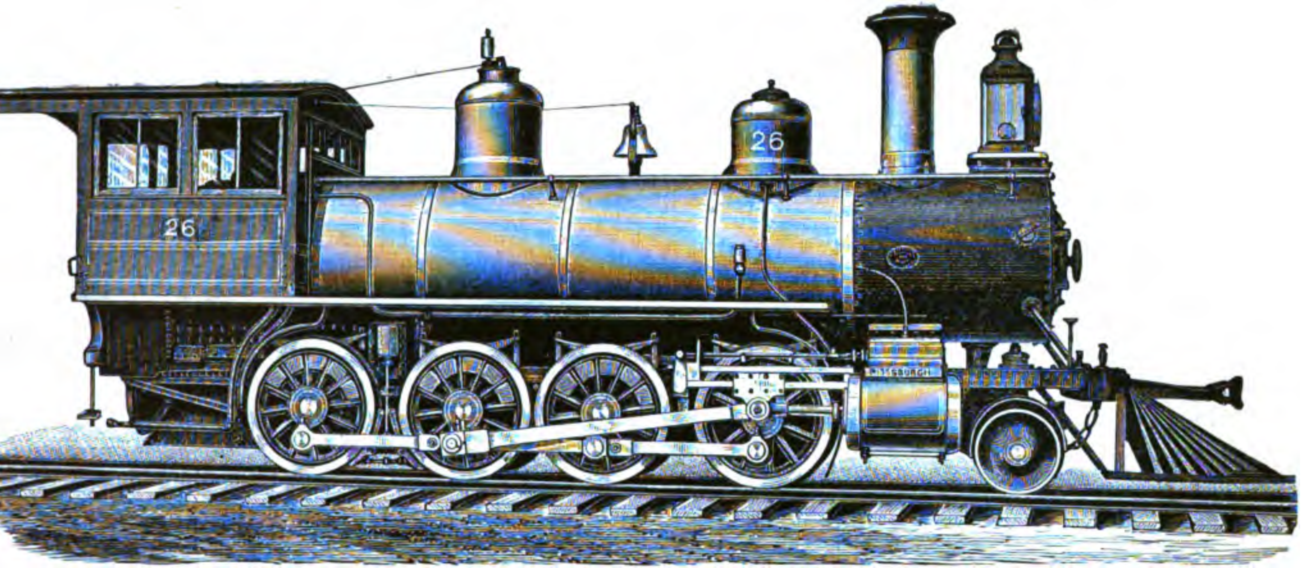


Fig. 114.

CONSOLIDATION LOCOMOTIVE.

BY THE PITTSBURGH LOCOMOTIVE WORKS, PITTSBURGH, PA.

FIG. 114.

DIMENSIONS, WEIGHT, ETC.,

OF

CONSOLIDATION LOCOMOTIVE,

BY THE

PITTSBURGH LOCOMOTIVE WORKS, PITTSBURGH, PA.

Total weight in working order	104,900 lbs.
Total weight on driving-wheels	94,150 "
Diameter of driving-wheels	4 ft. 2 in.
Diameter of truck-wheels	2 " 6 "
Diameter of main driving-axle journal	7 "
Length of main driving-axle journal	9 "
Distance from centre of front to centre of back driving-wheels,	14 " 2 "
Total wheel-base of engine	21 " 9 "
Total wheel-base of engine and tender	47 " 10½ "
Diameter of cylinders	20 "
Stroke of cylinders	24 "
Outside diameter of smallest boiler ring	4 ft. 8 "
Length of fire-box, inside	8 " 6 "
Width of fire-box, inside	2 " 10⅜ "
Depth of fire-box, crown-sheet to top of grate	4 " 5⅜ "
Number of tubes	202
Outside diameter of tubes	2 in.
Length of tubes	13 ft. 2 "
Grate surface	24.34 sq.ft.
Heating surface, fire-box	132.00 " "
Heating surface, tubes	1,383.00 " "
Heating surface, total	1,515.00 " "
Exhaust nozzles	Double.
Size of steam-ports	16 × 1¼ in.
Size of exhaust-ports	16 × 2½ "
Throw of eccentrics	5 "
Greatest travel of valve	5 "
Outside lap of valve	0¾ "
Smallest inside diameter of chimney	1 ft. 6 "
Height, top of rail to top of chimney	14 " 5½ "
Height, top of rail to centre of boiler	6 " 9⅜ "
Water capacity of tank	3,000 gals.

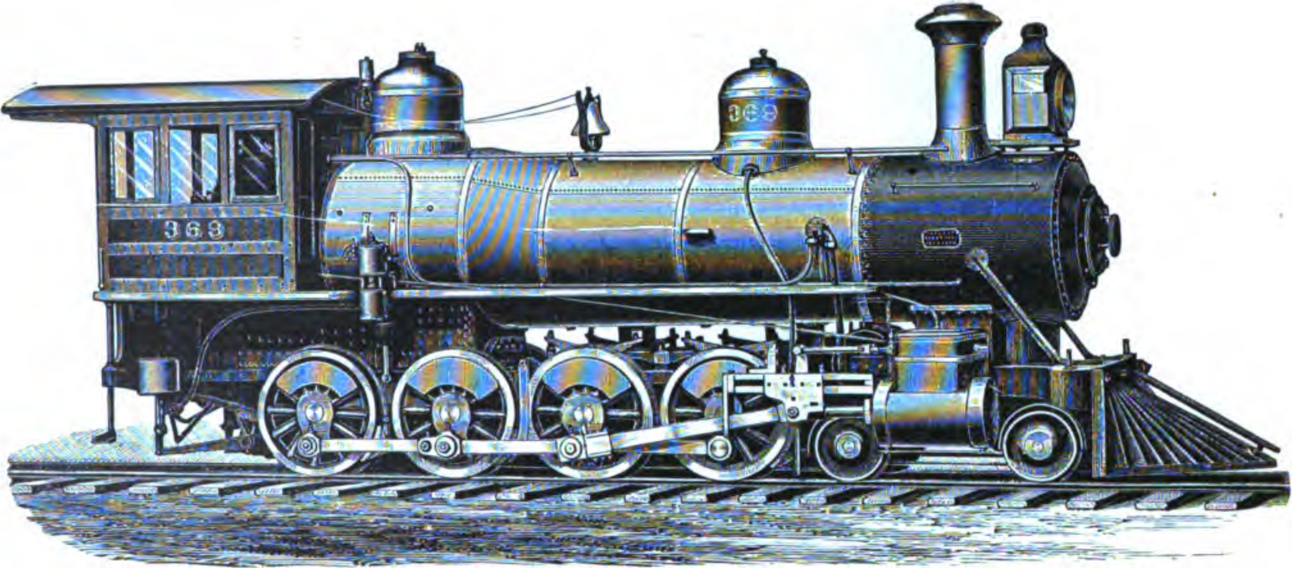


Fig. 115.

TWELVE-WHEELED LOCOMOTIVE.

BY THE SCHENECTADY LOCOMOTIVE WORKS, SCHENECTADY, N, Y.

FIG. 115.

DIMENSIONS, WEIGHT, ETC.,

OF

TWELVE-WHEELED LOCOMOTIVE,

BY THE

SCHENECTADY LOCOMOTIVE WORKS, SCHENECTADY, N. Y.

Total weight in working order	132,000 lbs.
Total weight on driving-wheels	112,000 "
Diameter of driving-wheels	4 ft. 3 in.
Diameter of truck-wheels	2 " 2 "
Diameter of main driving-axle journal	7½ "
Length of main driving-axle journal	8½ "
Distance from centre of front to centre of back driving-wheels	13 " 9 "
Total wheel-base of engine	23 " 6 "
Total wheel-base of engine and tender	47 " 10 "
Diameter of cylinders	20 "
Stroke of cylinders	26 "
Outside diameter of smallest boiler ring	5 " 0 "
Length of fire-box, inside	8 " 8 3/16 "
Width of fire-box, inside	3 " 6⅞ "
Depth of fire-box, crown-sheet to top of grate	4 " 11 "
Number of tubes	262
Outside diameter of tubes	2 in.
Length of tubes	12 ft. 8 "
Grate surface	31 sq. ft.
Heating surface, fire-box	156 " "
Heating surface, tubes	1,726 " "
Heating surface, total	1,882 " "
Exhaust nozzles	Single.
Size of steam-ports	18 × 1¼ in.
Size of exhaust-ports	18 × 2¾ "
Throw of eccentrics	5¼ "
Greatest travel of valve	5½ "
Outside lap of valve	0¾ "
Smallest inside diameter of chimney	1 ft. 4 "
Height, top of rail to top of chimney	14 " 10 "
Height, top of rail to centre of boiler	7 " 6½ "
Water capacity of tender tank	3,400 gals.

NOTE. In this engine the first and third pairs of driving-wheels have blank tires, so that the *rigid* wheel-base is only 9 ft. 2 in.

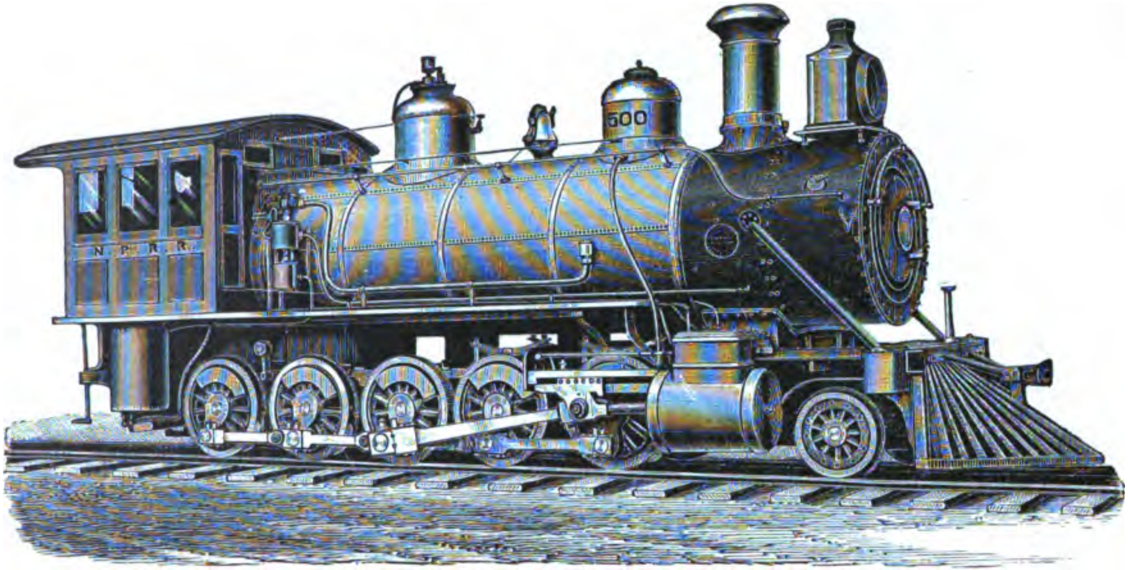


Fig. 116.

DECAPOD LOCOMOTIVE.

BY THE BALDWIN LOCOMOTIVE WORKS, PHILADELPHIA, PA.

FIG. 116.

DIMENSIONS, WEIGHT, ETC.,
OF
DECAPOD LOCOMOTIVE,
BY THE
BALDWIN LOCOMOTIVE WORKS, PHILADELPHIA, PA.

Total weight in working order	148,000 lbs.
Total weight on driving-wheels	133,000 "
Diameter of driving-wheels	3 ft. 9 in.
Diameter of truck-wheels	2 " 6 "
Diameter of main driving-axle journal	8 "
Length of main driving-axle journal	9 "
Distance from centre of front to centre of back driving-wheels	17 " 0 "
Total wheel-base of engine	24 " 4 "
Total wheel-base of engine and tender	49 " 2 "
Diameter of cylinders	22 "
Stroke of cylinders	26 "
Outside diameter of smallest boiler ring	5 " 8 "
Length of fire-box, inside	10 " 1¼ "
Width of fire-box, inside	3 " 6⅝ "
Depth of fire-box, crown-sheet to top of grate	4 " 6½ "
Number of tubes	270
Outside diameter of tubes	2¼ in.
Length of tubes	13 " 6 "
Grate surface	36 sq. ft.
Heating surface, fire-box	162 " "
Heating surface, tubes	2,148 " "
Heating surface, total	2,310 " "
Exhaust nozzles	Double.
Size of steam-ports	16 × 1¼ in.
Size of exhaust-ports	16 × 3 "
Throw of eccentric	5 "
Greatest travel of valve	5¾ "
Outside lap of valve	0¾ "
Smallest inside diameter of chimney	1 ft. 8 "
Height, top of rail to top of chimney	14 " 6 "
Height top of rail to centre of boiler	7 " 3½ "
Water capacity of tender tank	3,600 gals.

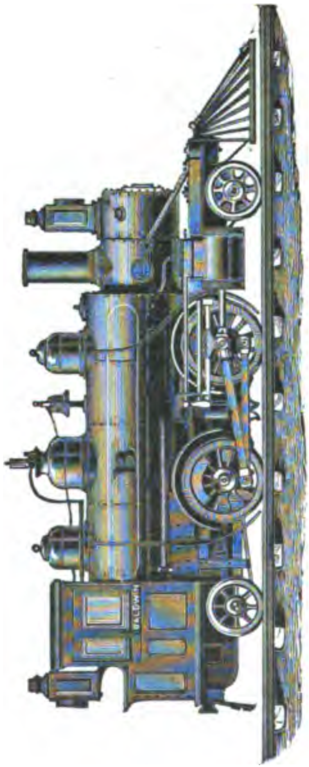


Fig. 117.

TANK LOCOMOTIVE, FOR PASSENGER SERVICE.

BY THE BALDWIN LOCOMOTIVE WORKS, PHILADELPHIA, PA.

FIG. 117.

DIMENSIONS, WEIGHT, ETC.,

OF

TANK LOCOMOTIVE FOR PASSENGER SERVICE,

BY THE

BALDWIN LOCOMOTIVE WORKS, PHILADELPHIA, PA.

Total weight	66,900 lbs.
Diameter of driving-wheels	50 in.
Diameter of main driving-axle journal	6½ "
Length of main driving-axle journal	8 "
Spread of driving-wheels	7 ft. 6 "
Total wheel-base	21 " 8 "
Diameter of cylinders	15 "
Stroke of piston	22 "
Outside diameter of smallest boiler ring	46 "
Number of tubes	130
Outside diameter of tubes	2 in.
Length of tubes	8 ft. 6 "
Exhaust-nozzles	Single.
Size of steam-ports	13 × 1¼ in.
Size of exhaust-ports	13 × 2½ "
Throw of eccentrics	4½ "
Greatest travel of valve	5 "
Outside lap	0¾ "
Smallest inside diameter of chimney	13 "
Height, top of rail to top of chimney	14 "
Water capacity of tank	900 gals.

Fig. 118.

LOCOMOTIVE FOR STREET RAILROADS.

BY THE BALDWIN LOCOMOTIVE WORKS, PHILADELPHIA, PA.

FIG. 118.

DIMENSIONS, WEIGHT, ETC.,

OF

LOCOMOTIVE FOR STREET RAILROADS,

BY THE

BALDWIN LOCOMOTIVE WORKS, PHILADELPHIA, PA.

Total weight	30,000 lbs.
Diameter of driving-wheels	35 in.
Diameter of main driving-axle journal	4¼ "
Length of main driving-axle journal	6⅛ "
Spread of driving-wheels	4 ft. 6 "
Total wheel-base	9 " 8 "
Diameter of cylinders	10 "
Stroke of piston	14 "
Outside diameter of smallest boiler ring	34 "
Number of tubes	100
Outside diameter of tubes	1⅛ in.
Length of tubes	6 ft. 0 "
Grate surface	9 sq. ft.
Heating surface, fire-box	35 " "
Heating surface, tubes	234 " "
Heating surface, total	269 " "
Exhaust-nozzles	Single.
Size of steam-ports	¾×7 in.
Size of exhaust-ports	1⅛×7 "
Throw of eccentrics	2¾ "
Greatest travel of valve	3¼ "
Outside lap of valve	0⅝ "
Smallest inside diameter of chimney	9 "
Height, top of rail to top of chimney	11 ft. 3 "
Water capacity of tank	400 gals.

Fig. 119.

STEAM CAR FOR STREET RAILROADS.

BY THE BALDWIN LOCOMOTIVE WORKS, PHILADELPHIA, PA.

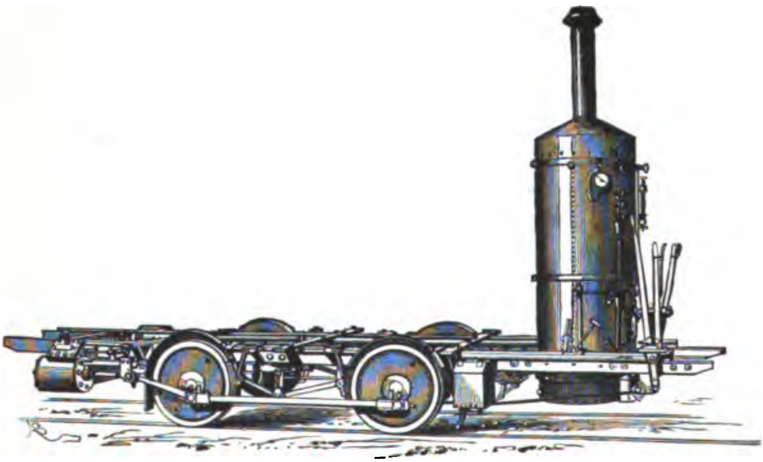


Fig. 120.

ENGINE OF STEAM CAR FOR STREET RAILROADS.

BY THE BALDWIN LOCOMOTIVE WORKS, PHILADELPHIA, PA.

FIGS. 119 AND 120.

DIMENSIONS, WEIGHT, ETC.,

OF

STEAM CAR FOR STREET RAILROAD,

BY THE

BALDWIN LOCOMOTIVE WORKS, PHILADELPHIA, PA.

Total weight with 20 passengers	21,000 lbs.
Diameter of driving-wheels	30 in.
Diameter of main driving-axle journal	4¼ "
Length of main driving-axle journal	6 "
Spread of wheels	6 ft. 6 "
Diameter of cylinders	8 "
Stroke of piston	10 "
Outside diameter of smallest boiler ring	32 "
Number of tubes	122
Outside diameter of tubes	1¼ in.
Length of tubes	46⅛ "
Grate surface	26⅞ diam.
Heating surface, fire-box	25⅛ in. high.
Heating surface, tubes	....
Heating surface, total	....
Exhaust nozzles	Single.
Size of steam-ports	3×0½ in.
Size of exhaust-ports	3×1 "
Throw of eccentrics	2 "
Greatest travel of valve	2¼ "
Outside lap of valve	$\frac{7}{16}$ "
Smallest inside diameter of chimney	7 "
Height, top of rail to top of chimney	11 ft.
Water capacity of tank	96 gals.

CHAPTER XII.

LOCOMOTIVE BOILERS.

QUESTION 217. *What are the principal parts or "organs" of a locomotive boiler?*

Answer. These are shown in figs. 121, 122, and 123. Fig. 121 is a longitudinal section; fig. 122 a transverse section through the fire-box, and fig. 123 is a plan of the grate. The principal parts or organs are:

1. A fire-place, or, as it is called, a *fire-box*, *A* (fig. 121), which is surrounded with water.

2. A cylindrical part, *C C*, attached to the fire-box at one end and to a chamber, *B*, called the *smoke-box*, at the other.

3. The tubes or flues, *a a'*, which connect the fire-box with the smoke-box and pass through the cylindrical part of the boiler and are surrounded with water.

4. The "smoke-stack" or chimney, *D*.

QUESTION 218. *What is each of these parts, or organs, for, and of what do they consist?*

Answer. The fire-box, *A*, is the fire-place, and furnishes the room for burning the fuel, and consists of an inner and outer shell, *b* and *c*, made of boiler plate, with the space between the two filled with water; a grate, *G*, formed of iron bars, with spaces between them for admitting air for the combustion of the fuel, which is placed on top of them; a door, *E*, called the *furnace-door*, for supplying the grate with fuel; a receptacle, *E E*, below the grate, to collect ashes, and therefore called the *ash-pan*, which is supplied with suitable doors or dampers for admitting or excluding air from the fire.

The cylindrical part, *C C*, or *waist* of the boiler, as it is sometimes called, contains the greater part of the water to be heated.

The smoke and products of combustion are conducted from the fire-box, at the back end, to the smoke-box at the front end of the boiler by means of the flues or tubes, *a a'*, which are usually about 2 inches in diameter and from 10 to 12 feet long. These tubes are surrounded with water and are made of small diameter so as to sub-divide the smoke into many

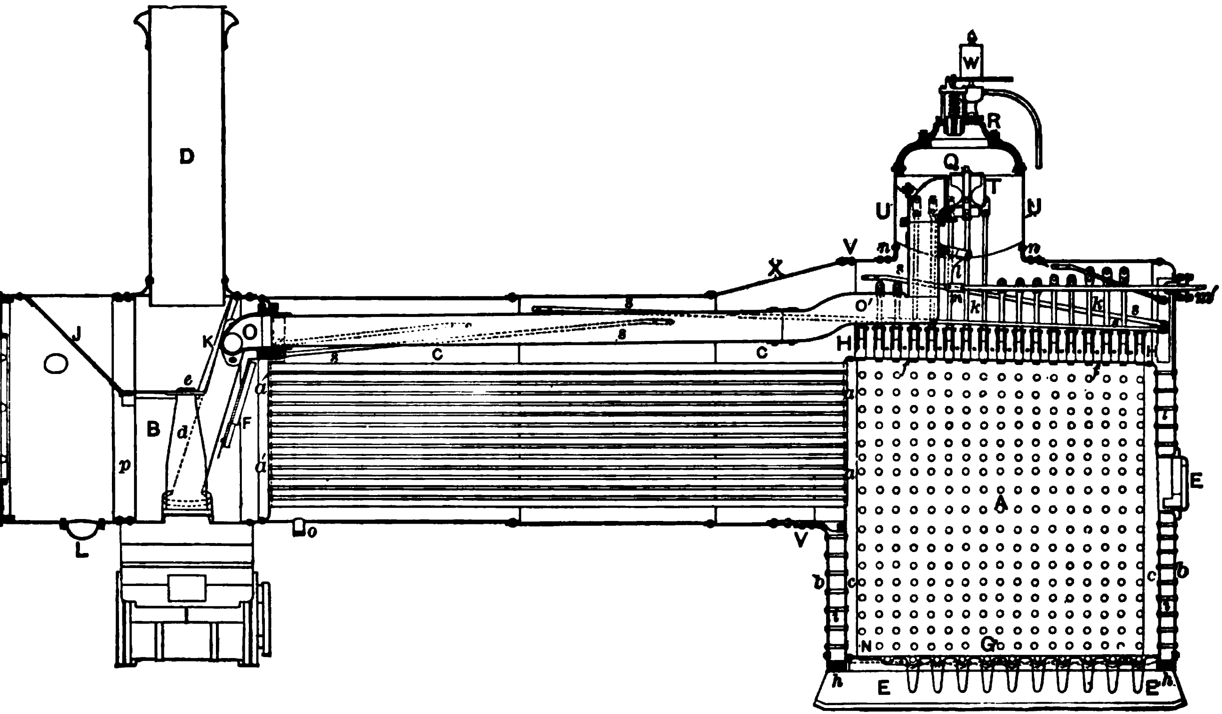


Fig. 121. Longitudinal Section of Locomotive Boiler. Scale ¼ in.—1 ft.

small streams and thus expose it to a large radiating surface through which the heat is conducted to the water.

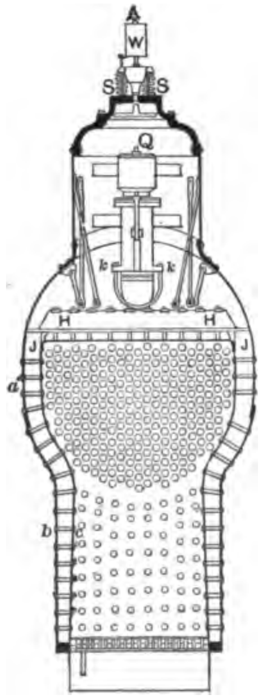


Fig. 122. Transverse Section of Boiler through Fire-Box. Scale ¼ in.—1 ft.

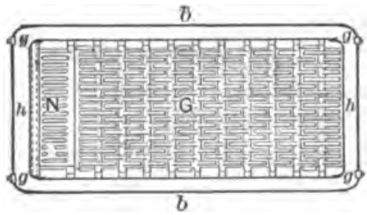


Fig. 123. Plan of Grate. Scale ¼ in.—1 ft.

The chimney or smoke-stack serves partly for removing into the open air the smoke which passes through the flues, and partly for producing a strong draft of air, which is indispensably necessary for the rapid combustion of the fuel. In some cases the smoke-stack is provided with appliances for arresting and extinguishing the sparks from the fire.

QUESTION 219. *How is the draft produced in locomotive boilers?*

Answer. By conducting the exhaust steam through one or more pipes (*d*, fig. 121) from the cylinders to the smoke-box and allowing it to escape up the chimney from an aperture or apertures, *e*, called *exhaust-nozzles.** The strong current of steam thus produced in the chimney creates a partial vacuum in the smoke-box, by which the smoke is sucked into it from the tubes with great power, and is then forced up the chimney into the open air by the "blast," as the action of the exhaust steam is called.

QUESTION 220. *How does the quantity of steam generated in locomotive boilers in a given time compare with that generated in the boilers of stationary and marine engines?*

Answer. Locomotive engine boilers must produce much more steam in a given time in proportion to their size than is required of the boilers of any other class of engines (excepting, perhaps, those of steam fire-engines), because the space which locomotive boilers can occupy and also their weight must be less in proportion to their capacity than that of boilers for other kinds of engines.

QUESTION 221. *How is their steam-generating capacity increased above that of marine and stationary boilers?*

Answer. By creating a very strong draft of air through the fire, by means of the blast, and then passing the smoke and heated air through the tubes. By this means the smoke and hot air are divided into many small streams or currents, which are exposed to the inside surface of the tubes, and the heat is thus imparted to the water which surrounds the tubes.

QUESTION 222. *How is the action of the exhaust steam in producing a draft in the chimney explained?*

Answer. The exhaust steam escapes from the cylinders through contracted openings or exhaust-nozzles, *e*, which point directly up the centre of the chimney. The exhaust steam escapes from this orifice with great velocity, and expands as it rises, so that it fills the chimney, *D*. It thus acts somewhat like a plunger or piston forced violently up the chimney, and pushes up the air above it, and carries that which surrounds it along

* The term *blast-orifice* is also often used to designate these parts of locomotives.

with it. They finally escape into the open air, thus leaving a partial vacuum behind in the smoke-box. The external pressure of the atmosphere then forces in air through any and every opening in the smoke-box, to take the place of that already drawn out or exhausted from it. As the only inlet is through the tubes, to which the gases of combustion have free access from the fire-box, and as the external air can only pass through the fire-grate, and through the burning fuel, to reach the fire-box, there is a constant draft of air through the grate as long as the waste steam escapes from the blast-pipe and up the chimney. It is thus that, within certain limits, the more the steam that is required, the more the steam that is produced; for all the steam used in the engine draws in the air in its final escape, to excite the fire to generate more steam.* Sometimes one blast-orifice is used for each cylinder; in other cases the exhaust steam from each cylinder escapes through the same orifice.

QUESTION 223. *How much water is it necessary to evaporate in order to furnish the steam required to run an ordinary train at its usual speed?*

Answer. An ordinary "American" locomotive, weighing 80,000 lbs. and with cylinders of 18 inches diameter and 24 inches stroke, will evaporate from 7,500 to 15,000 lbs. of water per hour.

QUESTION 224. *How much water will a pound of coal evaporate in ordinary practice?*

Answer. The quantity of water which is converted into steam by a pound of coal varies very materially with the quality of the coal and the construction and condition of the boiler; but from 6 to 8 lbs. of water per pound of coal is about the average performance of ordinary locomotives. It is, therefore, necessary at times to burn 2,500 lbs. of coal per hour in order to generate the quantity of steam required by such an engine.

QUESTION 225. *How large a grate is needed to burn this quantity of coal?*

Answer. The maximum rate of combustion may be taken at about 125 lbs. of coal on each square foot of grate surface per hour, so that to burn 2,500 lbs. we need a grate with about 20 square feet of surface.

QUESTION 226. *How much heating surface is needed for a given size of grate?*

Answer. In common practice about 50 to 75 square feet of heating surface are given for each square foot of grate. There are, however, no reasons for the proportions of either grate or heating surface which are given, excepting that it has been found that they give good results in

* Colburn's "Locomotive Engineering."

ordinary working. The proportion of grate to heating surface is governed to a very great extent by the kind of fuel used. Anthracite coal and the poorer qualities of fuel require larger grates than good bituminous coal or wood. It is, however, quite certain that the larger a boiler is, and the greater its heating surface in proportion to the steam it must generate, other things being equal, the more economical will it be in its consumption of fuel, or, in other words, the more water will it evaporate per pound of coal.

QUESTION 227. *Why is it necessary to use small tubes or flues in order to have the required amount of heating surface?*

Answer. Because there is a great deal more surface in a small tube of a given length, in proportion to the space it occupies, than in a large one. Thus a tube 2 inches in diameter and 12 feet long has 6.28 square feet of surface, and one 4 inches in diameter has 12.56 square inches, or just *double* the quantity. But the 4-inch tube occupies *four times* as much space as the other, as it is twice as high and twice as wide. Therefore, in proportion to the space it occupies, the tube which is 2 inches in diameter has twice as much surface as the larger one. If we compare a 2-inch with an 8-inch tube, we will find that the former has *four* times as much surface, in proportion to its size, as the 8-inch tube. As the size and weight of locomotive boilers are limited, it is therefore necessary, in order to get the requisite heating surface in the space to which we are confined, to use tubes of small diameter.

Small tubes also have the advantage that they may be made of thinner material, and yet have the same strength to resist a bursting pressure from within, or a collapsing pressure from without, as larger tubes made of thicker metal. The advantage of thin tubes is, that the heat inside of them is conducted to the water outside more rapidly than it would be through thicker metal, which is important when combustion is as rapid as it is in locomotive boilers.

The reason tubes of smaller diameter than 2 inches are not ordinarily used is because they are then liable to become stopped up with cinders and pieces of unconsumed fuel.

QUESTION 228. *How is the fire-box of a locomotive constructed?*

Answer. It usually consists of a rectangular box (*A*, figs. 121, 122 and 123,) about 3 feet wide,* and, for the size of engine we have selected as an example, about 6 or 6½ feet long inside. This box is composed of either

* The width is dependent upon the distance between the rails, or *gauge* of the road, as it is called. The above size is for a 4 ft. 8½ in. gauge.

iron or steel plates, *c c*,* which, excepting on the front side, are from $\frac{5}{16}$ to $\frac{3}{8}$ inch thick. These plates form the *inside shell* of the fire-box, which is surrounded by an outside shell, *b b*, of either iron or steel plates, of about the same thickness as those composing the inside, and, as already explained, it is so much larger than the inside that there is a space, called the *water-space*, from $2\frac{1}{2}$ to $4\frac{1}{2}$ inches wide, on all the sides of the fire-box between the inner and outer plates.

The top, *f f*, of the inside shell, which is called the *crown-sheet* or *crown-plate*, is usually flat, whereas the outside shell is generally arched, as shown in figs. 122 and 96. To the front plate, *a′ a′*, of the inside shell, the tubes, *a a′*, *a a′*, are attached. For this reason its thickness is usually made greater than that of the other plates, and is usually from $\frac{5}{8}$ to $\frac{3}{4}$ inch. The edges of one of the plates at each corner of the fire-box, where they are united together, as shown at *g g*, in fig. 123, are bent at right angles, and the other is fastened to it with rivets, not shown in the engraving, from $\frac{5}{8}$ to $\frac{3}{4}$ inch in diameter.

The inside and the outside shells of the fire-box are united to each other by a wrought-iron bar or *ring*, *h h*, fig. 121, called a *mud-ring*, which completely surrounds the inner shell and closes the water-space between the two shells. This bar is bent and welded to the proper form to extend around the bottom of the inside fire-box, and it is riveted to both shells. The water in the water-space is in free communication with the rest of the water in the boiler, and thus the flat sides of the respective shells of the fire-box are exposed to the full pressure of the steam, which tends to burst the outside shell and collapse the inside one. These flat sides, by themselves, would be unable to resist the strain upon them, but as the strain upon the respective fire-boxes is in opposite directions, and necessarily equal for equal areas of surface, tie-bolts, *i i*, fig. 121, or, as they are called, *stay-bolts*, which are from $\frac{3}{4}$ to 1 inch in diameter, and have a screw cut in their whole length, are screwed through the plates at frequent intervals, usually from 4 to $4\frac{1}{2}$ inches apart, so as to connect the inner and the outer plates of the fire-box securely together, the ends of the stay-bolts being also riveted or spread out by hammering so as still further to increase their holding power. These bolts, owing to the expansion and contraction of the boiler and other strains to which they are subjected, very frequently break, and if they are made of solid bars of metal there is no way of discovering with certainty whether they are in good condition or not without taking the boiler to pieces. They should therefore be made of the best

* The inside plates are sometimes made of copper.

quality of wrought iron, brass, or copper, and should be made tubular or have a hole drilled into one end, as shown at *a*, fig. 124, and extending into the bolt a distance greater than the thickness of the place into which it is screwed, so that if the bolt breaks the water will escape at the fracture

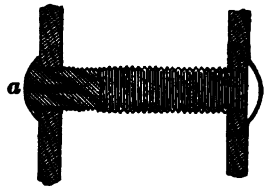


Fig. 124. Stay-Bolt. Scale ¼ in.—1 in.

into the hole, and the leak will thus indicate the defect and danger. The latter is much greater from this cause than is usually supposed, and it is not unusual to find in taking a boiler to pieces that a large number of the stay-bolts are broken. Experience shows, too, that when stay-bolts break, the fracture nearly always occurs next to the outside plate, so that if holes are drilled in the outer ends of the bolts they will, in nearly all cases, show when a bolt is broken.

QUESTION 229. *How can the strain on the flat surface of a boiler between the stay-bolts be calculated?*

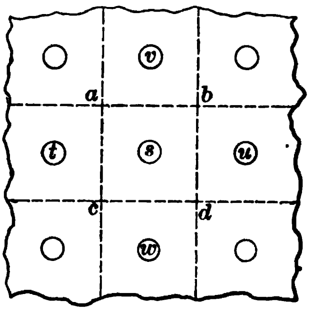


Fig. 125. Arrangement of Stay-Bolts. Scale ⅛ in.—1 in.

Answer. BY MULTIPLYING THE AREA IN INCHES BETWEEN ADJACENT STAY-BOLTS BY THE PRESSURE. The reason for this is, that each stay-bolt must sustain the pressure on a part of the plate to which it is attached. Thus, in fig. 125, it is plain that the bolt, *s*, must sustain the pressure on one-half of that part of the plate between it and the bolts, *v t w u*, around it, or the pressure on the square, *a b d c*, whose sides are equal to the distance (4 inches) between the centres of the bolts. With a pressure of 150 lbs. per square inch, the calculation would therefore be: $4 \times 4 \times 150 = 2,400$ lbs. on each bolt.

Stay-bolts should never be subjected to a strain of more than $\frac{1}{10}$ or $\frac{1}{12}$ of their breaking strength.

QUESTION 230. *How do stay-bolts often fail without breaking?*

Answer. By tearing or *stripping* the thread of the bolt, or that in the plate, but oftener perhaps by the stretching of the plates around the holes. With a heavy pressure, the tendency of the plates between the holes, especially if they are heated very hot, is to "bulge" outward, and thus stretch the hole in every direction until it is so large that the bolt is drawn out without much injury to the screw-thread.

QUESTION 231. *How is the flat-top or crown-sheet strengthened?*

Answer. Usually the crown-sheet is strengthened by a series of iron bars (*H H*, figs. 121 and 122), called *crown-bars*, placed on edge, and of considerable depth, which are firmly fastened to it by rivets or bolts. The crown-sheet can therefore only be crushed downward by bending these bars, which are of great strength. They usually extend crosswise of the length of the fire-box, but are sometimes placed lengthwise. These bars bear on the fire-box at each end only, as shown in fig. 122, and are usually made with projections, *j j*, which rest on the edges of the side plates. Iron rings or washers are interposed between the plate and the bars at the points where the bolts or rivets which secure the rivets pass through. This permits the water to circulate under the bars, and prevents the crown-sheet from being burned or over-heated, as it would be if the water were excluded from the whole under-surface of the crown-bars.* The crown-bars are also connected to the outer shell and the dome by *braces, k k*.

Crown-sheets are sometimes supported by stay-bolts, which are screwed into it and the outer shell of the boiler, as shown in figs. 126 and 127. A difficulty with this form of construction is that to resist the strains produced by the steam pressure on the crown-sheet the bolts should be placed at right angles to its surface, and to resist the pressure against the inner side of the shell of the boiler they should be radial to its cylindrical form. As it is impossible to locate them so as to be both radial to the shell and at right angles to the crown-sheet, all that can be done is to make as close an approximation to each position as is possible. Under these conditions

* Colburn's "Locomotive Engineering."

it is difficult to know how much pressure the stay-bolts bear, and consequently the strains to which they are subjected are liable to be excessive.

QUESTION 232. *Is there any form of construction which obviates the difficulty of staying crown-sheets which has been pointed out?*

Answer. Yes. In what is known as the Belpaire fire-box both the crown-sheet and the shell of the boiler over it are made flat, as shown in figs. 128 and 129, which show longitudinal and transverse sections of this

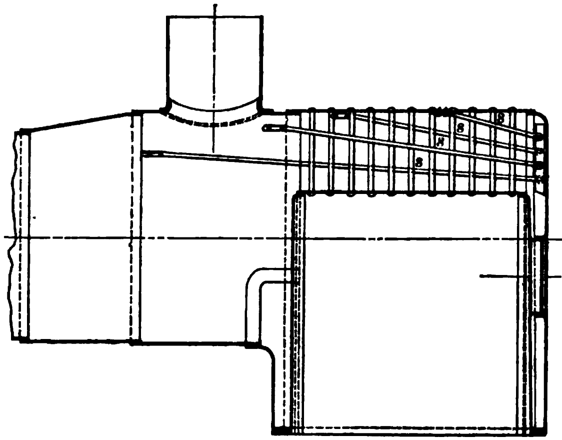


Fig. 126. Longitudinal Section of Fire-Box with Radial Stays. Scale ¼ in.=1 ft.

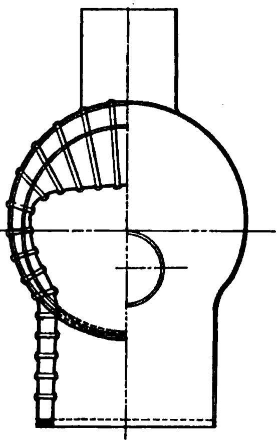


Fig. 127. Transverse Section and Back End View of Fire-Box with Radial Stays. Scale ¼ in.=1 ft.

form of fire-box. These plates are stayed with screw-bolts, *b b b*, at right angles to the plates. The sides, which are also flat, are stayed with rods, *r r*, *r r*, which pass through both the sides.

This form of boiler also has the advantage that the flat plates have more or less flexibility. In a boiler like that shown in figs. 122 or 127, if the inside plates of a fire-box become heated while the outside plate remains cold, they expand and push the top upward. This strain is transmitted to the outside shell, above the fire-box, by the braces or stay-bolts, and as the circular form of the centre shell gives it great rigidity, the parts must be severely strained. In a Belpaire fire-box the flat plates above it can spring or bend, and they thus allow the inside plates to expand without injury to the other parts.

The crown-sheets of fire-boxes should be made to slope downward from the front end towards the back, so as to be several inches lower behind than in front, so that in case the water in the boiler is allowed to get low, only the front part of the crown-sheet will be uncovered, and be liable to be injured by exposure to the heat below it.

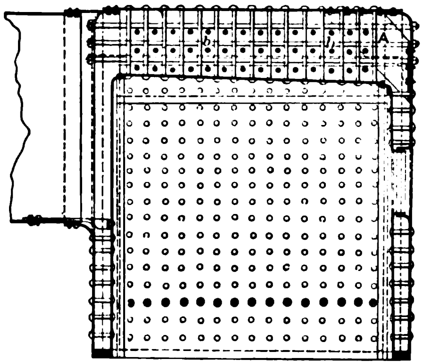


Fig. 128.
Longitudinal Section of Belpaire Fire-Box.
Scale ⅛ in.—1 ft.

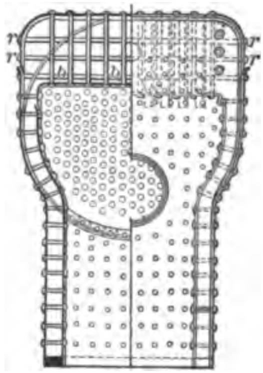


Fig. 129.
Transverse Section and Back End View of Belpaine Fire-Box.
Scale ¼ in.—1 ft.

QUESTION 233. *How are the ends or heads of boilers strengthened?*

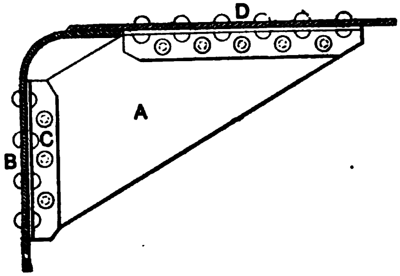
Answer. Usually diagonal stays or braces, *s s s*, figs. 121 and 126, are arranged with one of their ends attached to the end or head of the boiler, and the other fastened to its outside shell.

QUESTION 234. *What precaution should be taken in the design and construction of stays or braces like those which are used for strengthening the ends or heads of boilers and supporting the crown-bars?*

Answer. Great care should be taken to make the parts by which the stays are fastened as strong as the main part of the bar which forms the brace. The principle that the greatest strength of any part of a structure is only that of its weakest part applies with especial force to boiler-stays. Often the grossest carelessness and ignorance is shown in designing and constructing these parts. The eyes and the pins or keys by which they are fastened are often made so that they are much weaker than the body of the bar, and the riveted attachments to the boiler-plates often have only a small percentage of the strength of the main part of the brace or stay.

QUESTION 235. *What other method of staying boiler-heads is sometimes used?*

Answer. What are called "*gusset stays*" are used a great deal in European locomotives. These consist of triangular pieces of boiler-plate, *A*, figs. 130 and 131, which are fastened to the boiler-head, *B*, and to the



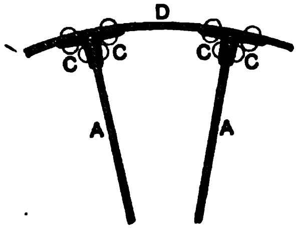


Fig. 130. Gusset Stays. Scale 1/8 in.—1 in. Fig. 131.

shell, *D*, by angle-irons, *C* and *C*, which are riveted to the head and to the shell. The plate, *A*, is placed between the angle-irons with rivets through all three, as shown in fig. 131. Stays of this kind are often used for Belpaire fire-boxes, an example of which is shown in fig. 128.

QUESTION 236. *How are the grates constructed?*

Answer. They are generally made of cast-iron bars, and for burning coal are usually arranged so that the fire can be shaken by moving the bars. Their construction will be more fully explained in chapter XIII. For burning anthracite coal, the grates are sometimes made of wrought-iron tubes, inside of which a current of water circulates to prevent them from being overheated.

QUESTION 237. *How are cinders and burning coals which fall through the grate prevented from falling upon the road?*

Answer. By attaching a sheet-iron receptacle or *ash-pan* (*E E*, figs. 121 and 122), as it is called, under the grate, which is thus completely enclosed from the outside air. As it is often important when the engine is standing still to prevent any access of air to the fire-box, the ash-pan is made to fit tightly to the fire-box, so that air can be excluded from the grate. Suitable doors, or *dampers*, as they are called, are placed in front and behind, and sometimes on the sides, which can be opened or closed to admit or shut out air as may be needed.

QUESTION 238. *How are the tubes or flues of a locomotive arranged?*

Answer. They are fastened into accurately drilled holes in a plate, called a tube-plate or tube-sheet (*a a*, figs. 121 and 122), which forms the front of the fire-box, and in similar holes in another plate (a' a', fig. 121), which forms the front end of the cylindrical part of the boiler. They thus connect the fire-box with the smoke-box. The tubes are arranged so that each one will have a space of from $\frac{5}{8}$ to $\frac{7}{8}$ inch between it and those next

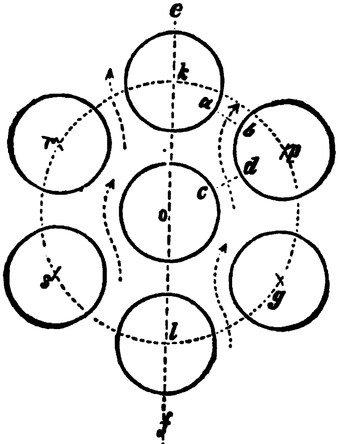


Fig. 132.

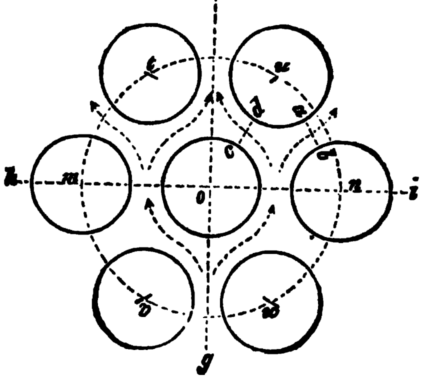


Fig. 133.

Arrangement of Tubes. Scale ¼ in.—1 in.

to it. The position of the holes for the tubes in relation to each other is determined by describing from the centre of one tube (*o*, fig. 132), a circle with a radius, *o k*, equal to the sum of the outside diameter of the tubes and the distance which they are intended to be apart, and then subdividing this circle with its radius into six parts, *k r, r s, s l, l g, g p* and *p k*. Each point of subdivision and also the centre, *o*, of the circle will be a centre of a tube. By laying them off from these centres, it will be found that the least distances, *a b, c d*, between adjoining tubes will be the same between all of them. By describing circles from the centres of the outside tubes and subdividing the circles as before, the position of other tubes will be determined around those first laid down. This can, of course, be carried out indefinitely.

A difference in the arrangement of the tubes will be observed by comparing figs. 132 with 133. If, when we subdivide the first circle shown in fig. 132, instead of commencing from the intersection of a vertical line, *k l*,

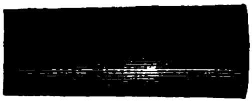
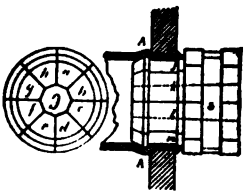


Fig. 134.

Fig. 135.



Figs. 136, 137.
Prosser's Tube Expander. Scale 1¼in.—1 in.

drawn through the centre, *o*, we begin from a horizontal line, *h i*, as shown in fig. 133, then in the former case the tubes will be in *vertical rows*, and in the latter in *horizontal rows*. It is apparent from the figures and as shown by the arrows that the water can circulate in ascending currents more freely when tubes are arranged in vertical rows than when they are arranged horizontally.

QUESTION 239. *How are the tubes fastened and made water-tight in the tube sheets?*

Answer. They are inserted into the holes drilled to receive them, and the ends are allowed to project about a quarter of an inch beyond the tube-sheets. A tool, or "*tube expander*," as it is called, is then inserted into the end of the tube and it is expanded so that it completely fills the hole in the tube-plate. A number of different kinds of tools have been devised for expanding tubes in the tube-plates and making a shoulder on each side of the plate so as to keep the tubes water-tight. Figs. 184–187 represent Prosser's expander. When this is used a tapered plug, fig. 184, is first driven into the tube to expand it so that it will fill the hole. Fig. 185 represents a perspective view, and figs. 186 and 187 side and end elevations of the "spring expander." This may be called an expanding plug composed of eight or more sector-shaped pieces, *a b c d e f g* and *h*, which are held together by an open steel spring-ring or clasp, *s*, which embraces

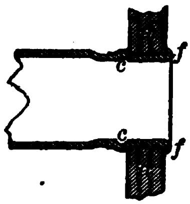


Fig. 188. Section of End of Tube with Copper Ferrule. Scale ¼ in.—1 in.

them as shown in figs. 185–187. The inner portion of the sectors is cut away so as to leave a hole, *C*, fig. 185 and 186, in the middle of the plug. When the sections are drawn together the plug is inserted into the mouth of the tube, and a tapered plug, *p p*, fig. 185, is then driven into the hole, *C*. The spring-ring or clasp, *s*, permits the sectors to separate when the tapered plug is driven into the opening in the centre of the cluster of sectors. Each of the sectors has a projection, *j k l m*, where it comes in contact with the outer edge of the tube, and another just inside of the tube-plate. These projections form a ridge, *a b c d*, fig. 185, and another, *j k l m*, on the plug. When the tapered plug or mandrel is driven into the central opening the sectors are forced apart, and they thus expand the tube and at the same time their projections form a ridge in the tube around the inner and outer edges of the hole in the plate, as shown at *c c*, fig. 138. By slightly turning the expander each time the mandrel is driven in, and repeating the process, the tubes can be made perfectly water-tight. In many cases, after the tubes are expanded with the tool described, the outer edge is turned over still more with what is called a *thumb-tool*, figs. 139 and 140, probably from its resemblance in form to a man's thumb. By placing the curved shoulder, *a*, on the end, *f*, fig. 139, of the tube it is turned over, somewhat in the form shown in the engraving, by repeated blows of a hammer on the end of the tool.

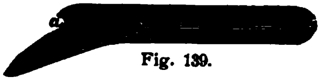


Fig. 139.

Fig. 140. Caulker's Thumb Tool. Scale ¼in.--1 in.

Fig. 141 represents Dudgeon's roller expander. This may be described as a hollow plug which has three rollers, which are contained in cavities in the plug in which they can revolve, and in which they can also move a short distance radially—that is, from the centre of the plug outward. When the expander is inserted into the end of the tube a tapered mandrel, fig. 141, is driven into the central opening, and the plug then bears

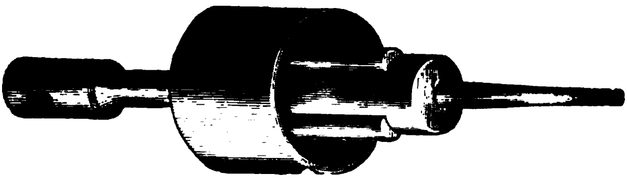


Fig. 141. Dudgeon's Roller Tube Expander.

against the rollers and forces them outward against the tubes. A crank handle is then attached to the end of the mandrel, and is turned around, which causes the rollers to revolve on their own axes. This also causes the hollow plug to revolve around its axis. The two thus have a sort of sun and planet motion in relation to each other. As the rollers bear hard against the tube, the effect is to elongate it circumferentially, and thus enlarge it so as to completely fill the opening in the tube-plate.

There are other forms of tube-expanders, but those described are more generally used than any others.

Copper ferrules, represented by the black shading, *a a*, fig. 138, are also much used now on the outside of locomotive tubes, and it is said that

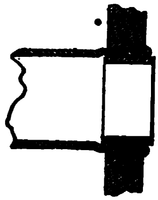


Fig. 142. Section of End of Tube with Inside Ferrule. Scale ¼ in.—1 ft.

with them the joints can be kept tight much easier than without. By turning over the outside edge of the tube, as shown in fig. 138, it not only protects the copper ferrule, but, as the tubes must act as braces to sustain the pressure of steam in the flat tube-sheets, it gives the joints the requisite strength for resisting such strains.

Cast iron or steel ferrules, which are made tapered and driven into the mouths of the tubes, as shown in fig. 142, are also used in some cases. These are simply driven into the tube after it has been expanded.

QUESTION 240. *How can the strain on the cylindrical part of a boiler be calculated?*

Answer. BY MULTIPLYING ITS DIAMETER IN INCHES BY ITS LENGTH IN INCHES AND ITS PRODUCT BY THE STEAM PRESSURE PER SQUARE INCH. Thus, for a boiler 48 inches in diameter and 10 feet long with 100 lbs. pressure the calculation would be $48 \times 120 \times 100 = 576{,}000$ lbs.

QUESTION 241. *Why do we multiply the diameter, instead of the circumference, by the length, to get the strain on the cylindrical part?*

Answer. The reason for multiplying by the diameter instead of by the circumference is because only a portion of the pressure on the inside surface of the boiler exerts a force to burst the shell at any one point. Thus, supposing the diagram, fig. 143, to represent a section of a boiler, if we have a force acting on the shell in the direction of the line, *a b*, at the point, *b*, where it is exerted against the shell of the boiler, it may be resolved into two forces, one acting in the direction, *b e*, and tending to tear the boiler apart on the line, *c d*, and the other acting in the direction, *f b*, to tear it apart on the line, *h g*. It is so with all pressure inside the boiler, excepting that, say *a h*, which acts exactly at right angles to the line of rupture, *c d*; it may all be resolved into two forces, only one of which tends to tear the boiler apart at one point. It is, therefore, only a part of the pressure on the circumference which tends to burst the boiler at a given place, and that part is equivalent to the pressure on a surface whose width is equal to the diameter and not the circumference.

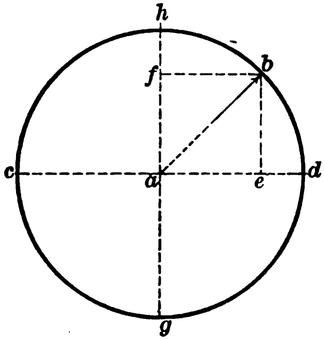


Fig. 143.
Diagram Showing Strain in Boiler.

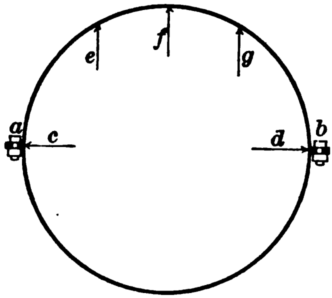


Fig. 144.
Diagram Showing Pressure in Boiler.

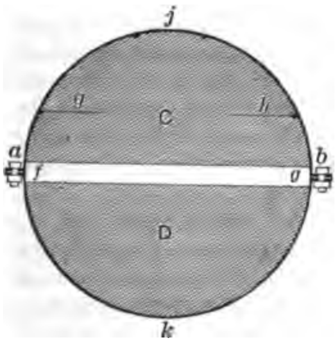


Fig. 145.

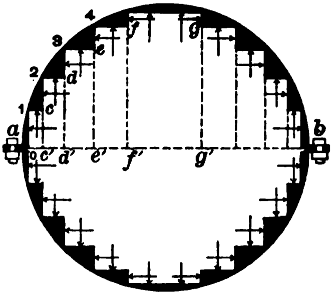


Fig. 146.

Diagrams Showing Pressure and Strain in Boiler. Scale 1/8 in.—1 ft.

This may be difficult for those to understand who are not familiar with the principle of the "resolution of forces," which was explained in Chapter II; but it may be made clear in another way.

Let it be supposed that we have a boiler, *a b*, fig. 144, made in two halves and bolted together at *a* and *b* by flanges. It is evident that if we brought a pressure against the inside of the flanges in the direction of the darts, *c* and *d*, such a pressure would not have a tendency to tear apart the bolts, *a* and *b*, by which the two halves of the boiler are fastened together. Some distortion of the boiler might, in fact, take place if, for example, we put a jack-screw inside and forced the flanges, *a* and *b*, outward as indicated by the darts, *c d*, without subjecting the bolts to a tensile strain. We see, therefore, that the forces acting in the direction, *c* and *d*, have no tendency to tear the bolts at *a* and *b* asunder, but it is only such forces as *e f* and *g* which act at right angles to the diameter, *c d*, that exert a strain on the flanges.

That this force is equivalent to a pressure on a surface with a width equal to the diameter will be apparent if we suppose that we have a boiler, *a b*, fig. 145, and that each half, *C* and *D*, is nearly filled with some substance, say wood or cement, which is fitted so tight that no steam can get between it and the shell of the boiler. It will be apparent that if we admits team into the space, *f g*, the force exerted on the bolts, *a* and *b*, is that due to the pressure on the surface of the wood or cement exposed to the steam whose width is equal to the diameter of the boiler. It may be said, though, that if this substance were elastic, like india-rubber, the effect of the steam would be different.

But even if it were elastic, the pressure of the steam would be exerted at right angles to the surfaces, *f g*, and the pressure on these surfaces would not be increased or diminished if the elastic substance should spread laterally. If it should do so and thus produce pressures in the direction *g* or *h*, it would not produce any strain on the bolts, *a* and *b*, to tear them apart, but such pressures would have a tendency to rupture the boiler on the line, *j k*.

The effect of internal pressure in a boiler may be made clear in still another way. Let it be supposed that we have a cast-iron boiler the inside surface of which is formed as shown in fig. 146—that is, it is serrated or formed like steps, with vertical and horizontal surfaces as shown. It may be assumed, without leading us into error, that the pressure of the steam is exerted at right angles to these surfaces—that is, that it acts in the direction indicated by the darts. Obviously the pressure which tends to pull apart the bolts, *a* and *b*, is only that represented by the vertical darts, and which acts on the horizontal surfaces, and the total strain which these bolts must resist is equal to the area of these surfaces multiplied by the pressure per square inch. But if we draw vertical lines, $c\,c'$, $d\,d'$, $e\,e'$, etc., from the stepped surfaces to the diameter, $a\,b$, it will be apparent that the area of the horizontal stepped surfaces, 1 c, 2 d, 3 e, 4 f, $f\,g$, etc., are equal to $o\,c'$, $c'\,d'$, $d'\,e'$, $e'\,f'$, $f'\,g'$, etc., and that they are equal in length to the diameter, $a\,b$, so that if we multiply this diameter by the length of the boiler and the pressure per square inch, it will give the pressure which is exerted on the horizontal surfaces, 1 c, 2 d, 3 e, etc. It may now be imagined that the steps are infinitely small. In that case the internal stepped or notched surface would coincide and be equivalent to that of a cylinder without such notches. Therefore, the reasoning which applies to the one will apply to the other. The effect of the pressure which acts horizontally or in any other direction can be shown in the same way.

The sides of a boiler must therefore be made strong enough to resist the pressure which the steam exerts on a surface the length of which is equal to that of the boiler, and the width equal to its diameter.

QUESTION 242. *What are the metals principally used in boiler construction?*

Answer. Formerly wrought-iron was the principal metal used in the construction of boilers, but it has now, to a very great extent, been superseded by soft steel.

QUESTION 243. *What advantages has soft steel as a material for boilers?*

Answer. Its strength to resist strains of tension and compression is considerably greater than that of iron, thus permitting the use of thinner plates. Its ductility is greater, its structure more homogeneous, and its quality more uniform.

QUESTION 244. *How much strain per square inch is good boiler-plate capable of resisting, and how much is it safe to subject it to?*

Answer. There is great difference in the tensile strength* of rolled iron boiler-plate, but that of good plate will average about 50,000 lbs. per square inch, if the strain is applied in the direction of the "grain" or the fibres of the iron,† and about 10 per cent. less if the strain is applied crosswise of the grain. It has, however, been found by experiment that when a tensile strain is applied to a bar of iron or other material, it is stretched a certain amount in proportion to the length of the bar, and to the degree of strain to which it is subjected. If this strain does not exceed about

* A force exerted to pull any material apart is called a *tensile strain*, and if exerted to compress it is called a *compressive strain*.

† It should be explained that in the process of manufacturing iron by rolling, the iron is stretched out into fibres in the direction in which it passes between the rolls.

one-fifth of that which would break the bar, it will recover its original length, or will contract after being stretched, when the strain is removed. The greatest strain which any material will bear without being permanently stretched is called its *limit of elasticity*, and so long as this is not exceeded, no appreciable permanent elongation or "set" will be given to iron by any number of applications of such strains or loads. If, however, the limit of elasticity is exceeded, the metal will be permanently elongated, and this elongation will be increased by repeated applications of the strain until finally the bar will break. At the same time the character of the metal will be altered by the repeated application of strains greater than its elastic limit, and it will become brittle and less able to resist a sudden strain, and will ultimately break short off. It is therefore unsafe to subject iron, or, in fact, any other material, to strains greater than its elastic limit. This limit for iron or steel boiler-plates may be taken at about one-fifth its breaking, or, as it is called, *ultimate* strength. It should be remembered, however, in this connection, that it often happens that the steam pressure is not the greatest force the boiler must withstand, as sudden or unequal expansion and contraction are probably more destructive, to locomotive boilers especially, than the pressure of the steam.

QUESTION 245. *What is the relative strength of wrought-iron and mild steel plates?*

Answer. Good wrought-iron boiler-plates, as already stated, have a tensile strength of about 50,000 lbs. per square inch, and mild steel about 60,000 lbs.

QUESTION 246. *What are the most important qualities which boiler-plates should possess?*

Answer. The first quality to be sought for in a boiler-plate is strength. This does not necessarily imply the mere power to resist being torn asunder by a dead weight, as in a testing machine, but the quality to withstand, without injury, the many and varying shocks and strains it is exposed to in the boiler-shop and in actual work. Many inferior plates exhibit as great a cohesive strength as those of better quality, their inferiority consisting in their brittleness or shortness, want of "body" or soundness, imperfect manufacture, and uncertain character or quality. Toughness and ductility, combined with great tenacity, and also closeness and uniformity of texture and constancy of quality, are the properties and character to be sought for.

QUESTION 247. *What qualities should boiler-plates and rivets have?*

Answer. All iron or steel plates of the *best* quality should have a longitudinal tenacity of not less than 50,000 lbs. per square inch of section, and an ultimate elongation before breaking of about 12 per cent., and if not exceeding 1 inch in thickness, should bend double along or across the fibre when red hot, and if $\frac{7}{16}$ inch thick and under, they should bend double when cold without fracture.

Good iron plates should bend cold, without fracture, to the following angles:

Thickness of Plate.	Along the Fibre.	Across the Fibre.
$\frac{1}{4}$ inch...............	90 degrees............	55 degrees.
$\frac{5}{16}$ "	80 "	45 "
$\frac{3}{8}$ "	70 "	35 "
$\frac{7}{16}$ "	55 "	25 "
$\frac{1}{2}$ "	40 "	20 "
$\frac{5}{8}$ "	30 "	15 "
$\frac{7}{8}$ "	20 "	10 "
1 "	15 "	7 "

The radius of the corner over which the plates are bent should not exceed half an inch.

Steel boiler-plates should have a tensile strength of about 60,000 lbs. per square inch, and it should not be less than 50,000, nor more than 70,000 lbs., and when broken under tension the ultimate elongation of a test piece 8 inches in length, after fracture, should be not less than 20 per cent. of the original length. Strips not less than 2 inches broad and 10 inches long, cut from plates *not* exposed to the fire in service, should bear bending cold without fracture until the sides are parallel at a distance from each other of not less than three times the thickness of the plate. Strips taken from plates which, in service, will be exposed to the fire, should be heated, before bending, to a cherry red, then plunged into water of about 80 degrees temperature, and kept there until of the same temperature as the water. They should then stand the same test required for the pieces which are bent cold.

The material of which rivets are made should have a high degree of ductility. A good iron rivet, cold, should bend double without fracture, and its head should flatten out by hammering when hot to about $\frac{1}{8}$ inch thick without fracture or fraying at the edge. A hot rivet-shank, when flattened down to a thickness equal to about one-half its diameter, should bear a punch driven through it without fracture at the hole.*

The steel of which rivets are made should always be of the mildest—that is, the most ductile—material, because if it is not of this character they are liable to become hard and brittle while being worked and in use.

The resistance of steel rivets to shearing should therefore not be greater than that of iron rivets, or about 50,000 lbs. per square inch of section.

The following are the specifications to which all boiler and fire-box steel, bought by the Pennsylvania Railroad, must conform:

SPECIFICATIONS FOR BOILER AND FIRE-BOX STEEL FOR PENNSYLVANIA RAILROAD COMPANY.

1st. A careful examination will be made of every plate, and none will be accepted that show mechanical defects.

2d. A test strip, taken lengthwise of each plate, without annealing, should have a tensile strength of 55,000 lbs. per square inch, and an elongation of 30 per cent. in section originally 2 inches long.

3d. Plates will not be accepted if the test shows a tensile strength less than 50,000 lbs., or greater than 65,000 lbs. per square inch, nor if the elongation falls below 25 per cent.

4th. Should any plates develop defects in working, they will be rejected.

5th. Manufacturers must send one test piece, which must be as near straight as possible, 24 inches long and not less than 1¼ inches wide, for each plate.

6th. Both test piece and plate must be stamped with the shear mark designated by this company, the letter designating the plate and with a serial number according to the number of plates of the same kind on order, all to be placed near together. In addition to this, and in order to facilitate matching, a circle of white lead must be drawn around the shear marks, stamp numbers and letters, and the two latter repeated in white lead on both test piece and plate.

7th. The sheared edges, at shear marks, of both test piece and plate, must show a fresh shear and it will be considered sufficient cause for rejection of the plate if either show signs of having been annealed after separation.

8th. No plate or test piece will be accepted unless it shows the before-mentioned marks.

* Wilson's "Treatise on Steam Boilers."

QUESTION 248. *Why should the greatest strength steel-plates and rivets not exceed a certain limit?*

Answer. Because steel of a very high tensile strength is usually brittle and liable to fracture, whereas soft ductile steel usually has a comparatively low tensile strength.

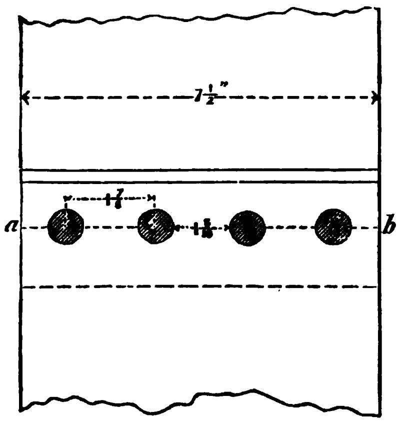
QUESTION 249. *How are boiler-plates fastened together?*

Answer. By rivets which are made with a head on one end, and are inserted red hot in holes, drilled or punched in the plates, and another head is then formed by hammering, or by steam, or hydraulic pressure, on the other end of the rivet. The rivets are thus made to fill the holes, and in cooling contract and draw the plates together.

QUESTION 250. *What is the strength of riveted seams compared with that of the solid plate?*

Answer. The strength of a riveted seam depends very much upon the arrangement and proportion of the rivets; but with the best design and

Fig. 147.



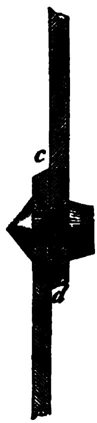


Fig. 148.

Single Riveted Lap Seam. Scale ¼ in.—1 in.

construction, the seams are always weaker than the solid plates, as it is always necessary to cut away a part of the plate for the rivet-holes, which weakens the plate in two ways: 1. By lessening the amount of material to resist the strains. 2. By weakening that left between the holes. The first cause of weakness is obvious from an inspection of an ordinary seam, riveted with a single row of rivets, figs. 147 and 148. In this we have two plates 7½ inches wide and ⅜ thick fastened with four rivets $\frac{11}{16}$ inch in diameter and 1⅞ inches from centre to centre. The section of the plate calculated with decimals* would therefore be $.375 \times 7.5 = 2.81$ square inches. A piece $\frac{11}{16}$ inch wide and ⅜ inch thick would be removed to form each hole, or a sectional area for the whole plate of $.375 \times .6875 \times 4 = 1.03$ square inches, so that the section of the plate would be reduced through the holes $2.81 - 1.03 = 1.78$ square inches. In other words, on the dotted line, *a b*, it will have only about 63 per cent. of the sectional area of the solid plate.

The second cause of the reduction of strength is owing to the injury sustained by the plates during the process of punching. The knowledge existing regarding this subject is not very satisfactory, although numerous experiments have been made to determine the exact amount of weakening caused by punching plates. It is, however, certain that in many cases the strength of the metal *left* between the holes of boiler-plates is reduced from 10 to 25 per cent. by the process of punching. It is probable, however, that soft ductile metal is injured less than that which is harder and more brittle. Some kinds of steel plates are especially liable to injury from punching. It is also probable that the condition of the punch, and the proportions of the die used with it, have much to do with its effect upon the metal.

QUESTION 251. *How can the injury done to boiler-plates by punching be prevented?*

Answer. It has been shown that the injury to plates from punching is confined to a narrow area around the hole, and that by punching the hole smaller than required, and then reaming it or drilling it to the required size, the weakened portion of the plate is removed, leaving that portion between the holes equal, or, as has been shown in some experiments,† of greater strength than the original plate. It has also been shown by some experiments that annealing steel plates after punching restores them to their original strength; but with the mild steel now made there is little need of this precaution, and there is, perhaps, more danger of damaging the plates by careless attempts at annealing than by deterioration of metal in punching.

* In the following calculations all the dimensions have for convenience been reduced to decimals.

† See a description of Tensile Tests of Iron and Steel Bars, by Peter D. Bennett, in the Proceedings of the Institution of Mechanical Engineers, for February, 1886.

QUESTION 252. *How may a boiler seam like that shown in fig. 147 and 148 break?*

Answer. It may break in three different ways:

1. By a plate tearing between the rivet holes on the line *a b*.
2. By the rivets shearing off.
3. By the plate in front of the rivets crushing, as shown in fig. 149, or splitting the plate at right angles to the seam, as shown in fig. 150.

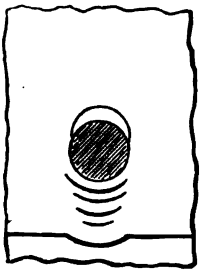


Fig. 149. Plate Crushed by Rivet.

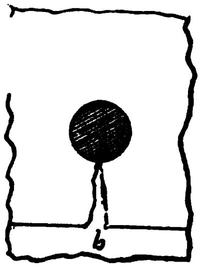


Fig. 150. Plate Split by Rivet.

Scale ½ in.—1 in.

QUESTION 253. *How can the strength of a boiler seam be calculated at each of these three points?*

Answer. The strength through the rivet holes is calculated by TAKING THE AREA IN SQUARE INCHES OF THE METAL WHICH IS LEFT BETWEEN THE RIVET HOLES, AND MULTIPLYING IT BY THE ULTIMATE STRENGTH OF THE METAL AFTER THE HOLES ARE MADE. Thus, in fig. 147, the area of each of the plates between the rivet holes is 1.78 square inches. As already stated, good iron boiler-plate will break at a strain of about 50,000 lbs. in the direction of its fibres.* The calculation for the strength through the holes would therefore be: $1.78 \times 50{,}000 = 89{,}000$ lbs. If the holes are punched and not afterward reamed or drilled the strength of the plates, as already explained, would be considerably reduced, and a lower tensile strength must be used in calculating the strength of the seam.

It has also been found by experiment that the strength of rivets to resist

* Boiler-plates should always be so arranged that the greatest strain will come on them in the direction of their greatest strength, which is parallel with the fibres of the metal.

shearing is about the same as that of good boiler-plate to resist tearing apart, or 50,000 lbs. per square inch. The strength of the rivets, therefore, is calculated by MULTIPLYING THE AREA IN SQUARE INCHES OF ONE RIVET BY THE NUMBER OF RIVETS, AND THE PRODUCT BY THE STRENGTH OF THE METAL TO RESIST SHEARING. The calculation for figs. 147 and 148 would therefore be:

$$\text{Area of } \tfrac{11}{16} \text{ rivet} = .3712 \times 4 \times 50{,}000 = 74{,}240,$$

or somewhat less than the strength of the plates through the holes.

The resistance offered by a plate to the crushing strain of a rivet has been found also by experiment to be about 90,000 lbs. per square inch. It can be proved that the area which resists the crushing strain of a rivet in a plate, fig. 149, IS MEASURED BY MULTIPLYING THE DIAMETER OF THE RIVET BY THE THICKNESS OF THE PLATE. The calculation for the strength of this part of the seam will therefore be: diameter of hole= $.6875 \times .375 \times 4 \times 90{,}000 = 92{,}812$.

The strength of the solid plate without any holes in it would be EQUAL TO ITS SECTIONAL AREA MULTIPLIED BY 50,000 LBS., or $7.5 \times .375 \times 50{,}000 = 140{,}625$ lbs. The ultimate strength of the seam would then be as follows:

Rivets............................	(shearing) =	72,240 lbs.
Plates through rivet holes...........	(tearing) =	89,000 "
Plates in front of rivets............	(crushing) =	92,812 "
Solid plate.........................	(tearing) =	140,625 "

It will thus be seen that the strength of the weakest part of the above seam, fastened with a single row of rivets, is very little more than half (51.3 per cent.) of that of the solid plates. It will be noticed that the plates between the holes have an excess of strength over the rivets, which is desirable, because the plates are liable to more or less injury from punching.

QUESTION 254. *What are the usual proportions for single-riveted lap seams?*

Answer. The following table gives the usual proportions for such seams:

SINGLE-RIVETED LAP JOINTS.

IRON PLATES, IRON RIVETS.			STEEL PLATES, IRON RIVETS.		
Thickness of Plates.	* Diameter of Rivets.	Pitch of Rivets.	Thickness of Plates.	* Diameter of Rivets.	Pitch of Rivets.
5/16 inch.	11/16 inch.	1 13/16 inch.	5/16 inch.	11/16 inch.	1 9/16 inch.
3/8 "	3/4 "	1 7/8 "	3/8 "	3/4 "	1 9/16 "
7/16 "	13/16 "	1 15/16 "	7/16 "	13/16 "	1 11/16 "
1/2 "	7/8 "	2 "	1/2 "	7/8 "	1 11/16 "
5/8 "	15/16 "	2 1/16 "	5/8 "	15/16 "	1 13/16 "
3/4 "	1 1/16 "	2 3/16 "	3/4 "	1 1/16 "	1 7/8 "
7/8 "	1 1/8 "	2 1/4 "	7/8 "	1 1/8 "	2 "
1 "	1 1/4 "	2 5/16 "	1 "	1 1/4 "	2 1/16 "

QUESTION 255. *Is the maximum strength of seams the chief aim in designing a boiler?*

Answer. No; a tight joint is of the first importance, for should leakage occur corrosion may soon alter any carefully calculated proportions of the respective sections in the joint. Indeed, it may be affirmed that in the majority of cases the safety of a boiler depends, in the long run, more upon the tightness than the actual strength of the joints, since a large factor of safety is usually allowed.†

QUESTION 256. *How may a single-riveted lap seam be made stronger than that illustrated by figs. 147 and 148?*

Answer. The most obvious way of doing this is to increase the *pitch*—that is, the distance from centre to centre—and the diameters of the rivets, which would leave more metal between the holes, and thus strengthen the seam at its weakest part. But if this is done, it is said that there is difficulty in keeping the seams water-tight, as the plates are then liable to spring apart between the rivets. Another way of increasing the strength of the seam is to drill the rivet holes. As already stated, the difference in the strength of the metal left between drilled and punched holes has been shown to be from 10 to 25 per cent. There is also another advantage in drilling the holes for rivets. In punching them, it is necessary to punch each plate separately, and even with the utmost care and skill it is im-

* This is the diameter of the rivets before being driven; the holes are usually made 1/16 inch larger.

† Wilson's "Treatise on Steam Boilers."

possible to get the holes to match perfectly. Some of them will overlap each other, as shown in fig. 151, so that when the rivet is set, it will assume somewhat the form shown in fig. 152. There is then danger that those rivets which fill the holes that match each other will be subjected to an undue strain. If, for example, we have five rivet holes, as shown in fig. 153, and only the centre ones correspond with each other, then the rivets in all the other holes will assume somewhat the form shown in fig. 152, and therefore the centre rivet, *c*, in fig. 153, which fits

Fig. 151.

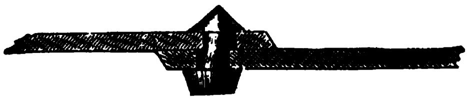


Fig. 152.

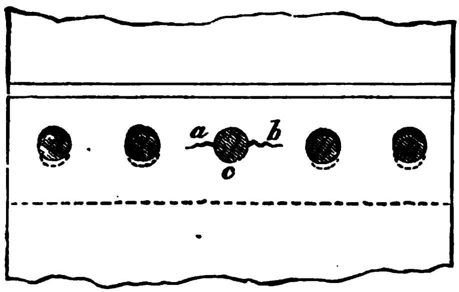


Fig. 153.
Unmatched Rivet Holes. Scale ¼ in.—1 in.

the holes accurately, must take the strain of the other four until they draw up "to a bearing." Under such circumstances, which are not unusual, there will be great danger either of shearing off the rivet, *c*, or of starting a fracture in the plates, as indicated by the irregular line, *a b*, between the adjoining rivets. It is also obvious that a rivet like the one in fig. 152 will not hold the plates together so well as one which fits better, as shown in section in fig. 148, and therefore there is more danger of leakage between the plates from badly fitted rivets than from those which fill the holes more perfectly; consequently rivets which fit badly must be placed nearer together than those which are well fitted. It is true that rivets which are set with a riveting machine fill any inaccuracies of the holes better than those which are set by hand. But even if they are made to fill the holes, as shown in fig. 154, they are still not so strong to resist shearing nor so efficient in holding the plates together as they would be if

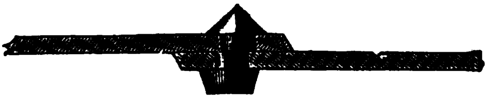


Fig. 154.

the holes conformed more perfectly to each other. In drilling the holes, the second plate can be drilled from the holes in the first, so that the holes in each one will correspond with the other perfectly. The rivets will therefore fit more accurately, and consequently can be spaced further apart, and still keep the plates tight, and thus there will be more material between the holes, which is the weakest part of the seam. It has been shown that a rivet $\frac{11}{16}$ inches in diameter has a resistance to shearing of 18,560 lbs. There is therefore no advantage with plates $\frac{3}{8}$ inch thick in spacing such rivets further apart than $1\frac{11}{16}$ from centre to centre, because the metal of 50,000 lbs. of tensile strength which is left between drilled holes that distance apart would be slightly stronger than the rivets. If, therefore, the rivets are placed further apart, their diameter must be increased. There is, however, a limit beyond which the diameters of rivets cannot be increased with advantage, because if we increase their diameters, their sectional area to resist shearing is increased in proportion *to the square of the diameter*, whereas the section of metal in the plate to resist crushing is increased only *in proportion to the diameter*. This will be apparent if we compare a rivet $\frac{1}{2}$ inch with one 1 inch in diameter. The first has a sectional area of .1963 inches, the other .7854 inches, or *four* times that of the first one. Now the area which resists the crushing strain of the rivets is increased only in proportion to their diameters, or is *twice* as much for the one as for the other. If, therefore, we increase the diameters, of the rivets, we very soon reach a point at which the plate has less strength to resist crushing than the rivet has to resist shearing. The diameter of rivet which will give just the same resistance to both strains varies with the thickness of the plates; with $\frac{3}{8}$ inch plates a $\frac{7}{8}$ inch rivet will have a resistance to shearing of 30,065 lbs. and the plate in front of it a resistance to crushing of 29,530 lbs. A $\frac{7}{8}$ inch rivet is, therefore, the largest size which can be used to advantage in ⅜ inch plates. If now we were to space such rivets so far apart that the metal left between the holes would have a strength just equal to that of the rivets, we would have the strongest possible seam that can be made with a single row of rivets. This distance would be 1¾ inches between the edges of the rivets, or 2⅝

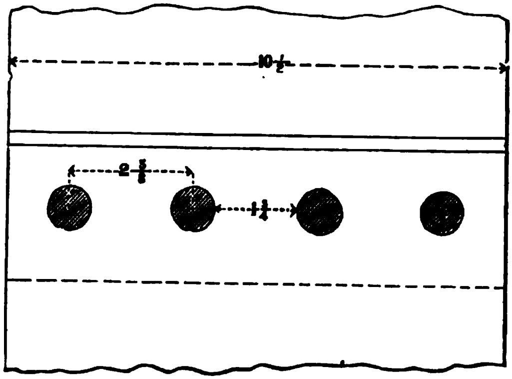


Fig. 155. Single-Riveted Lap Seam. Scale ¼ in.—1 in.

inches from centre to centre, as shown in fig. 155. The following table will show the strength of such a seam composed of four rivets, and two plates 10½ inches wide,* with drilled holes:

Plates through rivet holes	(tearing)	118,125 lbs.
Rivets	(shearing)	120,260 "
Plates in front of rivets	(crushing)	118,125 "
Solid plates	(tearing)	196,875 "

From this it is seen that the strength of the seam with drilled plates is 60 per cent. of that of the solid plates, or it is about 18½ per cent. stronger than that made with plates having punched holes and the rivets nearer together. It should be noted that a great part of the superiority of the seams made with drilled holes is due to the superior accuracy of the work done in that way, which makes it possible to use larger rivets spaced further apart. It is probable that with the use of some recently designed machines, intended to produce greater accuracy in punching rivet holes,

* It has been necessary to take for an illustration plates of a different width from the preceding example, in order to get an even number of spaces between the rivets in each case.

part of the above advantage may be realized with that kind of work. The greatest distance that rivets may be spaced apart without incurring danger of leakage between the plates must, however, be determined more by practical than theoretical considerations. It is certain, however, that if their heads are made sufficiently large, rivets may be spaced much further apart than they are in ordinary practice, and the seams still be kept tight, if the work is done with the requisite accuracy and care.

QUESTION 257. *What must be the proportions for a single-riveted lap seam made of iron plates and with iron rivets to get the maximum strength?*

Answer. If the plates have a tensile strength and the rivets a resistance to the shearing equal to 50,000 lbs. per square inch, THE RIVET HOLES (not the diameter of the rivets cold) SHOULD BE 2⅓ TIMES THE THICKNESS OF THE PLATES, AND THE PITCH OF THE RIVETS FROM CENTRE TO CENTRE SHOULD BE 7 TIMES AND THE OVERLAP OF THE PLATES 6 TIMES THEIR THICKNESS. Fig. 155 represents a seam of these proportions. In the table on the next page the strength of a seam like that represented by figs. 147 and 148 is given in the vertical column, *A*, and that of the one shown by fig. 155 is given in column *B*. The strength per lineal inch of the seams is given in the eighth horizontal line. That of the first one is 9,898 lbs., whereas that of the second one is 11,250 lbs. per lineal inch.

QUESTION 258. *What difference should there be in the proportions of single-riveted lap seams if made of steel instead of iron plates, and with steel rivets?*

Answer. As steel rivets with sufficient ductility have no greater strength to resist shearing than iron rivets, the one kind should be of the same size as the other; but as steel plates have about 20 per cent. more tensile strength than iron ones, the amount of metal between the rivet holes may be less if the plates are made of steel than if they are of iron. Thus in the seam represented by fig. 155 the rivet hole is $\frac{7}{8}$ inch in diameter, and the width of the metal between the holes is $1\frac{3}{4}$ inches. Their sectional area and strength is as follows:

Rivet area, $.6013 \times 50{,}000 =$ 30,065 lbs.
Plate area, $1\frac{3}{4} \times \frac{3}{8} = .65625 \times 50{,}000 = 32{,}812$ lbs.

If the plate is of steel and the space between the rivets is made $1\frac{3}{8}$ or 20 per cent. less than shown in fig 155, then its strength would be as follows:

$$1\tfrac{3}{8} \times \tfrac{3}{8} = .5156 \times 60{,}000 = 30{,}937 \text{ lbs.},$$

STRENGTH OF DIFFERENT KINDS OF RIVETED SEAMS.

		A	B	C	D	E	F	G	H	I
		Single-Riveted Lap Seam, Figs. 147 and 148.	Single-Riveted Lap Seam, Fig. 155.	Single-Riveted Lap Seam.	Double-Riveted Lap Seam, Fig. 157.	Double-Riveted Lap Seam.	Double-Riveted Lap Seam, Fig. 157.	Single-Riveted Lap Seam, Fig. 147, with Welt.	Single-Riveted Lap Seam, Fig. 155, with Welt.	Single-Riveted Lap Seam, with Welt.
1	Material of plates	Iron.	Iron.	Steel.	Iron.	Iron.	Steel.	Iron.	Iron.	Steel.
2	Diameter of rivet holes	11/16 in.	7/8 in.	5/8 in.	3/4 in.	7/8 in.	7/8 in.	11/16 in.	7/8 in.	7/8 in.
3	Straight pitch of rivets	1 7/8 "	2 5/8 "	2 1/4 "	3 "	3 5/8 "	3 5/8 "	1 7/8 "	2 5/8 "	2 5/8 "
4	Diagonal pitch of rivets	......	......	......	2 1/4 "	2 3/4 "	2 3/16 "	......	......	......
5	Strength of rivets to resist *shearing*	lbs. 74,240	lbs. 131,250	lbs. 131,250	lbs. 132,010	lbs. 180,390	lbs. 180,390	lbs. 148,480	lbs. 262,500	lbs. 262,500
6	Strength of plates through rivet holes to resist *tearing*	89.060	120,260	123,748	126,562	182,810	177,185	114,840	153,070	163,190
7	Strength of plates in front of rivets to resist *crushing*	92,812	118,125	118,125	151,875	177,183	177.183	185,624	236,250	236,250
8	Minimum strength of seam per lineal inch	9,898	11,250	13,125	14,062	14,318	16,874	15,812	14,578	18,194
9	Strength of plate per lineal inch	18,750	18,750	22,500	18,750	18,750	22,500	18,750	18,750	22,500
10	Strength of seam in percentage of solid plate	per ct. 52.78	per ct. 60.	per ct. 58.33	per ct. 74.46	per ct. 76.36	per ct. 75.	per ct. 81.66	per ct. 77.75	per ct. 80.55

or a little in excess of the strength of the rivets. THEREFORE, IF STEEL PLATES ARE USED THE PITCH OF THE RIVETS MAY BE 6 TIMES THE THICKNESS OF THE PLATES FOR A SINGLE-RIVETED LAP SEAM OF MAXIMUM STRENGTH.

The strength of a seam proportioned in this way is given in column *C* of the table, and is 22,500 lbs. per lineal inch. A comparison of the strength per lineal inch shows the advantage which is gained in strength by using larger rivets spaced further apart than those ordinarily used, and also the greater strength of seams made of steel plates.

QUESTION 259. *What other methods are there of making boiler seams which are stronger than those which have been described?*

Answer. In order to increase the strength of seams they are often made with two rows of rivets, and what is called a "*welt*," or *covering-strip*, is sometimes used, the latter with both single and double-riveted seams. What are called "*butt-joints*," or seams, have been used a great deal in Europe, and of late years have been adopted to a limited extent in this country.

QUESTION 260. *How are the rivets arranged when two rows are used?*

Answer. They are sometimes placed just behind each other, as shown in fig. 156, which is called *chain-riveting*.

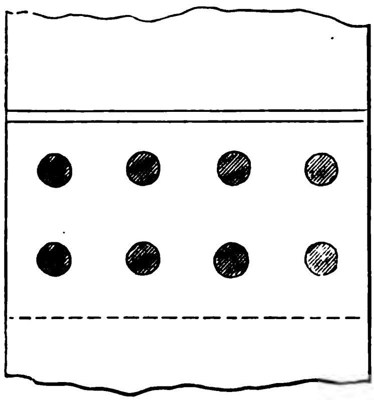


Fig. 156. Chain-Riveted Seams. Scale ¼ in. = 1 in.

A much better arrangement is to place them alternately rows, as shown in fig. 157. Rivets arranged in that way are "*staggered*," or placed *zig-zag*.

In a single-riveted seam each rivet must resist a strain equal to that on the metal between two adjoining rivets. In a double-riveted seam one-half the strain on the metal between two contiguous rivets, in one row, is resisted by a rivet in the other row. Thus in fig. 157 the rivet, *g*, will take one-half the strain on the metal between the rivets *c* and *f*. Consequently, the area of the metal between *c* and *f*, and their distance apart, may be very much greater than it would be in a single-riveted seam.

QUESTION 261. *What are the usual proportions for double-riveted seams?*

Answer. The following table, copied from "The Elements of Machine Design," by W. C. Unwin, gives proportions for such seams which are very commonly used:

PROPORTIONS FOR DOUBLE-RIVETED SEAMS.

IRON PLATES, IRON RIVETS.			STEEL PLATES, IRON RIVETS.		
Thickness of Plates.	Diameter of Rivets.	Pitch of Rivets.	Thickness of Plates.	Diameter of Rivets.	Pitch of Rivets.
3/8 inch.	3/4 inch.	3 inch.	3/8 inch.	3/4 inch.	2 7/16 inch.
7/16 "	13/16 "	3 1/16 "	7/16 "	13/16 "	2 1/2 "
1/2 "	7/8 "	3 1/8 "	1/2 "	7/8 "	2 9/16 "
9/16 "	7/8 "	3 1/8 "	9/16 "	7/8 "	2 9/16 "
5/8 "	15/16 "	3 3/16 "	5/8 "	15/16 "	2 5/8 "
3/4 "	1 1/16 "	3 5/16 "	3/4 "	1 1/16 "	2 3/4 "
7/8 "	1 1/8 "	3 3/8 "	7/8 "	1 1/8 "	2 13/16 "
1 "	1 1/4 "	3 1/2 "	1 "	1 1/4 "	2 15/16 "

QUESTION 262. *What should be the diagonal pitch of the rivets in a double-riveted seam—that is, the distance between the centres of the rivets, c and g, or g and f, of fig. 157?*

Answer. It has been found by experiment* that the net metal measured on zigzag line, *c g f*, fig. 157, should be about one-third in excess of that measured straight across. If there is not that much excess the plates will be weaker straight across, and will break on the line, *a b*. IF THE DIAGONAL PITCH (or the distance from centre to centre of rivets, *c* and *g*, or *g*

* See "Report upon Experiments and Abstract of Results of Experiments on Riveted Joints," in Proceedings of the Institution of Mechanical Engineers for April, 1885.

and *f*) IS MADE THREE-QUARTERS OF THE PITCH OR DISTANCE BETWEEN THE CENTRES OF RIVETS (*c* and *f*) ON THE SAME LINE, it will give a good proportion for such a seam.

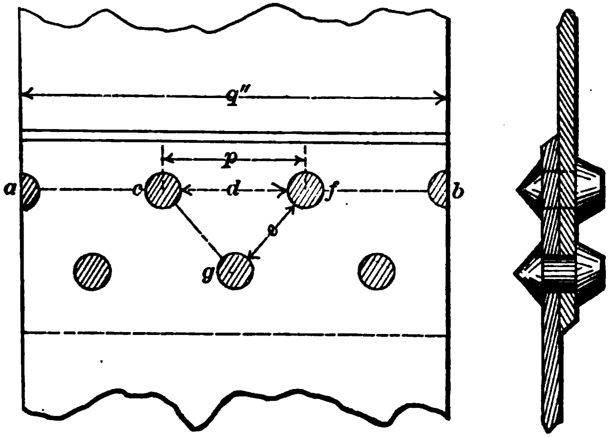


Fig. 157. Double-Riveted Lap Seams. Scale ¼ in.=1 in. Fig. 158.

QUESTION 263. *How should a double-riveted seam be proportioned to have the maximum amount of strength?*

Answer. To proportion such a seam the rivet hole, for the reasons explained, should be made of the same diameter as for a single-riveted seam—that is, 2¼ times the thickness of the plates. For plates ⅜ inch thick the rivet holes would therefore be ⅞ inch diameter. It has been explained, and is shown in fig. 157, that the seam with two rows of rivets the rivet strength—that is, their resistance to shearing, is twice that of a seam with one row, because the number of rivets is doubled. Consequently the amount of metal between the rivets may be twice as great as in a single-riveted seam. It has been found by experiment and calculation that if the diameter of rivets for a double-riveted seam is made 2¼ times the thickness of the plates, and the pitch—with iron plates—is made 11 times, and for steel plates 9½ times their thickness, that it will give a seam of nearly equal strength to resist the shearing of the rivets and the tearing and crushing of the plates.

The strength of such seams has been calculated, and the results are given in columns *E* and *F* of the table on page 200. Column *D* gives the strength of a seam, represented by fig. 157 and proportioned as specified in the above table of proportions for double-riveted seams. The strength per lineal inch is given in the eighth horizontal line of the large table, on page 200, and shows the superiority of double-riveting, and also the gain from the use of large rivets and greater pitch and of steel plates.

The distance that the rivets for a double-riveted seam should be spaced on a zigzag line is three-quarters of the pitch on a straight line, or 8¼ times the thickness of iron and 7 times that of steel plates.

QUESTION 264. *What is the form of construction of boiler seams made with a lap and a welt or covering-strip?*

Answer. The plates (*a b*, figs. 159 and 160) are lapped over each other as for an ordinary seam. Another plate, *c*, is then placed on the inside of the seam and bent so as to conform to the lap of the two plates. The rivets, *r r*, fig. 160, whether a double or single row, pass through all three plates, and two more rows of rivets, *d d*, are put next to the edges of the

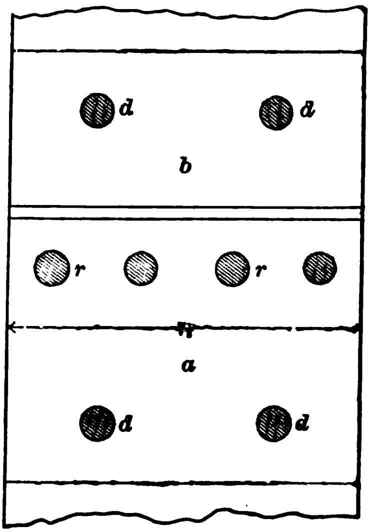


Fig. 159. Fig. 160.
Single-Riveted Seam with Welt. Scale ¼ in.—1 in.

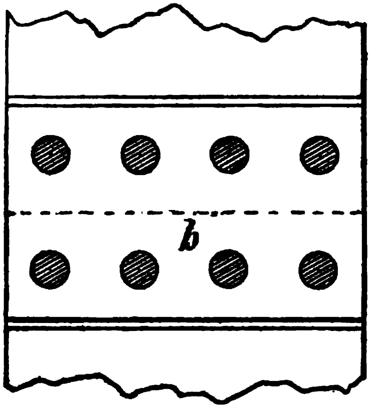
covering plate or welt, *c*. It is plain that the strength of the seam, *r r*, is increased up to a certain point by an amount just equal to that of the rivets, *d d*, in the edges of the covering plate. If, however, these are placed too close together, the plates, *a* and *b*, will be weaker through the outside rows of rivets, *d d*, than the seam is through either of the outside ones and the middle one taken together. If, for example, we take a single-riveted seam, like that shown in fig. 118, whose strength is only a little more than half that of the solid plate, and should add to it a covering plate, as shown in fig. 159, and then space the rivets in the edges of the covering plate the same distance apart as in the middle seam, then obviously the plates would be just as liable to break through the outer rows of holes as through the centre row before the covering plate was added. If, however, the holes in the two outside plates are spaced at say twice the distance apart, or 3¼ inches, then the only way the seam can break through the outer rows of holes is by shearing the rivets, because the plates between the holes are then stronger than the rivets. But before these rivets can be sheared, the centre seam must give way. Thus the strength of such a seam is equal to THE SUM OF THE STRENGTH AT THE WEAKEST POINTS OF THE MIDDLE AND THE OUTSIDE SEAMS. The strength of the plates between the holes of the outside rows of rivets must, however, be as great as the sum referred to, otherwise the seam will be the weakest at that point, and the failure will occur there. The rivets in the outside rows should be spaced at least twice as far apart as those in the middle seam. The number of rivets to resist shearing will then be 50 per cent. greater than in a single-riveted seam. Welted seams of this kind are sometimes made with a double row of rivets between the two outer rows.

QUESTION 265. *What advantage has such a seam over seams without a welt?*

Answer. The strength of a seam is increased by an amount equal to that of the welt. Thus, column *G*, in the table on page 200, gives the strength of a seam like that in column *A*, but with a welt added; column *H* gives the strength of seam *B* with a welt added and column *I* gives the strength of seam *C*, welted. A comparison of the strength of the different seams per lineal inch in the eighth horizontal line shows the great increase in strength which results from the addition of a welt.

QUESTION 266. *How are butt-joints or seams made?*

Answer. In these the ends of the two plates abut against each other, as shown at *a*, in figs. 162, with a covering strip or welt, *b*, which is shaded black in the engravings, on one or both sides. In some cases a single welt or covering strip, *b*, figs. 161 and 162, is used with either two or four rows of rivets. Such a seam has no more strength than a lap



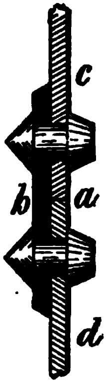
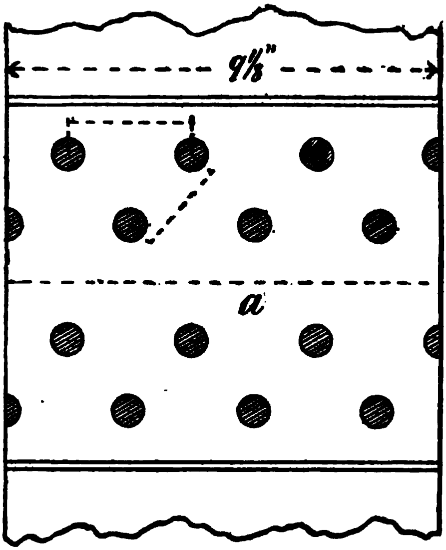


Fig. 161. Fig. 162.
Single-Riveted and Single-Welt Butt Seam. Scale ¼ in.—1 in.



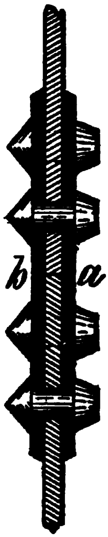


Fig. 163. Fig. 164.
Double-Riveted and Double-Welt Seam. Scale ¼ in.—1 in.

seam like those shown by figs. 148 or 157. In fact, it consists of two lap seams. The circumferential seams of boilers are, however, often made in this way in Europe, so as to get all the plates in the cylindrical part of the boiler flush with each other. Another method of making a butt seam is shown by figs. 165 and 166. In this the outside covering strip, *b*, is made narrower than the inside one, *a*, and the two middle rows of rivets, *r r*, are spaced as in a single-riveted seam. The outside rivets, *d d*, are then

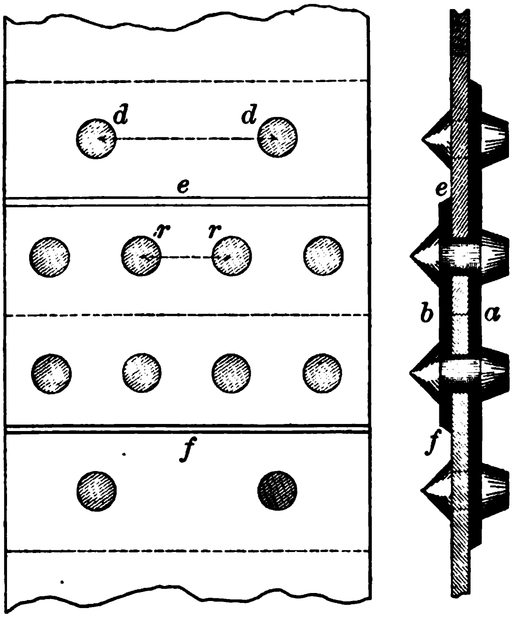


Fig. 165. Fig. 166.
Double-Riveted and Double-Welt Seam. Scale ¼ in.--1 in.

spaced twice as far apart. By this means the strength of the middle rivets is reinforced by the outside rows. As the middle rivets are near together, they thus make a tight joint at *e* and *f*, whereas if the outside welt, *b*, was made as wide as *a*, there would be difficulty in keeping the edges on the outside tight on account of the great distance apart of the outer rivets.

QUESTION 267. *What is the strength of butt seams or joints compared with those which have been described?*

Answer. A butt seam with double strips and quadruple rows of rivets is little, if any, stronger than a double-riveted lap seam properly proportioned. The resistance to the crushing action of the rivets limits the strength of both kinds of seams, and in that respect they may be nearly equally strong.

QUESTION 268. *What other advantages have butt seams with double welts, as shown in figs. 163–166?*

Answer. Such seams are often used for the longitudinal seams of boilers because a lap seam like that shown in fig. 167, when subjected to a tensile strain, will tend to draw into the form shown in fig. 168—that is,

Fig. 167.

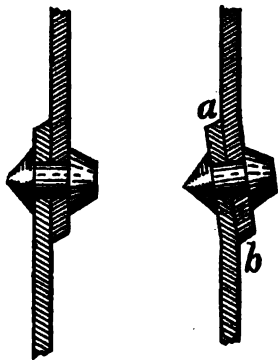


Fig. 168.

Bending Action on Lap Seam. Scale ¼ in.—1 in.

the tendency is to draw into a straight line, and a bending strain will be exerted on the plates at *a* and *b*. This strain also tends to pull the plates apart where they lap over each other, whereas in seams like those shown in figs. 163–166, the strain on the plates and on the covering strips, *a* and *b*, is in a line parallel with their surfaces, and therefore no bending action is exerted on them. It is found by experience that boilers are very often corroded along the edges of the plates of lap seams just where the bending action takes place. It is probable that when iron or steel is subjected to a high degree of tension, and at the same time exposed to substances which corrode them, that the action of the latter is most rapid where the strain is greatest. At any rate, it is found that much less corrosion occurs with butt seams which have double welts than with lap seams.

QUESTION 269. *What are the proportions commonly used for butt seams?*

Answer. The following table is from Wilson's "Treatise on Steam Boilers," and gives the proportions for double-riveted butt seams which are very commonly used:

PROPORTIONS FOR BUTT SEAMS WITH DOUBLE STRIPS AND TWO ROWS OF RIVETS.

Thickness of Plate.	Diameter of Rivet.	Thickness of Strip.	Pitch of Rivets.
⅜ inch.	⅝ inch.	¼ inch.	2½ inch.
7/16 "	⅝ "	¼ "	2⅝ "
½ "	⅝ "	5/16 "	2¾ "
9/16 "	11/16 "	5/16 "	2⅞ "
⅝ "	¾ "	⅜ "	3 "
11/16 "	¾ "	⅜ "	3⅛ "
¾ "	⅞ "	7/16 "	3¼ "
13/16 "	⅞ "	7/16 "	3½ "
⅞ "	1 "	½ "	3⅝ "
15/16 "	1 "	½ "	3¾ "
1 "	1⅛ "	9/16 "	4 "

QUESTION 270. *How should a quadruple-riveted butt seam with double strips of maximum strength be proportioned?*

Answer. The diameter and pitch of rivets should be proportioned in the same way as for a double-riveted lap seam. A butt seam has usually an excess of rivet area to resist shearing, because the rivets are subjected to a double shear. The strength of such a seam is, however, limited by the resistance of the metal in front of the holes to crushing. There is, therefore, not much difference in the strength of well-proportioned double-riveted lap and butt seams.

QUESTION 271. *What influence does the size of the rivet-heads and ends have on the strength of a seam?*

Answer. It has been found that an increase of about one-third in the weight of the rivets (all this increase going to the heads and ends) was found to add about 8½ per cent. to the resistance of the joint. RIVETS, BEFORE THEIR HEADS ARE FORMED, SHOULD PROJECT BEYOND THE PLATES A DISTANCE EQUAL TO ABOUT THREE TIMES THEIR DIAMETERS TO GIVE SUFFICIENT MATERIAL FOR THE HEADS.

QUESTION 272. *What practical consideration must govern the proportions of riveted seams?*

Answer. It must be determined what is the greatest pitch of rivets which can be used in any particular case. Generally it becomes a question of how wide a pitch can be used and the boiler be made tight by caulking. The proportions for riveted seams given in the tables are such as have been extensively used in practice. With improved material and workmanship, doubtless larger rivets than the sizes given in the tables can be used, and they can be spaced farther apart and still make a tight joint, and a nearer approximation can be made to the dimensions given by the rules for proportioning seams of maximum strength.

QUESTION 273. *How are the seams of boilers made tight?*

Answer. By what is called *caulking*—that is, by the use of a blunt instrument, *A*, fig. 169, somewhat resembling a chisel, the end, *a*, of which

Fig. 169.

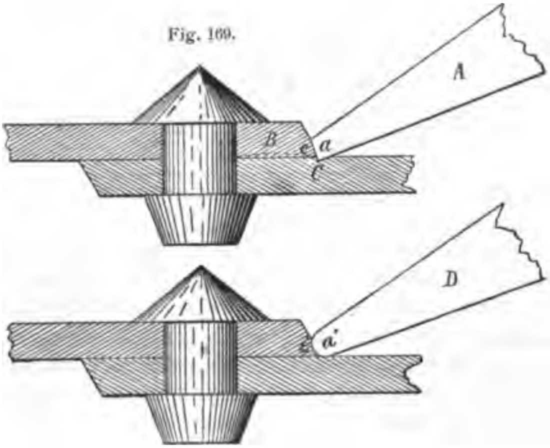


Fig. 170. Method of Caulking Seams. Scale ⅛ in.—1 in.

is placed against one of the edges of the plate, *B*, which is then compressed or riveted down by blows of a hammer, somewhat as the joints between the planks of a ship are made tight. The edges, *e*, of the plates—called the *caulking edges*—are sometimes planed before they are put together, but more commonly they are cut or trimmed off with a chisel. In this process the plate is often injured seriously by the carelessness of workmen, who sometimes allow the chisel to cut a groove in the plate at *C*, under the edge, thus weakening it at a point where the greatest strength is needed. If driven too hard the tool is liable to force the plates, *B* and *C*, apart, as indicated by the dotted line below *B*. For these reasons Mr. Connery, foreman of the boiler-shop at the Baldwin Locomotive Works in Philadelphia, devised a system of caulking with a tool, *D*, having a round nose, *a'*, as shown in fig. 170. With this there is no liability to groove the lower plate nor force the plates apart.

QUESTION 274. *How much water is usually carried in a locomotive boiler?*

Answer. There must always be enough water in the boiler to cover completely all the parts which are exposed to the fire, otherwise they will be heated to so high a temperature as to be very much weakened or permanently injured. In order to be sure that all the heating surface will at all times be covered with water, it is usually carried so that its surface will be from 4 to 8 inches above the crown-sheet.

QUESTION 275. *How much space should there be over the water for steam?*

Answer. No exact rule can be given to determine this. It may, however, generally be assumed that the more steam space the better. In order to increase the steam room, locomotive boilers are very generally made in this country with what is called a *wagon-top*, *V*, fig. 121—that is, the outside shell of the boiler over the fire-box is elevated at *V*, from 4 to 12 or even 18 inches above the cylindrical part.

QUESTION 276. *What is a steam-dome, and for what purpose is it intended?*

Answer. A *steam-dome*, *U U*, fig. 121, is a cylindrical chamber made of boiler-plate and attached to the top of the boiler. Its object is to increase the steam room and to furnish a reservoir which is elevated considerably above the surface of the water, from which the supply of steam to be used in the cylinders can be drawn. The reason for drawing the steam from a point considerably above the water is that during ebullition more or less spray or particles of water are thrown up and mixed with the steam. When this is the case, steam is said to be *wet*, and when there is little or no unevaporated water mixed with it, it is said to be *dry*. It is found by experience that wet steam is much less efficient than that which is dry. There is also danger that the cylinders, pistons, or other parts of the machinery may be injured if much water is carried over from the boiler with the steam, because water will be discharged so slowly from the cylinders that there is not time when the engine is running fast for it to escape before the piston must complete its stroke, so that the cylinder-heads will be "*knocked out,*" or the cylinder itself, or the piston will be broken. The reason for drawing or "*taking*" steam from a point considerably above the water is because there is less spray there than there is near the surface, and the hottest steam, which is also the dryest, ascends to the highest part of the steam space.

QUESTION 277. *Where is the dome usually placed?*

Answer. In this country it is usually placed over the fire-box, but in Europe it is often placed further forward, either about the centre of the boiler or near the front ends of the tubes.

QUESTION 278. *How is the steam conducted from the dome to the cylinders?*

Answer. By a pipe, *T O' O*, fig. 121, called the *dry-pipe*, which extends from the top of the dome to the front tube-plate. On the front side of the tube-plate and inside the smoke-box two curved pipes, 84 84, fig. 98, called *steam-pipes*, are attached to the dry-pipe at one end, and to the cylinders at the other. The vertical portion, *Q*, of the dry-pipe in the dome, sometimes called the *throttle-pipe*, is usually made of cast iron, the horizontal part of wrought iron, and the steam-pipes of cast iron.

QUESTION 279. *How is the loss of heat from locomotive boilers by radiation and convection prevented?*

Answer. Usually by covering the boiler and dome with wood, called *lagging*, about ⅞ inch thick, which is a poor conductor of heat, and then covering the outside of the wood with Russia iron, the smooth, polished surface of which is a poor radiator of heat. Sometimes locomotive boilers are first covered with felt and then with wood and Russia iron. Recently plastic material, which hardens after it is applied to the boiler, has been used a good deal. This is also covered with Russia iron.

QUESTION 280. *What is the smoke-box for?*

Answer. The smoke-box, *B*, fig. 121, is simply a convenient receptacle for the smoke before it escapes into the chimney or smoke-stack, which is attached to the top of the smoke-box. It also affords a convenient place for the steam and exhaust-pipes, where they are surrounded with hot air and smoke, and not exposed to loss of heat by radiation.

Formerly smoke-boxes were made without the portion shown in fig. 121, which extends in front of the ring, *p*. This part, called the *extended front end*, has been added to give room for appliances to arrest the sparks. These consist of a deflector, *F*, in front of the tubes and wire netting, *J K*, which cause the heavy sparks and cinders to be thrown forward, and prevent them from being carried up the chimney. They are thus deposited in the front end, from which they can be removed by a suitable aperture, *L*, at the bottom.

The front of the smoke-box is usually made of cast iron, with a large door, *M*, in the centre, which affords access to the inside.

QUESTION 281. *How are the chimneys or smoke-stacks of locomotives constructed?*

Answer. The forms of smoke-stacks which have been used are almost numberless. When an extended front-end, such as is shown in fig. 121, is used, the chimney often consists of merely a straight pipe, *D*, as represented. A larger drawing of this stack is given in fig. 171. For burning

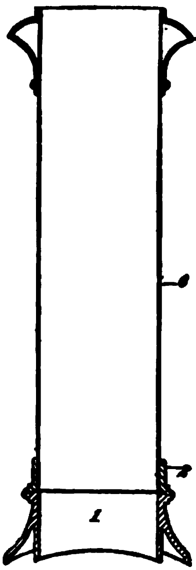


Fig. 171.
Straight "Smoke-Stack" or Chimney.

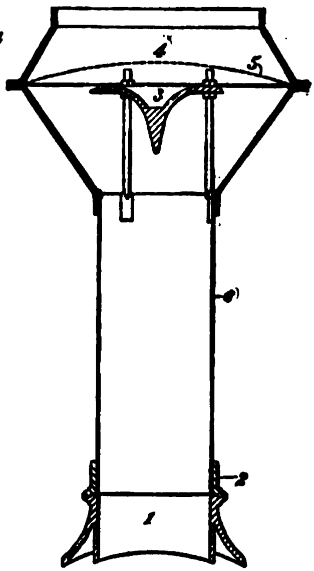


Fig. 172.
Diamond "Smoke-Stack" or Chimney.

bituminous coal and wood, what is called a *diamond stack*—probably from the shape of the outline of the top—as shown in fig. 172, is used a great deal. This consists of a central pipe, 4 1, and a conical-shaped cast-iron plate, 3, called the *cone* or *spark deflector*, which, as the latter name implies, is intended to deflect the motion of the sparks and cinders which are carried up with the ascending current of smoke and air in the pipe, 1, so as to prevent them from escaping into the open air while they are incandescent, or "alive." A wire netting, 4 5, is also provided, which is intended as a sort of sieve to enclose the sparks and cinders, and at the same time allow the smoke to escape. The receptacle below the cone is intended as a chamber in which the burning cinders will be extinguished before they escape. For burning anthracite coal, a simple straight pipe, as shown in fig. 171, without a deflector or wire netting, is ordinarily used. For burning wood a chimney or smoke-stack of the form shown in fig. 172 is sometimes used, but more generally one of the form shown in fig. 173, which is a wide stack, with a straight interior pipe, 8, a cone, 3, and

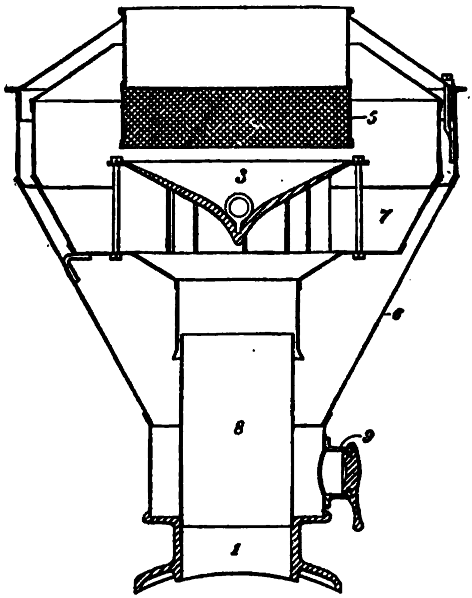


Fig. 173. Wood Burning "Smoke-Stack" or Chimney.

wire netting, 5. Inside the outer shell, 6, there is an inner box or bonnet, 7. The sparks collect in the space outside the straight pipe, 8, and can be removed through the hand-hole, 9.

QUESTION 282. *What are the proportions and materials usually employed in the construction of smoke-stacks?*

Answer. The pipe, 6, fig. 171, is usually made of the same inside diameter as the cylinders, or an inch or two smaller. For the other dimensions there are no established rules, excepting for the height of the top of the chimney above the rail, which is usually from 14 to 15 feet. The outside of smoke-stacks are made of sheet iron, but the upper part is now sometimes made of cast iron, so as to withstand the abrasion of the sparks and cinders longer than sheet iron will. For very warm and damp climates, the outsides of smoke-stacks are sometimes made of copper to resist corrosion, which is very destructive to all iron structures in those countries. The wire netting is made of iron or steel wire from $\frac{1}{10}$ to $\frac{1}{20}$ inch in diameter, and with from 8 to 4 meshes to the inch.

CHAPTER XIII.

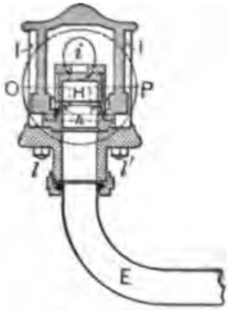
THE BOILER ATTACHMENTS.

QUESTION 283. *How is water supplied to the boiler to replace that which is converted into steam?*

Answer. It is forced into the boiler against the steam pressure by a force or feed pump, or by an instrument called an *injector*.

QUESTION 284. *How is a feed pump constructed and what is the principle of its operation?*

Answer. The ordinary single-acting pump, fig. 174, used on locomotive and other steam-engines, consists of a *pump-barrel*, *A A*, which is a cast iron or brass cylinder in which a tight-fitting piston, *B B*, called the *pump-plunger*, works. This piston or plunger is simply a round rod which works air-tight through a *stuffing-box*, *C*, the construction of which is similar to that used in piston-rods and described in answer to Question 95. The plunger is usually connected to the cross-head, and receives a reciprocating motion from it, but sometimes the plunger is worked by a small crank attached to one of the crank-pins or by an eccentric on one of the axles. The pump-barrel is connected with the water-tank of the tender by the *suction-pipe*, *D*, and with the water-space of the boiler by the *feed pipe*, *E E*. Over the suction-pipe, *D*, is a valve, *F*, called the *suction-valve*, which opens upward, and below the feed pipe, *E*, is another valve, *G*, called the *pressure-valve*. These valves are cylindrical or of the form of an inverted cup. They are made of brass, and rest on brass seats, *g g'*, to which they are fitted so as to be water-tight. They work in guides, *k k*, called *cages*, the form of which is more clearly shown in the sectional plan, fig. 176. When the plunger is drawn out of the pump-cylinder it creates a vacuum behind it, and the pressure above the valve, *G*, closes it, while the atmospheric pressure on the water in the tank forces it into the suction-pipe, *D*, opens the valve, *F*, and fills the pump-cylinder. When the plunger is forced back again the force with which it presses against the water in the pump-barrel, *A*, closes the valve, *F*, and lifts the pressure-valve, *G*, and the water is then forced through the feed pipe into the boiler. In order to be certain that the water in the



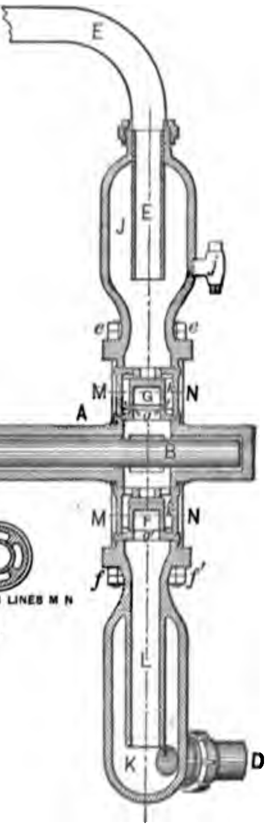


Fig. 174.

Fig. 175.

Fig. 176.

Section of Pump. Scale 1 in.—1 ft.

boiler will not flow back into the pump, and also to prevent all the water and steam in the boiler from escaping in case of accident to either the feed pipe or pump, another valve, *H*, called a *check-valve*, is placed between the feed pipe and the boiler. The construction of this valve is similar to that of the pressure and suction-valves. It is enclosed in a cast iron or brass case, *I I*. All of these valves have cages or guides in which they work and which also act as stops, to prevent them from rising from their seats further than a certain distance. This distance is called their *lift*, and the successful working of the pumps depends very much on the amount of lift which the valves have. This is usually from $\frac{3}{16}$ to $\frac{1}{4}$ inch. The valves, *G* and *H*, are represented open and the darts at *g* show the directions of the flow of the water. The valve, *F*, is shown closed.

Over the pressure-valve, *G*, is a chamber, *J*, called an air-chamber. When water is forced into this chamber, it is obvious that as soon as it rises above the mouth of the pipe, *E*, the air above the surface of the water will be confined in this chamber. This confined air, being elastic, will be compressed and expanded by the pressure of the water, so that it forms a sort of cushion, which relieves the pump and the pipes from the sudden shocks to which they are subject, owing to the rapid motion of the pump-plunger.

Another air-chamber, *K*, is sometimes placed below the suction-valve, *F*. The object of this is to supply a cushion to relieve the suction-pipe from the shock which is caused by the sudden arrest of the motion of the water in the pipe, *D*, when the valve, *F*, is closed. When the pump-plunger is drawn out, the water flows up through the valve, *F*, to fill the vacuum in the pump-barrel, *A A*, and consequently all the water in the suction-pipe is put in motion. As soon as the plunger returns, the valve, *F*, is closed and the motion of the water is suddenly arrested, thus producing more or less of a shock in the pipe, *D*. When the water in the air-chamber, *K*, rises above the mouth of the pipe, *L*, it is evident that the air above that line will be confined in the space surrounding the pipe. This air then forms a cushion in the same way as that in the upper air-chamber, *J*, does, which has already been explained.

QUESTION 285. *How can the pump be taken apart and the valves examined?*

Answer. By removing the nuts, *e e*, on the bolts by which the pump-barrel, *A A*, and the air-chamber, *J*, are held together, they can be taken apart, and the valve, *G*, and cage, *k*, can then be removed. In the same way, by removing the nuts, *f f*, the lower chamber, *K*, can be detached from *A A*, and the valve, *F*, and cage, *k'*, can be taken out. The check-valve, *H*, can be taken out by removing the nuts, *l l'*, which hold up the valve-seat, *h*, and also the valve and cage.

QUESTION 286. *To what risk is a check-valve like that shown in fig. 174 exposed?*

Answer. In case of a collision or other accident it may be broken off, and the hot water then escapes from the boiler, and is liable to scald persons who cannot escape from the wreck. In several instances many persons were scalded to death and others terribly injured in this way.

QUESTION 287. *How can the danger of such accidents be lessened?*

Answer. By putting the check-valve inside the boiler instead of outside. Fig. 177 shows a check-valve of this kind. *A A* is the boiler plate, and *B B* is a cast iron flange cast in one piece with the valve-seat, *C*. The flange is bolted or riveted to the outside of the boiler, and the seat is let into the inside through an opening cut into the boiler plate. *D* is a flap-valve

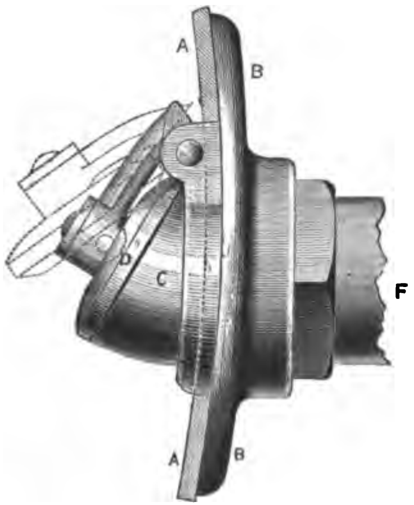


Fig. 177. Inside Check-Valve.

which covers the opening in the seat. Its position when open is indicated by the dotted lines. *F* is an elbow pipe screwed into the casting *B B*, and is connected with the pump or injector. In case of an accident, if this elbow pipe is broken the valve will still keep its opening closed and prevent the escape of the hot water from the boiler. This or some similar safeguard against the terrible accidents which sometimes result from injury to check-valves should be generally adopted.

QUESTION 288. *How can it be known whether the pump is forcing water into the boiler?*

Answer. To show this a cock, called a *pet-cock, j*, fig. 174, is attached to the upper air-chamber or to the feed pipe. By opening this cock, if the pump is working, a strong jet of water will be discharged from it during the backward stroke of the pump-plunger. If the pump is not forcing water into the boiler, or is working imperfectly, the stream discharged from the pet-cock will be weak, and the backward and forward strokes of the plunger will not be very definitely indicated by the discharge from the pet-cock.

Another small cock, called a frost-cock, is often attached to the lower air-chamber, or to the feed pipe, to allow the water in them to escape in cold weather, when the engine is not working, so as to prevent it from freezing and bursting the pipe or pump.

QUESTION 289. *Why is it necessary to be able to regulate the quantity of water which is forced into the boiler by the pump?*

Answer. Because when the engine is working hard—that is, in starting or pulling a heavy load up a grade, more steam and consequently more water are consumed than when it is not working so hard, and therefore more water must be forced in to supply the place of that which is used in the form of steam. If more water is forced in than is consumed, the water will rise and fill the steam space, and a part of it will then be carried into the cylinders without being evaporated. If too little water is forced into the boiler, the heating surface will not be covered, and there will consequently be danger that those portions which are exposed to the fire will be overheated and injured.

QUESTION 290. *How is the supply of water which is fed into the boiler by the pump regulated?*

Answer. By a cock in the suction-pipe called a *feed-cock*, which can be regulated by the locomotive engineer, so that more or less water is supplied to the pump. There is also a valve in the water-tank, the construction of which is explained in Chapter XXIV, by which the supply of water can be regulated.

QUESTION 291. *On what part of the locomotive are the pumps usually placed?*

Answer. They are usually attached to the frames behind the cylinders, and are connected to the cross-head, as has been explained; but they are sometimes, but rarely, placed inside of the frames—that is, between the wheels, and worked from an eccentric on one of the axles, and sometimes they are placed outside of the wheels near the back part of the locomotive, and worked from short cranks attached to the crank-pins although this plan is now seldom employed. Pumps have now, to a very great extent, been displaced by injectors for feeding boilers.

QUESTION 292. *What provision is made for preventing the water in the pumps, pipes and tank from freezing in cold weather?*

Answer. Pipes which communicate with the steam-space of the boiler are attached to each of the suction-pipes, so that, by opening the valves in the former, steam is admitted into the suction-pipes to heat the water in them.* By admitting this hot water into the pump and tank, it is kept warm, and the water is thus prevented from freezing.

QUESTION 293. *What is an "injector"?*

Answer. It is an instrument in which a jet of steam imparts its velocity to water, and thus forces it into the boiler against the pressure of the steam.

QUESTION 294. *What are the principles of the action of an injector?*

Answer. The action of an injector is due to the fact that the velocity of steam which escapes from the boiler at a given pressure is very much greater than that of water under the same conditions. If water is brought in contact with a jet of steam, the latter will impart its velocity to the water, and by mixing with it the steam will be condensed.

QUESTION 295. *How is an injector constructed?*

Answer. Fig. 178 represents what may be called a rudimentary form of an injector. *B* is a boiler and *W* a water-tank. *A* is a pipe to carry steam from the boiler to the injector, and *C* one for supplying it with water, and *D* another pipe to conduct the water to the boiler. The end of the pipe, *A*, terminates with the nozzle, *F*, in the inside of a cone, *E*, on the end of the pipe, *C*. When steam is admitted to the pipe, *A*, by opening the valve, *K*, it escapes from the nozzle, *F*, and the lower end of *E*, and the current of steam creates a partial vacuum in the cone, *E* and in *C*. The water is thus sucked up from the tank, *W*, and flows through the pipe, *C*, into *E*, where it meets the current of steam escaping from *F*. This carries part of the water with it, and they escape at *e*. Below *E*

* Injectors are now made so that the steam can be admitted through them to the heater pipes.

there is another tube, *G*, which is connected to the boiler by the pipe, *D*, and has a valve, *H*, which is raised up by the pressure of the water below it in the pipe, *D*, and it thus closes the lower end of *G* so that no water can escape from the boiler through the pipe, *D*. It will be noticed that there is some space at *e* between the lower end of *E* and the top of *G*. When steam is admitted to *F*, as has been explained, it sucks the water

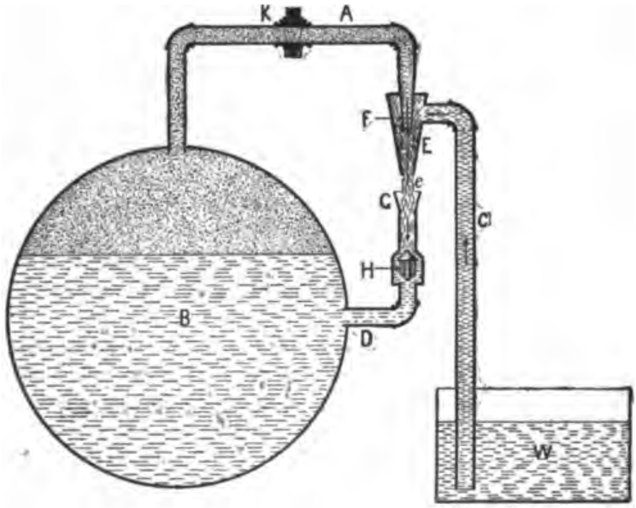


Fig. 178. Rudimentary Injector

up the pipe, *C*, and forces it out at *e*. When the stream of steam meets the water in *E*, the steam imparts its velocity to the water, but in mixing with it the steam is condensed so that the jet, which escapes from *E*, is composed of water alone. This at first escapes from *e*, but after flowing a few seconds its velocity and momentum become so great that it forces the valve, *H*, down, and the jet of water then flows into the boiler against the pressure of the steam. As soon as the injector ceases to work, the check-valve, *H*, is closed by the pressure of the water below it, so that no water can escape from the boiler. This diagram has been given only to illustrate the principles of the injector, and it should be understood that it does not represent an actual working instrument.

QUESTION 296. *How is the operation of the injector explained?*

Answer. The escaping steam from the nozzle, *F*, unites with the feed-water in the cone, *E*, and gives to this water a velocity greater than it would have if escaping directly from the water-space in the boiler. The power of this water to enter the boiler comes from *its weight* moving at the *velocity* acquired from the steam, and its momentum thus enables it to overcome the boiler pressure.

This can be illustrated with a wooden ball, which will float on the surface of water and will require some force to make it sink, but if it is thrown violently into the water, it will sink to a considerable depth before its buoyancy will overcome its momentum, or *actual energy*. If, however, we were to take a cork or very light, hollow wooden or india-rubber ball, no matter how violently we throw it into the water, it will not sink, because the total *actual energy* of the body IS PROPORTIONAL TO ITS WEIGHT MULTIPLIED BY THE SQUARE OF ITS VELOCITY, and, therefore, if we throw the hollow ball at the same velocity as the solid one, the former will still have much less energy than the latter. Now, as already stated, steam under a given pressure escapes from an orifice with a very much greater velocity whan water. But steam being very light, if its weight is multiplied by its velocity its total energy will be comparatively small. But in an injector, a portion of the high velocity of the steam is imparted to the heavy water, because this water is presented to the action of the steam, not in a mass, as in the boiler, but in small quantity and in such a position that it can easily escape, so that it gradually acquires as high a velocity as the escaping steam can impart, and at the same time the steam is condensed, and therefore there is a heavy substance with a high velocity, whose actual energy is sufficient to overcome the pressure in the boiler. If the steam were not condensed we would have a comparatively light substance moving at a high velocity, which, as has already been explained, would have little actual energy, and would therefore not overcome the boiler pressure.

QUESTION 297. *Will the injector feed hot water?*

Answer. The instrument will not work when the feed-water is too hot to condense the steam, for the reasons given above, and the amount of water thrown is always the greatest when the feed-water is the coldest. Steam at a low pressure can be condensed more readily than steam of higher pressure, because it contains less heat. The feed-water may be used hotter to condense low steam than to condense high steam. In using the injector, the lower the boiler pressure the hotter may be the water within certain limits, the limit being the possible condensation of the steam.

QUESTION 298. *How are injectors constructed?*

Answer. The simplest form of injector which is made is that shown in fig. 179, in which all the details of construction are omitted. In this the nozzle, *F*, called the *steam-nozzle*, the cone, *E*, called the *combining-tube*, and the pipe, *G*, called the *delivery-tube*, are all fixed. In this the steam from the boiler, passing through the pipe, *A*, enters the *steam-nozzle*, *F*. Here it is joined by the water which enters the pipe, *C*. The water condenses the steam in the *combining-tube*, *E*, and a water jet is formed which is driven across the *overflow* space, *e e*, and enters the *delivery-tube*, *G*,

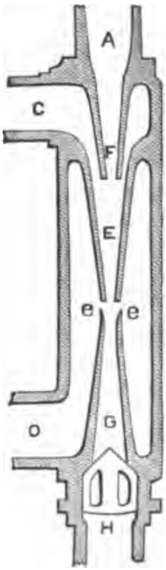


Fig. 179. Simple Form of Injector.

thence past the *check-valve*, *H*, into the boiler. During the passage of the water from *E* to *G*, as it passes across the *overflow* space, *e e*, if too much water has been supplied to the steam, some will escape at this point and flow out through the *overflow nozzle*, *O*, while if too little water has been supplied, air will be drawn in at *O*, and carried into the boiler with the water.

QUESTION 299. *Is a fixed nozzle injector, such as has been described, well adapted as a boiler feeder in locomotives?*

Answer. It will work very well within a small range of steam pressures, but if the boiler pressure rises above that for which the tubes are especially adapted, the capacity and range of the instrument are proportionately decreased. On the other hand with lower steam pressures, the injector will waste at the overflow unless readjusted by careful handling of the "lazy cock."

QUESTION 300. *What is required in an injector to adapt it to work satisfactorily at different steam pressures?*

Answer. The instrument must be so made that the water passage between the steam-nozzle and the combining-tube can be varied in size automatically or by hand. This is usually done by making the steam-nozzle and combining-tube conical and moving the former to or from the latter, thus contracting or enlarging the water-space. Such adjustment must be made at each change of steam pressure in the boiler.

QUESTION 301. *Is it essential that injectors should be in a vertical position, as shown in figs. 178 and 179?*

Answer. No. Injectors will work equally well in any position. For convenience they are usually attached to locomotives, so that their axis or centre lines stand horizontal.

QUESTION 302. *What different forms of injectors are used?*

Answer. A great variety of these instruments are made, only a few of which will be illustrated and described.

Figs. 180 and 181 represent an outside view and section of a self-acting injector manufactured by Messrs. William Sellers & Co. (incorporated), of Philadelphia. It consists of a case, *A*, fig. 181, provided with a steam inlet, *B*, a water inlet, *C*, an outlet, *D*, through which the water is conveyed to the boiler, an overflow opening, *E*, a lever, *F*, by which to admit steam, start and stop its working, a hand wheel, *G*, to regulate the supply of water, and an eccentric lever, *H*, to close the waste-valve, *L*, when it is desired to make a heater of the injector.

The operation of the injector is as follows: The water inlet, *C*, being in communication with the water-supply, the valve, *a*, is opened by turning the wheel, *G*, to allow the water to enter the chamber, *I*. Steam is admitted to the chamber, *B*, and the lever, *F*, is operated to lift the valve, *b*, slightly from its seat. This permits steam to enter the annular lifting steam-nozzle, *c*, through the holes, *d d*, while the plug, *i*, attached to the valve, *h*, still fills and keeps the tube, *K*, closed. The steam issuing from the nozzle, *c*, passes through the annular combining-tube, *e*, and escapes from the instrument partly through the overflow opening, *f*, and partly through the overflow openings provided in the combining-tube, *g g'*, through the overflow-chamber, *J*, and passage, *E' E*, and produces a strong vacuum in the water-chamber, *I*, into which the water from the

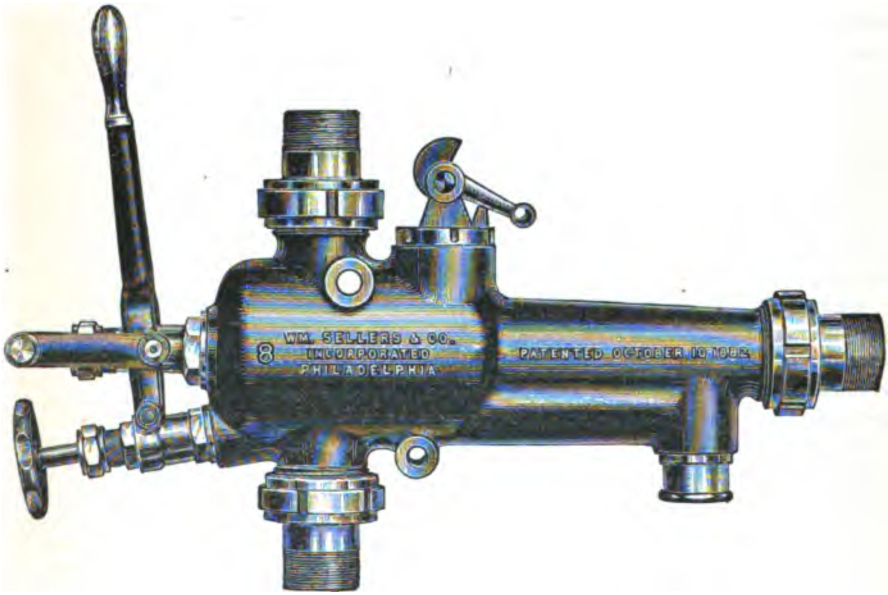


Fig. 180. Sellers' Injector.

source of supply is forced by air pressure, and the united jet of steam and water is, by reason of its velocity, discharged into the combining-tube, *g*. The spindle, *h*, is now withdrawn by the lever, *F*, until the steam plug, *i*, is out of the forcing nozzle, *K*, thus allowing the steam to pass through the forcing nozzle, *K*, and come in contact with the annular jet of water which is flowing into the combining-tube around the nozzle, *K*. This jet of water has already considerable velocity, and the forcing steam jet imparts to it the necessary increase of velocity to enable it to open the valve, *k*, and thus enter the boiler through the pipe, *D*.

If from any cause the jet should be broken—say from a failure in the water-supply—the steam issuing from the forcing nozzle, *K*, into the combining-tube, *g*, will escape through the overflows, *m* and *n*, and intermediate openings with such freedom that the steam which returns through the annular space formed between the nozzle, *K*, and combining-tube, *g*, and escapes into the overflow-chamber through the opening, *f*, will not have sufficient volume or force to interfere with the free discharge of the steam issuing from the annular lifting steam-nozzle and escaping through the same overflow, *f*, and hence the lifting jet will always tend to produce

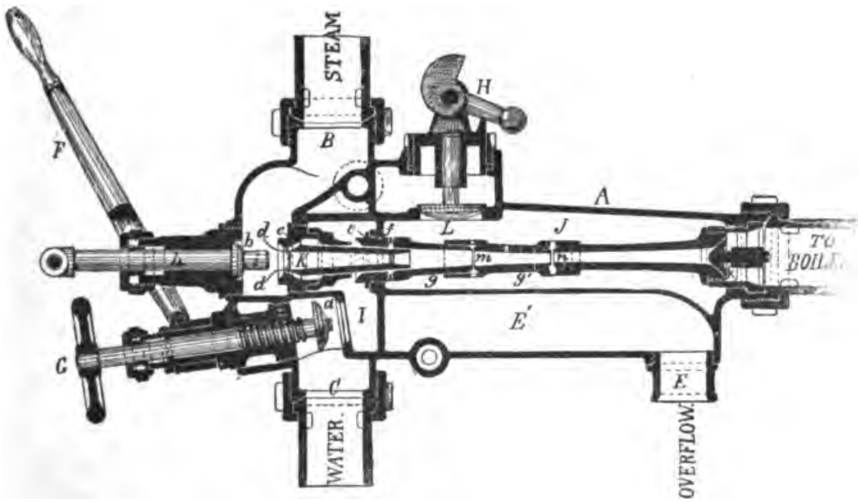


Fig. 181. Section of Sellers' Injector.

a vacuum in the water-chamber, *I*, which will again lift the water when the supply is renewed, and the combined annular jet of steam and water will be forced into the combining-tube, *g*, against the feeble current of steam returning, when the jet will again be formed and will enter the boiler as before.

If the overflow valve, *L*, is closed by the lever, *H*, and steam is then admitted by opening the valve, *b*, there will be no outlet for the steam excepting into the chambers, *J* and *I*, and if the valve, *a*, is open the steam will flow into the pipe, *C*, and thence back to the water-tank. Therefore, if it is necessary to turn steam into the supply-pipe or tank to prevent them from freezing, it can be done by closing the valve, *L*, and opening the valves *a* and *b*.

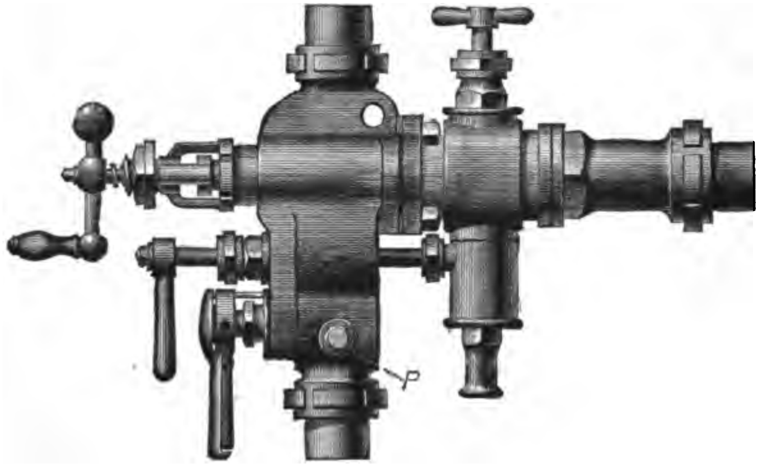


Fig. 182. "Monitor" Injector.

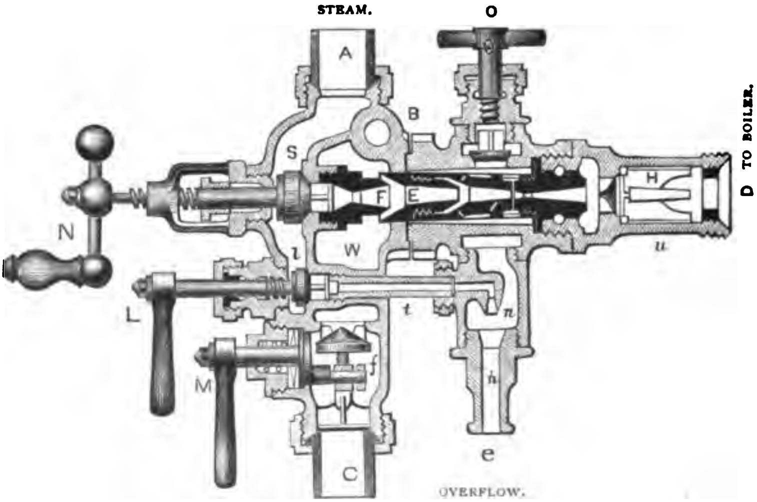


Fig. 183. Section of "Monitor" Injector.

Figs. 182 and 183 represent the "Monitor" injector, made by the Nathan Manufacturing Company, of New York. It consists of a body, *B*, fig. 183, made in two parts and provided with the usual inlets for steam and water, at *A* and *C*, and with a delivery end, *D*. It is further provided with a lifting steam-valve, *l*, which is worked by a handle, *L*; a forcing steam-valve, *S*, worked by the handle, *N*, and a water-valve, *f*, worked by a handle, *M*. The handle, *O*, serves for closing the waste-valve when it is desired to use the injector as a heater.

Fig. 184. Mack's Injector.

Fig. 185. Section of Mack's Injector.

The operation of the injector is as follows: The water-valve, *f*, being open, and the steam inlet, *A*, in communication with the boiler, the valve, *l*, is opened. This operation will admit steam into the tube, *t*, which flows through the nozzles, *n n'*, into the atmosphere, and creates a partial vacuum in the water-chamber, *W*. Water is thus drawn from the supply-tank into the chamber, *W*, and is discharged into the combining-nozzle, *E*, and through openings in this combining-tube into and out through the passage, *n n'*, and overflow at *e*. As soon as the water appears at *e*, the valve, *S*, is opened and the valve, *l*, is closed. The steam issuing from the nozzle, *F*, meets the water in the nozzle, *E*, and imparts to it sufficient force and velocity to open the check-valve, *H*, and discharge the fluid, at *D*, into the pipes leading to the boiler. The supply is regulated by the water-valve, *f*.

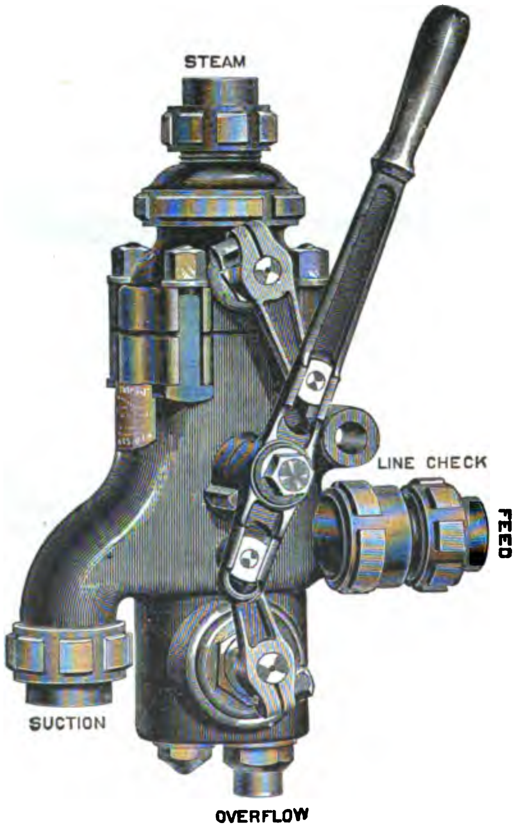


Fig. 186. Hancock Inspirator.

The lifting apparatus in this injector, it will be seen, is separate from and independent of the forcing nozzles, and has a free discharge into the atmosphere. The forcing nozzles are all fixed nozzles, plain in construction, with large and unobstructed water ways. The parts can easily be removed, and as the lifting as well as the forcing nozzles are in straight lines, small obstructions can be removed by passing a wire through them.

Figs. 184 and 185 represent Mack's injector, manufactured by the

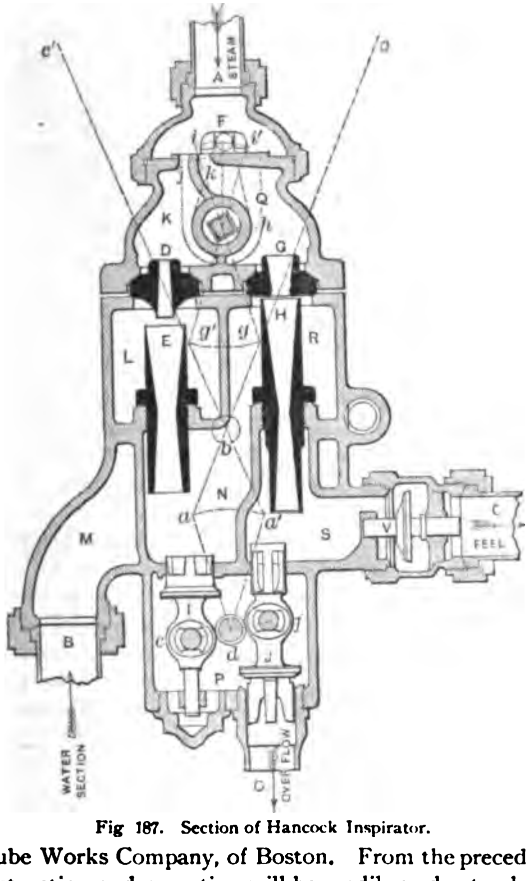


Fig 187. Section of Hancock Inspirator.

National Tube Works Company, of Boston. From the preceding description its construction and operation will be readily understood. The parts can be easily removed and cleaned, or renewed if worn by the action of impure water.

Figs. 186 and 187 represent outside and sectional views of the Hancock

Inspirator, made by the Hancock Inspirator Company, of Boston. In this the lifting and forcing jets and nozzles are independent of each other. *A*, fig. 187, is the steam-supply pipe, *B* is the water-supply pipe, *C* is the feed pipe leading to the boiler, and *O* is the overflow. *D* is the lifting jet, *E* the lifting nozzle, *G* the forcing jet, and *H* the forcing nozzle. *F* is a slide-valve which governs the admission of steam to the nozzles. *I* is an overflow valve for the lifting side of the injector, and *J* a similar valve for the forcing side. In fig. 186 a lever and handle is shown by which the working of the instrument is controlled. Two positions of this lever are represented by the dotted centre lines, *a b c* and *a' b c'*, in fig. 187. It is connected to a fixed pivot or fulcrum, *b*, and at its lower end to a short lever, pivoted at *d*, shown in fig. 186, and represented by the centre lines, *a d* and *a' d*, in fig. 187. This lever has a short arm, indicated by the dotted line, *e d f*, on its lower end and connected to the overflow valves, *I* and *J*. Above the fulcrum, *b*, the lever, *a b c*, is connected to another lever shown in fig. 186, and represented by the centre lines, *g h i* and *g' h i'*, in fig. 187, and which is pivoted at *h*.

When steam and water are shut off, the long lever and handle stand in the position shown in fig. 186, and indicated by the dotted line, *a b c*, in fig. 187. The valve, *F*, then covers both the steam-ports, *j* and *k*, and the two overflow valves, *I* and *J*, are both open. When the upper end, *c*, of the lever, *a b c*, is moved toward the left, the action of the lever, *g h i*, moves the valve, *F*, toward the right, which uncovers the steam-port, *j*, and admits steam into the chamber, *K*; this steam flows through the jet, *D*, and the nozzle, *E*, which produces a partial vacuum in *L*, which communicates with *M*, and water is thus drawn up through the pipe, *B*, and is carried along by the jet and escapes through the overflow valve, *I*, into the chamber, *P*, and thence through the passage, *O*. After a current is thus established the lever, *a b c*, is moved still farther toward the left-hand side, which closes the valve, *I*, and the water then fills the chamber, *N*, and rises until it reaches the top of the nozzle, *H*. The upper end of the lever, *a b c*, is moved still farther toward the left, which moves the valve, *F*, so as to admit steam to the port, *k*, and chamber, *Q*. This steam flows through the jet, *G*, and nozzle, *H*, and carries the water in the chamber, *R*, with it into the chamber, *S*, from which it escapes through overflow valve, *J*, and pipe, *O*. After the current is established the upper end of the lever, *a b c*, is moved still farther to the left, which closes the valve, *J*, and the water is then forced from the chamber, *S*, through the check-valve, *V*, and pipe, *C*, into the boiler.

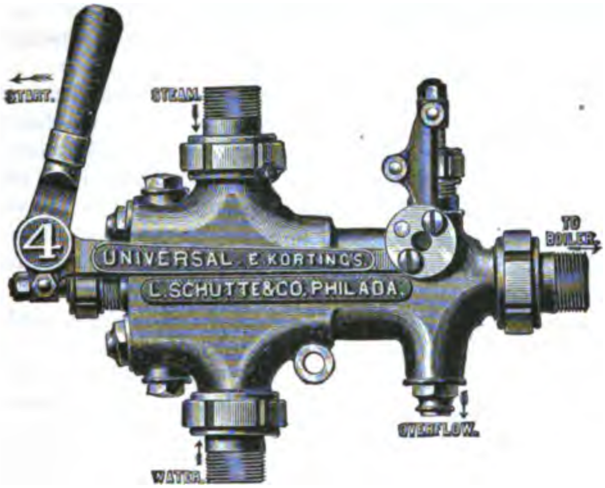


Fig. 188. Korting's Universal Injector.

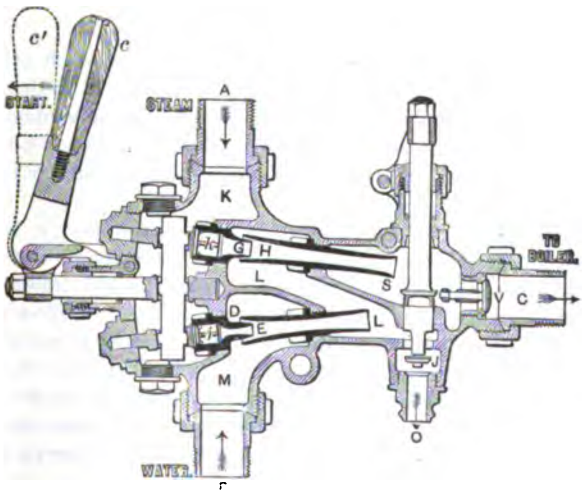


Fig. 189. Section of Korting's Universal Injector.

The action of the instrument is thus controlled by the movement of the one lever. A valve for regulating the supply of water is attached to the pipe, *B*, but is not shown in the engraving.

Figs. 188 and 189 represent the "Universal Double Tube Injector," made by L. Schutte & Co., of Philadelphia. As will be observed from fig. 189, there is a combination of two steam jets in this instrument. The first or lower one, *E*, is proportioned as an ejector, that is, an instrument which will give suction but discharges against a moderate pressure only. It takes water through the supply pipe, *B*, and chamber, *M*, from which it is discharged through the tube, *E*, into the second chamber, *L L*, which communicates with the combining tube, *H*, of the second or upper apparatus, which is the injector proper, and is proportioned to feed against the high pressure in the boiler. In this way the first tube acts as a feeder to the injector proper, and its duty is to supply automatically the water required by the injector proper at different steam pressures. The volume of the discharge of the lower tube, *E*, is diminished when the pressure in the chamber, *L*, is reduced, and *vice versa;* therefore, if the upper tube, *H*, takes the discharge from *L* rapidly it reduces the pressure therein and thus increases the supply from the tube, *E*, while if the discharge from *E* is greater than is required by the upper tube, *H*, the pressure in *L* is increased which reduces the volume of water supplied by *E*.

The two tubes are so proportioned and adjusted to each other that a small pressure is always maintained in the chamber, *L*, so that the upper tube always receives its supply under pressure. The advantage of this is that the temperature of the feed-water can be correspondingly high. In starting, the lower tube discharges free into the atmosphere through the outlet, *O*.

The injector is started and stopped by moving the lever, *c*, in the direction indicated by the dart. This opens the lower steam valve, *j*, which produces a current of steam through the tube, *E*, and draws water from the supply branch, *B*, and discharges it through the overflow passage, *O*. Continuing the movement of the lever and it partially closes the overflow valve, *J*, and the chamber, *L*, is then filled with water which flows through the tube, *H*, of the second injector, and through the centre of the overflow valve. Further movement of the lever opens the upper steam valve, *k*, and closes the overflow valve, *J*, entirely, and the instrument then forces water to the boiler through the pipe, *C*. These operations are performed without stop and by one continuous slow movement of the starting lever.

QUESTION 303. *What attachments are needed in connection with an injector to make it effective?*

Answer. A valve should be placed in the pipe by which the injector is supplied with steam. This valve is to be closed only when there is occasion to remove the injector when steam is up, and in cold weather, to prevent the condensation of steam in the pipes at the end of its trips. During the time that the injector is working this valve should be wide open.

QUESTION 304. *In what position are injectors usually placed?*

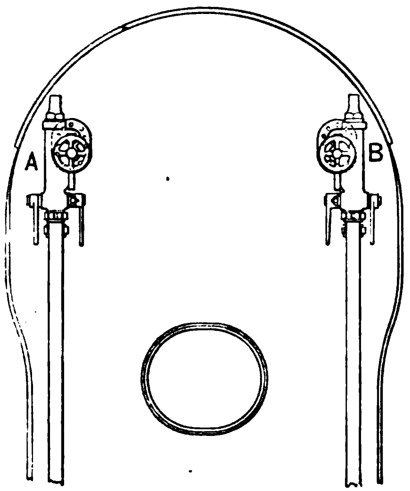


Fig. 190.

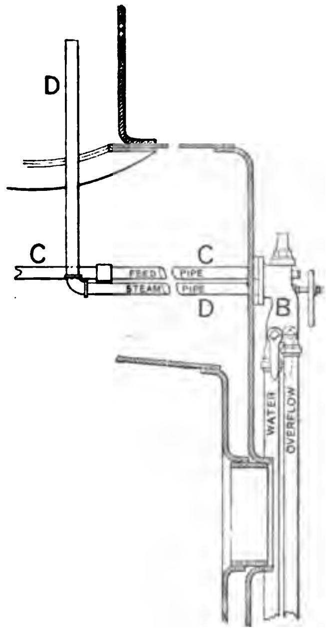


Fig. 191.

Location of Injector on End of Boiler.

Answer. They are put inside the cab, usually on the side of the boiler, in a position where they can be easily inspected by the locomotive runner. A check-valve similar to that shown in connection with the pump in fig. 174, is attached to the front part of the boiler and the feed-pipe of the injector is connected to it. A better arrangement, and one which is not liable to the danger to which a check-valve in such a position is exposed, and which has been described, is in common use in European engines and on the Canadian Pacific Railway, and is represented by fig. 190, which is a view of the back end of the boiler, and fig. 191, which is a longitudinal section of that part of the boiler. The injectors, *A* and *B*, are placed vertically and are attached to the boiler. The feed pipe is connected directly to the boiler, and is carried forward inside of it, and discharges the water at its front end. By this means neither the check-valve nor the feed-pipe are exposed to injury in case of accident, nor to frost in cold weather. The steam pipe, *D*, for supplying steam to the injector is also placed inside of the boiler. On the outside of the boiler the pipes are very unsightly, besides being exposed to injury.

QUESTION 305. *What is required to keep an injector in good working order?*

Answer. Constant use is better than occasional use. When there are two injectors on an engine, one on each side, the one on the engineer's side should be used while running, and the other one when the engine is standing still. All pipe connections should be tight so as to prevent the leaking of air. The pipe which conveys steam to the instrument should take its supply from such part of the boiler as will insure the use of dry steam, and the waste-pipe must not be contracted.

QUESTION 306. *How can the height of the water in the boiler be known?*

Answer. Two appliances are used by which the height of the water in the boiler can be observed. These are: 1. *Gauge* or *try-cocks*. 2. A *glass water-gauge*.

Every locomotive is provided with three or more gauge-cocks, which are usually placed at the back end of the boiler where they can easily be seen and reached. These cocks, *S S S*, are shown in fig. 192, which represents a longitudinal section of the end of the boiler, and fig. 193, which is an end view of the cocks. The position of these cocks is also shown at 94, in fig. 99. They communicate with the inside of the boiler and are so placed that one is 3 or 4 inches above the other. The upper cock is placed above the point where the surface of the water should be when the engine is working, and the lower one below it, so that the upper one communicates with the steam-space and the lower one with the water. When these cocks are opened, if the water is at its proper height, steam is discharged from the upper one, and water from the lower one.

When a gauge-cock which communicates with the steam-space is first opened, it is usually filled with condensed water, so that it should generally be kept open for a little while until this water is discharged. If the upper cock is opened and continues to discharge *water*, it indicates that there is *too much* water in the boiler; on the other hand, if steam is discharged when the lower cock is opened, then there is too little water in the boiler, and the heating surface is in danger of being exposed to the fire without being covered with water, and consequently overheated, or, as it is called, "burned," and so injured as to become too weak to bear the strain to which it is subjected by the pressure of the steam. There is then great danger that the crown-sheet may be crushed down by the pressure of the steam above it, or that the boiler may be exploded. Even if no accident occur, the boiler is in great danger of permanent injury from overheating when the water is allowed to get too low.

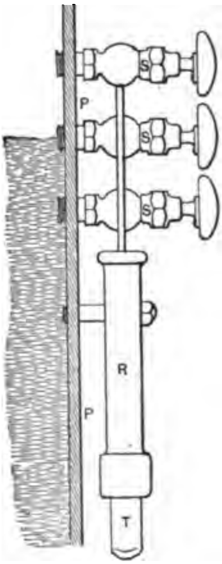


Fig. 192. Gauge-Cocks.

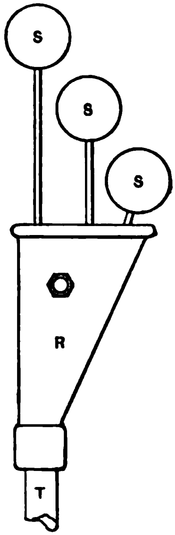


Fig. 193.

Below the gauge-cock, figs. 192 and 193, a receptacle, *R*, called *a drip*, is placed to receive the water and steam which are discharged from the cocks. This water is conducted away by the pipe, *T*.

The *water-gauge*, fig. 194, also shown at 104, fig. 99, consists of an upright* glass tube, *a a*, which is from ⅛ to ¾ inch in diameter, and from 12 to 15 inches long. The glass is about ⅛ inch thick. At its ends it communicates with the steam and water of the boiler through brass elbows,

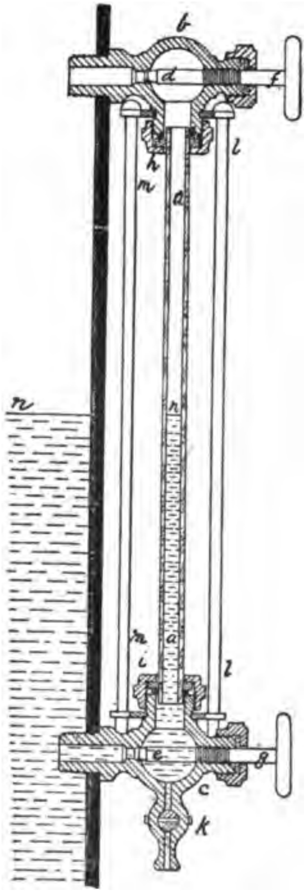


Fig. 194. Glass Water-Gauge.

b c. The openings in these elbows, which communicate with the boiler, are closed by the valves or plugs, *d* and *e*, which are worked by screws

* Sometimes these tubes are, for convenience, inclined.

and handles, *f g*. The glass tube, when it is attached to the elbows, is made steam-tight by rubber rings, which are pressed tight around the tube by *packing-nuts*, *h* and *i*. The elbows are provided with the valves, *d* and *e*, so that in case the glass tube breaks the steam and water can be shut off, so as not to escape through the elbows. The lower elbow is provided with a blow-off cock, *k*, through which any sediment or dirt which collects in the glass tube or elbows can be blown out. When the valves in the upper and lower elbows are opened the steam flows into the glass tube through the upper one, and water through the lower one, and the water assumes a position in the glass tube on a level with the surface of that in the inside of the boiler—thus, the position of the water in the boiler becomes visible in the glass tube. On account of the constant variations of the water in the boiler, the column of water in the glass never remains stationary, but plays up and down as long as the boiler is working. But if the communication between the glass tube and the boiler is closed, then the water in the tube becomes stationary and the water-gauge is useless. In order that there may be no obstruction of the glass tube by mud or dirt from the water, it must be *blown out* often. To do this the lower valve, *e*, is closed, and the blow-off cock, *k*, and the steam-valve, *d*, are opened. The steam pressure in the tube on top of the column of water will force it out of the blow-off cock, and the mud and dirt will be carried with it.

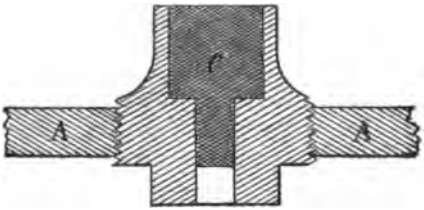
If from any cause the glass tube is broken, first of all the water-valve, *e*, should be closed, and then the steam-valve, *d*, so as to prevent the hot water and steam which will escape from the broken glass from scalding those who are working the engine. By unscrewing the nuts, *h* and *i*, the old glass can easily be removed and a new one substituted in its place. Care should be taken in putting in new glasses not to screw the packing-nuts down any more than just sufficiently to make the rubber rings steam-tight around the glass tubes. If they are screwed too tight they are apt to produce a strain on the tube, so that the slightest expansion by heat or contraction from cold will break it.

QUESTION 307. *What safeguard is used in locomotives to guard against the danger of low water?*

Answer. What are called *safety-plugs* are inserted in the highest part of the crown-sheet. These consist of hollow brass plugs, fig. 195, with a cavity, *C*, in the centre, which is filled with metal that melts at a low temperature. The plug is screwed into the crown-sheet, *A A*, and its lower end is exposed to the fire. In case the water gets low and the plate dangerously overheated, the fusible metal melts and runs out of the plug, so that steam can escape through it, which thus gives warning of the danger, and relieves the pressure in the boiler.

QUESTION 308. *How is the steam pressure in boilers prevented from exceeding a certain limit?*

Answer. By what are called *safety-valves*. These consist of circular openings, shown at 44, Plate IV, about 3 inches in diameter, placed usually on the top of the dome, and covered by a valve which is pressed down by a spring. Two of these valves are usually placed on the top of the dome,



No. 195. Fusible Plug.

so that if one gets out of order the other one will allow the steam to escape as soon as its pressure exceeds that which it has been decided the boiler can safely bear. This pressure in locomotive boilers is usually from 120 to 170 lbs. per square inch. One of these valves should be provided with a lever so that in case of accident or other cause it should be necessary to relieve the steam pressure in the boiler, there will be some means of doing it.

QUESTION 309. *How is the amount of pressure which must bear on top of the safety-valve determined?*

Answer. The pressure is determined BY MULTIPLYING THE AREA OF THE OPENING FOR THE VALVE IN SQUARE INCHES BY THE GREATEST STEAM PRESSURE, IN POUNDS PER SQUARE INCH, WHICH THE BOILER IS INTENDED TO BEAR. Thus, if the opening for a safety-valve is 3 inches in diameter, its area will be 7 square inches, and, therefore, if the greatest steam pressure which it is intended that the boiler shall bear is 150 lbs. per square inch, the valve must be pressed down with a pressure equivalent to $7 \times 150 = 1{,}050$ lbs.

QUESTION 310. *How are safety-valves constructed?*

Answer. They are made in a variety of forms. Fig. 196 represents a section of Richardson's safety-valve, which is now very generally used. *a* is the valve which rests on the seat, *b b*. $c\ c'$ is a spindle, the lower end of which rests on the bottom of the hole in the centre of the valve, *a*. A spiral spring, *m*, rests on a shoulder, *d*, on the spindle. The pressure on the spring is regulated by the nut, *n*, which screws to the case, *e*. This case is connected by ribs, *f f*, to the outer case, *g g*, into which the seat, *b b*, is screwed at *h h*. The valve has a grove, *i i*, around its outside rim. As the valve raises it compresses the spring, which increases its resistance, and therefore without some provision to obviate this difficulty it would

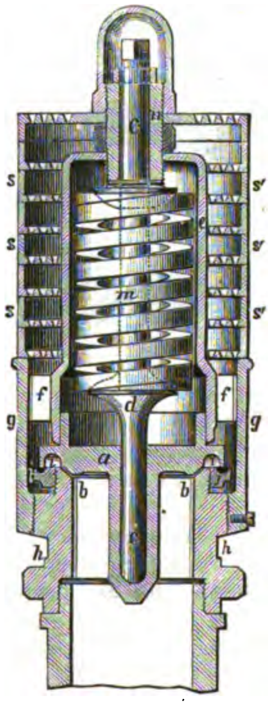


Fig. 196. Section of Richardson's Safety-Valve.

be raised only a very short distance above the seat after steam commenced to blow off. For this reason the top, *a*, of the valve is made considerably larger in diameter than the opening at *b b*. In the under side of the valve a grove, *i i*, is turned. When the valve lifts, this grove is filled with steam, which presses against that portion of the valve outside of the opening, *b b*.

which causes the valve to raise higher and remain open longer than it would without this device. A ring, *j*, is screwed to the outside of the seat, *b b*. This can be screwed up or down, and in this way the amount of opening around the edge of the valve can be regulated.

The valve is usually fitted into a conical seat, shown at *b b*, so as to be perfectly steam-tight, and is made with wings or guides. These guides are intended to keep the valve in its proper position in relation to its seat.

QUESTION 311. *What precaution must be taken to prevent reckless or ignorant persons from increasing the pressure in the boiler beyond that which it is thought it will safely bear?*

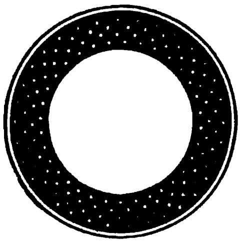


Fig. 197.

Answer. This is usually done by arranging one of the safety-valves with a lever and the other without. The latter is often covered and sealed or locked up, so as to be beyond the control of the locomotive engineer.

QUESTION 312. *How can it be known that the safety-valves are in good working order?*

Answer. The one which has a lever should be frequently opened, as there is always danger that the safety-valve, or some of its attachments, may become corroded or otherwise disordered, so that it will not act promptly or with certainty.

QUESTION 313. *How is the noise of the steam which escapes from the safety-valve diminished?*

Answer. By what are called *mufflers*. These are constructed in a variety of ways. The principle on which they all act is to subdivide the current of steam, into many small streams, which reduces its noise. Sometimes a vessel is filled with pebbles or glass beads, and the escaping steam is made to pass among them. Figs. 196 and 197 show the arrangement used with Richardson's valve. This consists of a series of perforated plates or discs, *s s'*, *s s'*, fig. 196, which are shown in a plan view in fig. 197. These are placed one above the other, with a space between them. The steam is thus alternately contracted in passing through the holes and expanded in the spaces above them, and in this way escapes through the top plate with very little noise.

QUESTION 814. *How is the steam pressure in the boiler indicated?*

Answer. By an instrument called a *steam-gauge*. There are a great variety of such instruments made, but they may all be divided into two classes, and they all operate upon one of two principles. In the one class the pressure of the steam acts upon diaphragms or plates of some kind, shown in fig. 198, which represents a section of a pair of metal plates, *A A*, of this kind. These are made with circular corrugations, as shown in section and also by the shading. The steam enters by the pipe, *c*, and fills the chamber between the metal plates or diaphragms. The corru-

Fig. 198. Diaphragm of Steam-Gauge.

gations of the latter give them sufficient elasticity, so that when the pressure is exerted between them they will be pressed apart by the steam. If they were flat, it is plain that they would not yield, or only to a very slight degree, to the pressure of the steam.

Fig. 199 represents a view of a steam-gauge of this kind, with its face removed, made by the Utica Steam-Gauge Company. The diaphragms are shown just below *a*. A bent lever, *a*, whose fulcrum is at *c*, bears on the diaphragm at *a*, and is connected by a short rod, *o d*, to another bent lever, *b*, whose fulcrum is at *e*. This lever has a toothed segment, *f g*, which gears into a pinion on a spindle, *k*. This spindle carries an index hand or pointer, *h i*. It is plain that any upward movement of the diaphragm below *a* will lift the lever *o a c*, and its motion will be communicated to the lever, *b*, and by the segment and pinion to the pointer, and it will indicate the steam pressure on a dial similar to that shown in fig. 201.

QUESTION 315. *What other kind of steam-gauge is used?*

Answer. In the other class of gauges, shown in figs. 201 and 202, the steam acts upon a bent metal tube, *a b c*, fig. 202, of a flattened or elliptical section. It may not be known to all readers that if a tube having a section of that form is bent, say in the shape of the letter **U** or **C**, and is subjected to the pressure of a liquid or gas on the inside, the force exerted

Fig. 199. Steam Gauge.

by the pressure will tend to straighten out the tube. This is due to the effect of pressure on the inside of an elliptical or flat section, which changes its shape and causes it to approximate to a circular form. Thus let *A B*, fig. 200, represent a cross section, and *a b d c* a longitudinal section of a part of such a tube contained between two radii, *o a* and *o b*, drawn from the centre, *o*, of the curve in which the tube is bent. If now we subject the inside of *A B* to a pressure it will have a tendency to assume the form of the circle *C D*, and would then be represented in the longitudinal section by the dotted lines, *a' b' d' c'*. If we draw radial lines through *a' c'* and *b' d'*, it will be found that they intersect at *o'* instead of *o*, which was the original centre of the curve of the tube. It will be seen that as the section of the tube approximates to the form of a circle, the side, *a b*, which is outside the curve will be moved farther from the centre, while the other side, *c d*, is moved nearer to it. As indicated by the radial lines, when this occurs either the outside must be lengthened and the inside shortened, to conform to the radial lines, *a o* and *b o*, or else the tube will be straightened so that the radial lines will assume *a' o'* and *b' o'*.

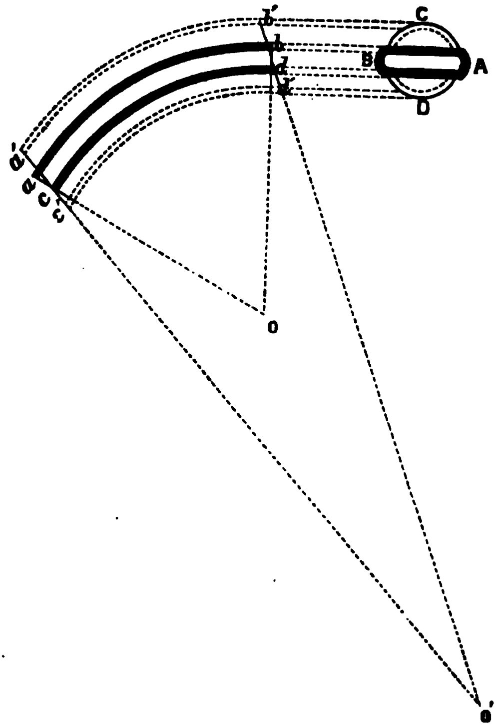


Fig. 200. Diagram Showing Action of Steam on Bent Tube.

In the gauge represented in figs. 202—in which the face or dial plate is removed—one end, *c*, of the tube is attached to a bent lever, *c f l m*, which is connected by a rod, *g*, to a toothed segment, *e*. The end, *a*, of the tube is connected to the lever at *f*. It is obvious that as the two ends of the bent tube are forced apart by the steam pressure, the lower end of the lever and the segment will be moved toward the left hand side. The segment gears into a pinion on the spindle, *s*, which

Fig. 201.

Fig. 202. Ashcroft Steam-Gauge.

carries the index or pointer, *p p*, which indicates on the dial, shown in fig. 201, the degree of pressure in the tube. The latter is connected with the boiler by a tube attached at *h*. The gauge shown by figs. 201 and 202 is made by the Ashcroft Manufacturing Company, of New York. Various forms of this kind of steam-gauge are made, but all act on essentially the same principle.

The pipe which connects the steam-gauge with the boiler is usually bent to prevent the hot steam from coming in contact with the metal plate or tube, as it is found that the heat of the steam affects their elasticity. When a bent tube is used, the steam from the boiler is condensed and fills the bent portion so that when the steam pressure comes on the surface of the water it forces it up the other leg of the tube into the gauge. A cock is attached to this pipe so that the steam can be shut off in case the gauge should get out of order or require to be removed while there is steam in the boiler.

QUESTION 816. *How can the accuracy of a steam-gauge be tested?*

Answer. When the gauge is in good working order, the index or pointer moves easily with every change of pressure in the boiler, and if the steam is shut off from the gauge, the index should always go back to 0. In order to determine the accuracy of its indications, however, it should be tested with a column of mercury, This consists of a long, vertical tube, terminating at its base in a closed vessel filled with mercury. The gauge is then attached to the top of this vessel and water or oil is forced into the vessel on top of the mercury and into the gauge. A pressure of one pound per square inch will force up the column of the mercury 2.04 inches, so that by graduating the tube into spaces that distance apart, the divisions will indicate the pressure in pounds per square inch. Thus, a pressure of 50 lbs. would force up the column of mercury 102 inches, and with 100 lbs. pressure the column would rise 204 inches, and, therefore, when the mercury reaches these or any other points, the steam-gauge, if it is accurate, should indicate equivalent pressures.

The ordinary steam-gauges are very liable to get out of order, and therefore they should be frequently tested to ascertain whether their indications are correct.

QUESTION 817. *What is a steam-whistle, and for what purpose is it used?*

Answer. A *steam-whistle* shown in section in fig. 203, consists of an inverted metal cup or bell, *A*, made usually of brass. The lower edge of this cup is placed immediately over an annular opening, *a a*, from which the steam escapes and strikes the edge of the cup or bell, which produces a deep shrill sound, according to the size or proportions of the whistle. The annular opening, *a a*, is formed by the plate or cover, *a a*, which nearly fills the mouth of the cup, *B*, which is attached to the stem, *c*. The latter is screwed into the top, *D*, of the dome of the boiler. Communication with the steam-space of the boiler is either opened or closed by a valve, *b*, which is attached to a sort of spindle, *d*, which extends upward inside of the stem, *c*. This spindle does not entirely fill the opening in the stem, *c*, so that the steam which enters when the valve, *b*, is opened

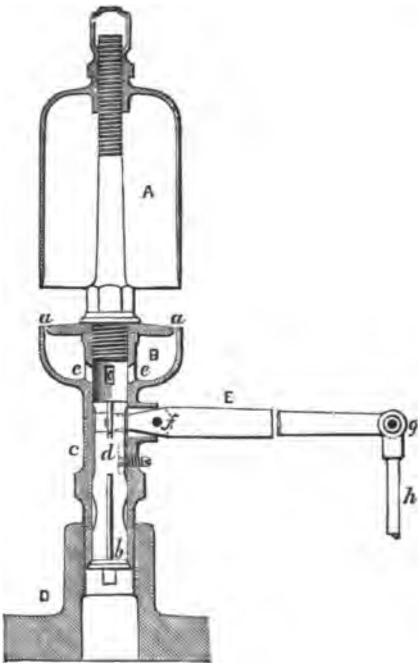


Fig. 203. Steam-Whistle. Scale 1/8 in.—1 in.

rises and escapes through the holes, *e e e*, into the cup, *B*, and out through the annular opening, *a a*. The valve is opened by the lever, *E*, whose fulcrum is at *f*. The end, *g*, of this lever is connected by a rod, *h*, with the cab, and by a suitable handle or lever the valve can be opened and the whistle be blown at any time by the locomotive runner or fireman to give signals to the trainmen, or of the approach of a train to the station, or to warn persons to get off the track.

QUESTION 318. *How is a locomotive boiler emptied and cleaned?*

Answer. One or two large cocks, called *blow-off* cocks, are placed near the bottom of the fire-box, either in front or behind, and sometimes on the side. By opening either of these the water in the boiler is blown out, and much of the loose mud and dirt is carried out with the water.

In order to clean out the mud and scale which are not entirely loose, what are called *mud-plugs* or *hand-holes* are placed in the corners of the fire-box near the bottom. The former are screw-plugs, which can easily be unscrewed. The latter are oval-shaped holes, about 4½ inches long and 2½ inches wide, and covered with two metal plates, one of which is put inside the boiler and the other outside, and fastened with a bolt through both. Another hand-hole is sometimes placed at the bottom of the front tube-sheet. When the boiler is emptied of water the hand-holes are opened by unscrewing the plugs or taking off the covers, and as much dirt is removed as can be scraped out of these holes. A hose-pipe is then inserted and a strong stream of water is forced in, which washes out nearly all the loose dirt, so as to leave the boiler comparatively clean.

When the water is very impure, what is called a *mud-drum* is sometimes used. This is a cylinder of wrought iron attached to the under side of the boiler usually near the smoke-box. It has a cast-iron cover on the bottom which can be removed to clean it. It also has a blow-off cock to discharge the water in it. Much of the mud and dirt is deposited in this receptacle, from which it can easily be removed by taking off the cast-iron cover or blown out through the blow-off cock.

QUESTION 319. *What other attachments are there to the boiler of a locomotive?*

Answer. There is a cock, called a *blower-cock*, attached to the top of the boiler and connected to the chimney by a pipe. Steam is conducted through this pipe, and escapes up the chimney in a jet, thus producing a draft when the engine is not working. This arrangement is called a *blower*, and is used to blow the fire when the engine is standing still. The action of the jet is similar to that of the exhaust steam which escapes up the chimney, excepting that the steam from the jet escapes in a continuous stream instead of distinct "puffs," as it does when it is liberated alternately from one end of the cylinders and then from the other.

E, fig. 121, is the furnace door, which is fastened by a latch. The latter has a chain attached to it, by which it can be conveniently opened or closed.

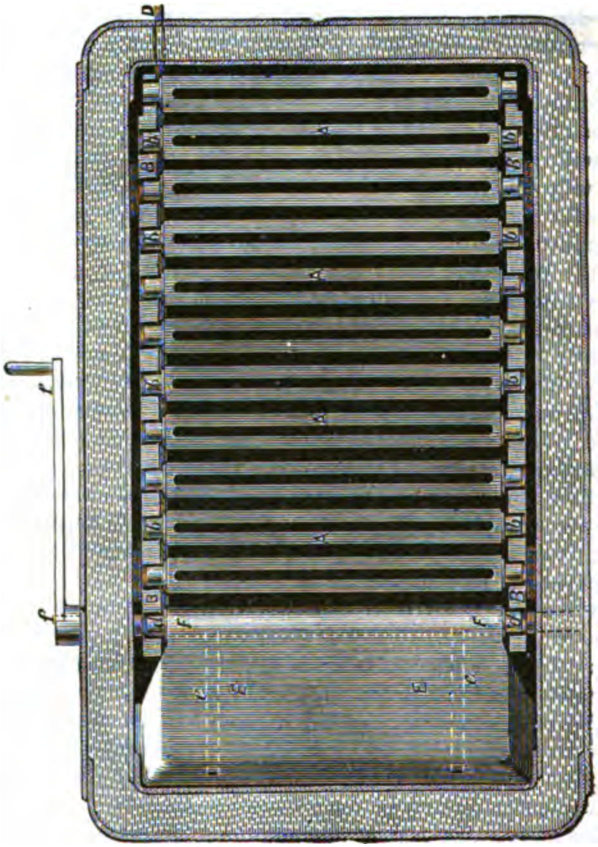


Fig. 204. Plan of Grate. Scale ¾ in.—1 ft.

Fig. 205.

Fig. 206.
Longitudinal Sections of Grate. Scale ¾ in.=1 ft.

QUESTION 320. *How are the grates constructed?*

Answer. As has already been explained, they are made usually of cast-iron bars,* *A A A*, figs. 204 and 205, called *grate-bars*. Fig. 204 is a plan, and fig. 205 a horizontal section of one form of grate. The bars in this kind of grate are usually cast in pairs, or sometimes three or more are cast together. They are made wider on the top than on the bottom edges, as shown in the section, fig. 205, so that cinders and ashes will fall through easily, and also to give free access to the air from below. They are usually from ¾ to 1⅛ inch wide on the top, and about ⅜ inch on the lower edges. The spaces between the bars are made from ⅜ to 1¼ inch wide. For burning wood the bars are placed comparatively close together and are stationary, but for burning bituminous coal they are usually made so that they can be moved, in order to shake or stir up the fire, just as is necessary in an ordinary stove or grate fire. In the grate we have illustrated, the bars, *A A*, are cast in pairs, and run crosswise of the fire-box. The ends are made with a sort of journal, *b b*, fig. 204, which rest on supports, *B B*, called *bearing-bars*, which have suitable indentations to receive the ends of the grate-bars. The latter have arms, *C C*, fig. 205, cast on the under side, to which a bar, *D D*, is attached. By moving this bar back and forth, the grate-bars have a rocking motion imparted to them, as shown in fig. 206. It is evident that in this way the fire over the whole surface of the grates will be disturbed or shaken. The bar, *D D*, is moved by a suitable lever in the cab. Grates which have movable bars are called *shaking* or *rocking-grates*. A great variety of such grates are made and in use, to describe which would require more room than is available here.

For burning anthracite coal, what are called *water-grates* are used, see fig. 481. These consist of wrought-iron tubes, 2 inches in diameter outside, which are fastened in the front and back plates of the fire-box, and are inclined upward from the front end, so that there will be a continued circulation of water through them to keep them cool and thus prevent them from being burned out by the intense heat of the fire.

The tubes usually have about four solid wrought-iron bars between that number of tubes. These bars can be withdrawn, and the fire then falls into the ash-pan through the opening left by the withdrawal of the tubes.

QUESTION 321. *How is the fire removed from the fire-box when it is necessary to do so?*

Answer. In bituminous coal-burning engines, what is called a *drop-*

* In Europe generally, and in some few cases in this country, the grate-bars are made of wrought-iron.

door, *E E*, figs. 204, 205 and 206, is provided for that purpose. This door is supported partly on journals, *d d*, similar to those in the grate-bars, on which it can turn, and is held up or prevented from dropping by arms, *e e*, attached to a shaft, *F F*. This shaft is operated by a lever, *f f*, fig. 204, outside the fire-box.

When the arms are in the position represented in fig. 205, the drop-door is held up in the place in which it is shown; but when they are turned, as in fig. 206, the door falls down so that the burning coal can be taken out of the opening at *G*, and, by raising up the ash-pan damper, *H*, can be raked out on the track or into suitable pits usually provided for this purpose. The drop-doors are sometimes perforated so as to admit air to the fuel on top of them.

QUESTION 322. *How is the damper of the ash-pan operated?*

Answer. It is connected by a rod to a bell-crank, which is moved by a handle in the cab that is raised or lowered, thus opening or closing the damper.

CHAPTER XIV.

THE THROTTLE-VALVE AND STEAM-PIPES.

QUESTION 323. *How is the steam admitted to and the supply regulated or shut off from the cylinders?*

Answer. By a valve, *T*, fig. 121, called a *throttle-valve*, which is usually placed at the end of the pipe, *O O′ Q*, near the top of the dome. Throttle-valves are sometimes placed in the smoke-box at the front end, *O*, of the dry-pipe. Until within a few years they consisted of plain slide-valves which covered openings similar in form to the steam-ports, but smaller in size. The pressure on such valves was of course greatest when there was no steam underneath, which was the case when the valves were closed. It was then very difficult to open them, and as it is important that the supply of steam admitted to the cylinders when the locomotive is started should be easily regulated, such valves were objectionable, and therefore the form has been introduced which is illustrated in fig. 121, and also on a larger scale in figs. 207 and 208, which represent a longitudinal section and plan of the throttle-pipe, valve and throttle-lever. The valve, *T*, is what is called a *double-poppet valve*, and consists of two circular disks, *a* and *b*, which cover two corresponding openings in the case, *h*, on the end of the pipe, *Q*. When these disks are raised up, as shown in fig. 207, steam flows in around their edges, as represented by the darts. It will be observed that the steam pressure in the boiler comes on top of the disk, *a*, and against the under side of *b*. The pressure on the one thus neutralizes or balances that on the other. If the two disks were of the same size, the pressure of the one would be exactly the same as on the other; but as they are joined together and are made to fit steam-tight on their seats by *beveled joints*, their diameters must be somewhat larger than the openings they cover. The only practicable way, therefore, by which the lower disk, *b*, can be introduced into the upper end of the pipe, *Q*, so as to cover the lower opening, is through the upper opening, *a*. For this reason the lower disk must be made smaller than the upper one, and therefore the pressure on the upper one, being in proportion to its size, it is in excess of that on the lower one and has a constant tendency to close the valve. As it is of the greatest importance that a throttle-valve should remain closed after steam is shut off, and never be opened at any time accidentally, the arrangement described accomplishes just what is needed—that is, makes the valve work comparatively easy, and at the same time keeps it closed after the steam has been shut off.

QUESTION 324. *How is the valve opened and closed?*

Answer. By a lever, *A B C*, called a *throttle-lever*, figs. 207 and 208.* This lever is connected by a rod, *d B*, called the *throttle-stem*, with the lower arm of a bell-crank, *d c e*, the other arm of which is connected by the rod, *e f*, with the throttle-valve, *T*. The rod, *d B*, works through a steam-tight stuffing-box, *E*, in the back end of the boiler. The end of the throttle-lever is attached to a link, *D C*, fig. 208, which is fastened by a pin to the stud, *D*. This link has a slight vibratory motion, which enables the pin, *B*, by which the lever, *A B C*, is fastened to the rod, *d B*, to move in a straight line, which is necessary in order that the rod may work steam-tight in the stuffing-box, *E*. The throttle-lever has a latch, *l*, which gears into a curved rack, *n m*, so has to hold the lever and valve in any required position. This latch is operated by a trigger, *k*, which is connected to the latch by a rod, *r*. Various other devices are used to fasten throttle-levers and thus hold them in any position required.

QUESTION 325. *How are the steam-pipes constructed?*

Answer. The steam, after it is admitted by the throttle-valve, as was explained in answer to Question 323, passes into the throttle-pipe, *Q*, and the dry-pipe, *O′ O*, fig. 121. At the front end of the dry-pipe, a pipe, *O*, which divides into two branches like the top of the letter **T**, and is therefore called a T-pipe, is attached. This pipe is indicated by number 85 in fig. 98. The steam-pipes, 84 84′, fig. 98, are connected to each of the two branches of the T-pipe at one end and to the cylinder castings at the other.†

These pipes, being in the smoke-box, are exposed to great changes of temperature, and are therefore subjected to expansion by heat and contraction by cold. The joints are therefore constantly liable to disturbance by the contraction and expansion of the pipes, and so are difficult to keep tight. It is also practically impossible to construct the boiler, the cylinders, and the pipes, with perfect accuracy, and therefore a small amount of adjustability and flexibility is necessary in the joints of the pipes. If,

* Fig. 208 shows a plan of the valve and lever.

† In fig. 98 the right-hand side represents a section through the steam-pipe, 84 84′, and the left a section through the exhaust-pipe, 80′.

Fig. 207.

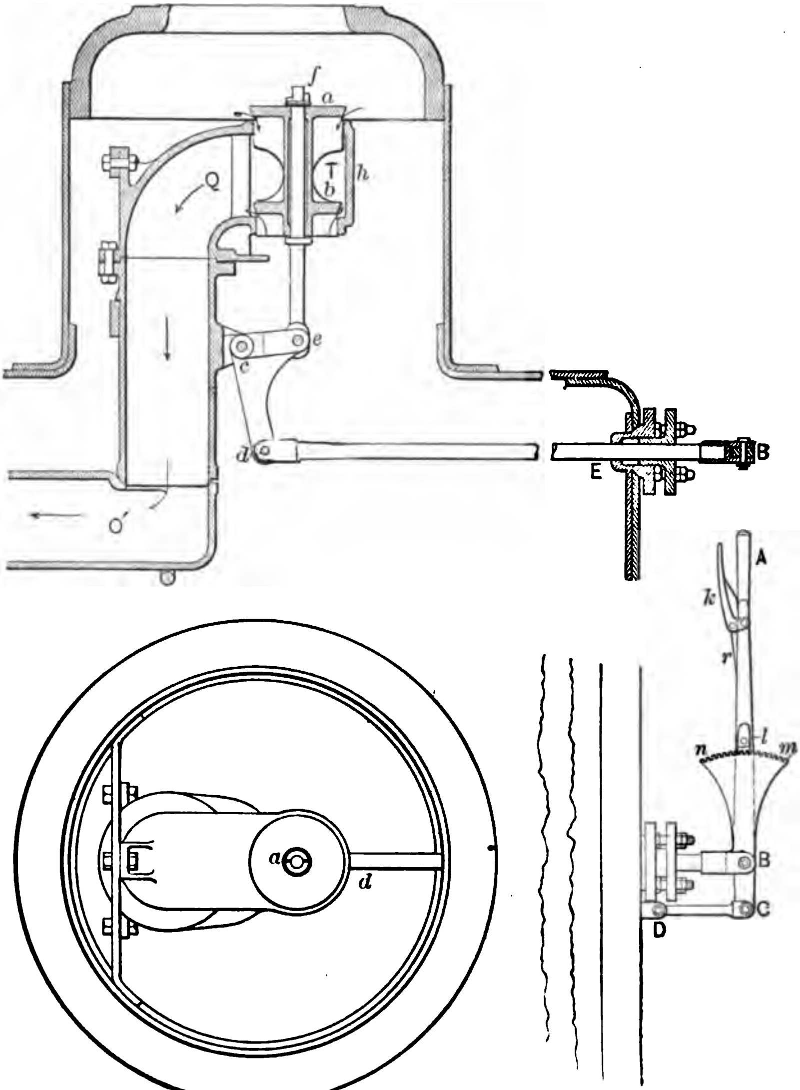


Fig. 208.

Throttle-Valve and Lever. Scale ¾ in. = 1 ft.

for example, the upper end of the pipe, 84′, in the cylinder, fig. 98, were either too near or too far from the centre of the engine, it would be necessary to move the end of the pipe, 84, either to the right or to the left in order to connect it with 84′. If the joint of the upper end of the steam-pipe were attached to the T-pipe, with a flat joint like that shown at *a b*, fig. 209, it would be impossible to move the lower end of the steam-pipe

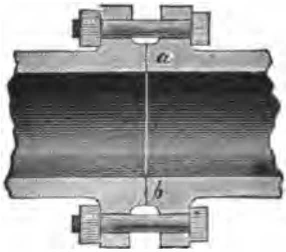


Fig. 209. Steam-Pipe Joint. Scale ⅛ in. = 1 in.

either to the right or to the left without disturbing the joint and causing it to leak. For this reason these pipes are connected with what are called *ball-joints*, fig. 210—that is, the end, *a b*, of one of the pipes is turned into

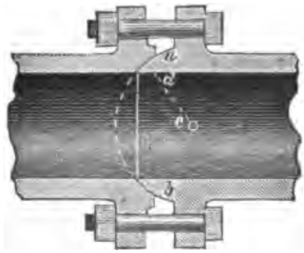


Fig. 210. Steam-Pipe Joint. Scale ⅛ in. = 1 in.

the form of a part of a sphere,* and the end of the other one into a corresponding concave form. It is known that a sphere will fit into a spherical socket in any position; for example, an acorn in its cup or the bones at

* The dotted lines indicate what would be the form of the sphere if the pipe was solid instead of hollow.

the hip or shoulder joints. If, therefore, the pipes are joined with such spherical or *ball-joints*, as they are called, the lower end can be moved sideways several inches either way, and the joint will still be steam tight if it is then firmly bolted together. Even after it is bolted together it will have so much flexibility that the expansion and contraction of the pipes will not cause it to leak.

There is, however, still another difficulty. Although the lower end of the pipe, 84, fig. 98, can, with a ball-joint above, be moved in any direction horizontally, yet if the pipe is too long or too short it is obvious such a joint will not permit it to be moved up or down. A joint with a flat surface, like that shown in fig. 209, would, however, permit such motion in the pipe without leaking. If, for example, the steam-pipe were ⅛ inch too short, it might be drawn down that distance, and if the upper joint were then screwed up it would still be steam-tight. In order, then, to get both vertical and lateral flexibility in the joints of the steam-pipes, a ring, *a b*, fig. 211, is interposed between the pipes. One side of this ring is

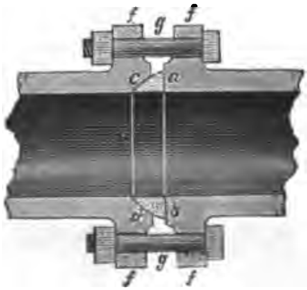


Fig. 211. Steam-Pipe Joint. Scale ⅛ in.—1 in.

spherical and the other flat, so that the pipes can move either around the spherical part or slip up or down or sideways on the flat surface of the ring. In this way the pipes are flexible and adjustable in every direction, and for all kinds of motion caused by expansion, or which may be needed when the parts are put together. Sometimes the joints at one end only of the steam-pipes are made in this way, and the other is connected with a simple ball-joint.

In designing these joints their form should be drawn with a radius, *c d*, fig. 210, from one centre, *c*, so that the surface of the joint will form a part

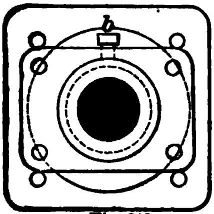


Fig. 212.

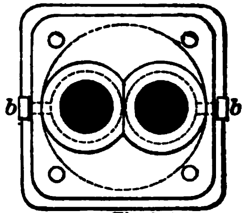


Fig. 215.

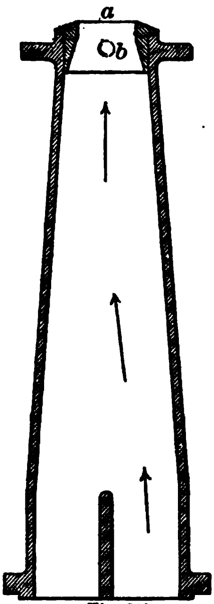


Fig. 213.

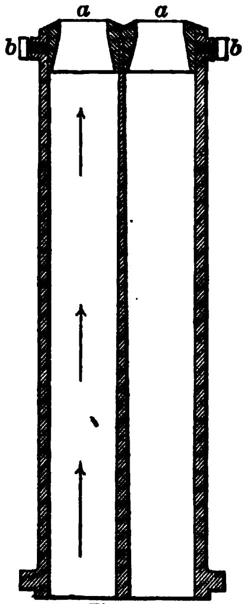


Fig. 216.

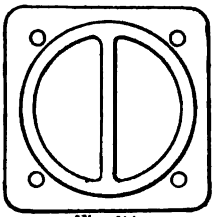


Fig. 214.

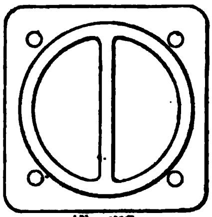


Fig. 217.

Exhaust-Pipes. Scale 1 in.=1 ft.

of a sphere. If they are drawn from two centres, as is sometimes done, it is obvious that the surface of the joint will not be a part of a sphere, and therefore will not have the requisite flexibility. The surfaces of the joints are carefully turned to the proper form, and then made steam-tight by scraping or grinding them with emery and oil, and the pipes are then fastened together with bolts, *g g*, fig, 211, and flanges, *f f*, cast on the pipes.

QUESTION 326. *How are the exhaust-pipes made?*

Answer. They are made of cast iron. Two forms of such pipes are shown by figs. 212 to 217. These figures show vertical sections, plans, and inverted plans of the pipes. In some cases a single blast orifice or exhaust-nozzle is used, as shown in figs. 212 and 213, and in others they are made double, as they are represented in figs. 215 and 216. Where two nozzles are used they are generally cast together, as shown in figs. 215–217. When only one is used, the form of the pipes resembles somewhat that of an inverted letter ⅄, as shown in fig. 213, so as to cover the two openings which connect with the cylinders. The tops of these pipes have rings or bushings, *a a*, fitted into them, which are held by set screws, *b b*, so that they can easily be removed and others with larger or smaller openings be substituted. If the openings in the exhaust-nozzles are small, the steam must be discharged at a higher rate of speed, in order to exhaust that which is in the cylinders, than if the blast orifices are larger. Therefore, if the latter are reduced in size, the draft becomes more violent, but at the same time the *back-pressure* in the cylinder (which will be explained hereafter) is increased. It therefore becomes necessary to adjust the size of the blast orifices with the greatest care, so as to have them just small enough to produce the required draft and yet leave them as large as possible, so as to reduce the back-pressure. For these reasons what are called *variable exhausts* are sometimes used. In these the blast orifice can be increased or diminished at pleasure, and thus regulated to suit the conditions under which an engine is working. A great variety of such devices has been used, but now nearly all have been abandoned for the simpler arrangement described, which is not variable when the engine is working.

Figs. 218 and 219 represent longitudinal and transverse sections of Adams' "vortex blast-pipe," which is the invention of Mr. W. Adams, locomotive superintendent of the London & South Western Railway.* The main object of this invention is to equalize the draft through the tubes of the locomotive and thus to prevent the destructive action of the

* This has been patented in this country and in England.

blast, which, with ordinary blast-pipes, act with too great intensity through the upper rows of tubes. To overcome this, Mr. Adams makes the exhaust orifice, *A A*, of annular form, as shown clearly in the plan below, fig. 219. The lower part of the exhaust-pipe is made of a bifurcated form,

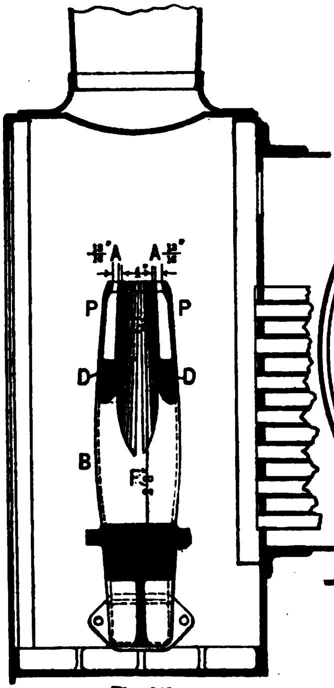


Fig. 218

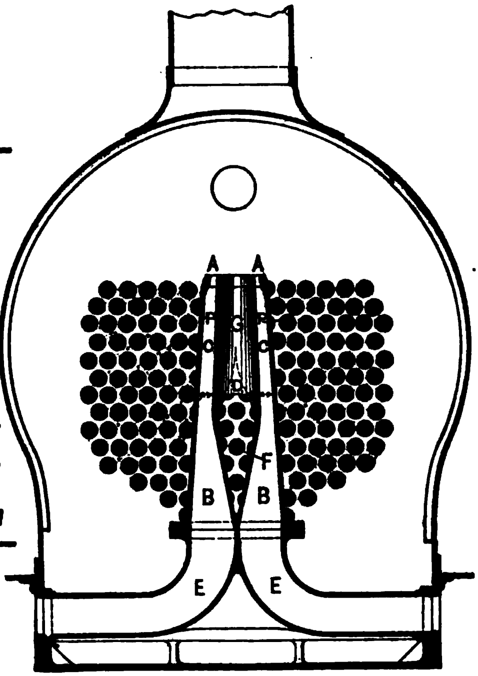
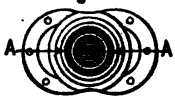


Fig. 219



somewhat like a pair of trousers, the two legs or branches, *B B*, being attached to the exhaust pipes, *E E*. The branches, *B B*, have an opening, *F*, between them, and unite in the annular opening, *C C*, above the partitions, *D D*, shown by dotted lines in fig. 219, and black shading in fig. 218. Inside of the annular nozzle, *A A*, there is a cylindrical central passage, *G*, which communicates directly with the opening, *F*. When steam escapes from the opening, *A A*, it draws the air with it on the outside of the exhaust pipe, *P P*, and of the escaping current of steam. It also creates a partial vacuum in the central passage, *G*, which draws air from the opening, *F*, and from the lower part of the smoke-box and lower rows of tubes. In this way the draft in the upper and lower tubes is equalized which, it is said, results in a material economy in fuel consumption.

CHAPTER XV.

THE CYLINDERS, PISTONS, GUIDE-BARS, CROSS-HEADS AND CONNECTING-RODS.

QUESTION 327. *How are the steam cylinders constructed?*

Answer. They are made of hard cast iron, and have the steam and exhaust-ports and valve-seats cast with them. The harder the iron the better will the cylinders withstand the wear of the pistons and valves, but they must at the same time be made soft enough, so that after they are cast the inside can be bored out perfectly cylindrical, the ends turned off, the bolt-holes drilled, and the valve-seats planed smooth.

Fig. 220 represents a longitudinal section through the centre of the cylinder and steam-chest. Fig. 221 is a plan of the same parts with the cover of the steam-chest and the valve removed. Fig. 222 is a front end view, and fig. 223 a transverse section, through *c d*, fig. 221, of the cylinder. Fig. 224 is a transverse section through the guide-bars, *N N*, fig. 221, looking backward towards the cross-head and cylinder. The same letters indicate like parts in the different views.

The cylinders of locomotives in this country are now universally placed on the outside of the wheels, as has already been described. In order to fasten them securely together and to the boiler, they are attached to what is called *bed-plates* or *bed-castings*, *D D*, figs. 222 and 223, which are placed between them. Sometimes the bed-castings are made separate from the cylinders and in one piece, and the cylinders are then bolted to it on the outside, about at the dotted lines, *l m*, fig. 222. The usual practice now is to cast one-half of the bed-casting with each cylinder, as shown in the engravings, and then bolt them together at the line, *i i*, which is the centre of the engine. The bed-castings are also bolted to the smoke-box by the flanges, *E E*. The cylinders are bolted to the frames, *F F*, with bolts, *m* and *k*, figs. 222 and 223.

After the cylinders are bored out and the ends turned off, *heads*, *A* and *B*, fig. 220, are fitted with steam-tight joints to each end. These heads are fastened with bolts and nuts, *a a a*, to flanges, *C C*, fig. 221.

QUESTION 328. *How is the steam conducted to and from the cylinder?*

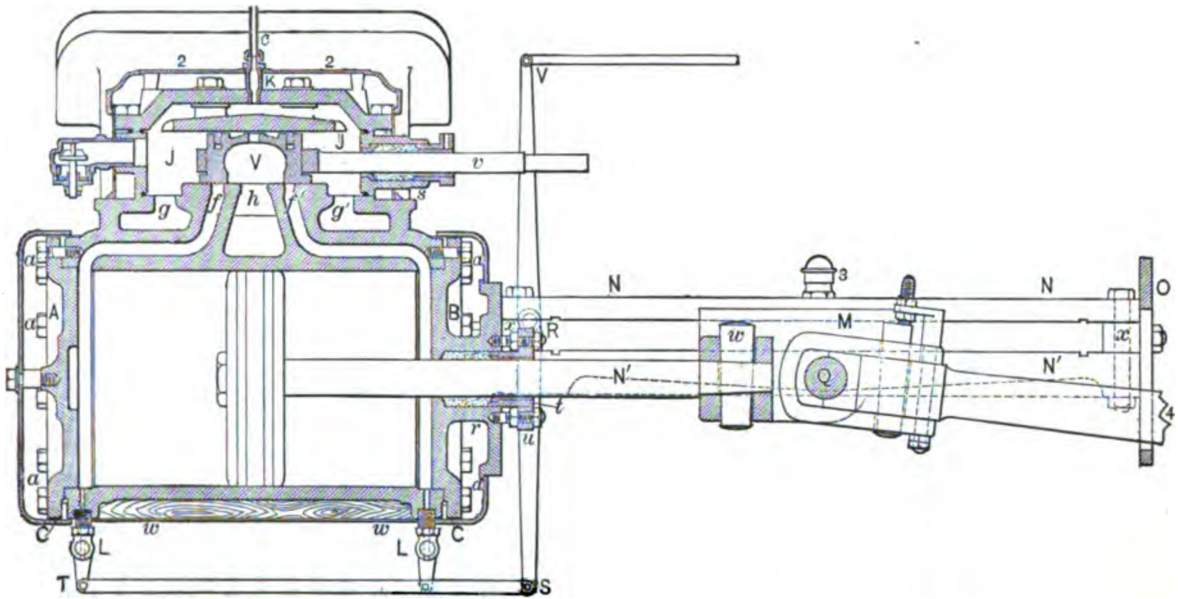


Fig. 220. Longitudinal Section of Cylinder, etc. Scale ⅛ in.—1 in.

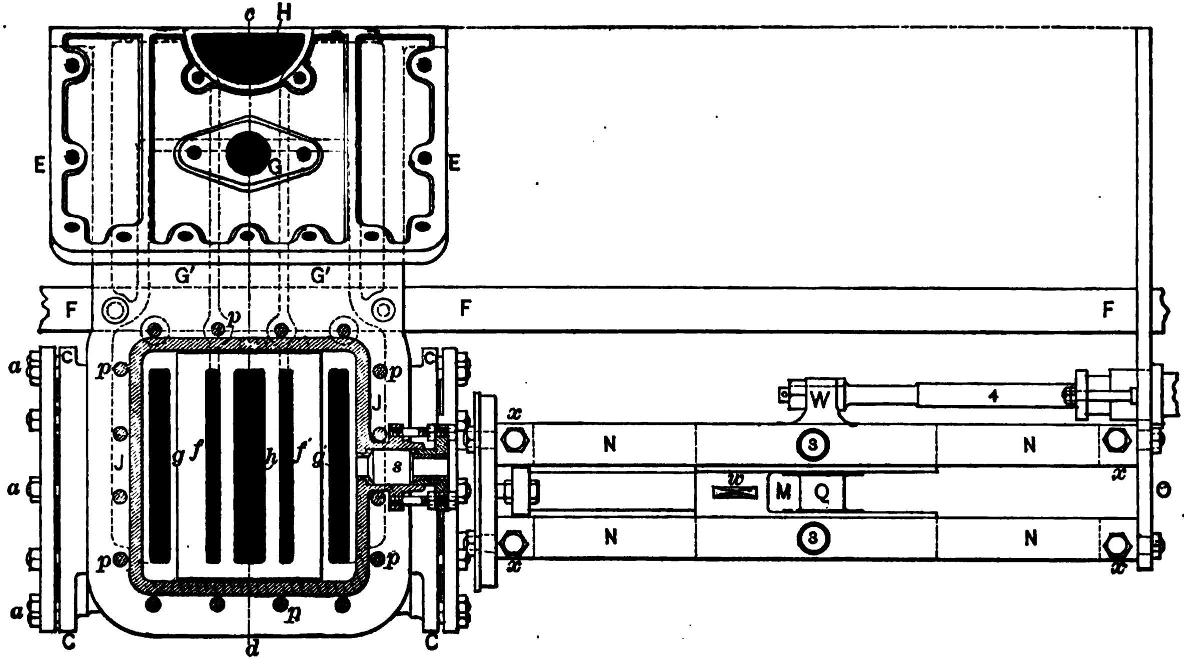


Fig. 221. Plan of Cylinder, etc. Scale 1/8 in.—1 in.

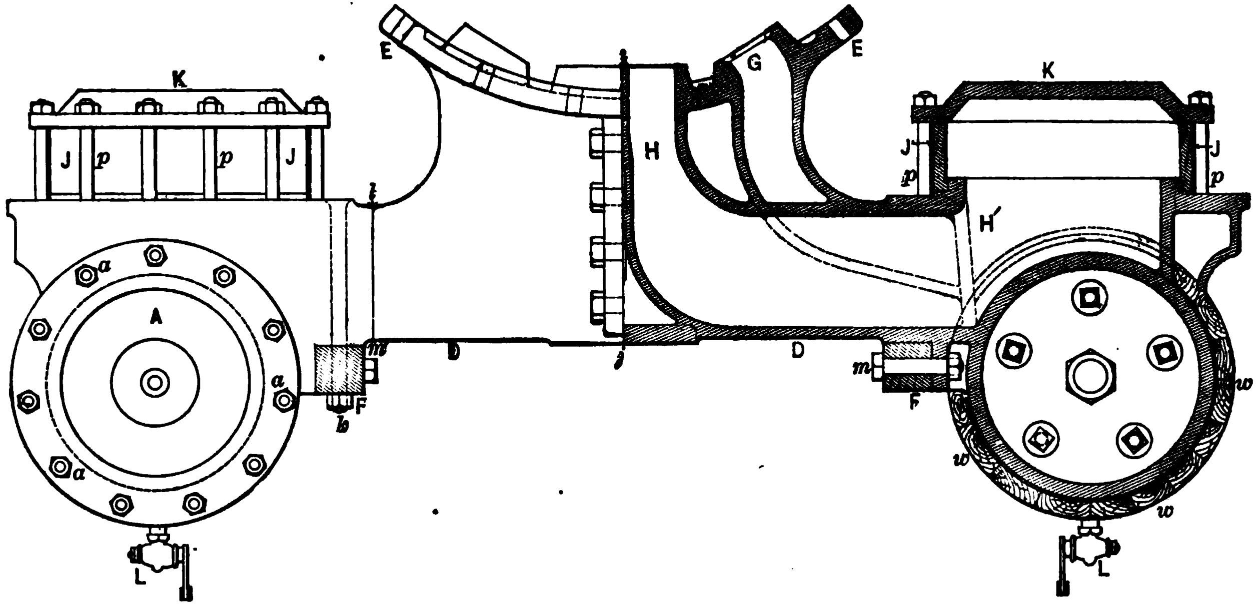


Fig. 222. Front-end View of Cylinder.

Fig. 223. Transverse Section of Cylinder.

Scale ⅛ in.—1 in.

Answer. Two pipes or passages are cast in each cylinder, the one, *G*, fig. 223, for admitting steam into the steam-chest, and the other, *H H'*, the *exhaust-passage*. The steam-passage terminates at one end with a round opening, *G*, figs. 221 and 223, to which the steam-pipe, 84 84', fig. 98, are attached inside of the smoke-box. At the other end it divides into two branches, *G' G'*, shown by dotted lines in fig. 221, each of which terminates in an opening, *g g'*, inside of the steam-chest. The steam is thus delivered at both ends of the chest, and can pass freely into each of the steam-ports, *f f*, when they are open. By making the cylinders in this way, they are exactly alike for each side of the engine, or, to use a shop phrase, there are "*no rights and lefts*," so that a cylinder casting can be used for either side of the engine. This method of making cylinders has been adopted by nearly all the principal builders in this country.

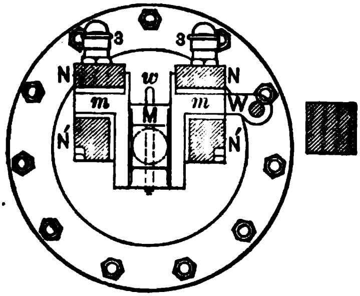


Fig. 224. Back-end View of Cylinder and Cross-Head. Scale ½ in.—1 in.

QUESTION 329. *How are the steam-chests constructed?*

Answer. They usually consist of two castings, one of which, *J J*, figs. 220, 221, 222 and 223, is a square cast-iron box made open at the top and bottom. This rests on the top of the cylinder casting and is joined to the latter with a steam-tight joint. On top of it is a cast-iron cover, *K*. The steam-chest and cover are held down by bolts, *p p*, which are screwed into the cylinder casting and have nuts on top.

QUESTION 330. *How are the slide-valves made to work steam-tight on the valve-seats?*

Answer. They are first planed off smooth, and then filed and scraped until the two touch each other over the whole of their surfaces in contact. The valve-stem, *v*, fig. 220, works steam-tight through a stuffing-box, *s*, on the steam-chest.

QUESTION 331. *How are the valves and pistons oiled?*

Answer. The oil is usually introduced into the steam-chest through a pipe, *c*, which is connected with a cock in the cab, called the *cylinder oil-cock* or "*oiler*." From this cock the oil flows through the pipe and down upon the valve, and is conducted by suitable holes and channels to the valve-face, and from there through the steam-ports to the cylinder and piston. The construction of these "oilers" is explained in Chapter XXI.

Sometimes the valves are oiled by pouring oil or melted tallow into the oil-cocks when the steam is shut off from the steam-chests and cylinders. When the pistons are working in the cylinders without steam, they create a partial vacuum, so that if oil is then poured into the oil-cocks it will be sucked into the steam-chests, or, in other words, it will be forced in by the pressure of the air above it. A shelf, 105, fig. 99, is attached to the boiler to receive an oil-can filled with oil or tallow, which is thus melted or kept in a fluid condition by the heat of the boiler.

QUESTION 332. *How are the cylinders and steam-chests protected so as to prevent, as far as possible, the heat in the steam from being lost?*

Answer. The sides of the cylinders are covered with wood, shown at *w w w*, figs. 220 and 223, called the *cylinder-lagging*, and the wood is covered outside with Russia iron, which is called the *cylinder-casing*. The ends of the cylinders have light metal covers, called *cylinder-head covers*, shown in section at *a a*, fig. 220, made of cast-iron, brass, or sheet metal, The steam-chest has a similar cover, 2 2, fig. 220. Sometimes coarse felt is used for lagging the cylinder and steam-chest.

QUESTION 333. *For what purpose are the cocks, L L, figs. 220, 222 and 223, at each end of the cylinder, used?*

Answer, They are used to exhaust the water which collects in the cylinders. When the engine is not working the cylinders and steam-pipes are all cooled off, so that when steam is first introduced into them a great deal of it is condensed until they become warmed. Water is also frequently carried over from the boiler with the steam. When this occurs the boiler is said to *prime*, or to "*work water*." This water and that produced by the condensation of steam, collects in the bottoms of the cylinders and will not escape through the exhaust-pipes until the piston moves up so near to the end of the cylinder that the water will fill the whole space between it and the cylinder-head. As has already been stated, it will then escape so slowly that the momentum of the piston and other machinery is liable to "knock out" the cylinder-heads or even break the cylinder itself. The cocks, *L L*, called *cylinder-cocks*, are therefore placed in the under side of the cylinder, so that when they are open if there is any water in the cylinder it will escape through them. They are therefore always opened when the engine is starting, or at any other time when there is any indication that there is water in the cylinders.

QUESTION 334. *How are these cocks opened or closed?*

Answer. A shaft, *R*, fig. 220, which extends across the frames, has an arm, *R S*, at each end. These arms are connected by rods, *S T*, with the handles of the cylinder-cocks. The shaft also has a verticle arm, *R V*,

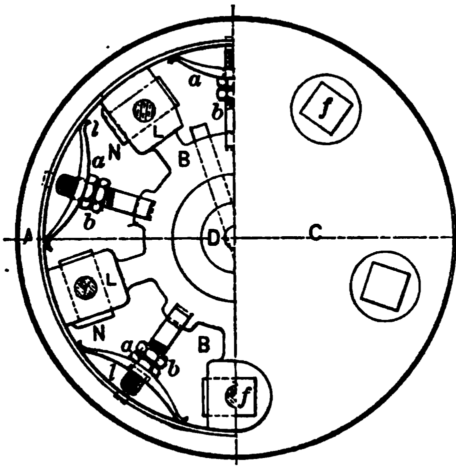


Fig. 225.

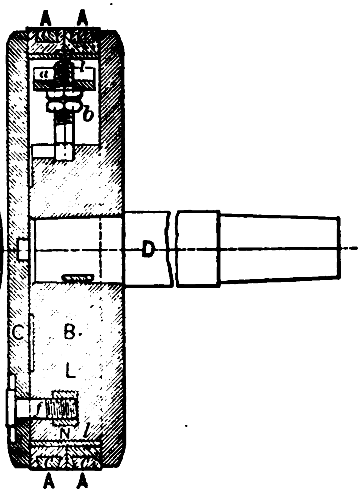


Fig. 226.

Piston with Spring Packing. Scale 1/8 in.—1 in.

the upper end of which is connected by a rod with the cab. At the end of the rod is a suitable handle by which the cocks can be either opened or closed at pleasure by the locomotive engineer.

QUESTION 335. *How is the piston-rod fastened to the piston?*

Answer. It fits into a straight or tapered hole in the piston-head, in which it is fastened either with a key or by a nut on the front side of the piston.

QUESTION 336. *How are pistons constructed?*

Answer. They are made in a variety of ways. Figs. 225 and 226 represent a form of piston which has been used for many years and is still preferred by some engineers. Fig. 225 shows the front side of the piston with one-half of the follower-plate removed, and fig. 226 is a longitudinal section.

They are made of two cast-iron pieces, *B* and *C*, fig. 226, the one, *B*, called the *piston-head* or *spider*, to which the piston-rod, *D*, is attached. The other part, *C*, called the *follower-plate*, is bolted to the piston-head by the bolts, *f f*, called *follower-bolts*.

QUESTION 337. *How are pistons made to work steam-tight in the cylinder?*

Answer. The old way of making pistons is shown, as noted above, in figs. 225 and 226. Pistons of this kind have two rings, *A A*, called *packing-rings*. These rings are turned of the same size or a little larger in diameter than the cylinder. They are then cut open at one point in their circumference so that they can be pressed apart or expanded by the springs, *a a*, called *packing-springs*, on the inside of the rings. These springs are pressed out by the nuts and bolts, *b b*, called *packing-bolts* and *packing-nuts*, so that when the rings wear they can be expanded so as to fill the cylinder completely. The place where the one ring is cut is placed on the opposite side of the piston from that of the opening in the other ring, or they are made to *break joints*, as it is called. This is done to prevent the steam which leaks through the opening where the one ring is cut from passing through to the other side of the piston. These rings are usually made of brass and have groves, *c c*, fig. 226, turned in them, which are filled with what is called Babbitt's metal. This metal is used because it is less liable to scratch the cylinders than brass. Another ring, *l l*, made of cast-iron and as wide as the two brass rings, is placed inside of the latter and is intended to furnish a bearing for the springs, and thus distribute their pressure equally on the packing rings. This iron ring is also cut open at one point. The follower-bolts, *f f*, are screwed into brass nuts, *N N*, which are contained in cavities cast in the lugs, *L L*, on the piston-head. These brass nuts are used to prevent the bolts from rusting fast, as they are liable to when screwed into the cast-iron of which the piston-head is made.

QUESTION 338. *What other kinds of pistons are there?*

Answer. A number of different kinds are used with packing-rings of various forms which are usually made larger in diameter than the inside of the cylinders. After being cut apart they are compressed so as to enter the cylinders, and their own elasticity or tendency to spring apart keeps them tight. Figs. 227, 228 and 229 represent one form of this kind of packing. It consists of a main ring, *l l*, which has two grooves turned in it which receives the two rings, *A A*; these, as explained, are made somewhat larger than the cylinder. They are cut apart and are held in the grooves by a flange on the piston-head on one side, and by the follower-plate on the other. The ring, *l l*, is not cut open, but is left solid, and the weight of the piston causes this ring to bear on the bottom of the cylin-

Fig. 227.

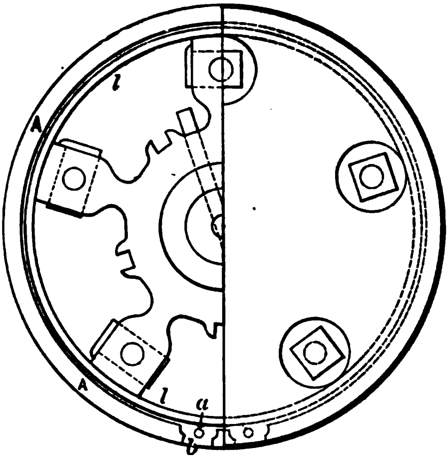
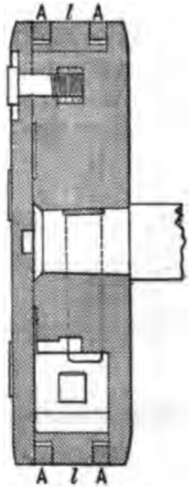


Fig. 228.



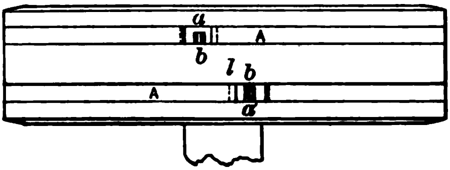


Fig. 229.
Piston with Steam Packing. Scale ⅛ in.—1 in.

der. The openings, *b b*, where the ring, *A A*, are cut apart, are placed at the bottom of the piston, as shown in figs. 227 and 228. Fig. 229 is an inverted plan of the piston, and shows the position of the openings. As the ring, *l*, bears on the bottom of the cylinder it keeps the piston tight at that point, so that any steam which may leak through either of the openings, *b b*, could get no further than the ring, *l*. The elasticity of the rings, *A A*, cause them to bear against the top and sides of the cylinder and in that way keep them tight; *a a* are pins to prevent the rings, *A A*, from turning.

In some other pistons the packing-rings are cut into sections and are either pressed out by some form of springs, or steam is admitted to the grooves in which they are held so as to press them out against the inner surface of the cylinder, and thus keep the piston tight.

QUESTION 339. *How is the piston-rod made to work steam-tight through the cylinder-head?*

Answer. By what is called a *stuffing-box*, similar to that illustrated in figs. 44 and 45, and described in the answer to Question 95. Such a stuffing-box is shown at *r*, fig. 220 and on a larger scale in figs. 230 and 231. Fig. 230 is a longitudinal section, and fig. 231 a front view of such a stuffing-box.

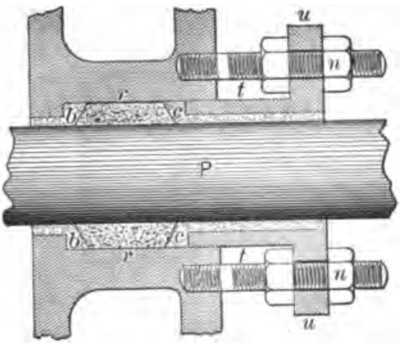


Fig. 230.

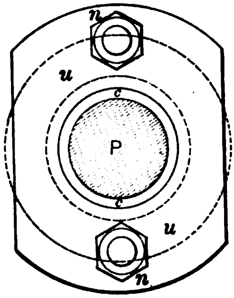


Fig. 231.

Stuffing-Box. Scale $\frac{1}{8}$ in.—1 in.

QUESTION 340. *How is metal packing for piston-rods and valve-stems made?*

Answer. A number of different kinds of metal packing are now used. One of these kinds, made by the United States Metallic Packing Company, of Philadelphia, is illustrated by fig. 232. It consists of a cap, 1 1, which is bolted over the stuffing-box. The latter contains a number of metal rings, in which the piston-rod, *B*, works. These rings are made as follows: 3 3 is a solid ring made of brass, with a spherical surface on one side, which bears against the cap, 1 1, and has a flat surface on the other side. A solid cast-iron ring, 4 4, bears against the flat surface of 3 3; 4 4 has a conical cavity on the inside which contains a number of soft metal rings, 5 6 6, which are cut into a number of pieces or sectors. A solid brass ring, 7 7, bears on these, and is pressed against them by a spiral spring, 8. The steam in the cylinder also presses on these rings and forces the soft metal packing rings into the conical cavity in ring 4, which causes them to contract and bear against the piston-rod, and thus make them steam-tight. The spiral spring holds the rings in place on the return

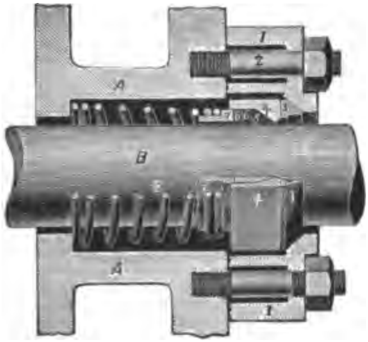


Fig. 232. Metallic Piston-Rod Packing. Scale 1/6 in.—1 in.

stroke of the piston, when the steam in the back end of the cylinder is exhausted or when steam is shut off from the cylinders. The purpose of the spherical and flat surfaces of the ring, 3, is to permit it to adjust itself to any position of the piston-rod in case it should "get out of line," somewhat as steam-pipes are kept tight by a similar method of construction, as explained in Chapter XIV.

QUESTION 341. *Why is the end of the piston-rod made to work in guides?*

Answer. Because, as was explained in answer to Questions 96, 97 and 98, it must move in a straight line if it and the piston work steam-tight in the cylinder. By referring to fig. A, Plate I, it is obvious that if a pressure be exerted against the piston, *B*, and communicated to the crank-pin, *N*, by the connecting-rod, *E*, the latter, excepting at the dead-points, will exert a pressure either upward or downward, according to the direction the piston is moving. This pressure would bend the piston-rod if no provision were made to prevent it. For this reason the end of the piston-rod is attached to what is called a *cross-head, M*, figs. 220, 221 and 224, which works in guides, *N N, N′ N′*, called *guide-bars* or *guides*.

QUESTION 342. *What are the different forms of cross-heads and guides that are used?*

Answer. The cross-head shown in the figures last referred to is the one that is generally used on passenger engines. The cross-head is made of cast iron or cast steel, and has slides, *m m*, fig. 224, one on each side, which work between pairs of guide-bars, *N N′*, shown in section in fig. 224. These

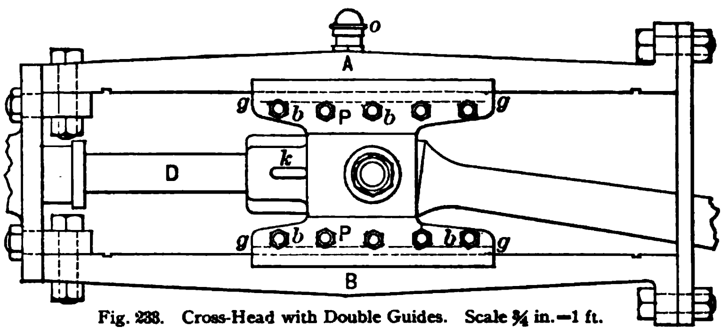


Fig. 233. Cross-Head with Double Guides. Scale ¾ in.=1 ft.

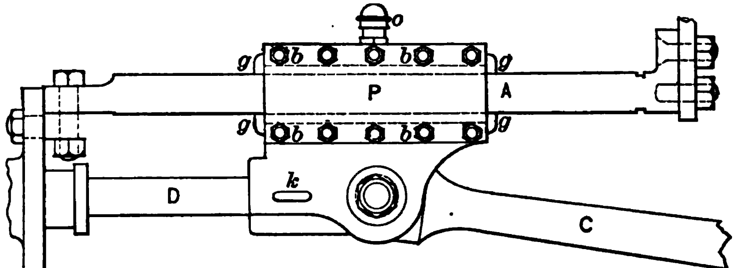


Fig. 234. Cross-Head with Single Guide. Scale ¾ in.=1 ft.

guide-bars are planed and finished with great accuracy, so as to be straight and smooth, and are attached to the back cylinder-head and to a support, *O*, fig. 220, called the *guide-yoke*, which is a plate fastened to the frame at *F*, fig. 221, and is also usually attached to the boiler. The guides are set with great care, so as to be exactly parallel with the axis or centre line of the cylinder, so that the cross-head will slide in exactly the same path that the piston-rod will if it moves in a straight line. If, then, the piston-rod and the connecting-rod are attached to the cross-head all the strain produced by the obliquity of the connecting-rod will be borne by the guides, thus relieving the piston-rod, and making it certain that it will move in a straight line.

Figs. 233 and 234 represent cross-heads which are used on freight engines. In fig. 233 there is a single guide-bar, *A*, above, and another, *B*, below the cross-head. In fig. 234 there is a single guide-bar, *A*, above the cross-head; sometimes two bars above the cross-head are used instead of the single bar. These forms are used when one of the driving-wheels is opposite to the guide-bars, as is the case on mogul, consolidation, and some other engines. In such cases there is not room enough to place the guide-bars on each side of the cross-head.

QUESTION 343. *How are the piston and connecting-rods attached to the cross-head?*

Answer. The end of the piston-rod fits into a tapered hole in the cross-head, and is held by a key, *w*, figs. 220 and 221, and *k k*, figs. 233 and 234. The connecting-rod is attached to a pin, *Q*, figs. 220 and 221, called a *wrist-pin*, which is cast with the cross-head.

QUESTION 344. *How is the wear of the slides lessened and compensated for?*

Answer. Sometimes they are made with brass wearing pieces called *gibs*, shown above and below, *m m*, fig. 224, which are placed between the slides and the guides. These gibs can either be removed and new ones substituted when they become very much worn, or by inserting thin pieces of metal, called liners, between them and the cross-head, they will be spread apart so as to fill the space between the slides. The slides are now, however, often made without gibs, and have recesses either cast or drilled in them, which are filled with Babbitt's metal. Double guide-bars are bolted at each end to blocks, *x x*, fig. 220, called *guide-blocks*, which can be planed off so as to bring the guides nearer together when they and the slides are worn. Sometimes liners are placed between the blocks and the guides, which can be removed when it is necessary to bring the guides nearer together.

QUESTION 345. *Are the guides worn alike?*

Answer. No; as explained in the answer to Question 154, when an engine is running forward the connecting-rod presses the cross-head upward during both the forward and the backward stroke of the piston, and in running backward the pressure of the rod is downward.

This will be understood by referring back to the series of figures from 30 to 43. It will be noticed that in the backward stroke of the piston, represented by figs. 30 to 36, the strain on the connecting-rod tends to *push* the cross-head upward, and in the forward part of the stroke, figs. 37 to 43, the connecting-rod *pulls* the cross-head in the same direction. If the crank turned the opposite way, this action would be reversed and the cross-head would then be alternately pushed and pulled downward. Consequently, when the engine is running forward the surfaces of the guide-bars, which resist the upward pressure of the cross-head will be worn most, and in running backward, those which resist its downward pressure will be worn most. As nearly all locomotives run forward more than backward, the under surfaces are usually worn the most.

QUESTION 346. *How are the slides oiled?*

Answer. Oil cups, 3 3, are attached either to the top guides, as shown in figs. 220, 221 and 222, or to the cross-head, as indicated by *o*, in fig. 234. These cups usually have a reservoir to hold a supply of oil, and are so constructed that it will be gradually fed on the slides, which are thus constantly and regularly lubricated. Their construction is explained in Chapter XXI.

QUESTION 347. *How are the pumps worked by the piston?*

Answer. The pump-plunger, 4, figs. 221 and 224, is attached to a projection, *W*, called the *pump-lug*, cast on one of the slides of the cross-head. The plunger thus receives a reciprocating motion from the piston.

QUESTION 348. *What are the connecting-rods for?*

Answer. The rods which connect the cross-heads to the main crank-pins—which are called *main connecting-rods*—commuuicate the pressure on the piston to the main crank-pin. The rods which connect or couple the crank-pins on adjoining driving-wheels together are called *coupling-rods*,* and they cause the wheels to revolve together.

QUESTION 349. *To what strains are the connecting-rods subjected?*

Answer. They are alternately subjected to a strain of tension and compression by the pressure of the steam on the pistons during their forward and backward strokes. They must also resist the centrifugal force due to their revolution, which produces a bending action on the rods.

QUESTION 350. *How are the connecting-rods made?*

* They are also often called *side* or *parallel-rods*, but the term *coupling-rods* is considered the best.

Answer. They are made of flat bars of wrought iron. Figs. 235 and 236 represent a side view and a plan of a main connecting-rod. It is attached to the wrist-pin of the cross-head at *A*, and to the crank-pin at *B*. Figs. 237 and 238 represent similar views of a coupling-rod. To save room in the engraving each of these rods is represented with a part of the middle broken away, and a transverse section of the middle of the rod is shown at *T* and *T*, between the broken ends. The main rods are usually made wider at *G*, next the crank-pin, than at the other end, as it has been found that they are most liable to break next to the "*big end*," *B*, as it is called, than at any other place. The coupling-rods are now made either straight or somewhat wider in the centre. To give them greater strength without increasing their weight too much, the sections of such rods are often made "*fluted*," as it is called—that is, with a section of the form of the letter I.

QUESTION 351. *How are these rods prevented from getting loose on the pins from the wear of the latter in the inside of the holes of the rods?*

Answer. By a stub-end or strap-end similar to that described in answer to Question 99. The ends of the rods are provided with what are called *brass bearings*, or "*brasses*," *c d* and *e f*, figs. 235 and 236. These brasses are made in pairs, so as to embrace the pins from each side. They are held by U-shaped clamps, *s s s*, called *straps*, which are bolted to the rods. When the brass bearings become worn, they are taken out of the straps, and a portion of their surfaces of contact with each other is filed away, thus allowing them to come nearer together, and thereby reducing the size of the hole which receives the pin or journal. In order to prevent their being loose in the straps, tapered or wedge-shaped *keys*, *k k*, are fitted in the straps and rods. By driving down these keys, the straps are drawn against the brass bearings and they are forced together, thus reducing the size of the hole for the journal, and making the rods fit tightly on the pins. A hard steel plate, *p*, fig. 235, is sometimes interposed between the keys and the brasses to prevent the key from indenting the surface of the soft brass. As the keys are very liable to get loose and fall out, they are held either by screws and nuts, *x x*, as shown on the left-hand side of the engraving, or, as shown at the other end of the rod, by a *set-screw*, *r*, on the other side of the rod. The ends of coupling-rods sometimes have stub-ends, as shown in figs. 237 and 238, but are often made without, and with simple *bushings* or brass-rings, *b b*, driven into holes in the ends, as shown in fig. 239. When these bushings become worn they are taken out and new ones are put in their places.

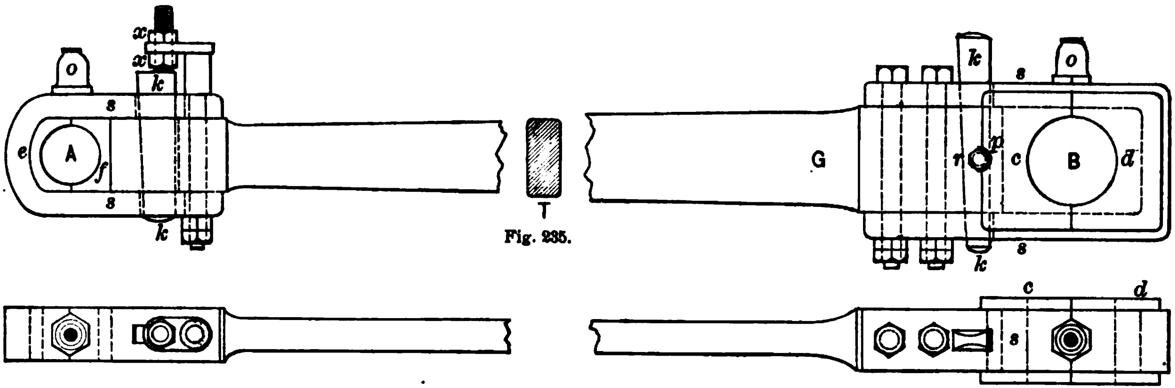


Fig. 236. Main Connecting-Rod. Scale 1 in. = 1 ft.

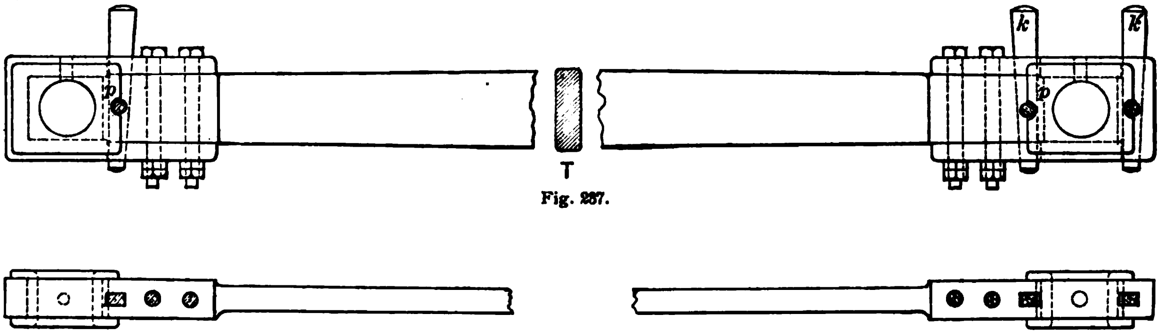


Fig. 238. Coupling-Rod. Scale 1 in. = 1 ft.

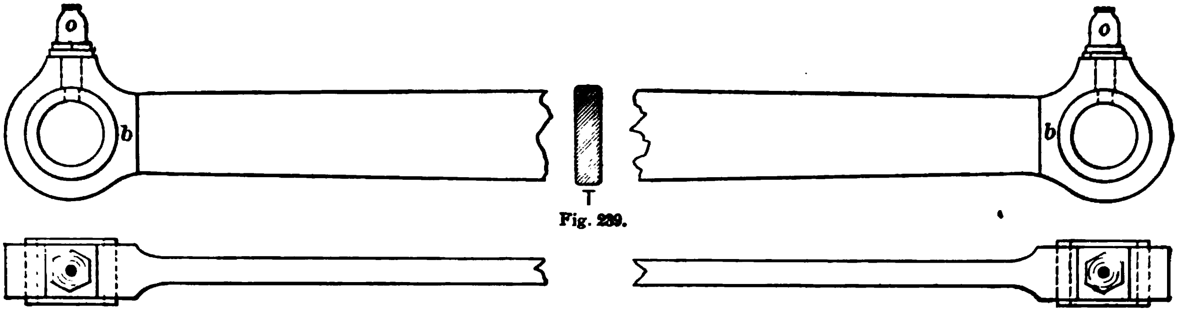


Fig. 239.

Fig. 240. Coupling-Rod. Scale 1 in.—1 ft.

QUESTION 352. *How are the journals of the crank-pins oiled?*

Answer. By oil-cups, *o o*, figs. 235-240, attached to the straps above the journals, similar to the cups used on the *guide-rods*. Sometimes *oil-cellars*, as they are called, are attached to the under side of the straps. These are metal boxes, which are filled with oil, which is agitated violently by the rapid motion of the rods, and is thus applied to the journals through holes drilled in the straps. In order to confine the oil and prevent its leaking out around the journals of the coupling-rods, the brasses are sometimes made so as to enclose the outside end of the crank-pin, which thus not only keeps the oil in, but excludes the dust. The brasses are usually lined with Babbitt's or some other kind of soft metal, which is thought to be less liable to heat from the friction of the journals.

QUESTION 353. *What is meant by the term "lost motion"?*

Answer. It is used to designate the wear of machinery, whicn causes a loss of motion in some of the parts. Thus, if the bearings of the main connecting-rods are worn, the piston must move a distance equal to the wear at each end of the stroke before it moves the crank-pin. Lost motion might therefore be called the looseness of the parts. When we speak of *taking up* the lost motion, we mean making parts which were loose, fit tightly.

CHAPTER XVI.

THE VALVE-GEAR.

QUESTION 354. *What is meant by the valve-gear of a locomotive?*

Answer. By the valve-gear is meant the arrangement of mechanism consisting of eccentrics, rods, links, rockers, etc., by which the valves are moved and their motion is regulated.

QUESTION 355. *What is required of the valve-gear in working a locomotive?*

Answer. It must be so arranged that the locomotive can be run either backward or forward, and so that the motion of the wheels can be reversed quickly and with certainty. It should enable the runner to employ the greatest power of the engine by admitting steam into the cylinders during the whole or nearly the whole of the stroke of the pistons, or, when less power is required, to use the steam more economically by working it expansively.

QUESTION 356. *How is the valve-gear constructed so as to run the engine backward or forward?*

Answer. As already explained, in answer to Question 189, two eccentrics are provided for each cylinder. These are set so that one of each pair will run the locomotive in one direction, and the other two the reverse way.

QUESTION 357. *How must the eccentrics for each cylinder be set in order that the one may run the engine forward and the other backward?*

Answer. This can be best explained by reference to fig. 241, in which the piston, *P*, is represented at the beginning of the backward stroke, and the valve, *V*, has the requisite lead, and is just about to open the front steam-port, *c*. It is obvious that, in order to complete the backward stroke of the piston, the front port, *c*, must be opened to admit steam into the front end of the cylinder, and, therefore, the valve must be moved in the direction indicated by the dart, *a*. To do this, the upper arm of the rocker, *R*, must move in the same direction indicated by the dart, *a'* and the lower arm must be moved the reverse way, as indicated by the dart, *b*. If the crank is intended to move in the direction indicated by the dart, *N*, then the centre of the eccentric, *J*, must be above the centre of the shaft or axle, to move the lower end of the rocker in the direction indicated by the darts, *b* and *m*. Supposing, however, it was intended to move the crank the reverse direction, as shown by the dart, *N*, in fig. 242, it is evident in that case that the valve must be moved in the same direction as before, to open the front steam-port, *c*, and thus admit steam to force the piston back. But if the crank turns in the direction shown by the dart, *N*, fig. 252, then the centre of the eccentric, *K*, must be placed *below* the centre of the axle to move the lower rocker arm in the direction of the darts, *b* and *n*, and the valve in that indicated by *a*. It will thus be seen that the centre of the eccentric for running forward and that of the one for running backward must be placed, the one, *J*, above and the other, *K*, below the centre of the axle at the beginning of the stroke of the piston, as shown in fig. 242.

QUESTION 358. *Why is it that the centres of the eccentrics are not placed opposite to each other on the axle?*

Answer. Because before the beginning of the stroke of the piston it is necessary to move the valve from its middle position a distance equal to the lap before the steam-port begins to open. If we had a valve without any lap, the centres of the eccentrics could be placed at right angles, or, as mechanics say, "square" with the crank, and exactly opposite to each other, because such a valve would begin to take steam as soon as it moved from the middle of the valve-face. But if we have a valve like that shown in fig. 67, it is plain that before it will admit or *take* steam as it is called, in either of the steam-ports, it must be moved from the centre of the valve-face, or its *middle position*, a distance equal to the lap, *L*. For this reason, therefore, the eccentric, instead of being placed at *half-throw*,* as it is called, must be so far ahead of the middle position as to have moved the valve a distance equal to its lap, and if any lead is given to the valve, equal to the lap and lead together. In figs. 241, 242 and 243, *f g* is a vertical line at right angles to the crank at the beginning of the stroke. It will be seen that the centre of each of the eccentrics is set far enough ahead of this line to give the valve the required lead. When the piston reaches the back end of the cylinder, the two eccentrics will occupy the position shown in fig. 243, in which position the lower one, *J*, would move the valve so as to turn the crank in the direction of the dart, *N*, and the upper one, *K*, will turn it in the reverse direction. It will be seen

* This would be at right angles to the crank when it is at a dead point, and the piston is at the end of the stroke.

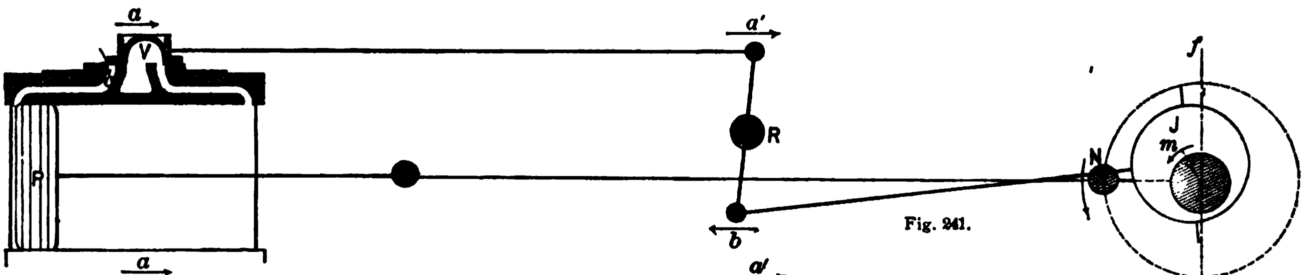


Fig. 241.

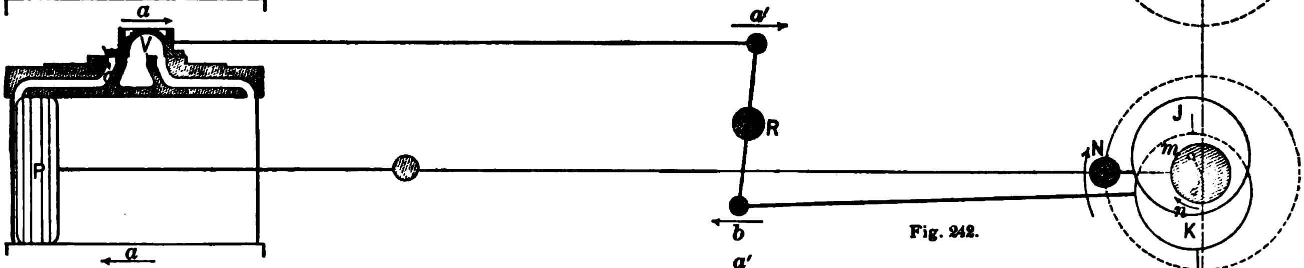


Fig. 242.

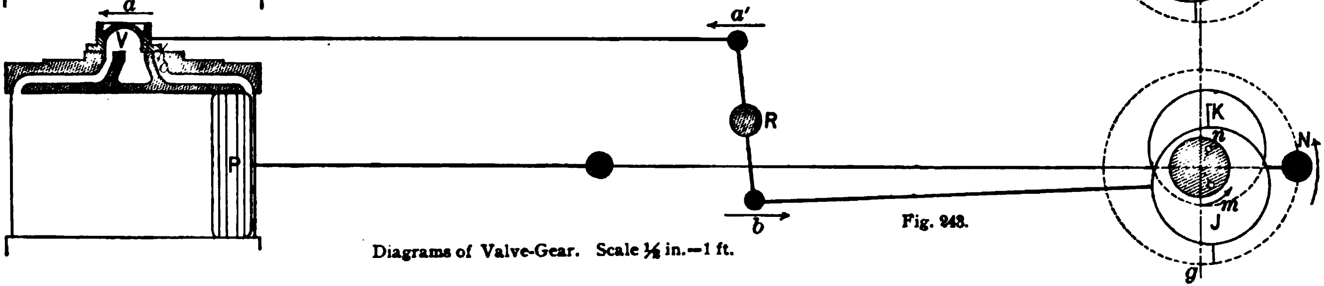


Fig. 243.

Diagrams of Valve-Gear. Scale ⅛ in.—1 ft.

that in this position both of the eccentrics are again ahead of their half-throw when the piston is at that end of the stroke.

QUESTION 359. *How is the motion of either eccentric communicated to the valve?*

Answer. The ends of each pair of eccentric-rods are connected to-

Fig. 244.

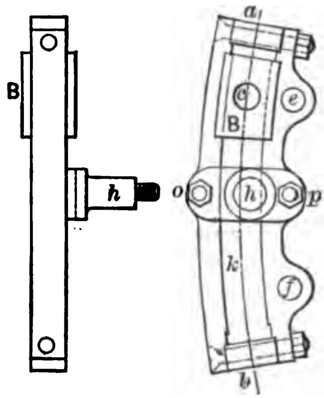


Fig. 245.

Link. Scale 1 in.—1 ft.

gether by a link, *a b*, figs. 244, 245 and 246. This link has a curved groove or slot, *k*, in it, in which a block, *B*, fits accurately, so that it can slide freely from one end to the other. This block is attached to the lower rocker-arm, *N*, Fig. 246, by a pin, *c*, which works freely in the block. The two eccentric-rods, *C* and *D*, are attached near the ends of the link, at *e* and *f*, by pins and knuckle-joints. It is apparent that if the link is down, or in the position shown in fig. 246, and also in the diagram, fig. 247, drawn on a smaller scale, the motion of the upper eccentric-rod, which is usually used for the forward motion, will be imparted to the rocker, and thus to the valve, and when the link is in the position shown in fig. 248 that the valve will be moved by the lower or backward eccentric-rod, *D*. In order to reverse the engine, it is then only necessary to provide the means of raising and lowering the link. This is done by a shaft, *A*, fig. 246, called a *lifting-shaft* which has two horizontal arms, *E*,* one for each link, and a vertical arm, *F*. Each link is suspended

* Only one of these is shown in the engraving.

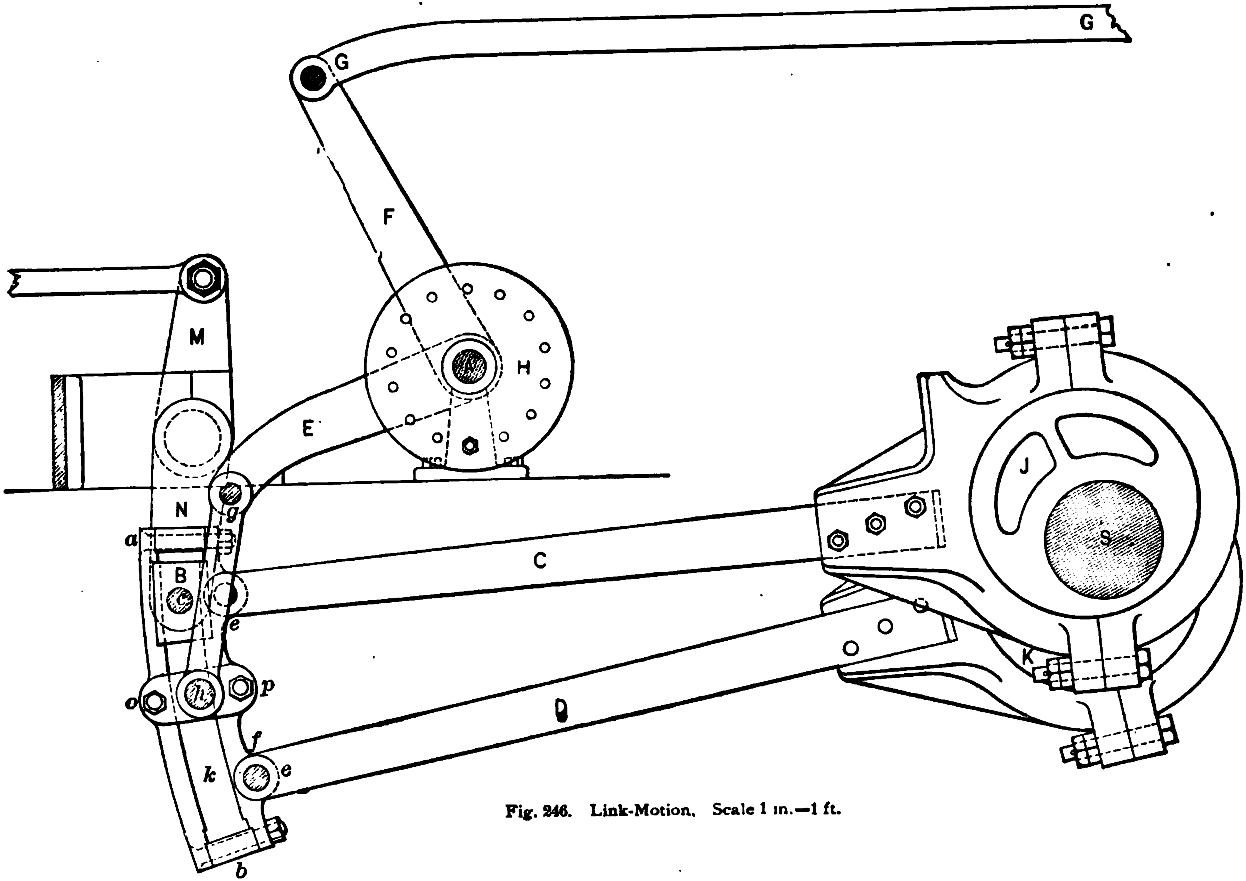


Fig. 246. Link-Motion. Scale 1 in.—1 ft.

from the end of one of the horizontal arms by a rod or bar, *g h*, called a *link-hanger*, which is connected to the link and to the arm above by pins, *h* and *g*, which enable the hanger to vibrate freely. The lower pin is attached to a plate, *o p*, called a *link-saddle*, which is bolted to the link. The vertical arm, *F*, of the lifting-shaft is connected by a rod, *G G*, called the *reverse-rod*, to a lever, 20 21, Plates III and IV, in the cab called a *reverse-lever*, the construction of which will be explained hereafter. This lever is worked by the locomotive runner, and by moving the upper end of it forward, the link will be lowered into the position shown in fig. 246, and also in the diagram, fig. 247, and the rocker and valve will then be moved by the forward eccentric; and if the reverse lever is moved back, the link will be raised into the position shown in fig. 248, and the backward eccentric will then move the valve. When this is done, the valve-gear is said to be thrown into the *forward* or *backward motion*, or *forward* or *back gear*.

QUESTION 360. *How is the steam made to work more or less expansively?*

Answer. By changing the travel of the valve.

QUESTION 361. *How is the travel of the valve changed?*

Answer. By either raising or lowering the link so that the link-block and rocker-pin will be some distance above or below the eccentric-rods. Thus in fig. 247, the motion of the upper eccentric-rod, and in fig. 248 that of the lower or *back* eccentric-rod is communicated to the rocker-pin and the valve. If, however, the link should be raised so that the link-block and rocker-pin are somewhat below the upper or forward eccentric-rod, as shown in fig. 249, then the motion imparted to the rocker and valve will partake somewhat of that of the upper and also of the lower eccentric-rod. So long as the rocker-pin is above the centre of the link, the motion of the valve will partake most of that of the upper or forward rod, and the engine will then run forward; but when the rocker-pin is below the centre of the link its motion will be influenced more by the back eccentric-rod, and the engine will then run backward.

The motion of the link, which is somewhat complex and difficult to understand clearly, will perhaps be understood better if we represent it in a number of successive positions of the whole stroke of the piston, as was done to show the motion of the eccentric in figs. 30 to 43. We will therefore suppose that the link is in what is called *full-gear forward*, as shown in figs. 251 to 262. In fig. 251 the link is in the position it would occupy when the piston is at the beginning of its stroke; in fig. 252 it is in that

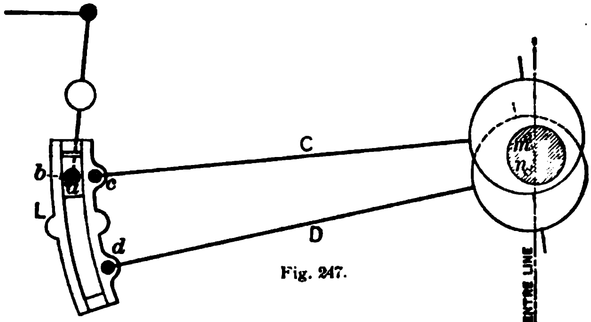


Fig. 247.

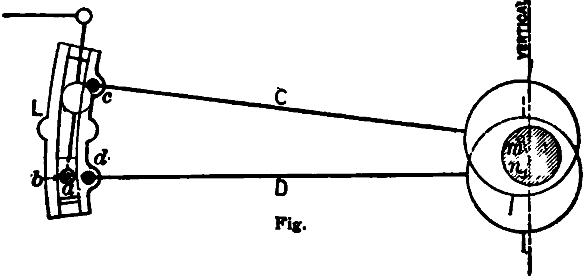


Fig.

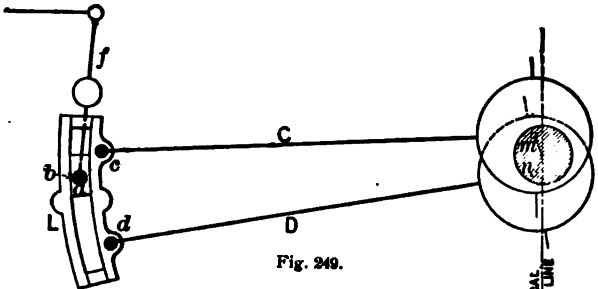


Fig. 249.

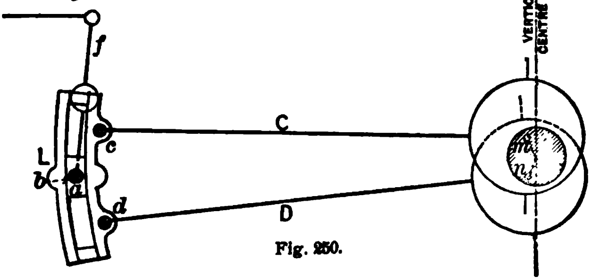


Fig. 250.

Diagrams of Link-Motion. Scale ⅛ in.—1 ft.

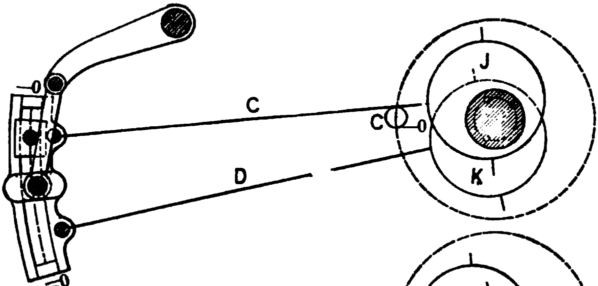


Fig. 251.

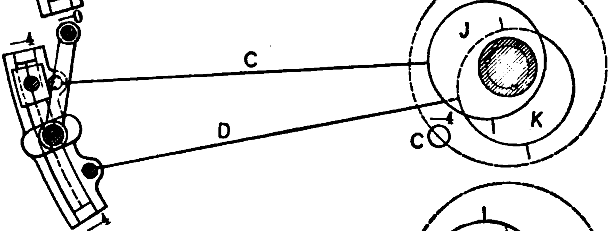


Fig. 252.

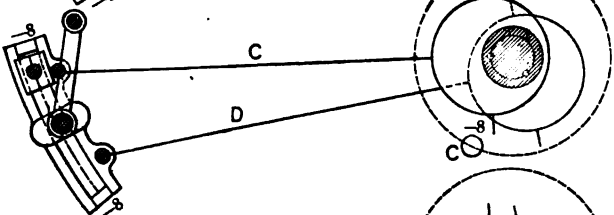


Fig. 253.

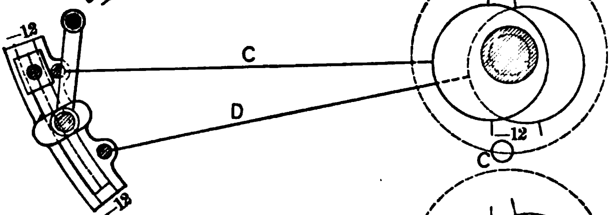


Fig. 254.

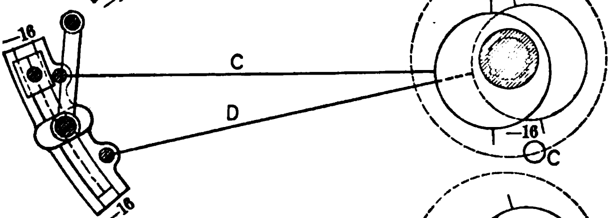


Fig. 255.

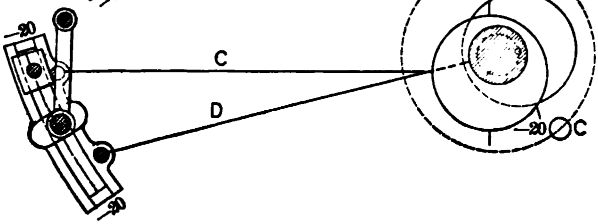


Fig. 256.

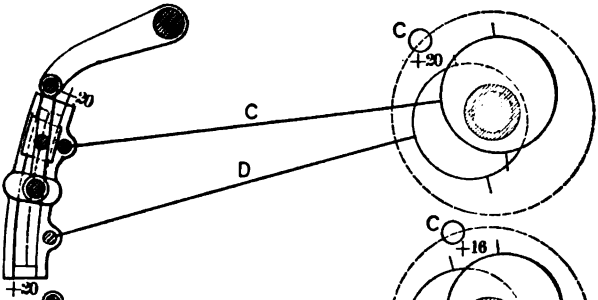


Fig. 262.

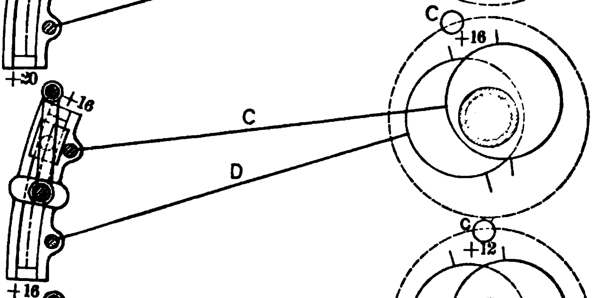


Fig. 261.

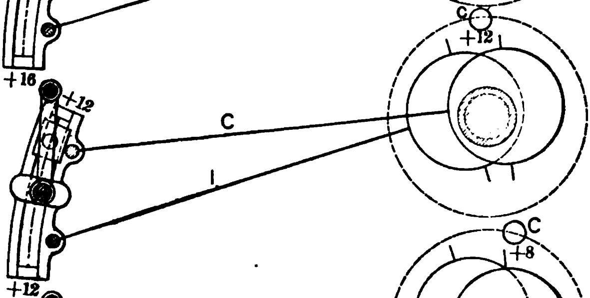


Fig. 260.

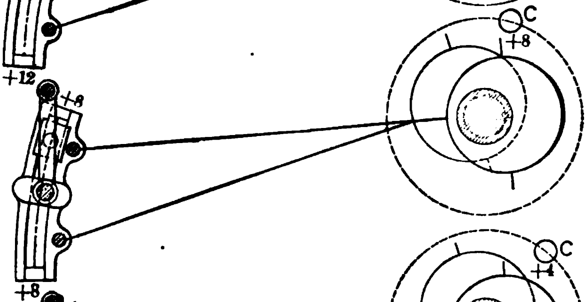


Fig. 259.

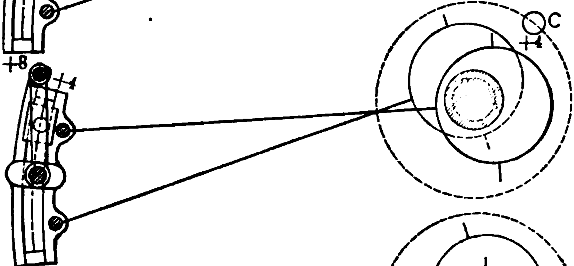


Fig. 258.

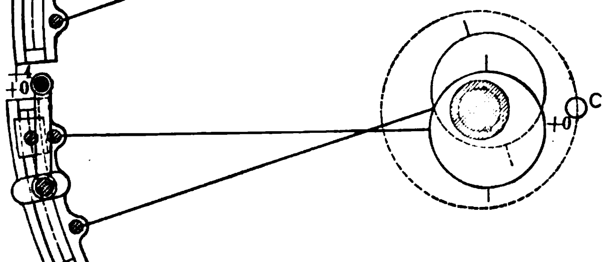


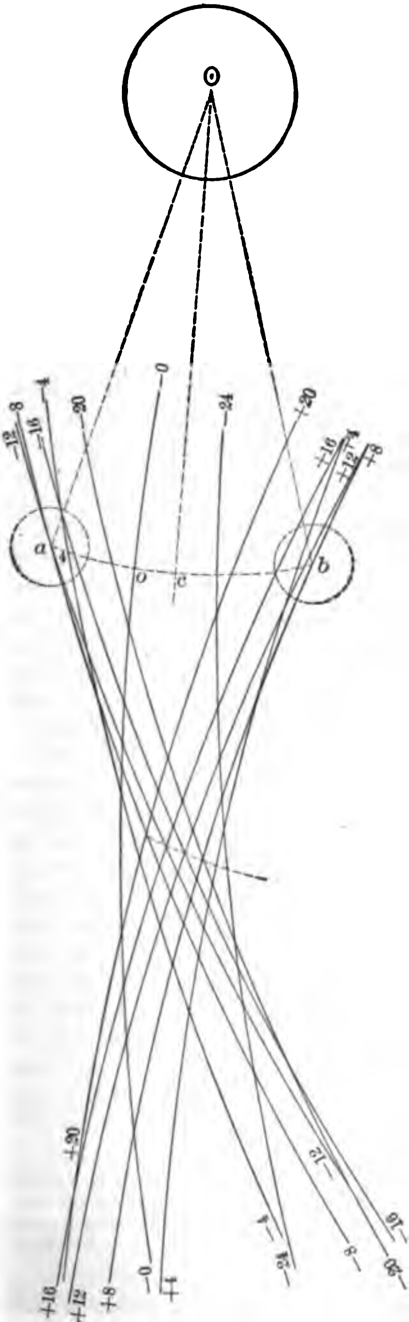
Fig. 257.

which it will be in when the piston has moved 4 inches; in fig. 253, when it has moved 8 inches; in fig. 254, 12; and in figs. 255, 256 and 257, 16, 20 and 24 inches. Figs. 257 to 262 represent the successive positions of the link during the return stroke.

In these figures the centre-line of the slot in the link is represented by dotted lines, which are indicated by numbers preceded by a — or + sign. The numbers represent the distance that the piston has moved from the beginning of the stroke, when the link is in the position shown, and the — sign indicates the backward stroke of the piston, and the + sign its forward stroke. Thus in fig. 252 the figures — 4 — 4 indicate the dotted centre-line, and also designate that the piston has moved 4 inches from the beginning of its backward stroke; when the link is in the position represented, and — 8 — 8, in fig. 253, that it has moved 8 inches of its backward stroke. To show the action of the link, the successive positions of the centre-lines represented by figs. 251 to 262 have been laid down on a larger scale in the diagram, fig. 263. For greater clearness the centre-lines are represented in full instead of by dotted lines, and are indicated by the same sign and numbers in the diagram, fig. 263, that were used in figs. 251 to 262.

O, fig. 263, represents the rocker-shaft, and the arc, *a b*, the path in which the centre of the lower rocker-pin moves. As the centre of the rocker-pin is always in the centre-line, *a b*, fig. 245, of the link, it is evident that when the link is in the positions shown in figs. 251 to 262, and in 263, that the rocker-pin will be moved from *a* to *b* by the action of the link, or a total distance of 5¼ inches.

If, however, the link was raised up into the position shown in fig. 249, so that the rocker-pin is half-way between the end of the eccentric-rod and the centre of the link, then the action of the link in relation to the rocker would be as represented in fig. 264, in which the different positions of the centre-line of the link and of the rocker have been laid out with the link raised up for *half-gear*, as it is called, in the same way as was done for full-gear before. From this it will be seen that the travel, *a b*, fig. 264, imparted to the rocker-pin and valve by the link when it is in the position shown, instead of being 5¼ inches is now only 3¼ inches. In fig. 250 the link is represented in the position it would be in when it is raised up, so that the rocker-pin would be in the centre of it or midway between the eccentric-rods. This position is called *mid-gear*. The successive positions of the centre-line of the link in this position have been laid down in fig. 265, in the same way as was done for full and half-gear.



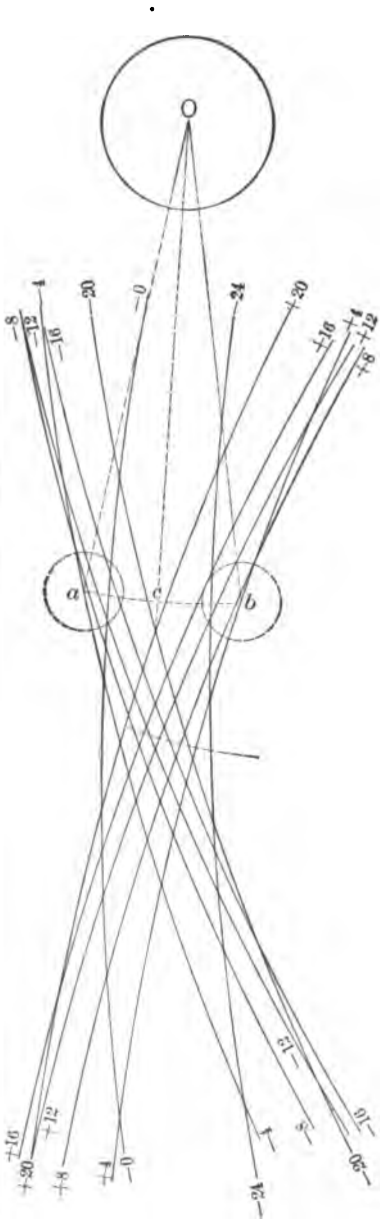


Fig. 264.

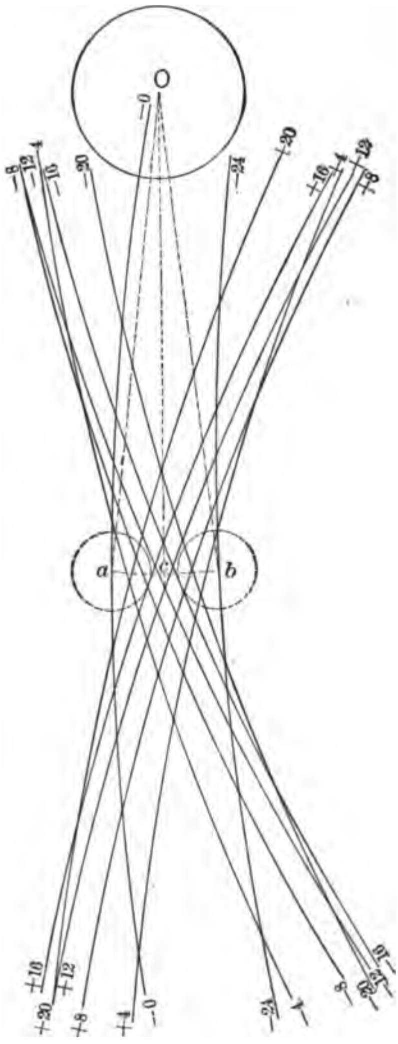


Fig. 265. Diagram of Movement of Link. Scale ¼ in.—1 in.

The movement of the rocker, it will be seen from this figure, is, for mid-gear, only 2¼ inches.

These diagrams show that when the rocker-pin is opposite the eccentric-rod, as in figs. 247 and 248, the valve receives the full or more than the full throw of the eccentric,* and that the motion imparted by the eccentric diminishes as the rocker-pin approaches the centre of the link, as in figs. 249 and 250, so that, with eccentrics having 5 inches throw, and a valve with ⅞ lap and ⅛ inch lead, we can increase or diminish the travel of the valve from 2¼ to 5⅛ inches by simply raising or lowering the link, which is done by the reverse-lever.

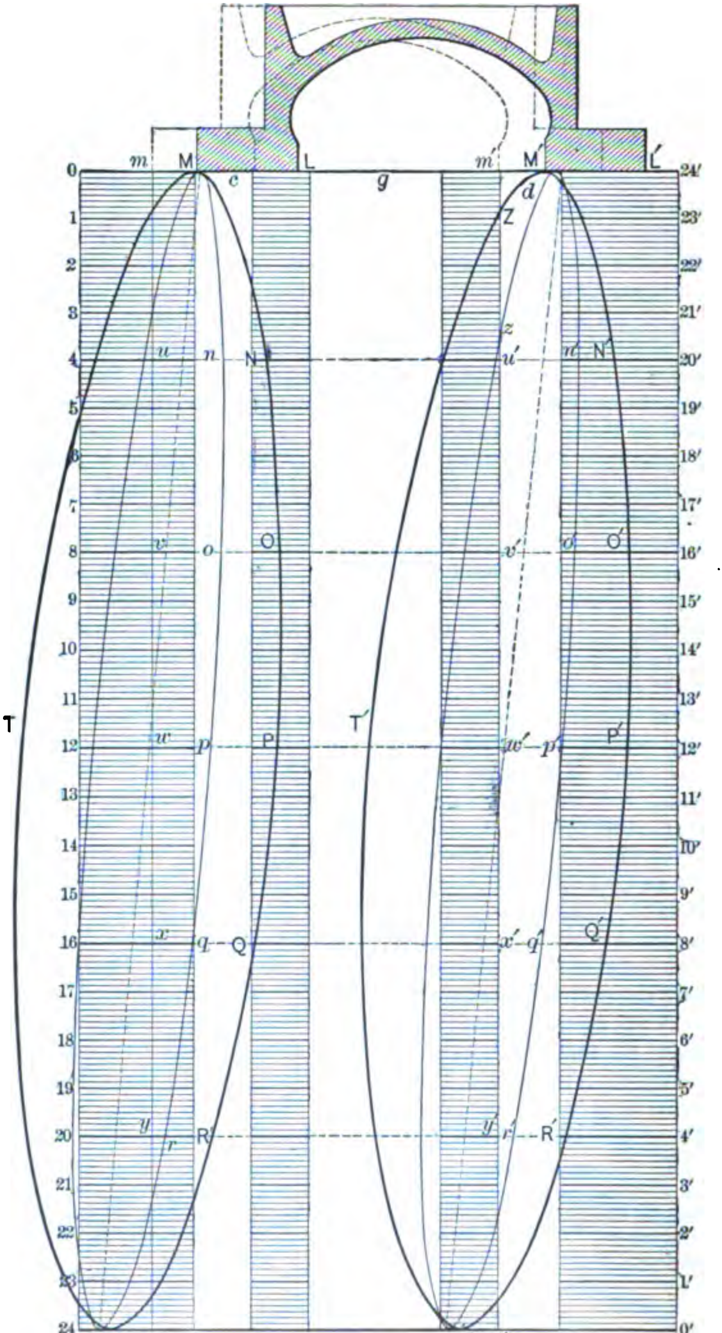
QUESTION 362. *What is the effect of this variation of travel on the working of the valve and the admission and release of steam to and from the cylinder?*

Answer. It is almost precisely the same as that which is effected by increasing or diminishing the throw of an eccentric, which was explained in the answer to Question 147. In order to show this effect more clearly, we have represented by motion-curves, fig. 266, the movement imparted to the valve by the link when it is in full, half, and mid-gear, as illustrated in the preceding figures. The curve for full-gear is engraved in full heavy lines; that for half-gear, in lighter lines, and for mid-gear, in dotted lines.

QUESTION 363. *What may be learned from these motion-curves?*

Answer. They show the exact motion of the valve in relation to the steam and exhaust-ports during a complete revolution of the crank. Thus, if we take the curve, *M N O P Q R S*, drawn in heavy lines, and which represents the movement of the outer edge of the valve in full-gear in relation to the port, *c*, it will show first the lead of the valve at *M*. Then the intersection of the curve with the inner edge of the port above the horizontal line, 3 21′, shows that the port, *c*, is then wide open. The outer edge of the valve then moves beyond the inner edge of the port, until the curve gets below the line, 16 8′. The horizontal lines, 0 24′, 1 23′, 2 22′, etc., represent inches of the stroke, and the intermediate lines divide the inches into eighths, as has been explained. The position of the curve on those lines, therefore, indicates that of the valve when the piston is at a corresponding distance from the beginning of its stroke. The diagram shows then that at 2⅛ inches of the stroke the port, *c*, is wide

* When the block is opposite the eccentric-rod at the beginning of the piston stroke, the link moves it a distance somewhat greater than the throw of the eccentric, owing to the fact that when the link assumes the inclined position, shown in figs. 206 and 207, the block slips upward in the link-slot. This slip of the block is, however, dependent on the way in which the link is suspended.



m M c L g m′ M′ L′ d Z z
u n N u′ n′ N′
v o O v′ o′ O′
T T′
w p P w′ p′ P′
x q Q x′ q′ Q′
y r R y′ r′ R′
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
24′ 23′ 22′ 21′ 20′ 19′ 18′ 17′ 16′ 15′ 14′ 13′ 12′ 11′ 10′ 9′ 8′ 7′ 6′ 5′ 4′ 3′ 2′ 1′ 0′

open, and that the valve begins to close it at 16¾ inches of the stroke. The intersection of the curve with the outer edge of the port, *c*, below the line, 21 3′, shows that this port is then closed, or the steam is cut off by the valve when it is working in full-gear.

The curve, *M′ N′ O′ P′ Q′ R′ S′*, shows the movement of the exhaust edge of the valve. It will be seen that at the beginning of the stroke, as shown at *M′*, the port, *d*, is nearly wide open for the escape of the steam, which is in the back end of the cylinder. The intersection of the curve with the outer edge of the port a little below the line, 20 4′, shows that the valve has then commenced to close the port, *d*, and another intersection with the inner edge below the line, 23 1′, indicates that it is entirely closed before the piston has reached the end of the cylinder. The steam which remains in it when the valve closes is then compressed by the piston as it advances to complete its stroke. For this reason the point where the valve closes the port to the exhaust is called the *point of compression.* If we follow up the reverse side of the curve it will be seen that it intersects the inner edge of the port, *e*, at *Z*, or near the line, 1 23′. This shows that the port, *e*, is opened to the exhaust before the piston has completed its stroke. This is called the *point of pre-release.*

In the same way we may follow the curve, *M n o p q r S*, which shows the movement of the valve in mid-gear. It shows that at no time is the port wide open, and steam is then cut off at about 15¾ inches of the stroke, and that the curve, *M′ n′ o′ p′ q′ r′ S′*, shows that the valve begins to close the exhaust-port, *e*, to the exhaust at about 12 inches of the stroke, and that compression begins at about 21½ inches. The intersection of the opposite side of this curve with the inner edge of the port, *d*, at *z*, shows that *pre-release* or exhaust begins while the piston must still move 3½ inches to complete its stroke.

The dotted lines, *M S* and *M′ S′*, show the motion of the valve in mid-gear, and the curve then becomes a straight line. The greatest opening of the steam-port, for the admission of steam, is then no greater than the lead.

It is of course possible to work the link in any intermediate position between those which have been represented.

QUESTION 364. *What is the greatest and the least admission of steam possible with the ordinary link motion?*

Answer. With 24 inches stroke of piston and 5½ inches travel and ⅞ inch lap, steam can be admitted as shown by the motion-curves during 21½ inches, or nearly 90 per cent. of the stroke, and can be cut off at about

3 inches or 12½ per cent. In mid-gear the *pre-admission* of steam—that is, the admission of steam before the piston reaches the end of the stroke, is equal to that admitted after, so that it is impossible to work the locomotive with the link in that position. Practically it is found that little useful work can be done with a link if the steam is cut off at less than 6 inches, or one-fourth of the stroke. Even then the opening of the steam-ports is so small that the steam which enters the cylinders is liable to be wire-drawn.

QUESTION 365. *How are the curves drawn which represent the motion of the valve?*

Answer. These motion-curves as produced by the link-motion are difficult to draw, as the motion of the link is very complicated. It is doubtful, therefore, whether those who have no knowledge of mechanical drawing will be able to understand the following description of the method of doing it.

In the first place, the centre, *S*, fig. 267, of the axle, *O* of the rocker, and *A* of the lifting-shaft must be laid down in their proper positions. If, now, the valve has ⅞ inch lap and $\frac{1}{16}$ lead, it must be $\frac{15}{16}$ inch from its middle position, and the lower rocker-pin, *c*, must be the same distance ahead when the piston is at the front end of the cylinder and at the beginning of the backward stroke. We will, therefore, mark the centre, *c*, of the rocker-pin that far ahead of the vertical centre-line, *m n*, which represents the central position of the rocker.

If from the centre of the axle a circle, *o p q*, be drawn, whose diameter is equal to the throw of the eccentrics, this circle will represent the path in which the centres of the eccentrics will revolve.

Another circle, *H I J N*, whose diameter is equal to the stroke of the piston, should be drawn from *S*, as a centre, to represent the path of the centre of the crank-pin. If the distance from the centre, *S*, of the axle to the centre of the lower rocker-pin, *c′*, when the latter is in its middle position, be taken for a radius, and from the position, *c*, of the rocker-pin, at the beginning of the stroke, as a centre, the circle representing the path of the eccentrics be intersected at two points, *o* and *p*, the points of intersection will represent the positions of the centres of the forward and backward eccentrics at the beginning of the stroke of the piston. Having determined these positions, lay off a distance, *c e*, from *c*, the centre of the rocker-pin, equal to the distance, *c e*, fig. 245, of the centre-line of the link from the centre of the pin, *e*, by which the eccentric-rod is connected to the link. Then the distance, *e o*, fig. 267, will be the length of the

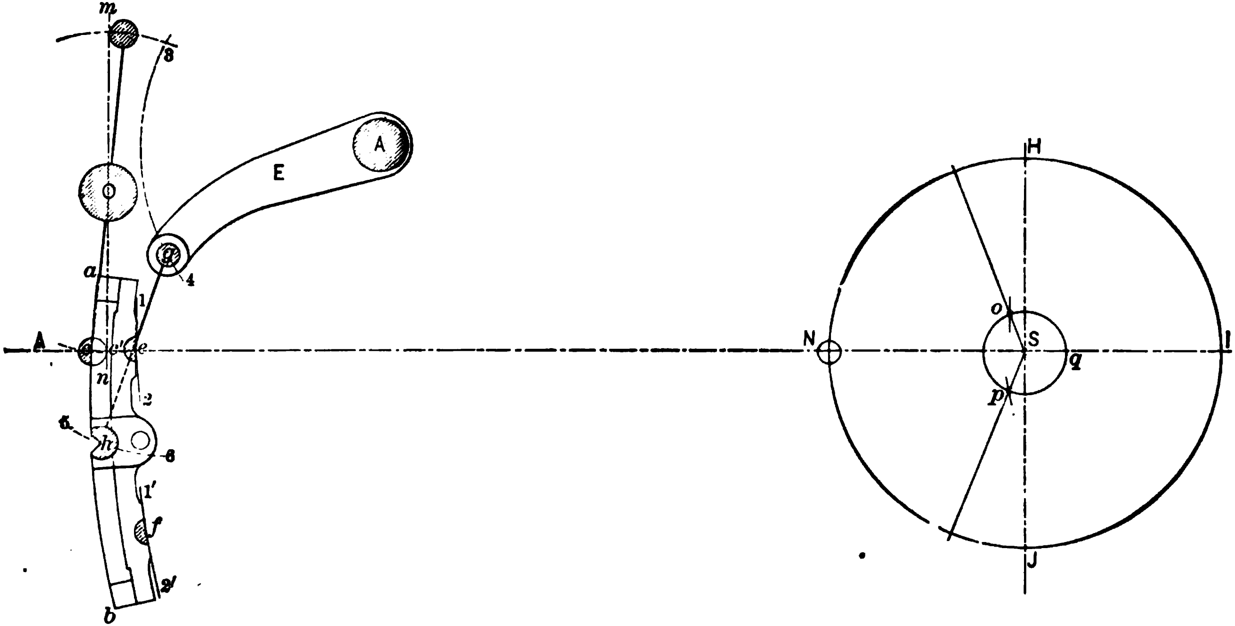


Fig. 267. Diagram Showing Method of Laying Out Motion of Valve. Scale 1 in.—1 ft.

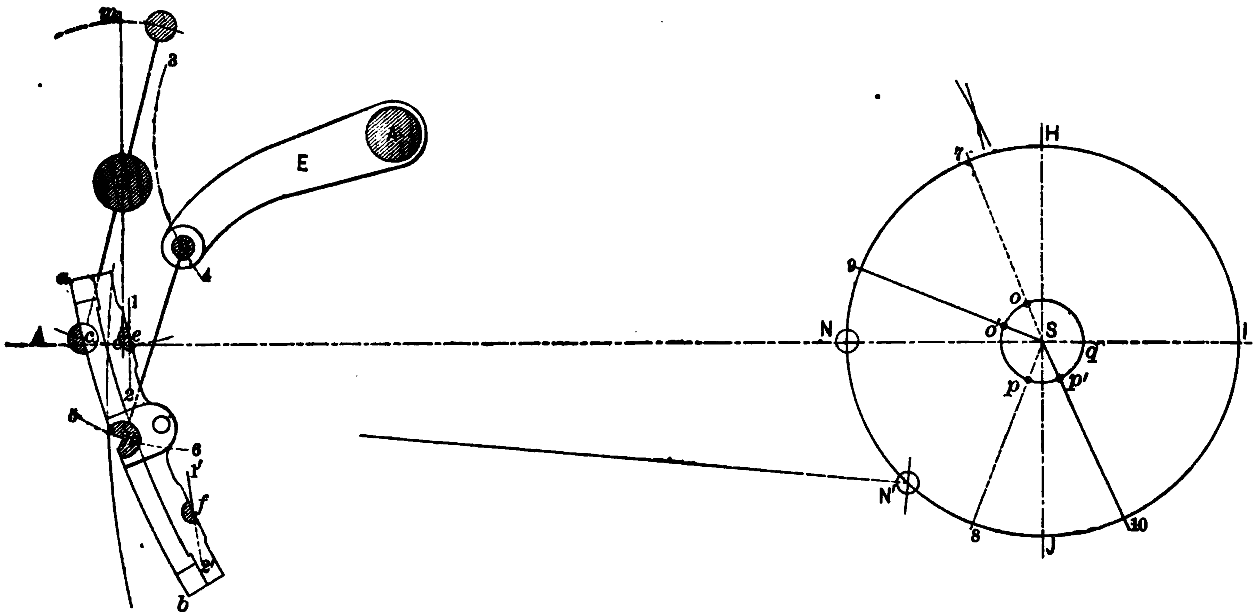


Fig. 268. Diagram Showing Method of Laying Out Motion of Valve. Scale 1 in.—1 ft.

eccentric-rod. With the distance as a radius, and *o* and *p* as centres, describe two arcs, 1 2 and 1′ 2′. Having laid down the position of the lifting-shaft, *A* with *A g*, equal to the length of the lifting-arm, *E*, describe an arc, 3 4. As the link is suspended from *g*, by the hanger, *g h*, which oscillates from the end, *g*, of the lifting-arm in the arc, 5 6, and as the lifting-arm, for any one point of cut-off, is stationary, therefore, the point of suspension of the link must always be on the arc, 5 6, described from the centre of the pin, *g*, in the lifting-arm, with a radius equal to the length of the hanger. As the eccentric-rods are connected to the link by pins, *e* and *f*, their centres must always coincide with the arcs, 1 2 and 1′ 2′, described from the centres of the eccentrics by the length between the centres of the eccentric-rods as a radius.

To locate the position of the link, a drawing like fig. 245 should be made on a thin board, card or a stiff piece of paper. Then cut away the portion on the left of the centre-line, *a b*, as shownin fig. 269, so as to

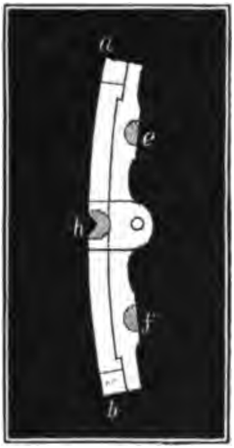


Fig. 269. Template of Link. Scale 1 in.—1 ft.

leave an exact outline of the centre-line of the link. Draw lines through the centres, *e* and *f*, of the pins by which the rods are attached to the link, and cut off the portion on the right-hand side of these lines. As the centre of suspension is usually back of the middle of the link, a notch should be made on the front side, as shown at *h*. Having cut the board or paper accurately to the form of the link, lay it on the drawing, fig. 267, so that the centres, *e* and *f*, will be on the arcs, 1 2 and 1′ 2′, and the centre of suspension, *h*, will be on the arc, 5 6. When these three points coincide with the three arcs, the template will be in the position that the link would occupy when it is suspended from the point, *g*, and the centres of the eccentric are in the position shown. When the position of the link is thus determined, draw a line on the edge, *a b*, to represent the centre-line of the link in that position.

Another position of the link may be laid out as follows: By the method described in answer to Question 143, lay down the position, *N′*, fig. 268, of the crank-pin when the piston has moved any distance, say 4 inches of its stroke. Lay out the position of the centres, *o* and *p*, of the eccentrics, the same as in fig. 267, and draw lines, *S o 7* and *S p 8*, from the centre, *S*, of the axle through the centres, *o* and *p*, and intersecting the circle, *H I J N*, at 7 and 8.

Now, the crank-pin turns from *N* to *N′*, while the piston is moving 4 inches from the front end of the cylinder. This is called its *angular motion*. As the crank and eccentrics are all fastened to the axle, they must all have an equal angular motion while the crank-pin is moving from *N* to *N′*. Therefore, if with a pair of dividers we take the distance, *N N′*, and lay it off from 7 to 9, and from 8 to 10, and draw lines from 9 and 10 to the centre, *S*, of the axles, the intersection of these lines at *o′* and *p′*, with the circle, *o p q*, will represent the angular motion of the eccentrics, while the crank-pin is moving from *N* to *N′*, and *o′* and *p′* will be the position of the centres of the eccentrics when the crank-pin is at *N′*. From these centres, with the length of the eccentric-rods as a radius, describe the arcs, 1 2 and 1′ 2′, as before. Draw the arc, 5 6, as in fig. 267, and then lay the template of the link, fig. 269, on the drawing, and make its centres, *h e* and *f*, coincide with these arcs as before, and it will then represent the position of the link when the piston has moved 4 inches, and the crank-pin is at *N′*. A line drawn along the edge, *a b*, will represent this position of the centre-line of the link. This process can be repeated for successive positions of the piston and crank-pin.

Such diagrams as have been described should be drawn to a larger scale than the engravings—preferably full size—and great care must be taken to lay them out with the greatest precision. A thin, white pine board—about $\frac{3}{32}$ inch thick—is the best material to make the template of the link of. The outline, *a b*, must conform accurately to the centre-line of the link.

QUESTION 366. *Having laid out the successive positions of the link, as shown in figs. 263-265, how are the motion-curves, fig. 266, drawn from them?*

Answer. In fig. 263 the arc, *a b*, represents the path of the centre of the rocker-pin, and the dotted line, *O c*, the middle position of the lower rocker-arm but on a larger scale than figs. 267 and 268. The distance from *c* of the point of intersection, *o*, of the line, — *o* — *o*, with the arc, *a b*, represents the movement of the valve from its middle position, when the piston is at the beginning of its backward stroke. In fig. 266 the dotted lines at *m* and *m'*, represent the position of the valve in the middle of the valve-face, the lines, *m* and *m'* representing the outer or steam edge and the inner or exhaust edge of the valve. As the valve will be moved a distance equal to *o c*, fig. 263, from its middle position when the piston begins its stroke,* and as the movement is reversed in direction by the rocker, if we lay off on the right side of *m* and *m'*, distances *m M* and *m' M'*, the points, *M* and *M'*, will represent the position of the edges of the valve at the beginning of the stroke. From *m* and *m'*, vertical lines, *m t* and *m' t'*, are drawn to represent the position of the two edges of the valve when it is in the middle of the valve-face for all points of the stroke.

Proceeding as before, in fig. 263, the distance from *c* of the point of intersection, 4, of the line, — 4 — 4, with the arc, *a b*, represents the movement of the valve from its middle position when the piston has moved 4 inches of its stroke. Taking this distance and laying it off from the vertical lines, *m t* and *m' t'*, on the horizontal line, 4 20', of fig. 266, we locate the points, *N* and *N'*, which represent the positions of the steam and exhaust edges of the valves when the piston has moved 4 inches. In the same way the distance from *c* of the intersections of the lines, — 8 — 8, — 12 — 12, — 16 — 16, etc., in fig. 263, with the arc, *a b*, can be laid down on the horizontal lines, 8 16', 12 12', 16 8', etc., of fig. 266, and the points, *O P Q*, etc., and *O' P' Q'*, etc., are thus located. The curves, *M N O P Q R S*, and *M' N' O' P' Q' R' S'*, can then be drawn through these points either by hand or by constructing wooden templates, and the intersection of these curves with the immediate horizontal lines, in fig. 266, will represent the position of the steam and exhaust edges of the valve in relation to the ports, *c g* and *e*, for any part of the stroke of the piston. The more points there are determined, the more accurate will be the

* This will be the case when the two arms of the rocker are of the same length, as they usually are, but sometimes they are of different lengths.

curves. It is, therefore, best to lay down the position of the valve for each inch of the stroke of the piston. The curves for the return stroke of the piston can be completed by drawing, *S T M*, and *S' T' M'*, in the same way.

The curves, *M n o p q r S*, and *M' n' o' p, q' r' S'*, which shows the motion of the valve when the link is in half-gear forward, or *M S*, *M' S'*, which show it in mid-gear, may be drawn in the same way from the diagrams, figs. 264 and 265, which represent the successive positions of the centre-line of the link when it is in half and mid-gear forward.

In the illustrations the upper and lower rocker-arms are represented as of the same length, as already explained; in some cases they are of unequal lengths, which of course affects the motion of the valve. In the diagram, figs. 267 and 268, the lower rocker-pin, *c*, is represented as being on the horizontal centre-line, *A N I*, drawn through the centre, *S*, of the axle. Usually the lower rocker-pin is located below this horizontal centre-line, so that the link will not strike the boiler when it is raised up to the back-gear.

QUESTION 367. *Is there any other method of drawing these motion-curves?*

Answer. Yes; models which show the working of the valve-gear have been constructed, to which the reciprocating motion of the valve is imparted, and which traces a curve with a pencil on the surface, having the same motion as the piston. This method has been employed by the writer in an instrument which he has applied to the locomotive itself. The principle upon which it works will be understood by supposing that the steam and exhaust-ports, as represented in the diagram for motion-curves, fig. 266, be drawn on a board, *A B C D*, fig. 270; but instead of standing vertical, as in fig. 266, the ports are represented in a horizontal position, and the board on which they are drawn is fastened to the cross-head, *L*, so that the former will move backward and forward simultaneously with the latter and the piston. A small shaft, *F*, is attached to suitable supports, *j*, which are fastened to the guide-bars. This shaft has two arms, *G* and *E*, one vertical and the other horizontal and of the same length. The upper end of the vertical one, *G*, is attached to the valve-stem or the rocker-arm by a short connecting-rod, *H*, or other suitable means, so that the movement of the upper rocker-pin and the valve-stem will be imparted to the arm and shaft. The end, *P*, of the horizontal arm, *E*, then has exactly the same motion vertically that the valve-stem and valve have horizontally, with the very trifling inaccuracy due to the

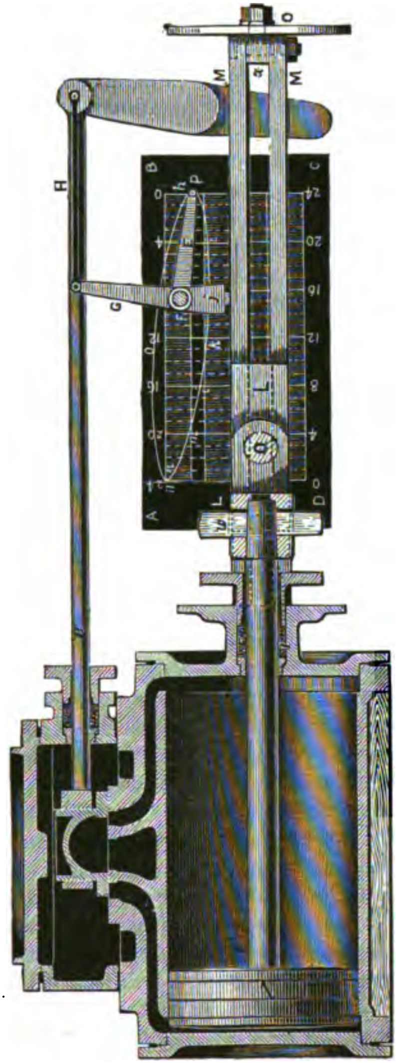


Fig. 270. Mechanism for Drawing Motion-Curves. Scale ¾ in.=1 ft.

fact that the movement of the one is in a straight line, whereas the other is now in the arc of a circle.

Now, if a pencil, *P*, is attached to the end of the horizontal arm, *E*, and is set so that its point indicates the exact position of the steam edge, *M*, of the valve, as shown in fig. 266, it is obvious that when the piston and board have moved 4 inches, the pencil will have moved downward and have drawn the portion of the motion-curve from *h* to *i*; and when the piston has moved 8 inches the curve will be drawn to *j*, and 12, 16, 20 and 24 inches of the stroke the curve will be drawn to *k l m* and *n*. During the return stroke a corresponding curve, *n o h*, will be drawn. With such an instrument curves can be drawn for any position of the link, and they will show the exact movement of the valve during the whole stroke, and will indicate all the defects resulting from bad proportions or construction, lost motion in the parts, or other causes of error or irregularity.

In using this instrument, however, it is usually impracticable to attach a board to the inside of the cross-head, and it must therefore be fastened to the outside. The horizontal arm, *E*, should be made of thin steel, so as to form a spring. The end has a small *boss*,* *P*, with a hole in it $\frac{3}{16}$ inch in diameter. This hole has a screw-thread cut in it, into which an ordinary hard drawing-pencil is screwed. The spring is so arranged that the pencil will not be in contact with the board unless it be pressed against it. The locomotive is then placed on a smooth piece of track with steam on and run very slowly, so that a person walking alongside can press the pencil against the surface of the board, which should be covered with drawing-paper. By watching the cross-head when it reaches the end of the stroke, the pencil can then be pressed against the paper and kept in contact through the whole stroke and instantly released when the motion-curve is completed. The link can then be placed in another position, and thus any number of curves can be drawn, which will furnish an accurate means of analyzing the motion of the valve.

In practice it is best not to draw the lines which represent the edges of the ports until after the curves are drawn and the paper removed from the board. A line must, however, be drawn on the engine from which to lay off the ports. This can be done by placing the valve in its middle position, and then fastening the shaft, *F*, with a nut which should be provided for that purpose on its end. After it is fastened in this position, detach the connecting-rod, *H*, and with one stroke of the piston a straight line can be drawn with the pencil, *P*. This line will correspond

* The term "*boss*" is used to imply an enlargemet or increased thickness of any part.

with the vertical line, *m t* or *m' t'*, fig. 266, and from it the ports, *c* or *d*, can be laid off so that the motion-curves will represent the movement of either the steam or exhaust edges of the valve in relation to the ports.

The valve can be placed in its middle position by putting the link in mid-gear and marking on the valve-stem its extreme movement each way at the stuffing-box of the valve-stem. Subdivide this distance on the valve-stem and move the subdivision to the point where the marks were made. The valve will then be in the middle of the valve-face, if the valve is set correctly.

QUESTION 368. *Can the position of each edge of the valve, with any given amount of travel, be shown in its relation to the ports by one motion-curve, or is it necessary to draw such curves for each edge of the valve?*

Answer. One motion-curve is sufficient to represent the movement of any part of the valve in relation to the ports during its entire travel. This will be apparent if it is remembered that the movement of any portion of the valve is exactly the same as that of every other part, and therefore the curve which represents the motion of one part is exactly like that which represents the movement of any other part. This is shown in fig. 266, in which the two sets of curves, *M S* and *M' S'*, are exactly alike. Therefore, all that is needed to show the movement of any part of the valve in relation to the ports is to draw lines to represent the ports in their relative positions to the valve. In this way one curve can be made to show the movements of all the parts of the valve in relation to the ports below it. To illustrate this, it will be assumed that a motion-curve, *M N O P Q R S T*, fig. 271, which represents the maximum travel of a valve, has been drawn with the instrument described in answer to the previous question. When this curve has been drawn, it will be supposed further that the crank-pin has been placed on the forward dead-centre, and the shaft, *F*, fig. 276, has been fastened by a nut provided for that purpose in the position it then occupies, and that the connecting-rod. *H*, is detached from the arm, *G*, and by a stroke of the piston the pencil, *P*, has drawn a straight line, *M s*, fig. 271. This line will represent the position of any part of the valve when the crank is on the front centre, and the curve will represent the movement and position of the same part during one revolution of the crank-pin. It will be supposed that the line, *M s*, represents the position of the steam-edge, *M*, fig. 266, of the valve at the beginning of the stroke. Usually, when a valve worked by a link motion has its greatest travel, it has no lead at the beginning of its stroke, but its edge conforms to that of the steam-port, or, as it is expressed, it is

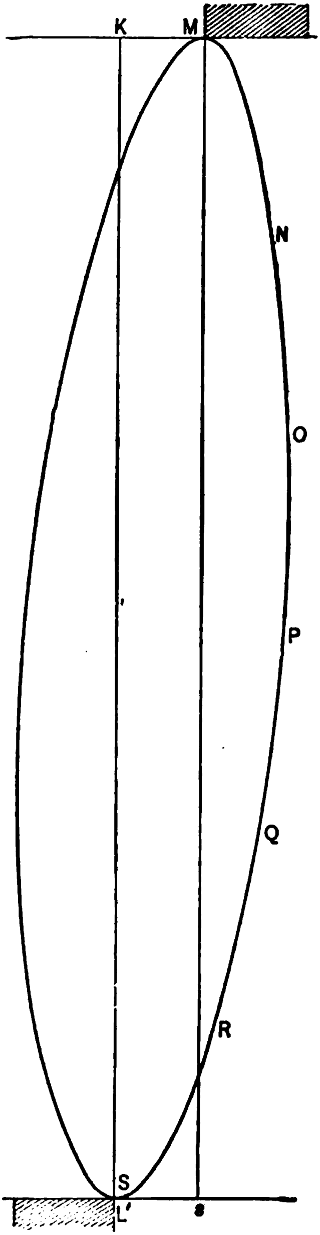


Fig. 271. Curve Showing Motion of Valves. Scale ¼ in.—1 in.

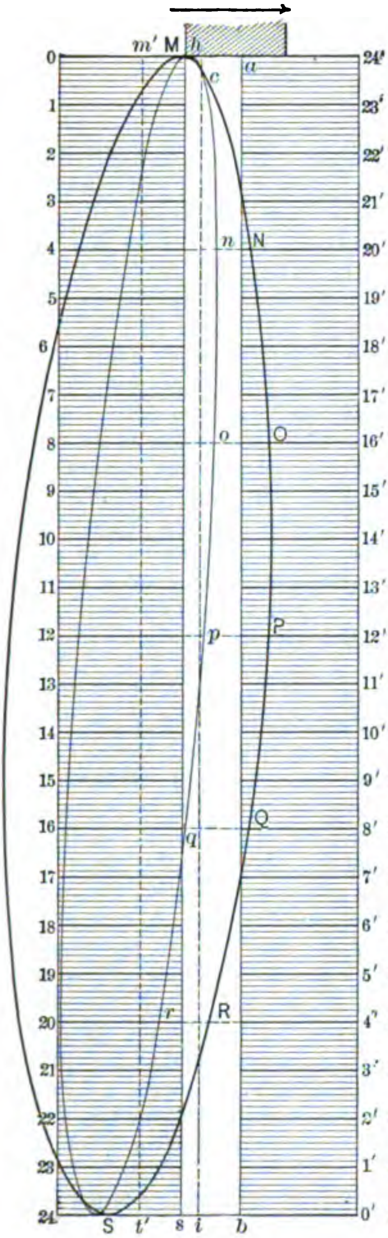


Fig. 272.

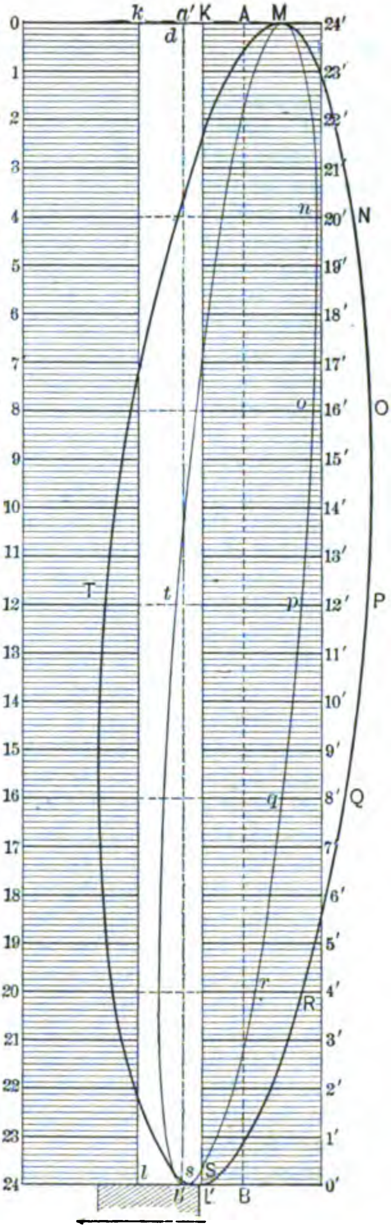


Fig. 273.

set "*line-and-line*" with the port. If that is the case, the line, *M s*, fig. 271, will represent the edge of the steam-port. If the valve has lead, then a line drawn parallel to *M s*, at a distance from it equal to the lead, will represent the edge of the port. In fig. 272 the valve is shown with $\frac{1}{16}$ inch lead, and another line, *a b*, has been drawn at a distance from *M s*, equal to the width of the port, *c*, fig. 266. The curves, *M N O P Q R S* and *M n o p q r S*, then represent the motion of the valve in relation to the port, *c*, in the same way as it is shown in fig. 266.

It has already been explained that the movement of the edges *M* and *M'* of the valve, and the two sets of curves in fig. 266, are exactly alike. They differ from each other only in their relation to the ports, *c* and *d*. The steam-edge, *M*, it will be seen, is $\frac{1}{16}$ of an inch—equal to the lead—from the line, *M s*, or the edge of the port, *c*, whereas the exhaust-edge, *M'*, is 1 inch from *m' t'*, the inner edge of the port, *d*. If, then, in fig. 272, we draw a line, *m' t'*, 1 inch from *M*, and another, *h i*, at a distance from *m' t'*, equal to the width of the port, *d*, fig. 266, and parallel to *M s*, and assume that *M*, fig. 272, represents the exhaust-edge of the valve, then the relation of the two curves to the lines, *m' t'* and *h i*, will represent, in fig. 272, the motion of the exhaust sides of the valve, in the same way as it is shown by the curves, *M' N' O' P' Q' R' S'* and *M' n' o' p' q' r' S'*, in fig. 266. Thus the one set of curves will represent the motion of the valve in relation to both of the steam-ports during the backward stroke of the piston. It remains to show its motion during its forward stroke.

It will be understood if a line, *K S*, fig. 271, is drawn at a distance from *M s*, equal to the width of the steam-port, that when the crank-pin is on the dead centre and the piston at the back end of the stroke, that the line will represent the position of the edge of the valve when the piston is in that position or is at the beginning of the forward stroke, just as *M s* represented it at the beginning of the backward stroke. A vertical line, *L'*, is therefore drawn below the horizontal line, *L' s*, to represent the steam-edge, *L'*, fig. 266, of the valve. In fig. 273, the line, *L'*, has been laid down in the same position as in fig. 271, but the line, *K L'*, has been drawn $\frac{1}{16}$ of an inch from *L'*, to represent the lead of the valve, and another line, *k l*, is drawn parallel to it at a distance equal to the width of the port, *d*, fig. 266. If this is done, the relation of the curves, *S T M* and *s t M*, in fig. 273, will represent the movement of the steam-edge, *L'*, fig. 266, of the valve in relation to the port, *d*, just as the movement of *M* is shown in fig. 272.

To show the motion of the exhaust-edge, *M'*, fig. 266, in relation to the port, *d*, a line, *A B*, is drawn in fig. 273, 1 inch from *L'*, or in the same relative position to *L'* that *m' t'* occupies to *M'* in fig. 266. Another dotted line, *a' b'*, is drawn in fig. 273, at a distance from *A B* equal to the width of the port, *d*, fig. 266. The relation of the curves, *S T M* and *s t M*, fig. 273, to these dotted lines will show the motion of the exhaust-edge, *M'*, of the valve to the port, *d*, fig. 266, just as that of *M*, was shown in fig. 272. It will require no explanation to show that by drawing the dotted lines, *m' t'* and *h i*, in fig. 272, the two diagrams, figs. 272 and 273, can be combined in one, as shown in fig. 272, and in that way the movement of the valve in relation to each of the steam and of the exhaust-port may be shown during a complete revolution of the crank by one set of motion-curves.

In this diagram the motion of the edge, *M*, of the valve in relation to the dotted lines, *m' t'* and *h i*, shows the action of the valve in the exhaust side, and the motion of *M*, in relation to the lines, *M s* and *a b*, its action in controlling the admission of steam. In fig. 274, *c* and *d* represent the two steam-ports, but their relative position is reversed from that in which they actually are, as shown in fig. 266. The relation of the edge, *M*, of the valve to the dotted vertical lines shows its action on the exhaust side. If desirable, the inner edges of the exhaust-port, *g*, of fig. 266, could also be laid down on the diagram, so that the motion of the valve with reference to them would be shown.

If the reader will cut a paper section of a valve, like that shown in fig. 69, and place the different edges, *a f* and *b*, so that they will successively correspond with the line, *M*, in fig. 274, the diagram will, perhaps, be more clear. If, for example, the paper section be placed to the right of the line, *M*, so that its edge, *a*, will correspond with *M*, then it will be seen that the port, *c*, occupies the same relation to it that it does in fig. 266. If the valve be placed so that the edge, *b*, corresponds with *M*, then it will be in the same relation to the port indicated by the dotted lines, *m' t'* and *h i*, that it has to *d*, in fig. 266.

Diagrams of this kind, which are made full size, will, of course, show the movement of the valve more distinctly than is possible in the space occupied by the illustrations herewith. When they are made full size, the lines indicating the ports should be drawn of different colors, so as to distinguish them from each other easily. Such diagrams will show the position of the valve in relation to the ports, and indicate the distribution of the steam during the whole stroke. It is only necessary to refer the curve to the proper line to determine the position of the valve in relation

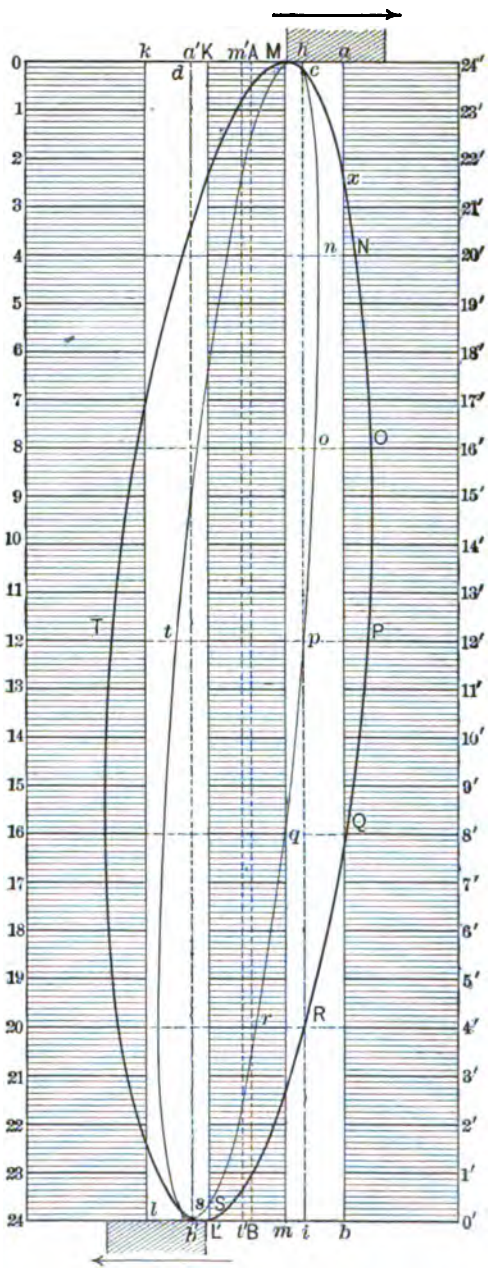


Fig. 274. Curves Showing Motion of Valve. Scale ¼ in.—1 in.

to either of the ports for either the admission or release of steam. If, for example, we want to observe how the admission of steam is governed by the valve, by referring to fig. 274, we see that at the beginning of the backward stroke the valve has $\frac{1}{16}$ inch lead; that at 2½ inches of the stroke the port, *c*, is wide open, as shown by the intersection of the motion-curve with the line, *a b* at *x*; that the valve has received its maximum backward travel at 10 inches of the stroke, and begins to close the port at 16½ inches, and completely closes it at 21⅝ inches of the stroke. By referring the motion-curve to the lines, *K L'* and *k l*, we see that the valve as shown, *L'* again has $\frac{1}{16}$ inch lead at the beginning of the forward stroke; that the steam-port is wide open at 1¾ inches of the stroke; begins to close at 16¾ inches, and is completely closed at 21⅝ inches. By referring the curve to the line, *m' t'* and *h i*, we see that the front port begins to open to the exhaust before the piston has completed its forward stroke, that, as shown at *c*, it is wide open almost immediately after the piston begins its stroke, does not begin to close until the piston has moved 20 inches of its stroke, and is completely closed at 23⅝ inches of the stroke. By referring the curve to the lines, *a' b'* and *A B*, almost the same phenomena will be observed for the forward stroke of the piston. In fact, from such a diagram the whole motion of the valve can be studied and analyzed with the greatest accuracy; and, as has already been shown, the motion imparted to a slide-valve by a link is of so complicated a nature that it is almost or quite impossible to observe its exact nature without diagrams of some kind.

QUESTION 369. *Can a diagram be constructed to represent the motion of the valve with different amounts of travel?*

Answer. Yes. In figs. 272, 273 and 274 two motion-curves are shown, one in heavy and the other in light lines. It is only necessary to construct motion-curves for the same diagram for each distance traveled, and they will show the movement of the valve for the given amount of travel represented by the curves. Fig. 275 is a reduced copy of a series of motion-curves taken from a locomotive. From this diagram the movement of a slide-valve worked by the link-motion can be seen from the highest to the lowest practicable point of cut-off. For convenience of reference the curves have been numbered.

The smallest travel of the valve represented by curve No. 1 is a little less than 2½ inches, and the ports are then opened only about ⅜ inch, and the steam is cut off at 8 inches on the backward and 6¾ inches on the forward stroke. The exhaust is opened or the steam is released during the

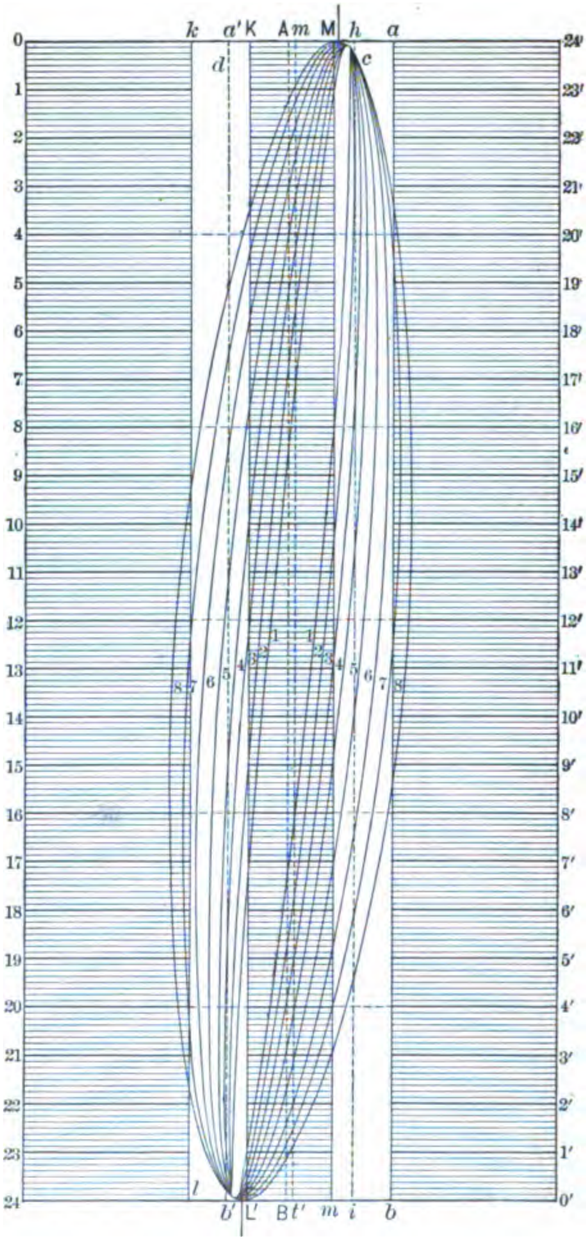


Fig. 275. Curves Showing Motion of Valve. Scale ¼ in. = 1 in.

backward stroke at 17 inches, and during the forward stroke at 16⅝. When the valve works with its greatest travel, as represented by curve 8, it travels 5 inches, and opens the steam-port wide at 3¼ inches of the backward stroke and 2¼ inches of the forward stroke. The steam is cut-off at 20⅝ and 20½ inches, and its release takes place at 23⅛ inches of each stroke. The following table gives the greatest width of opening, the

No. of Curves.	Travel of Valve.	Width of Opening of Steam-Port.		Point of Cut-Off.		Point of Release.		Lead.
		Backward Stroke.	Forward Stroke.	Backward Stroke.	Forward Stroke.	Backward Stroke.	Forward Stroke.	
	in.	in.	in.	in.	in.	in.	in.	in.
1	2½	11/32	1/16	8	6¾	17	16⅝	3/32
2	2⅝	7/16	11/32	9½	9½	18⅝	18 5/16	¼
3	2⅞	3/16	½	12	11¾	19¾	19 9/16	7/32
4	3⅛	11/16	11/32	14	14	20 11/16	20 9/16	3/16
5	3½	⅞	17/32	16½	16½	21 11/16	21½	5/32
6	4	1⅛	1 3/32	18¼	18⅛	22⅜	22¼	⅛
7	4½	1¼	1¼	19⅝	19½	22 11/16	22¾	3/32
8	5	1¼	1¼	20⅝	20½	23⅛	23⅛	1/16

point of cut-off, the point of release, and the lead for a series of motion-curves. This table was made up from the motion-curves drawn with an instrument like that described in answer to Question 867, on a locomotive which had been running about eighteen months and whose valve-gear, consequently, was considerably worn, as was indicated by the flatness of the motion-curves on each side at the point where the motion of the valve was reversed. This flatness was caused by the lost motion in the valve-gear, the pencil remaining for a time stationary when the motion was reversed and while the parts were moving from their bearings on the one side to those on the other. The curves and the table, therefore, showed the operation not of a theoretically perfect valve-gear, but are examples of actual practice, with such imperfections as are incidental to ordinary locomotives. It will be seen that the instrument shows not only what the valve-gear should, but what it actually does do, and delineates all its imperfections.

QUESTION 870. *What are the chief dimensions of the valve-gear whose motion is represented in fig. 275?*

Answer. The throw of eccentrics was 5 inches, the steam-ports were 1¼ inches, and the exhaust-port 2¾ inches wide, the valve had ⅞ inch outside and $\frac{1}{16}$ inside lap and $\frac{1}{16}$ inch lead at fuil stroke.

QUESTION 371. *What relation is there between the distance which the ports are opened by the valve and its travel when worked by a link?*

Answer. As explained in answer to Question 147, the width which the steam-ports are opened by the valve for the admission of steam diminished with the travel of the valve. This is shown very clearly by the motion-curves and also in the above table, from both of which it will be seen that when the valve travels only 2⅛ inches the steam-ports are opened only $\frac{11}{32}$ inch for the back stroke and $\frac{5}{16}$ for the front. With 2⅝ travel the opening is $\frac{7}{16}$ and $\frac{13}{32}$ inch. With 4 inches travel the port is opened 1⅛ and $1\frac{3}{32}$ inches, and with 4¼ inches travel they would be opened wide. With 4⅝ and 5 inches travel, as will be seen from the motion diagram, the ports are not only opened wide, but the valve throws "over" them, or travels beyond their inner edges.

QUESTION 372. *How is the point of cut-off affected by the link?*

Answer. Changing the travel of a valve with a link has a very similar effect to that produced by eccentrics of different throw—that is, the period of admission is increased with the throw of the eccentric and that for expansion lessened. This is shown clearly in both the motion diagrams and the table. With the first curve and a travel of 2⅛ inches the steam is cut off at 8 inches for the backward stroke and 6¾ inches for the front, and with 5 inch travel steam is admitted during 20⅝ inches of the backward and 20⅛ inches of the forward stroke.

QUESTION 373. *How is the point of release or exhaust of the steam affected by the link?*

Answer, As the travel increases, it is delayed until later in the stroke. Thus, with 2⅛ inches travel the steam is exhausted or released from the cylinder during the backward stroke when the piston has moved 17 inches, and on the return stroke at 16⅝ inches, whereas, with 5 inches travel of the valve, the release is delayed until 23⅛ inches of the stroke. An examination of the diagram and table will show very clearly the relation of the point of release to the travel.

QUESTION 374. *How is the lead affected by the ordinary link-motion?*

Answer. It is increased as the travel is diminished, as is shown in the table, and also by the inclination of the curves at the top and bottom of the diagram.

QUESTION 375. *What is the cause of this change of the amount of lead?*

Answer. This can be best explained by reference to fig. 276, which represents a link with very short eccentric-rods. If the centre from which the link was drawn was in the centre of the axle, *S*, and the eccentric straps embraced the axle instead of the eccentrics, their ends, *m* and *n*, from *S* as a centre, would each describe the same arc, *a b c*, parallel with the centre line, *x y*, of the link, and the latter could then obviously be raised and lowered without moving the block, *b*, or rocker-pin, *p*, at all. But the eccentric straps being attached to the eccentrics, as shown by the dotted lines, when the rods are raised or lowered they describe arcs, *e f* and *f g*, from the centres, *s* and *t*, of the eccentrics, and not from the centre of the axle. When the link is lowered, then the end, *m*, of the upper rod obviously moves in the arc, *m f*, and the top of the link is moved toward the axle, a distance equal to *b f*, as shown in fig. 277, equal to the interval between the arc, *a b c*, drawn from the centre of the axle, and *a f*, which the rod, *m s*, describes from the centre of its eccentric. When the link is raised from mid-gear, fig. 276, to back-gear, a similar action takes place, as the end, *n*, of the lower rod then describes an arc, *n f*, so that the whole link is again thrown toward the axle a distance, *b f*, equal to the space between the arcs described from the centre of the axle and the centres of the eccentrics. When the position of the eccentrics is reversed, as shown in fig. 278, the link is moved from the axle, thus causing an increase of lead on the opposite side of the valve. We have employed for our illustrations very short eccentric rods, in order to make this action apparent by exaggerating it. It is obvious from the engravings that the difference in the lead is increased as the eccentric rods are shortened, and also as the distance between the points of connection of the rods with the link is increased. It will also be plain that increasing the throw of the eccentrics—that is, increasing the distance of the centres, *s t*, of the eccentrics from the centre, *S*, of the axle will also increase the variation in the lead in full and mid-gear.

QUESTION 376. *What is meant by the distribution of steam in the cylinder?*

Answer. It means the admission and exhaust of steam to and from the cylinder in relation to the stroke of the piston or the revolution of the crank.

QUESTION 377. *What are the principal periods or elements of the distribution of steam by the slide-valve and link-motion?*

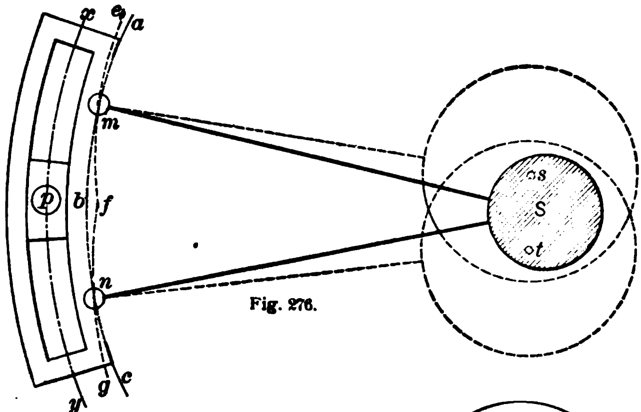


Fig. 276.

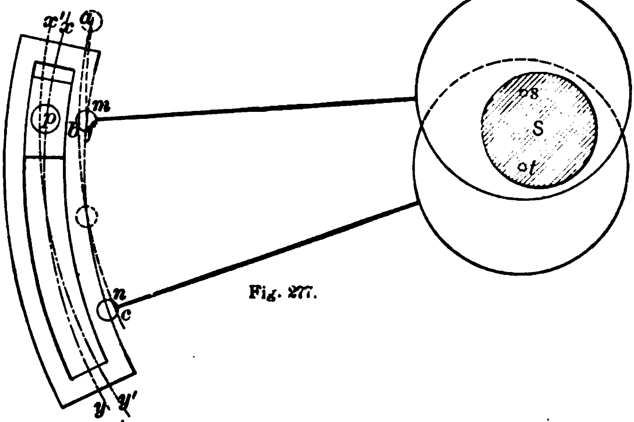


Fig. 277.

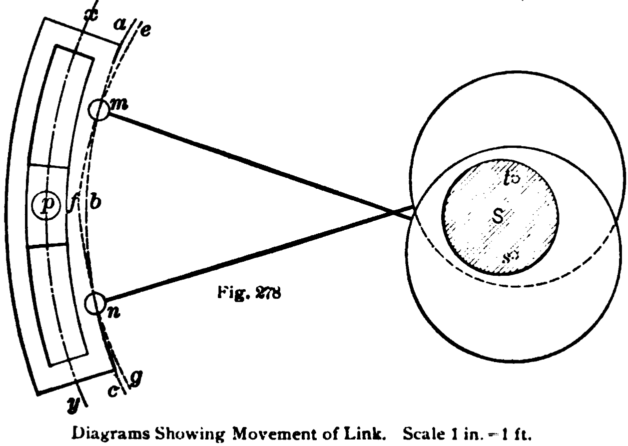


Fig. 278

Diagrams Showing Movement of Link. Scale 1 in. = 1 ft.

Answer. They are:

1. The *pre-admission* due to the lead—that is, the admission of steam into the cylinders in front of the piston before it reaches the end of its stroke.

2. The *admission* of steam after the piston has commenced its stroke.

3. The *expansion* of steam in the cylinder.

4. The *pre-release* or exhaust of steam before the piston has completed its stroke.

5. The *release* or exhaust during the return stroke of the piston.

6. The *compression* of steam or closing the exhaust before the piston has completed its return stroke.

QUESTION 378. *What is meant by the clearance of the piston?*

Answer. As explained in answer to Question 122, it is the space between the piston and the cylinder-head when the former is at the end of its stroke. If the piston touched the cylinder-head at the end of each stroke, it would cause a concussion or "thump," which would injure these parts. Owing to the impossibility of constructing machinery with absolute accuracy, it is therefore necessary to leave a space, usually from $\frac{1}{8}$ to $\frac{1}{4}$ inch wide, between the piston and the cylinder-heads, so as to be certain that they will not strike each other should there be any slight inaccuracies in the length of the piston-rods, connecting-rods, frames, or other parts.

QUESTION 379. *Why is it desirable to open the steam-port and admit steam at the end of the cylinder toward which the piston is moving BEFORE the latter has completed its stroke?*

Answer. Because it is essential, in order to insure a good action of the steam, that the maximum cylinder pressure should be attained at the very commencement of the stroke. If the steam-port was not opened until after the piston had commenced its stroke, some appreciable time would be consumed in filling the clearance space and the *steam-way* with steam. It is also found, especially if an engine is working at a high speed, that a slide-valve worked by the ordinary link-motion will not open the steam-port rapidly enough to enable steam of the maximum boiler pressure to fill the space after the receding piston, unless the valve begins to open the port *before* the piston reaches the end of the stroke.

Another advantage resulting from the pre-admission of steam consists in the smooth working of the engine at high speeds, a circumstance which reduces greatly the wear and tear of the working gear. As the piston approaches the end of its stroke, the pre-admitted steam forms a kind of elastic cushion, which is well calculated to absorb the momentum of the reciprocating parts at that instant. The pressure due to the momentum of these parts will, of course, depend upon their weight and the speed of working, increasing directly as the square of the speed. It follows from this that the lead should increase with the speed, and that it should be greatest at high speeds. As has been shown before, this condition is fully accomplished by the ordinary shifting-link motion.

QUESTION 380. *Upon what does the admission of steam into the cylinder depend?*

Answer. It depends in the first place upon the opening of the throttle-valve, and the size of the pipes and passages through which it is conveyed from the boiler to the cylinder. In the second place, it depends upon the time and amount of opening of the steam-port by the valve.

QUESTION 381. *What should be the pressure of the steam in the cylinder during admission?*

Answer. In order that the steam may be used to most advantage, it should be admitted and maintained in the cylinder as near full boiler pressure as possible during the whole period of admission. If the opening of either the throttle-valve or the steam-ports is not sufficient to allow the steam to flow into the cylinder at full boiler pressure, the steam is said to be wire-drawn, and some of the advantage of using it expansively is then lost.

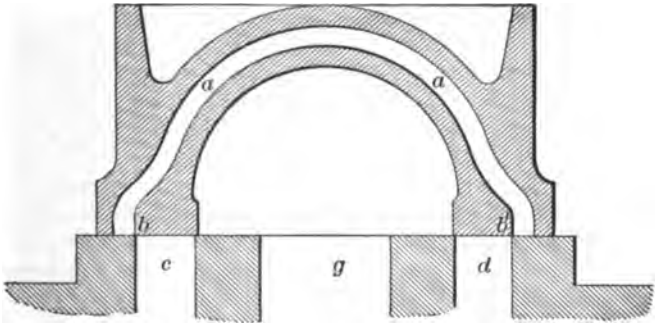
QUESTION 382. *Why is it difficult to admit and maintain steam at the full boiler pressure in the cylinder during admission?*

Answer. Because with the link motion the travel of the slide-valve must be reduced in order to cut off the steam "*short*," or soon after the beginning of the stroke of the piston. When the travel is reduced, the valve opens the port only a small distance, so that the area of the opening is not then sufficient to allow the steam to flow into the cylinder with sufficient rapidity to fill it at full boiler pressure, especially if the engine is working at a high speed. Thus, by referring to the table given on page 813, and to the motion-curves in fig. 275, it will be seen that when the steam is cut off at from $\frac{1}{4}$ to $\frac{1}{8}$ stroke, the port is opened for the admission of steam only from $\frac{1}{4}$ to $\frac{1}{8}$ inch wide. From the curves it will also be seen that the valve then acquires its maximum travel, and the steam-port its greatest width of opening very soon after the piston begins its stroke; after which the port is gradually closed, so that before the steam is entirely cut off the opening is so much reduced in area that the steam cannot flow through it rapidly enough to maintain the steam at full boiler pressure in the cylinder when the engine is working at high speeds.

QUESTION 383. *What means are used to overcome this difficulty and thus admit steam at fuller boiler pressure when the valve is cutting off short?*

Answer. In the first place, the steam-ports are made from ten to twelve times as long as they are wide, so that a narrow opening will have

Fig. 279.



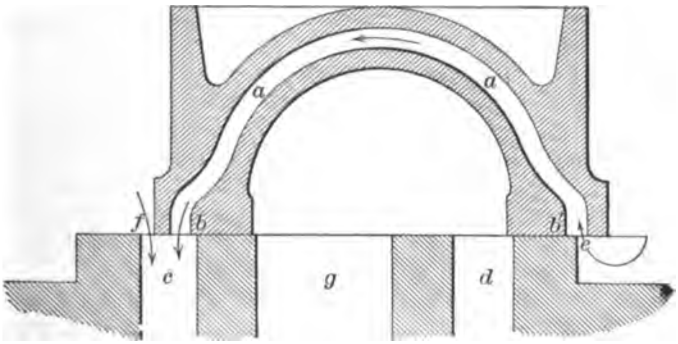


Fig. 280. Allen Valve. Scale ¼ in.—1 in.

a comparatively large area. In the second place, by giving the valve lead, not only are the clearance space and the steam-way filled with steam when the piston begins its stroke, but the port is then open a distance equal to the lead. With the ordinary link-motion, as has already been shown, this lead increases as the travel and period of admission diminish, so that the smaller the total distance that the port is opened, the greater is its opening at the beginning of the stroke. As the steam is usually cut off short when locomotives run at high speeds, it will be seen that the increased lead which is imparted to the valve by the shifting link is an advantage rather than a disadvantage. But while it is often possible in this way to secure a pressure of steam in the cylinder at the beginning of the stroke equal or nearly so to that in the boiler, yet it is almost impossible to maintain this pressure during the whole period of admission, when the steam is cut off short and the engine working at a high speed. To obviate this evil what is called the Allen Valve was designed, which is represented in fig. 279. This valve has a channel or supplementary port, *a a*, which passes over the exhaust cavity, and has two openings, *b b'*, in the valve-face. When the valve begins to admit or "*take*" steam, at *f*, as shown in fig. 280, it will be seen that it also uncovers the opening, *a a*, at *e*, and thus admits steam, at *e*, which passes through the channel, *a a*, and enters the steam-port, *c*, at *b*, and in this way there is a double opening for the admission of steam. The opening, *b*, of the supplementary port is closed as the valve advances, but when this takes place the steam-port is uncovered far enough, at *f*, to admit all the steam that is required. This form of valve is very efficient when the travel and point of cut-off are very short. It then gives just twice as much opening as the ordinary valve for the admission of steam.

QUESTION 384. *What is meant by the pre-release of steam?*

Answer. It is the release of the steam before the piston has completed its stroke. If the steam was confined in the cylinder until the piston had reached the end of its stroke, there would not be time, nor will it be possible, with a slide-valve and link-motion, to secure a sufficiently large opening of the port to permit the steam to escape from the cylinder before the piston begins its return stroke. If there were no pre-release, there would therefore be more or less back pressure on the piston.

QUESTION 385. *Upon what does the amount of pre-release depend?*

Answer. First, as has already been explained in answer to Question 150, on the amount of inside lap; and second, on the outside lap of the valve and the lead of the eccentrics; and third, on the travel of the valve. The less the inside lap, the greater the outside lap and consequent lead of the eccentrics, and the shorter the travel of the valve, the earlier will be the release. The proper amount of this pre-release depends upon the velocity of the piston and the quantity of steam to be discharged or the degree of expansion. From the motion-curves, in fig. 275, it will be seen that it is a marked feature of the shifting-link motion that the pre-release occurs earlier in the stroke as the link approaches mid-gear, or as the travel of the valve diminishes. As the link is usually worked near that position when the engine is run at a high speed, it will be seen that in this respect again the link-motion is well adapted for working the slide-valves of locomotives.

QUESTION 386. *What governs the period of release?*

Answer. The release, like the pre-release, is dependent upon the amount of inside lap, the outside lap and consequent lead of the eccentrics, and the travel of the valve. The addition of inside lap has the effect of closing the port earlier than it would be closed without, and thus shortening the period of release and also of reducing the area of the opening of the port.

With the same travel, increase of outside lap and lead shortens the period of release, but has no effect on the width of the opening of the port to the exhaust.

Increase of travel, with the same outside lap, lengthens the period of release and also increases the width of the opening of the port to the exhaust.

QUESTION 387. *What governs the period of compression?*

Answer. As compression begins when release ends, or when the port is closed to the exhaust, it is controlled by exactly the same causes, and as the two events occur simultaneously, of course whatever shortens the period of release lengthens that of compression.

QUESTION 388. *What effect do the clearance spaces and steam-ways have upon the compression of the confined steam?*

Answer. By referring to the motion-curves, in fig. 275, it will be seen that the steam-port is closed by the exhaust edge of the valve, or compression begins some time before the piston reaches the end of the stroke. This is especially the case when the travel of the valve is reduced and steam is cut off short. The result is that the remaining portion of the cylinder, through which the piston must move *after* the port is closed to the exhaust, is filled with steam of atmospheric pressure, or possibly a little above the pressure. As this is confined in the cylinder, it is compressed by the advance of the piston. If there was no room between it and the cylinder at the end of the stroke, then either the cylinder would be burst or the valve would lift so far as to allow the compressed steam to flow back into the steam-chest. The clearance and the steam passages, however, afford considerable room, into which the confined steam can be compressed without danger of bursting the cylinder or of raising the slide-valve when there is steam in the steam-chest. As the clearance spaces and steam-ways must be filled with high-pressure steam at the beginning of each stroke, it must be obtained either by taking a supply of "*live*"* steam from the steam-chest, or by compressing into the clearance spaces the low-pressure steam that still remained in the cylinder when the port was closed to the exhaust. By the latter process, a certain quantity of steam is saved at the expense of increased back pressure. It should be borne in mind, also, that the total heat of the compressed steam increases with its pressure, and as its pressure approaches that in the boiler, its temperature must also be raised from that due to about atmospheric pressure to near that in the boiler. These changes of temperature which the steam undergoes will affect the surface of the metal with which the steam is in contact during the period of compression; it follows from this, that the ends of the cylinder principally comprising the clearance spaces must acquire a higher temperature than those parts where expansion only takes place. This is an important consideration, since the fresh steam from the boiler comes first in contact with these spaces, and by touching surfaces which have thus previously been heated, as it were, by the high temperature of the compressed steam, less heat will be abstracted from the fresh steam, and therefore a less amount of water will be deposited in the cylinder.†

It will thus be seen that the effect of compression is to fill the clearance spaces and steam-ways with compressed steam before pre-admission begins. As already stated, this is done at the expense of back pressure in the cylinder. It must be remembered that all the energy, excepting that part which is wasted by loss of heat, friction, etc., which is consumed in compressing the confined steam, is again given out to the piston by expansion. The confined steam also acts as an elastic cushion to receive the piston, just as the steam which is admitted before the end of the stroke would if there was no compression. Compression, therefore, has the effect of saving the quantity of live steam which it would otherwise be necessary to admit before the end of the stroke to fill the clearance spaces and steam-ways, and also to "cushion" the piston. As the momentum of the piston and other parts depend upon their weight and the speed at which they are working, increasing directly as the square of the

* The term "live" steam means steam taken direct from the boiler and which has not been used in the cylinder or to do any work.

† Bauschinger's Indicator Experiments on Locomotives.

speed, from which it follows that the compression should increase rapidly with the speed and should be the greatest at high speeds. As the ports are prematurely closed to the exhaust with the shifting-link motion, and as the lead increases rapidly as the link approaches mid-gear, and the amount of compression is at the same time correspondingly augmented, it will be seen that the shifting-link motion fulfils these conditions very perfectly.

The pressure to which the confined steam will rise depends, of course, upon the amount of the period of compression, and also on the size of the clearance spaces. As it is possible to have such an amount of compression that it will exceed the boiler pressure, and thus raise the valve from its seat and be forced back into the steam-chest, some care must be exercised to proportion the one to the other, so that the degree of the confined steam may not be excessive.

QUESTION 389. *How can the effect of the distribution of the steam upon its action in the cylinder be determined by experiment?*

Answer. As already explained in answer to Question 108, this can be done by an instrument called a steam-indicator.

QUESTION 390. *What is the construction of this instrument?*

Answer. Fig. 281 represents the Tabor Indicator.* It consists of a cylinder, *B* (which is shown in section), into which a piston, *A*, is accurately fitted, but so that it will move freely in the cylinder. The piston-rod, *C*, is surrounded with a spiral spring, *D*, the lower end of which is attached to the top of the piston, and the upper end to the cylinder cover. When steam is introduced below the piston it pushes it up in the cylinder and the spring is compressed. If there should be a vacuum below the piston, the air above it will press the piston downward and extend the spring. This latter occurs only when the indicator is used on condensing engines. Of course the distance which the piston is forced up by the steam-pressure below it depends upon the amount of pressure, and also on the tension of the spring; and therefore if a pencil was attached to the piston-rod so that it could mark on a moving card in front of it, a diagram would be drawn, which would indicate the steam-pressure, as was explained in answer to Question 108. But there are some practical difficulties in the way of doing this. It is found that if the pencil is attached directly to the piston-rod of the indicator, the distance through which they must move in order to make the scale of the diagram sufficiently large to be clear, is so great that the momentum of the parts carries them

* Manufactured by the Ashcroft Manufacturing Company, 111 Liberty Street, New York.

farther than the pressure of the steam alone would move them. The distance through which the piston would move, moreover, makes it difficult to indicate the changes of pressure simultaneously with the position of the piston, as the latter must travel while the action is taking place, and thus the diagram shows changes of pressure later or more gradually than they occur.* To overcome these and other difficulties, the piston-rod of

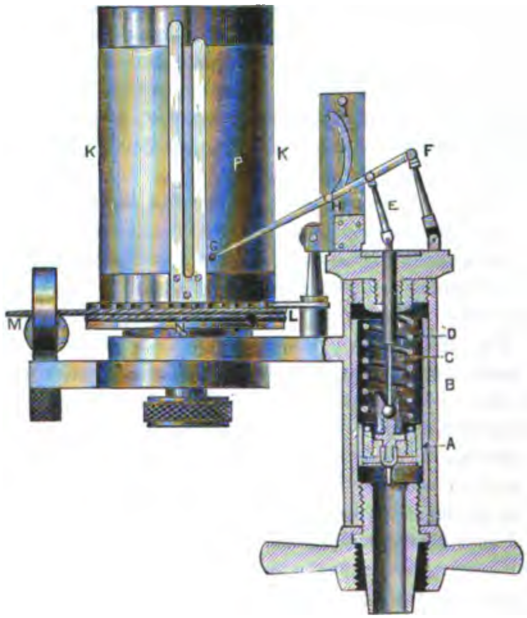


Fig. 281. Tabor Indicator.

the indicator which we have illustrated is attached by a link, *E*, to the lever, *F G*, which carries a pencil, *G*, on its outer end. By this means the piston has only one-fourth of the motion that it imparts to the pencil, so that the momentum of the moving parts is comparatively slight.

In order that the pencil may draw a straight line, instead of a curved one, a roller is attached to the lever at *H*. This moves in a curved slot, *H I*, which causes the end, *G*, to move in a straight line instead of the arc

* Richard's Steam Indicator, by Charles T. Porter.

of a circle. The levers and all the parts, are all made as light as possible, so that their weight will have little effect on the motion of the indicator piston.

The paper or card, *P*, on which the diagram is drawn, is wrapped around a brass cylinder, *K K*. This cylinder is made to revolve part of the way around by a strong twine, *L M*, which is wrapped around a pully, *N*, at the bottom of the cylinder. The twine is attached to a lever, simi-

Fig. 282. Crosby Indicator.

lar to that shown in fig. 38, which receives a reciprocating motion from the piston of the engine. The twine can, of course, move the cylinder in only one direction, and therefore a coiled spring similar to a clock spring is placed inside of the cylinder to draw it back when the twine is relaxed. In this way the paper cylinder or drum receives a part of a revolution at each stroke of the piston and moves simultaneously with it. This drum is used instead of a flat card, shown in fig. 52. The motion of the paper on this drum will, however, be exactly the same in relation to the pencil as the motion of a flat card would be.

Fig. 282 is an outside view, and fig. 283 a section of the Crosby* Indicator, which is similar to the one just described, excepting the mechanism for producing a rectillinear motion of the pencil, which differs somewhat from the other, as is shown in the engravings.

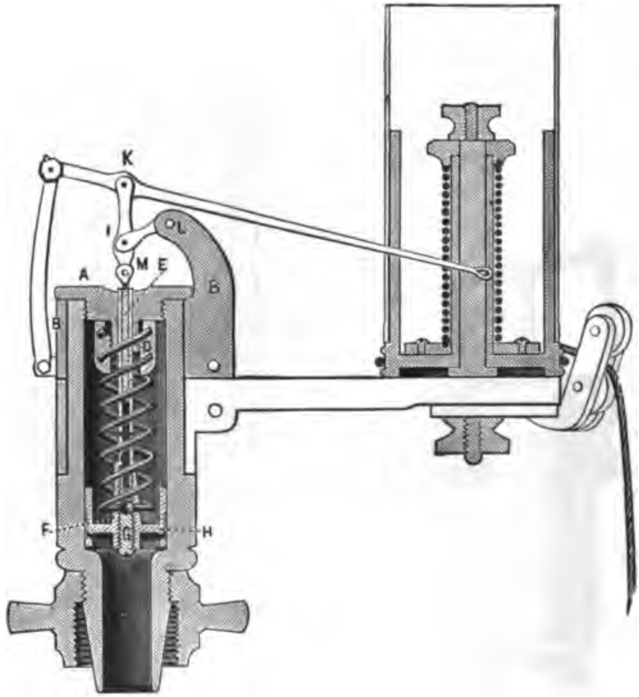


Fig. 283. Crosby Indicator.

The method of attaching an indicator to a locomotive is represented in fig. 284. It will be seen from this that it is placed over the middle of the steam-chest and is connected to each end of the cylinder with ¾ inch pipes. A three-way cock is placed at the point, *A*, where the horizontal

* Manufactured by the Crosby Steam Gauge & Valve Company, of Boston.

pipe connects with the vertical one leading to the indicator, by which steam can be entirely shut off from the indicator, or communication can be established with either end of the cylinder. The arrangement of the levers for giving motion to the indicator drum and that of the seat, which is very requisite for the experimenter, will be readily understood from the engraving without further explanation. It is thought by some engineers that the indicator should be applied as near to each end of the cylinder

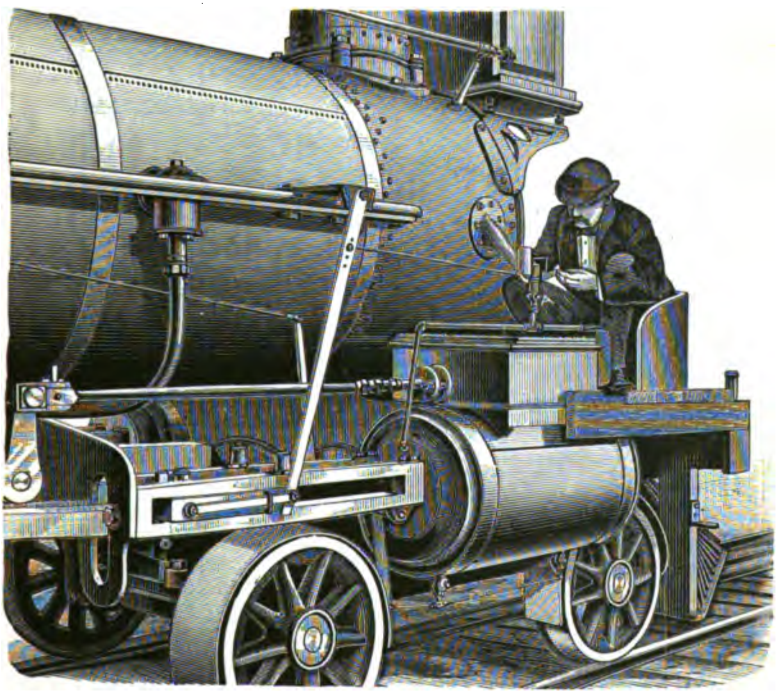


Fig. 284. Method of Applying Indicator.

as possible. It is believed, though, that if the pipes, cocks, and their connections, are made large enough so as not to impede the motion of the steam, no appreciable error will arise from the method illustrated in fig. 284.

QUESTION 391. *What is the form of an indicator diagram?*

Answer. This depends upon the pressure of the steam, the action and proportions of the valve, the speed of the engine, and a variety of other circumstances. To show the influence of the action of the valve, it will

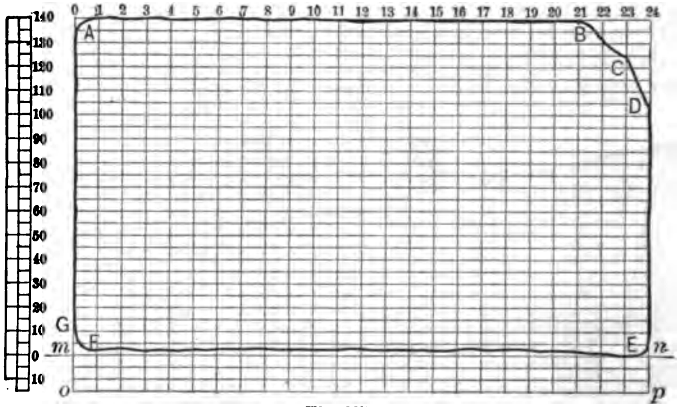


Fig. 265.

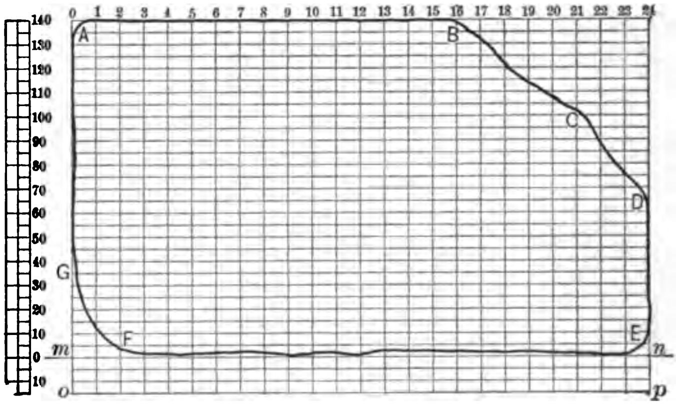


Fig. 266.
Indicator Diagrams.

be supposed that an indicator diagram is taken with a valve like that shown in fig. 67, and that its movement is represented by the two motion-curves shown by heavy lines in fig. 266.

It should be explained, first, that with ordinary indicators the size of the diagrams is from 3 to 4 inches long and 1½ to 2 inches wide. Therefore, the springs which resist the steam pressure under the indicator piston, are made of varying degrees of tension, which are designated as Nos. 4, 8, 12, 16, 20, 30, 40, 50, 60, 80, 100. The number of the spring represents the pressure in pounds per square inch required to compress it sufficiently to move the pencil vertically 1 inch on the diagram. Therefore, by dividing the boiler pressure in pounds by the desired height of diagram in inches, the result will be the number of the spring required. A boiler pressure of 140 lbs. per square inch will be assumed, so that if the diagram is not to exceed 1¾ inches in height, a number 80 spring should be used.

Fig. 285 is supposed to represent an indicator diagram which would be made by the valve, shown in fig. 266, when its movement is as represented by the heavy motion-curve. The horizontal line, *m n*, fig. 285, represents the *atmospheric line* which would be drawn by the pencil of the indicator if the card was moved horizontally when there is no steam on the indicator, but only atmospheric pressure above and below its piston. The pencil is supposed to stand at *G*, at the beginning of the backward stroke of the piston. As the valve has $\frac{1}{16}$ inch lead it opens the steam-port a little before the piston reaches the end of the stroke. While the crank is moving past the dead-point the valve has considerable movement, so that if the engine is moving slowly, steam of full boiler pressure will be admitted into the cylinder, and the piston of the indicator will be forced upward, and the pencil will draw the line, *G A*, which is called the "*admission line.*" At the beginning of the stroke the valve opens the port quickly, and it remains open until the piston has reached 21½ inches of its stroke, and during that period the pencil draws the horizontal line, *A B*, which is called the "*steam line.*" When the pencil gets to *B*, the steam-port is closed and the steam is *cut off* or confined in the cylinder and then expands, and the pencil draws the line, *B C*, which is called the "*expansion curve.*" *B* is therefore called "*the point of cut-off.*" When the pencil reaches *C*, the exhaust-port is opened and the steam escapes, so that the pressure is rapidly reduced, and the spring above the indicator-piston forces it down and the pencil draws the line, *C D E*. *C* is called the "*point of release,*" and *C D E* the "*exhaust line.*"

During the return stroke of the piston, not all the steam escapes from the cylinder, and, especially if the speed is rapid, there is more or less "*back pressure,*" as it is called, in front of the piston which causes the pencil to draw a line, *E F*, called the "*back-pressure line,*" somewhat above the atmospheric line, *m n*. Before the piston reaches the end of its return stroke the port is closed to the exhaust, and the steam and air enclosed in the cylinder is compressed by the advancing piston, so that

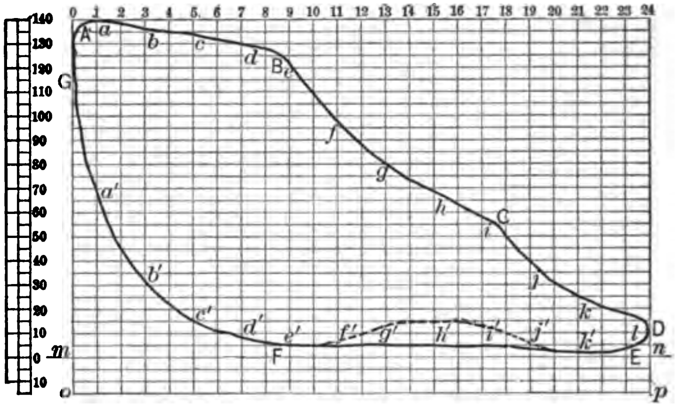


Fig. 287.

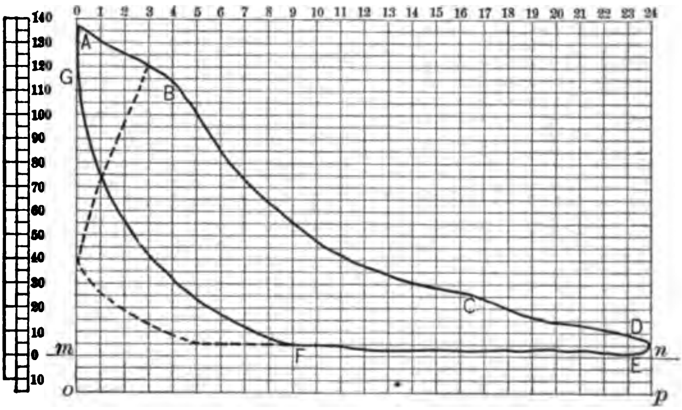


Fig. 288.
Indicator Diagrams.

the indicator pencil draws the line, *F G*, called the "*compression curve.*" The point, *F*, is called the "*point of compression,*" or "*point of exhaust closure.*"

Fig. 286 represents the form of diagram which would be made by the valve, if its movement was as represented by the smaller motion-curve drawn in light lines in fig. 266. It will be seen that steam is cut off at 16 inches instead of 21½ inches. Release occurs at 21 inches, and compression begins at a point 2 inches from the end of the stroke.

Fig. 287 is such a diagram as would be made when steam is cut off at 8 inches, and in fig. 288 expansion begins at 4½ inches. In order to make these diagrams clear a scale of the indicator spring is drawn on the left side of the engraving, and the horizontal lines on the diagram represent the steam-pressure, and the vertical lines indicate inches of the stroke of the piston.

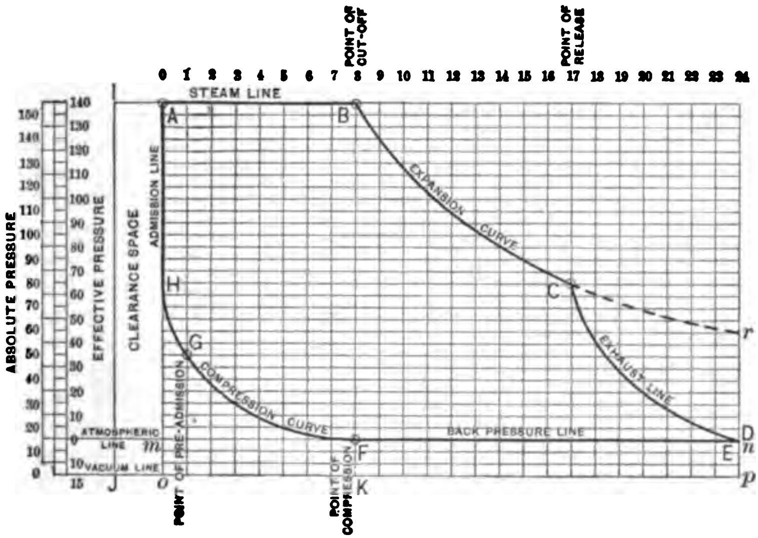


Fig. 289. Indicator Diagram.

QUESTION 392. *What should be the form of an indicator diagram, if the steam is distributed by a link-motion so as to produce the best practicable action in the cylinders?*

Answer. It should approximate to that shown in fig. 289. The atmospheric and vacuum lines, *m n* and *o p*, are indicated, as already explained. The points at which the different periods of the distribution begin are indicated by small circles, and the letters, *A B C D E F G* and *H*.

The diagram represents a distribution of steam produced by a valve having $\frac{7}{8}$ inch outside and $\frac{1}{16}$ inside lap. The eccentrics have 5 inches throw, and the steam-ports are $1\frac{1}{4}$ and the exhaust $2\frac{3}{4}$ inches wide. The valve is cutting off at 8 inches, or one-third of the stroke. Pre-admission begins at *G*, when the piston still has 1 inch to move before reaching the end of its stroke. Admission, of course, begins at *A* with the stroke, expansion at *B* or 8 inches, release or exhaust at *C*, 17 inches, and compression at *F*, 16 inches of the return stroke. The valve is supposed to be set with $\frac{1}{16}$ inch lead at full stroke. When the steam is cut off at 8 inches of the stroke, the valve has $2\frac{5}{8}$ inches travel and $\frac{1}{4}$ inch lead. The steam-pressure in the boiler is supposed to be 140 lbs. above the atmosphere. Of course when the valve cuts off at different points of the stroke, the periods of distribution will be somewhat changed; but from the above diagram the principal features of a good distribution can be explained.

These are: First that the steam-pressure should rise rapidly during the period of pre-admission, so that there will be nearly full boiler pressure in the cylinder at the beginning of the stroke. When this occurs, the pre-admission line will rise from *G*, to such a point as will indicate nearly or quite full boiler pressure in the cylinder. The same pressure should then be maintained in the cylinder during the whole period of admission, and the admission line from *A* to *B* should therefore approximate to a straight horizontal line. When expansion begins, the pressure will fall. The expansion line should approximate to a hyperbolic curve, but in laying out this curve allowance must be made for the clearance space between the piston and cylinder heads and the contents of the steam-ways. The cubical contents of these at each end of the cylinders of locomotives are usually from 5 to 10 per cent. of the space swept through by the piston. It will be assumed that this is equal to the space swept by the piston in moving 2 inches. A line, *I J*, is therefore drawn, 2 inches from *A O*, which represents the front end of the cylinder, and the space, *I J O A*, will represent the clearance. When the piston has moved 8 inches, then the steam in the cylinder, instead of filling only the space through which the piston has moved, which is represented by *A O K B*, also fills the clearance space and is represented by *I J K B*. Therefore, in laying out the expansion curve, *B C r*, we must calculate for the expansion of a quantity of steam sufficient to fill the cylinder in front of the piston *and* the clearance spaces, and which is represented by the area, *I J K B*. If there is much loss of heat by radiation or other causes, the diagram will fall considerably below the theoretical curve. With cylinders well protected and with dry steam, the expansion line will fall slightly below a hyperbolic curve at the beginning of the period of expansion, and rise above it during the latter part of the same period. The reason of this is that the cylinder is heated by the admission of live steam of comparatively high temperature, so that when the pressure becomes reduced by expansion, a part of the water which is condensed in the cylinder will be re-evaporated by the heat in the latter. From the point of the release or exhaust, *C*, to the end of the stroke, *D*, the exhaust line should fall rapidly, so that there will be no pressure behind the piston during its return stroke. To explain the theoretical form of the exhaust line would lead into a very abstruse discussion, which would be out of place here. It will be sufficient for our purpose to call attention to the fact that the pre-release should allow as much of the steam in the cylinder to escape as is possible before the piston reaches the end of the stroke, so that the back pressure during the return

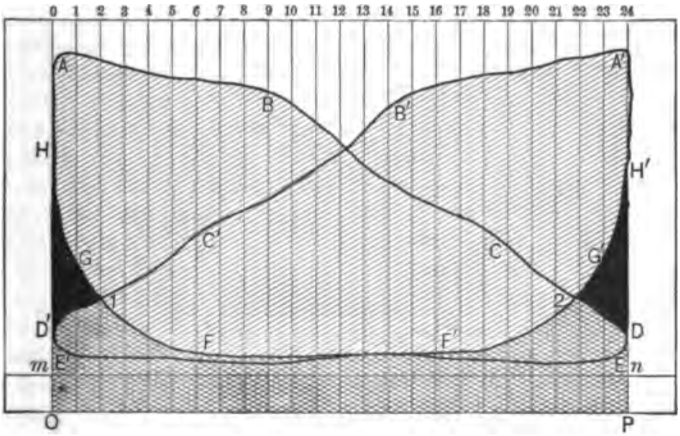


Fig. 290. Indicator Diagram.

stroke may be low. It is, however, only at comparatively slow speeds that the steam in locomotive cylinders escapes during the period of pre-release, so that the back pressure is reduced to that of the atmosphere. It is essential in locomotives, as has already been explained, to contract the area of the blast orifices or exhaust nozzles, more or less in order to stimulate the draft through the fire, so that the steam cannot escape with sufficient rapidity to reduce the back pressure to that of the atmosphere if the engine is running fast. Of course every pound of back pressure on the piston is equivalent to an equal amount deducted from the effective pressure on the other side.

QUESTION 393. *How can the net effective pressure on the piston be shown by indicator diagrams?*

Answer. This can be done by taking two indicator diagrams on the same card from opposite ends of the cylinder, as shown in fig. 290. The area, *A B C D P O* and *A′ B′ C′ D′ O P*, represent the absolute pressures ahead of the piston during the backward and forward strokes. The areas, *H G F E D P O* and *H′ G′ F′ E′ D′ O P*, represent the absolute pressures on the opposite side of the piston or the back pressure. As the one must be deducted from the other to get the net pressure, we have *A B C* 2 *F′*

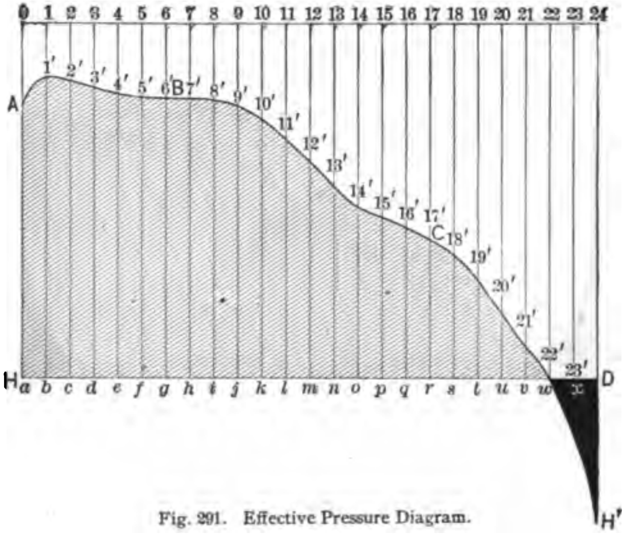


Fig. 291. Effective Pressure Diagram.

E′ D′ H and *A′ B′ C′* 1 *F E D H′*, as the areas which represent the net forward pressure on the piston. At each end of the stroke the back pressure exceeds the forward pressure, and therefore we have the two areas, *H* 1 *D′* and *H′* 2 *D*, shaded black, which represent the retarding effect on the piston at each end of the stroke. The length of the vertical lines between the curves, *A B C* 2 and *D′ E′ F′* 2, will give the effective pressure, and similar measures on the black areas will give the retarding pressures for any point of the stroke. This will be made still clearer if we take a line, *H D*, fig. 291, as the line of no pressure on the piston and then lay off vertical lines equal in length to those between the curves, *A B C* 2 and *D' E' F'* 2, of fig. 290, and draw a curve, *A B C w*, fig. 291, through their extremities. This curve will represent the net pressure on the piston, and by laying off vertical lines below *H D*, equal in length to those in the area, *H' D* 2, and drawing, *w H'*, through their extremities, this curve and the area, *w H' D*, colored black, will represent the net back pressure on the piston.

In studying the distribution of steam and designing valve-gear, every effort should be made to reduce the back pressure, excepting at the end of the stroke, as much as possible, and yet maintain a sufficient supply of steam, and therefore the line of back pressure should conform as closely as possible to the atmospheric line. The compression line should approximate to a hyperbolic curve, beginning with the period of compression. In calculating expansion, allowance must be made for the clearance space and steam-ways as has already been explained. The same thing is true of the compression. This occurs in the above example when the piston has 8 inches or more to move before completing its stroke. There is, therefore, a quantity of steam in front of it sufficient to fill a cylinder 10 inches long. This steam is, of course, compressed by the advance of the piston, and if its absolute pressure when compression begins is the same as that of the atmosphere, or 15 lbs., then it will be 18.75 lbs., when the piston has only 6 inches to move, and 25 and 37.5 lbs. absolute pressure when the piston has 4 and 2 inches to move, and when the pre-admission begins, the pressure will have risen to 75 lbs. If the back pressure is above that of the atmosphere, of course the compression will be correspondingly increased. It will also be seen that, without any or with very little clearance space, the compression would at the end of each stroke rise above the boiler pressure. It being a peculiarity of the ordinary shifting-link motion that as the period of admission is reduced that of compression is lengthened, the latter becomes very great when the steam is cut off at less than one-third or one-fourth of the stroke.

QUESTION 394. *In what respect would a diagram made by an indicator differ from a theoretical form represented in fig. 289?*

Answer. It would be drawn with less exactness—that is, the corners instead of being sharply defined, as in fig. 289, would be more or less rounded, as shown in figs. 285 to 288, and the curves and lines would vary somewhat from the exact mathematical form indicated in fig. 289. The higher the speed at which the engine is working when the diagrams are taken, the greater will be the variation from the theoretical form.

QUESTION 395. *If the amount of pre-admission is insufficient, how will it be shown in the indicator diagram?*

Answer. The effect of too little pre-admission is to lower the pressure of the steam at the beginning of the stroke, and at high speeds there will not be time enough nor sufficient opening of the steam-port to supply the deficiency after the stroke has commenced. The effect of this is shown by the dotted lines, in fig. 288, which shows that maximum pressure was not reached until some time after the beginning of the stroke. With a link motion, if the steam is cut off short the port is opened but a small distance, which is sufficient to maintain the pressure at the beginning of the stroke, when the piston is moving comparatively slowly. But when the piston has moved a short distance, its motion is accelerated and at the same time the port is being gradually closed by the valve, and the area available for the admission of the steam is thus gradually diminished. Consequently, the steam cannot enter fast enough to follow the piston, and the pressure falls, so that the admission line, *A B*, is no longer horizontal, but droops, as shown in figs. 287 and 288.

Another cause of loss of pressure at the commencement of the stroke, when the steam is worked expansively, is the partial condensation of the entering steam, which takes place in consequence of its coming in contact with the sides of the steam-ways and walls of the cylinder, which have been previously cooled down by contact with the exhaust steam of the preceding stroke. This condensation of the fresh steam causes a very serious loss of efficiency in the steam-engine.*

QUESTION 396. *If the opening of the steam-ports during admission is too small, what will be the form of the diagram?*

Answer. The effect will be very much the same as that produced by too little pre-admission or lead—that is, the pressure in the cylinder will be much lower than in the boiler and will fall rapidly during the periods of admission, as shown in fig. 288.

QUESTION 397. *What defects may be indicated by the expansion curve of indicator diagram?*

Answer. If the cylinders are not well protected, and there is much loss of heat from radiation, there will be a rapid fall of pressure during the period of expansion, which will be shown by the expansion curve falling below the theoretical curve. If, on the contrary, the indicator curve is

* "The Steam-Engine," by George C. V. Holmes.

much above the theoretical curve, it may be caused by a leak in the valve. As steam is quite as likely to leak from the steam-port into the exhaust as from the steam-chest into the steam-port, a valve which is not tight may produce just the contrary effect upon the indicator diagram. As it is usually quite easy to detect a leak in the valve by other means, the use of the indicator for this purpose is unnecessary. Attention is called to it, however, to show the impossibility of getting results of any value with the indicator if the valves are not steam-tight.

QUESTION 398. *What should be observed regarding the exhaust line of the indicator diagram?*

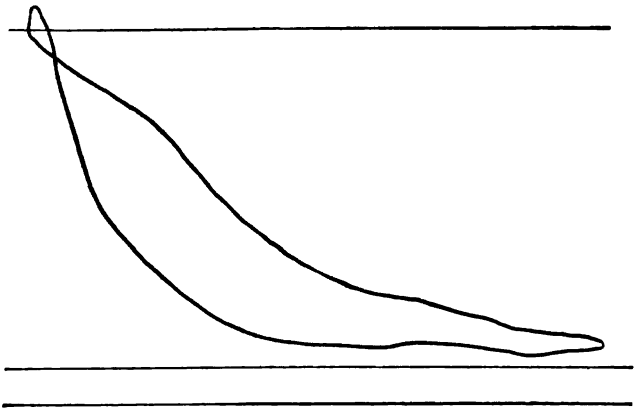


Fig. 292. Indicator Diagram.

Answer. The most important point to be observed is, whether the pressure at the end of the stroke is reduced as low as possible, as at high speeds it is usually much more difficult to exhaust the steam from than to admit it into the cylinder. As already stated, the blast in the chimney makes it almost impossible to exhaust the steam to atmospheric pressure when the locomotive is running fast. If the steam is released too late in the stroke, as already explained, there will not be time enough nor sufficient opening of the port to allow the confined steam to escape from the cylinder before the end of the stroke, and this will be indicated on the diagram by the space between the line of back pressure and the atmospheric line during the commencement of the return stroke, as shown in figs. 290–292.

QUESTION 399. *What should be observed regarding the line of back pressure?*

Answer. The most important point is, that it should approximate as closely as possible to the atmospheric line, as all the back pressure not only diminishes the efficiency of the engine, but is a total loss of energy. Too much inside lap will increase the amount of back pressure, but generally it is more influenced by the area of the blast orifices than by any other cause. Every effort should be made, therefore, to have them as large as possible, and yet have the boiler make as much steam as is needed.

When only one blast orifice is used for both cylinders, it often happens that when the steam is exhausted from the one cylinder it "blows" over into the other, and thus produces an additional amount of back pressure. This is shown by a rise or "hump" in the line of the back pressure, as indicated by the dotted line, $f' g' h' i' j'$, in fig. 287.

QUESTION 400. *What good effects result from compression?*

Answer. It serves to arrest the motion of the piston at the end of the stroke. As was explained in Chapter IX, the motion of a piston in the cylinder of a steam-engine is not a uniform one, but increases in speed from the beginning of the stroke to the middle, and diminishes in speed from the middle to the opposite end. It is obvious that if the momentum, or actual energy stored up in the piston or other reciprocating parts after they have passed the middle of the stroke, added to the pressure behind the piston, is greater than the resistance offered by the crank, the motion of the latter will then be accelerated and thus conveyed to the moving engine and train. If, however, there is any momentum in the piston when it reaches the end of the stroke, evidently it can exert no power to cause the crank to revolve, but the momentum must be expended by producing a pressure on the crank-pin and thus on the axle-boxes. Not only will such a pressure not cause the crank to revolve, but it will be more difficult to turn the crank with such a pressure against it than it would be without. The momentum of the piston and other reciprocating parts at dead points, therefore, creates a resistance to the movement of the crank instead of helping to turn it. It will also be observed that after the crank has moved slightly from the dead-point, any pressure on the piston will exert very little force which will tend to turn the crank. In fact, the nearer the piston is to the end of the stroke the greater is the proportion which the friction of the crank-pin and axle bears to the useful effect of the strain in causing the crank to turn. Calculation shows that for about three degrees on either side of the dead-points, the effect of pressure on the crank-pin is actually to retard the engine. If, then, the piston reaches the end of the stroke with a certain amount of momentum stored up in it, which is expended by producing pressure on the crank, then it will not only be a waste of energy but a double waste by retarding the motion of the crank. If, however, this energy can be absorbed by compressing steam which will fill the clearance spaces, it will not only prevent the retarding effect referred to, but the energy in the piston and other parts will be converted into steam pressure, which will be given out in useful work during the next stroke. It would, of course, be impossible to arrest the motion of the piston instantly, and therefore its momentum is gradually absorbed from the time compression begins until it reaches the end of the stroke. As the energy of a moving body is equal to its weight multiplied by the square of its speed, it is obvious that to overcome this a different amount of compression would be required for each speed, and also that it must be adjusted to the weight of the moving parts. Such adaptation is not practicable on locomotives, nor does the link-motion enable us to alter the amount of compression with so much exactness; but the explanation shows the value of increasing the amount of compression with the speed, which fortunately the peculiarities of the shifting-link motion enables us to do without difficulty.

QUESTION 401. *How does a link-motion increase the amount of compression with the speed?*

Answer. When a locomotive is running fast the steam is cut off short, and the lead and the amount of compression increases as the period of admission diminishes.

QUESTION 402. *What cause produces the form of diagram represented by fig. 292?*

Answer. It is produced by excessive compression, which causes the pressure in the cylinder to rise above boiler pressure before pre-admission begins. As soon as the port is opened, part of the steam in the cylinder flows back into the steam-chest, and thus the pressure is reduced, as shown by the diagram.

QUESTION 403. *What will an indicator diagram show?*

Answer. It will show:

1. The pressure of steam in the cylinder at the beginning of the stroke of the piston, or the *initial pressure*, as it is called.

2. Whether the initial pressure is increased or diminished during the period of admission.

3. The point of cut-off.
4. The pressure during the whole period of expansion.
5. The point of release—*i. e.*, when the exhaust is opened.
6. The rapidity with which the exhaust takes place.
7. The back pressure on the piston.
8. The point at which the exhaust is closed.
9. The compression after the exhaust is closed.
10. The power which is driving the engine.
11. Leakage of the valve or piston.

QUESTION 404. *What are the principal causes which affect the form of an indicator diagram?*

Answer. 1. The friction of the steam in the pipes and ports.

2. The variable size of the openings of the steam-ports as caused by the gradual motion of the slide-valve.

3. The action of the internal surfaces of the cylinder in causing the condensation and partial re-evaporation of some of the entering steam.

4. The steam contained in the clearance spaces which affects the curve of expansion.

5. The gradual opening of the exhaust-port, which makes it necessary to release the steam too early in the stroke.

6. The friction of the exhaust passages, which increases the back pressure.

7. The clearance spaces, which, combined with the unavoidable nature of the action of a slide-valve driven by a link-motion and the momentum of the moving parts, make compression necessary.*

QUESTION 405. *How can we determine whether the steam is distributed in the cylinders to the best advantage, and how can we discover the fault, if there is one, in the link-motion?*

Answer. The indicator will show the action of the steam in the cylinder, and motion-curves drawn with the instrument described in answer to Question 367 will show the exact movement of the valve. By comparing the indicator diagram with the motion-curves, the one will show the defects in the other.†

QUESTION 406. *To what extent can the movement of the valve be modified by alterations in the proportions of the link-motion?*

Answer. The motion of the valve is susceptible of an almost infinite

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* Questions 403 and 404 were suggested by George C. V. Holme's excellent book on the steam-engine, and the answers thereto are in substance taken therefrom.

† See description of Richards' Improved Steam-Engine Indicator, with directions for its use, by Charles T. Porter, London.

number of changes, by different variations and combinations of proportions of the working parts of the link-motion. These changes are, however, limited by the general laws which govern the motion of eccentrics, and therefore cannot influence the motion of the valve beyond certain limits. Hardly any variation can be made either in the proportions or arrangement of the working parts which will not have some influence upon the movement of the valve. Aside from the proportions of the valve itself, which have already been discussed, the throw of the eccentrics, the length of the rods and of the link, the point of connection of the rods with the link, the point of suspension, the position of the lifting-shaft, the length of the arms, the length and position of the rocker-arms, will each of them effect the distribution of steam. The number of combinations of all these different proportions is, of course, almost infinite, and therefore any full discussion of them will be impossible here.

QUESTION 407. *What are the most important points which require attention in designing a link-motion?*

Answer. It should be proportioned so that—

1. The lead and the period of admission should be the same for each end of the cylinder, at each point of cut-off, and, if possible, in back as well as forward gear.

2. The width of opening for both admission and exhaust should be as large as possible when steam is cut off short.

3. The exhaust or pre-release should occur early enough and be maintained long enough to reduce back-pressure as low as possible.

QUESTION 408. *In designing valve-gear how is it usually tested?*

Answer. Usually a full-sized model is made, the various parts of which are made adjustable, so that the proportions and position of the different parts may be varied, in order that the best possible movement of the valve may be obtained. If mechanism for drawing diagrams of the motion of the valve, similar to that illustrated in fig. 270, is added to the model, the action of the valve-gear can be completely delineated.

QUESTION 409. *How can the lead and periods of admission of a slide-valve be equalized at each end of the stroke of the piston?*

Answer. It is impossible to make the periods of admission absolutely alike for every point of cut-off in both fore and back gear. It is, therefore, customary to disregard the back gear, as engines are worked but little with the link in that position. Even for forward gear the periods of admission cannot be made exactly alike for each end of the cylinder and for each point of cut-off, and therefore it is usual to make the periods of admission alike for half-gear forward, in which position the link is worked most.

The periods of admissions for the front and back ends of the cylinder can be changed most in relation to each other by altering the position of the point of suspension on the link. This can be done either by moving this point up or down, or horizontally. Usually links are suspended from a point halfway between the points of connection of the eccentric-rods and from ½ to ¾ inch back of the centre line of the slot in the link. A somewhat better distribution can be secured by suspending them about 3 inches above the centre, but the suspending-links must then be made so short that they are subjected to very great strains by the motion of the link, and this evil is usually considered much greater than the advantage which is gained thereby in the more equal distribution. The point at which the upper end of the suspension-link is hung also influences the relative amount of admission front and back. This point, of course, varies as the end of the lifting-arm is raised or lowered. The best position for the lifting-shaft and the length of its arm can be determined, perhaps, most satisfactorily by placing the link in full-gear forward, then moving the point of suspension of the upper end of the link-hanger horizontally, so that the front and back admission will be alike, and then marking this position. The same process should then be repeated for half-gear and for the shortest point of cut-off. If the position of the lifting-shaft and the length of its arm are then so arranged that the end of the latter will move through the three points which have been thus determined, the admission will be very nearly equal for each end of the cylinder. Usually, however, it is impossible to arrange the shaft and arm so that they will conform exactly to these conditions, and therefore an approximation is made which will come as near as possible to what is required. It may be stated, however, that the lifting-shaft should be kept as low as possible, so as not to interfere with the eccentric-rods. In some cases the shaft has been suspended from the boiler, so that the outside eccentric-rod would work past or over the end of the lifting-shaft, thus allowing the latter to be located lower than would otherwise be possible.

QUESTION 410. *Which parts of the link-motion have the greatest influence on the distribution of steam?*

Answer. The lap of the valve and the throw of the eccentrics. The effect of any change of these upon the distribution is very similar to that produced if a single eccentric is used, which was explained in the answers to Questions 146 and 147.

QUESTION 411. *What is the effect upon the admission of increasing the throw of the eccentrics with the same lap?*

Answer. As already explained, the effect is to increase the period of admission, or, in other words, to cut off later in the stroke, and also to increase the width of the opening of the steam-port or the distance which the valve throws over the port. This has an important influence upon the admission when the link-motion is used.

QUESTION 412. *What is meant by the angular advance of the eccentrics?*

Answer. It is the angle which a line, *e f*, fig. 293, drawn through the

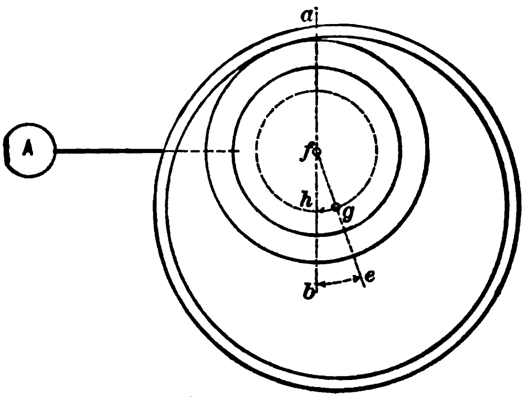


Fig. 293. Eccentric.

centre, *f*, of the axle and the centre, *g*, of the eccentric makes with a vertical line, *a b*, also drawn through the centre of the axle when the crank is on one of the dead-points or centres. Thus, in fig. 293, the crank-pin, *A*, is represented on the front centre. In order to give the valve the necessary lead, the eccentric must be moved back of the vertical line, *a b*. The angle, *b f e*, which the line, *e f* (drawn through the centre, *g*, of the eccentric and *f* of the axle) makes with the vertical line is called the *angular advance*.

QUESTION 413. *What is meant by linear advance?*

Answer. By linear advance is meant the distance which the valve has moved from its middle position at the beginning of the stroke of the piston. This, when the two rocker-arms are the same length, is the same as the distance, *g h*, of the centre of the eccentric, *g*, from the vertical line, *a b*, fig. 293.

QUESTION 414. *Why does the cut-off occur earlier with an eccentric having a short throw than with one which gives more travel to the valve?*

Answer. Because it is necessary to give the eccentric with the short throw more angular advance—that is, it must be set "farther ahead" in order to give the valve the required lead. This is illustrated in fig. 294,

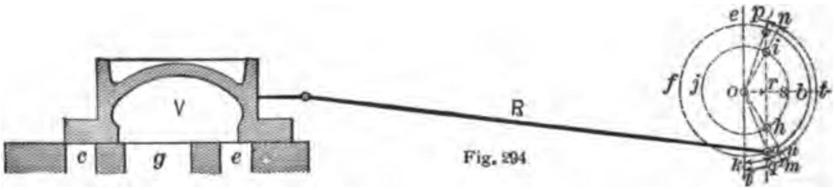


Fig. 294

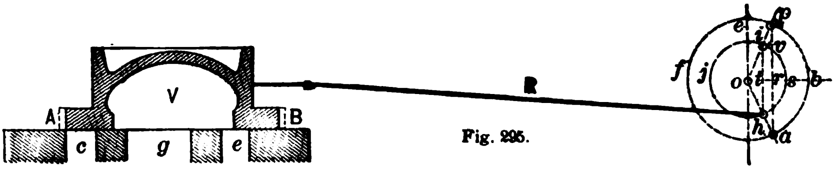


Fig. 295.

Diagrams showing Movement of Eccentrics. Scale ⅛ in.—1 in.

in which a section of a valve, *V*, and ports, *c g* and *e*, are represented. In order to simplify the diagram as much as possible, the rocker is left out and the valve is supposed to be moved by the rod, *R*, directly from the centre, *a*, of the eccentric.* The effect of the angularity of the connecting-rod and eccentric-rod is also neglected. The circle, *a b e f*, represents the path of the centre of an eccentric having 5 inches throw, and, *h s i j*, the path of one having 3½ inches throw. In order to give the valve the required lead, which is supposed to be just line-and-line at the beginning of the stroke, the linear advance of the valve must be equal to the lap, or ⅞ inch. If, therefore, we draw a line, *p q*, parallel to the vertical centre line, *e k*, and ⅞ inch from it, the intersection of *p q* at *a* and *h* with the paths of the eccentric will be the centres of the eccentrics. If through these centres and the centre of the circle, lines *o q* and *o h* be drawn, the angles, *k o q* and *l o m*, which they make with the vertical, *e k*, will represent the angular advance. It will be seen from these lines, and by com-

* It will be seen that this causes the position of the centre of the eccentric to be reversed.

paring these two angles, that in order to give the valve the required lead, it is necessary to give the eccentric with the small travel more angular advance than is necessary for the one with the larger throw. It is obvious, too, that when the centre of the larger eccentric has reached the point, *b*, the valve will have received its greatest travel, and that when it reaches *p*, the steam-port, *c*, will again be closed or the steam cut off. If the small eccentric is employed, the valve will have its maximum travel when the centre, *h*, reaches *s*, and the port will be closed when it reaches *i*. By drawing lines, *o p* and *o n*, through *i* and *p*, it will be seen that from the beginning of the stroke until the steam is cut off, if the large eccentric is employed, it, and consequently the shaft and crank, must move over an angle measured by the arc, *q t p*. If the small eccentric is used, it and the crank must move through an angle measured by the arc, *u t n*. In other words, the crank must turn a considerable greater distance before steam is cut off with an eccentric having a large, than with one having a small, throw.

It is also quite obvious from fig. 294 why the port is opened a shorter distance with a small than with a large eccentric. The distances, *o s* and *o b*, are equal to half the throws of the eccentrics, or $1\frac{3}{4}$ or $2\frac{1}{2}$ inches. The linear advance, *o r*, is in both cases $\frac{7}{8}$ inch, and therefore after the port begins to open, the valve will be moved by the small eccentric, a distance which is equal to $1\frac{3}{4}-\frac{7}{8}=\frac{7}{8}$ inches, and by the large one $2\frac{1}{2}-\frac{7}{8}=1\frac{5}{8}$ inches.

QUESTION 415. *What is the effect on the admission of giving an eccentric with a small throw the same angular advance as one with a large throw, and then reducing the lap of the valve so that the lead will be the same in both cases?*

Answer. The admission and the cut-off will then occur at the same points of the stroke, but the ports will not be opened so wide. This is illustrated in fig. 295, in which the paths of two eccentrics having the same throw as those in fig. 246 are represented. The centre, *a*, of the larger eccentric is represented in the same position in fig. 295 as in fig. 294. If a line is drawn from the centre of the larger eccentric to *o*, the centre of the axle, and if the centre, *h*, of the smaller eccentric is located on the intersection of this line with the circle, *h s i j*, which represents its path, then the smaller eccentric will have the same angular advance, but the linear advance measured by the distance, *o t*, will be only $\frac{5}{8}$ inch. If the valve has the same lap as in fig. 294 its steam edges at the beginning of the stroke—if the small eccentric is employed—will occupy the position represented by the dotted lines, *A* and *B*. If these edges are cut off and the valve is made as shown by the full lines and shading, then it will have the same lead as in fig. 294. It is obvious, too, that if the smaller eccentric has the same angular advance, its centre will move from *h* to *i*, at which point, with the reduced lap, the steam will be cut off at the same time that the centre of the large eccentric will move from *a* to *p*, at which point it cuts off the steam with the valve having the large lap. There is, however, this difference in the distribution, that in the one case the valve opens the port a distance equal to *t s*, and in the other a distance equal to *r b*. As *o t* is equal to the linear advance of the small eccentric, or ⅝ inch, and *o s* to half the throw of the eccentric, or 1¾, *t s* is equal to 1¾ — ⅝=1⅛ inches. The distance *r b*, as shown above, is equal to 2½ — ⅞=1⅝ inches, so that the effect produced upon the admission of using an eccentric with a small throw and corresponding amount of lap is, that the ports are not opened so wide as with an eccentric having a larger throw.

QUESTION 416. *How do eccentrics with a short throw and valves with a corresponding amount of lap, affect the admission with a link-motion as compared with eccentrics having a larger amount of throw and greater lap of valve?*

Answer. The chief difference, as has been explained, is that, with eccentrics having a short throw and valves with a corresponding amount of lap, the ports are not opened so wide for the same period of admission as they are with eccentrics having more throw and valves with greater lap. Thus a series of motion-curves is shown in fig. 296, drawn with a model of a link-motion like that illustrated in fig, 270. The eccentrics had 5 inches throw, and the valve ⅞ inch lap outside and 1/16 inch inside. Fig. 297 represents a series of curves, drawn with the same arrangement of valve-gear, excepting that the eccentrics had 3½ inches throw and the valve ½ inch lap. In both cases the curves represent the motion of the valve when cutting off at the same point of the stroke. The following table will show the relative amount of opening of the port:

POINT OF CUT-OFF.	WIDTH OF OPENING OF STEAM-PORT.	
	Eccentric 5 inches throw.	Eccentric 3½ inches throw.
6 inches.	7/32 inch.	5/32 inch.
10 "	11/32 "	7/32 "
15 "	⅝ "	⅜ "
18 "	31/32 "	11/16 "
21 "	1¼* "	1 1/32 "

* The valve throws over the steam-port ⅝ inch at this point.

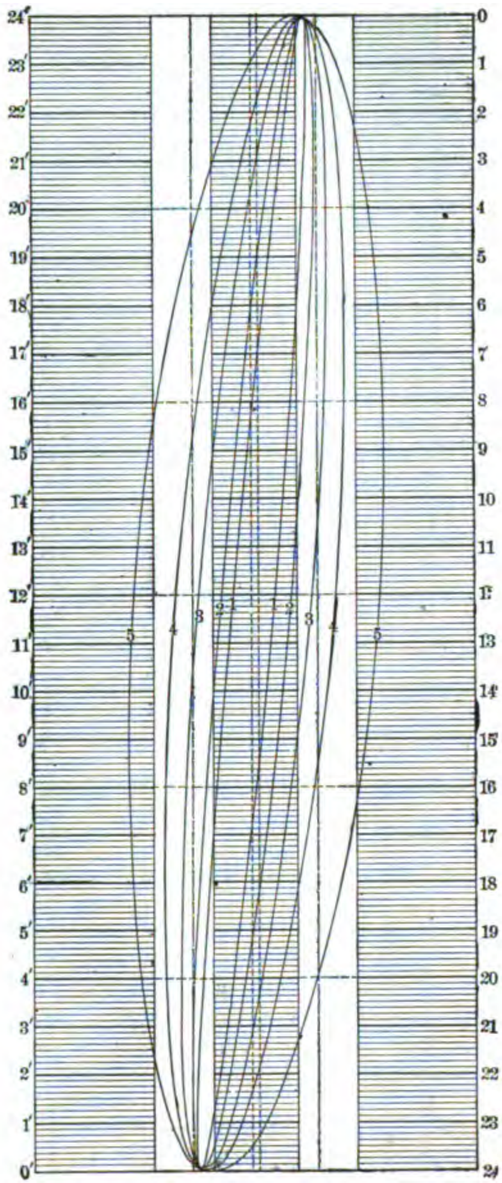


Fig. 296. Curves Showing Motion of Valve.

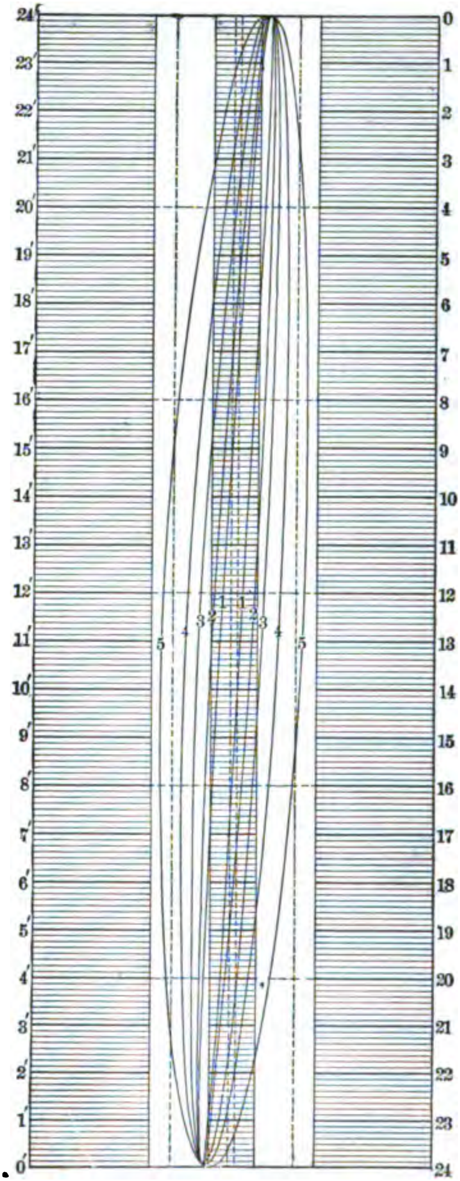


Fig. 297. Curves Showing Motion of Valve. Scale ¼ in. = 1 in.

It will be seen from this that the eccentric with 5 inches throw gives a greater width of opening for every point of cut-off than the one with 3½ inches throw. For the higher admissions this is not important, but when steam is cut off short it will be observed that the width of the opening is very small. At high speeds the small opening is a great disadvantage.

QUESTION 417. *Has it been determined what amount of opening is required for given speeds of the piston?*

Answer. Not with any degree of accuracy. It is customary to make the area of the ports about one-tenth of the piston. It is certain, however, that with steam-ports of this proportion, excepting at high speeds, an opening considerably less than their whole area is sufficient to maintain steam nearly equal to boiler pressure in the cylinders. One of the defects of the link-motion is that the opening of the port is very small when the steam is cut off short. When the valve begins to close the port the speed of the piston is increasing so that it is impossible to maintain full boiler pressure during the whole period of admission. It is best, therefore, to secure the largest practicable opening of the ports for the lower points of cut-off.

QUESTION 418. *What are the proportions of the valves and eccentrics used in the ordinary practice in this country?*

Answer. Excepting for very light locomotives the maximum travel varies from 4½ to 5½ inches, the outside lap from ⅝ to 1¼ inches, the inside lap from 1/16 to 3/16 inch, and the lead in full gear from 1/16 to ⅛ inch.

QUESTION 419. *What should be the width of the bridge between the steam and exhaust-ports?*

Answer. It is usually made about the same thickness as the sides of the cylinder, in order to secure a good casting; but sometimes it is necessary to make it wider, in order to prevent steam from escaping from the steam-chest into the exhaust, which is apt to be the case if a valve has little lap and a long travel.

QUESTION 420. *What determines the width of the exhaust-ports?*

Answer. The throw of the valve. This will be clear if we refer to fig. 70. As explained in answer to Question 134, the port, *g*, should be wide enough so that when the valve is at the end of its travel the opening, *h i*, of the exhaust-port is not contracted too much. If this opening is not wide enough it will prevent the free escape of the exhaust steam and increase the back pressure.

It is, therefore, best to make the exhaust-port so wide that with the greatest travel of the valve the width of its opening will be nearly equal to the width of the steam-ports.

QUESTION 421. *What effect does the steam have on a slide-valve?*

Answer. It exerts a pressure nearly or quite equal to the area of the top of the valve multiplied by the pressure of the steam on that area. Thus, a valve whose outside dimensions are 9×18 inches would have an area of 162 square inches. If a boiler pressure of 140 lbs. per square inch is exerted on the whole of this area it would be equal to $162 \times 140 =$ 22,680 lbs. The actual pressure exerted by the steam on the valve is, however, very irregular, as during some portions of the stroke the steam in the ports under the valve exerts an upward pressure, which opposes that on top. The pressure on top is also influenced by the fit of the valve to its seat. If it is not steam-tight more or less steam will get between the valve and its seat, and thus counteract the pressure on top, whereas if the valve is perfectly steam-tight, no such action will occur. In any event, the pressure on top of slide-valves is very considerable.

QUESTION 422. *How much of the whole power of the engine is absorbed in moving slide-valves?*

Answer. Experiments* with small engines have shown that from one to two per cent. of the whole power is absorbed in moving the slide-valves when the pressure on them is not relieved in any way.

QUESTION 423. *How is the pressure on slide-valves relieved?*

Answer. By excluding the steam from the top of the valve so that the pressure cannot be exerted on the valve. This is done by means of packing on the top of the valve, which bears against a plate above. This packing consists either of rings or straight strips of metal, *p p*, as shown in fig. 298. In the Richardson Balanced Valve, which is the one shown by fig. 298, the packing is arranged in rectangular form and held in grooves on top of the valve. This packing bears against a plate, *P*, attached to the steam-chest cover, which is planed and scraped so that the surfaces of contact of the packing against the plate are steam-tight. The packing is also made steam-tight where it is in contact with the valve, and is held up against the plate by springs underneath. Steam is thus excluded from the top of the valve, at *a a*. A hole, *o*, in the valve allows any steam which might leak past the packing to escape into the exhaust cavity, *V*. A relief valve, *R*, is attached to the steam-chest to admit air into the steam-chest and prevent it from being sucked in through the exhaust-

* See paper on "The Power Required to Move Slide-Valves," by Mr. C. M. Giddings, read at the Chicago Meeting of the American Society of Mechanical Engineers, in 1887.

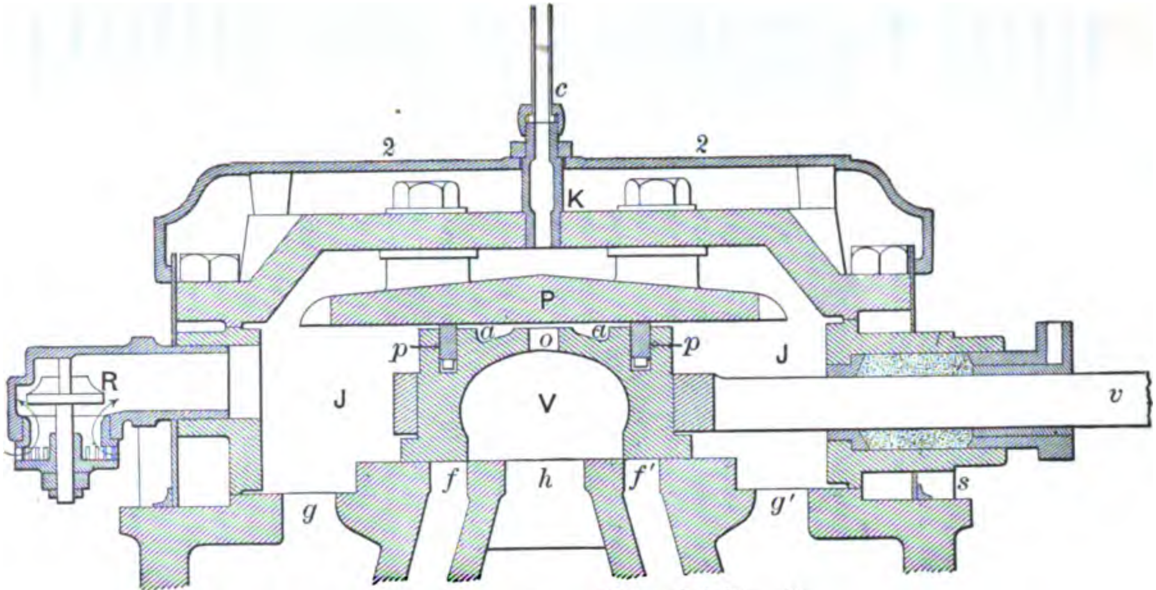


Fig. 298. Richardson Balanced Valve. Scale ¼ in. = 1 in.

pipes, when steam is shut off, and the action of the piston creates a partial vacuum in the steam-chest. If air was sucked in through the exhaust-pipes. cinders and other gritty substances would be drawn in with it, and would be liable to cut the valve-face and the inside of the cylinder. When a vacuum is produced in the steam-chest, the relief-valve, *R*, is raised up by the pressure of the air below, and it flows in through openings underneath, as indicated by the arrows.

QUESTION 424. *How are the notches in the sector of the reversing lever arranged?*

Answer. They are often arranged so that the steam will be cut off at some full number of inches of the stroke when the reverse lever is in each one of the notches. They are then located so that the steam will be cut off at 6, 9, 12, 15, 18 and 21 inches, or at 6, 8, 10, 12, 15, 18 and 21 inches of the stroke. A notch is also placed so as to hold the link in mid-gear. In other cases as many notches as there is room for are put into the sectors. The latter seems to be much the best plan, as it gives more gradations in which the valve-gear can be worked, and it is a matter of no consequence whatever in the working of an engine whether the steam is cut off at some full or some fractional number of inches of the stroke.

QUESTION 425. *Where is the reversing-lever located and how is it constructed?*

Answer. It is located in the cab and above the *foot-board**, 95, as shown in Plate IV. It consists of a lever, 20 21, with the fulcrum, 22, at its lower end. The *reversing-rod*, 19 21, which connects the lever with the vertical arm, 18, of the lifting-shaft, is attached above the fulcrum of the reversing-lever. Fig. 299 represents a side view of the lever on an enlarged scale and with some of the details attached, which are omitted on Plates III and IV. *S S′* is a curved bar, which, in this country, is usually called a *quadrant*, but in England it is called (and more properly) a *sector*. Sometimes a pair of these are used and they are then placed one on each side of the reversing-lever and are fastened to some portion of the engine. The sector has notches, *n n n*, cut in it to receive the *latch*, *l*, which slides in a clamp, *c*, and holds the reversing-lever in the notch in which it is placed. This latch is operated by a *trigger*, *t*, which is grasped by a locomotive engineer when he takes hold of the handle, *H*, of the reversing-lever. The trigger works on a pin, *e*, as a fulcrum, and is attached to the latch by a rod, *r r*. When the trigger is pressed up against the

* The *foot-board*, 93, Plates III and IV, is a platform for the locomotive runner and fireman to stand on, and is located at the back end of the engine.

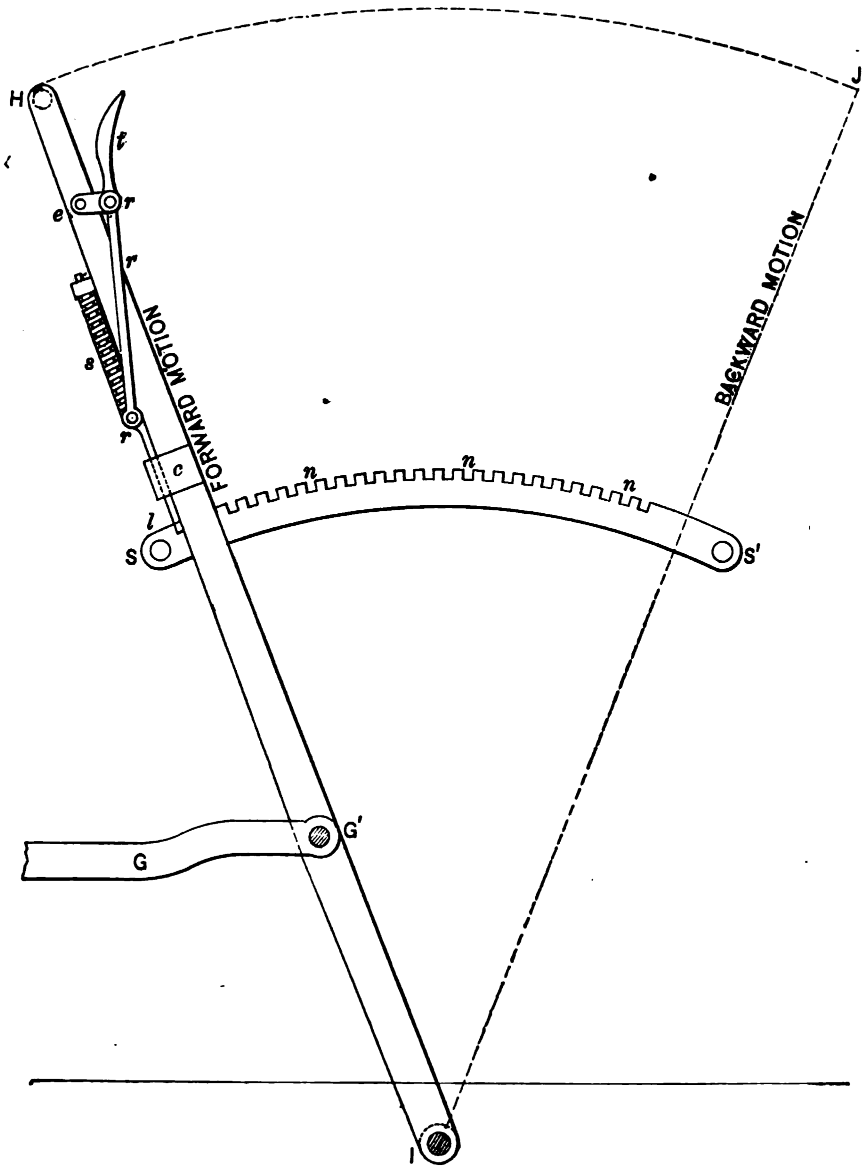


Fig. 299. Reversing-Lever. Scale 1 in.—1 ft.

handle, the latch is raised out of the notches by the rod, *r r*, and is pressed into them again by the spring, *s*, when the trigger is released. The reversing-rod, *G G'*, is connected to the lever at *G'*, and is part of the rod indicated by the same letter in fig. 246, and is shown by the dotted lines, 19 19, Plates III and IV.

QUESTION 426. *How long should the reversing-lever be?*

Answer. The lever should be sufficiently long, so that in throwing the link from full-gear forward to full-gear backward the handle, *H*, will move *not less* than four times the distance that the link is moved. It is much better to give the end of the handle five or even six times the motion of the link, as there will then be a much easier action in reversing the engine. This will also make it possible to use longer sectors and give room for more notches.

QUESTION 427. *What provision is made in the reversing-gear for overcoming or neutralizing the weight of the link and other parts of the valve-gear?*

Answer. Their weight is counterbalanced by the pressure of a spring of some kind. In fig. 246 the case, *H*, contains a spiral spring (of the form of a watch spring); the inner end is fastened to the shaft, *A*, and the outer end to a portion of the case which can be turned around the shaft. By this means the tension of the spring can be adjusted, and the case is then held in the required position by a bolt shown below the shaft, *A*. Different kinds of springs are used for this purpose, and sometimes are attached to the reversing-lever instead of to the lifting-shaft.

QUESTION 428. *What is meant by "setting" a slide-valve?*

Answer. It means the adjustment of the position of the eccentrics on the axle, and the length of the eccentric-rods and valve-stem, so that the valves will give the required distribution of steam.

QUESTION 429. *How are the valves of a locomotive set?*

Answer. After the wheels, axles, main connecting-rods and valve-gear are connected together, put the rocker-arm in its middle position, and lengthen or shorten the valve-stem, so that the valve will then be in the centre of the valve-face. Then place the crank on the forward centre and the full part of the forward motion eccentric above and that of the backward motion eccentric below the axle, and fasten them to the axle temporarily by tightening up the set-screws. Then throw the link down until the block comes nearly opposite to the end of the eccentric-rod, and turn the wheels,* and at the same time observe whether the travel of the

* This can be done by moving the engine on the track or by raising it off its wheels, so that the latter can be turned without moving the former. In some shops a pair of rollers is put in the track, so that by placing the driving-wheels on them they can be turned without any difficulty.

valve is equal to the throw of the eccentric, and also whether it travels equally on each side of the centre of the valve-face. If its travel is greater than the throw of the eccentric, raise the link up; if less, lower it down until the two are just equal, and then mark the position for the notches on the sectors or quadrants to receive the latch of the reversing-lever. If the valve does not travel equally on each side of the centre of the valve-face, either lengthen or shorten the eccentric-rod, as may be necessary. Repeat this operation for the backward motion, by raising the link up until the block is opposite the end of the lower eccentric-rod. After having done this, go over the whole process again to see whether it is all correct. Now with the crank on the forward centre and the link in full-gear forward, loosen the set-screws in the forward eccentric, and move it around the axle so that the valve will have the required lead, and then fasten it again. Now raise the link up into full back-gear, and set the backward eccentric in the same way. Then turn the wheels so as to bring the crank on the back centre, and observe whether the lead is correct for the back end of the cylinder. If it is not, lengthen or shorten the eccentric-rod so as to make the lead alike at both ends, and if then it is too much or too little, it can be increased or diminished by moving the eccentrics on the axle.

Great care must be taken in setting valves to be sure that the cranks are exactly on the centres or dead-points, and it is impossible to set them in that position with sufficient accuracy from the motion of the piston or cross-head alone, and therefore the centres of the crank-pins should always be set so as to conform to a line drawn through the centre of the cross-head pin, crank-pin, and the axle.

When the valves are set it should also be noticed whether the axle-boxes (whose construction will be explained hereafter) are in the middle of the jaws in the frames, and if not they should be moved to that position by driving wooden wedges between them and the frames, either above or below, as may be required. The position of the boxes has a very material influence on the valve-gear.

If it is intended to lay off the notches on the sectors so as to cut off steam at certain definite points of the stroke, these points should be laid off in the guides from the motion of the cross-head. The latter being placed in any of the required positions at which steam is to be cut off, the reversing-lever should then be moved so that the link will just close the admission port. The lever can then be clamped to the sectors, and the wheels turned so as to show whether its position is correct for each end of the stroke. It has been mentioned before that it is impossible to get the ordinary link-motion to cut off at exactly the same points at both ends of the cylinder, but a very close approximation can be made by proportioning the different parts properly. As has already been stated, it is a much better plan to put as many notches in the sectors as possible than to locate them for certain definite points of the stroke.

In setting the valves of locomotives, care must be taken to turn the wheels *forward* for the *forward motion* and *backward* for the *backward motion*.

After the valves are set, the position of the eccentrics on the shaft should be marked, so that in case they become loose on the road they can easily be set again. It is usual, too, to mark the position of the valves with centre-punch marks on the valve-stem and on the stuffing-box of the steam-chest, so that with a gauge made for the purpose the position of the valve can be determined without taking off the steam-chest cover.

In some cases the eccentrics are keyed on, which is done after their position is determined by setting the valves. The ends of the set-screws, which are used to fasten the eccentrics, should be cup-shaped and case-hardened, so as to hold as securely as possible to the axle when they are screwed down.

After the valve is set on one side of the engine, that on the other side should be tested for each point of cut-off, so as to be certain that the two valves work alike. It sometimes happens that the link-hanger or suspension link on one side must be either lengthened or shortened, so that the two links will occupy the same relation to their rocker-pins.

After the valves have been set with the pistons at the end of the stroke, the valves on each side should be tested with the pistons at half stroke, to see whether they work alike on each side with the reversing-lever in different positions. It should be noticed whether the link-blocks stand in the same position in the links at the beginning of the stroke of each piston. This can be known by cutting a stick to fit between the top or bottom of the block and the end of the link. Sometimes the two horizontal arms on the reversing-shaft are not in the same horizontal line, and the shaft must, therefore, be heated and twisted so as to make the valve-motion work alike on both sides.

If the valves are set when the engine is cold, they should be tested after it has been fired up, as the expansion of the parts may affect the action of the valves.

CHAPTER XVII.

ACTION OF THE PISTONS, CRANKS, AND DRIVING-WHEELS.

QUESTION 430. *Is the whole of the net effective pressure which is exerted on the pistons communicated to the crank-pin?*

Answer. No; a part of this pressure is exerted to overcome the inertia of the pistons and other reciprocating parts during the first half of the stroke, while the back pressure resists their movement and helps to stop them at the end of the stroke.

QUESTION 431. *How can we show the pressure which is exerted on the crank-pin?*

Answer. By first constructing a diagram similar to fig. 97, to show the pressure for any given speed which must be exerted on the piston during the first half of the stroke to accelerate it, and that which must resist it to bring it to a state of rest during the last half, and then laying off the net effective pressure, as indicated in fig. 291, on the line that represents the pressure which must be imparted to and is given out by the piston.

Thus, a line, *E F*, fig. 300, should be drawn to represent the length of the stroke on the same scale as that used for *H D*, fig. 291. *E F* may also represent the line of atmospheric pressure. From the extremity, *E*, a perpendicular, *E N*, should then be drawn, below *E F*, and another, *F L*, from *F*, above *E F*. The centrifugal force of the reciprocating parts should now be calculated. With the same data and calculations given in Question 169 and its answer, we will have a centrifugal force of 14,660 lbs., which must be exerted at the beginning of the stroke to accelerate the piston. The influence of a connecting-rod seven times the length of the crank will increase this force one-seventh, as explained in answer to Question 174, so that it will be equal to

$$14{,}660 + 2{,}094 = 16{,}754 \text{ lbs.}$$

At the end of the stroke the force which will be exerted by the momentum of the reciprocating parts will be

$$14{,}660 - 2{,}094 = 12{,}566 \text{ lbs.}$$

If, now, we divide these forces by the area of the piston (which is 17 inches in diameter) = 227 square inches, and it will give 73.8 and 55.3 lbs. as the pressure per square inch which must be exerted at the beginning and end of the stroke to start and stop the piston. A distance, $E\,H = 73.8$, should then be laid off on the perpendicular, $E\,N$, below the atmospheric line, $E\,F$, and a distance, $F\,D = 55.3$ lbs., above the atmospheric line. The point at which there is neither acceleration nor retardation of the piston is where the centre lines of the crank and of the connecting-rod are

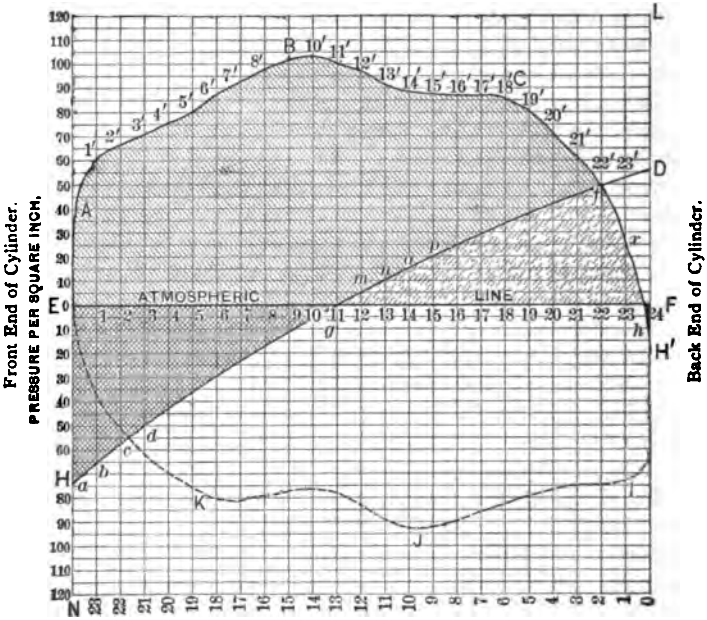


Fig. 300. Diagram Showing Pressure Exerted on Crank-Pin.

at right angles. This is the case where the piston is still one inch ahead of the middle of its stroke, or has moved 11 inches. If, now, we mark this point, *g*, on the atmospheric line, $E\,F$, and draw the arc of a circle, $H g D$,* through the three points which have been laid down, the vertical distance of this line, below $E\,F$, will indicate the pressure per square inch

* This curve is not exactly an arc of a circle, but such an arc is a sufficiently close approximation to the actual curve for the present purpose.

at each point of the stroke which must be exerted on the piston at the speed named to accelerate it, and the distance of *g D*, above *E F*, the pressure required to retard the piston. In other words, the vertical distance of *H g* below the atmospheric line, *E F*, represents the pressure on the piston which is needed to move the reciprocating parts alone during the first part of the stroke, and the vertical distance of *g D*, above *E F*, shows the pressure which the momentum of these parts will exert on the crank-pin during the last half of the stroke, or the force which must be exerted to bring them to a state of rest. If we take the vertical distances, *H A*, *b* 1′ *c* 2′, *d* 3′, etc., from fig. 291, in which they represent the net pressure on the piston, and lay them off on the vertical lines above and from the curved line, *H g D*, fig. 300, and draw a curve, *A B C f*, through their extremities, then the vertical distance of this curve above the atmospheric line, *E F*, will represent the net effective pressure which is exerted on the crank-pin. It has been explained that the distance of the curve, *H g*, *below E g*, represents the pressure required to move the reciprocating parts *alone*, and therefore it must be deducted from the total steam pressure on the piston to get that which is exerted on the crank-pin. Consequently the distances 1 1′, 2 2′, 3 3′, etc., above *E D*, represent the pressure on the crank-pin during the first portion of the stroke. As the momentum of the piston exerts pressure on the crank-pin during the latter half of the stroke—which is represented by the vertical distance of *g D*, above *g F*—therefore the steam pressure on the piston must be *added* to this momentum and the pressure represented by the distances, *m* 12′, *n* 13′, *o* 14′, etc., of fig. 291, are laid off above and from the curve, *g D*, fig. 300, and are indicated by the same letters and numbers in both figures. The pressure exerted on the crank-pin during the latter part of the stroke, therefore, is equal to that of the steam acting on the piston *added* to the momentum of the piston, and is represented in fig. 300 by the vertical distances, 12 12′, 13 13′, 14 14′, etc.

The back pressure on the piston indicated by the area shaded black, in fig. 291, is laid off below the line, *g D*, fig. 300, and is *deducted* from the momentum of the piston.

Thus, at 23 inches of the stroke this pressure is measured by the line, 23′ *x*, fig. 291. This distance is therefore laid off below the line, *g D*, fig. 300, and is indicated by the same number and letter as in fig. 291. The pressure represented by the distance, *D H′*, of fig. 291, is laid off in the same way on fig. 300. By extending the curve, *A B C f*, through *x* and *H′*, its distance above the line, *E F*, will then represent the pressure on the crank-pin during the whole of the backward stroke, and its distance below *g F*, the back pressure exerted on the pin.

The length, *a A*, *b* 1′, *c* 2′, etc., of the vertical lines in the shaded area, *H E A B C f*, fig. 300, represents the steam pressure in pounds per square inch on the piston. Their length, *a* 0, *b* 1, *c* 2, etc., in the area, *H E g*, represents in the same way the portion of the pressure which must be exerted on the piston to move and accelerate the reciprocating parts from the beginning to the middle of the stroke. The area, *g D F*, represents the horizontal pressure exerted by the reciprocating parts during the last half of the stroke. The area, *f D H′*, shows the net back pressure on the piston near the end of its stroke, *g f h*, the net effective pressure exerted by the momentum of the reciprocating parts during the last half of the stroke, and the area, *E A B C f F*, above the horizontal line, *E F*, shows the net effective horizontal pressure exerted on the crank-pin. A similar diagram has been made for the forward stroke of the piston, but has been laid off *below* the lines, *E g F*, and *H g D*, and is represented by the dotted line, *H′ I J K E*.

QUESTION 432. *In what way does the momentum of the reciprocating parts modify the effect of the pressure of the steam when it is worked expansively?*

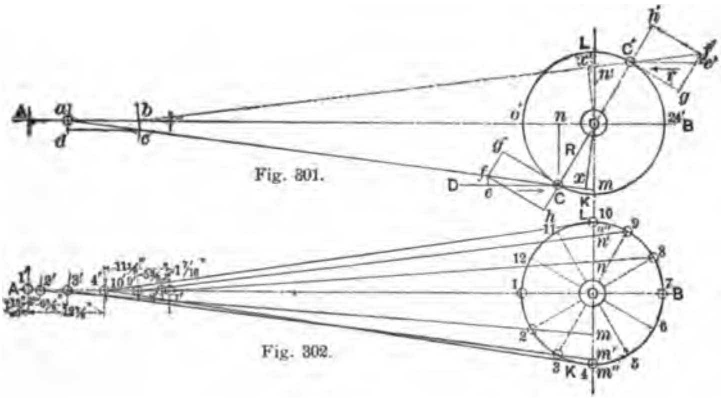
Answer. It equalizes the pressure on the crank-pin during the early and latter part of the stroke. This will be seen if the diagram, figs. 291 and 300, are compared. Fig. 291 shows that the steam pressure on the piston during the early part of the stroke is much greater than during the latter part, whereas the effect of the reciprocating parts, as shown in fig. 300, is to reduce the pressure on the crank-pin in the first half of the stroke and increase it in the last half.

QUESTION 433. *What is meant by the rotative effect of the steam on the crank?*

Answer. It is the pressure which the steam exerts at right angles to the centre line of the crank, the direct effect of which is to turn the crank.

QUESTION 434. *How can the rotative effect of the pressure on the crank-pin be ascertained?*

Answer. This can be done by first constructing a diagram similar to fig. 300 for any given speed, point of cut-off, pressure of steam, or dimensions of engine. Then let *A B*, fig. 301, represent a horizontal centre line drawn through the centre of the cylinder and centre, *O*, of the axle. From *O* as a centre draw a circle, *O′ L B K*, whose diameter is equal to the stroke of the piston, to represent the path of the centre of the crank-pin. From the front dead-point, *o'*, with a distance equal to the connecting-rod, lay off the mark, *A*, on *A B*, which will be the position of the centre of the cross-head pin at the beginning of the stroke. Now, for any position of the crank-pin, such as *C* as a centre, and with the length of the connecting-rod as a radius, describe a short arc, *a*, intersecting the line, *A B*. Then the distance, *A a*, will be equal to the movement of the cross-head pin, which is equal to that of the piston from the beginning of the stroke. Then draw *a C* to represent the centre line of the connecting-rod when the piston has moved the distance, *A a*. From *a*, a distance, *a b*, should be laid off equal to the horizontal pressure, in pounds



Diagrams Showing Rotation Effect on Crank-Pin. Scale ⅜ in.=1 ft.

per square inch, exerted by the combined action of the steam pressure and momentum of the reciprocating parts. Now, if this pressure is exerted against the end of the connecting-rod, *a C*, which at this point of the stroke is inclined to the centre line, *A B*, its inclination will cause an upward verticle pressure to be exerted at *a*, which must be resisted by the guides. If, then, *a b* is drawn equal to the horizontal force, and *b c* parallel to the vertical line, *a d*, and if from the intersection, *c*, of *b c*, with *a C*, a line, *d c*, is drawn parallel to *a b*, we will have a parallelogram, *a b c d*, of which the centre line, *a c*, of the connecting-rod forms a diagonal, and the side, *a b*, being equal to the horizontal force, *b c*, will be equal to the vertical pressure, and *a c* will represent the pressure exerted in the direction of the centre line of the connecting-rod.

To ascertain the pressure exerted on the crank-pin, it is a little more convenient to draw a horizontal line, *C D*, through the centre of the crank-pin and parallel with *A B*. Then from *C* lay off *C e*, equal to the horizontal pressure, and draw the vertical line *e f*, then *f C* will be the pressure exerted by the connecting-rod in the direction, *a C*, of its centre line. To determine the pressure that is exerted in the direction, *g C*, at right angles to the crank, *C O*, the force, *f C*, may be resolved into two components, one acting in the direction, *g C*, at right angles to the crank, and the other in the direction of *C O*, of its centre line. If we extend *C O* to *h*, and from *f*, the end of *f C*, we draw *f g* parallel to *O h*, the centre line of the crank, and from the centre, *C*, draw *C g*, at the right angles to *C O*, and complete the parallelogram, *f g C h*, then we have a parallelogram of which the diagonal represents the magnitude and direction of the force acting through the connecting-rod, and the sides are parallel to the direction into which we want to resolve this force. Therefore, *g C* represents the force exerted by *f C*, at right angles to the crank, and *h C* that in the direction of its centre line.

If the crank is in the position shown by the dotted lines at *C'*, and the pressure of the connecting-rod is exerted on the crank-pin in the direction of the arrow, *r*, then the rotative effect can be ascertained in a similar way to that already described—the horizontal line, *C' e'*, equal to the horizontal pressure, is drawn through the centre of the crank-pin, and the centre line, *b C'*, of the connecting-rod is extended to *f'*. A perpendicular, *e' f'*, is then drawn from *f'* through *e'*, and *C' f'* is equal to the pressure of the connecting-rod on the crank-pin. A line, *C' g'*, is drawn perpendicular to the centre line, *C' O*, of the crank, and through *C'* and *f'*, lines *C' h'* and *f' g'* are drawn parallel to the crank, and from *f'* *f' h'* is drawn parallel to *C' g'*. We then have the parallelogram, *C' h' f' g'*, of which *C' g'* or *h' f'* represents the rotative effect.

QUESTION 435. *In what other way may we ascertain the pressure exerted at right angles to the crank, or the rotative effect?*

Answer. It can be shown that if the crank and connecting-rod are drawn for any position of the piston, as in fig. 301, that if the line, *e C*, representing the horizontal pressure exerted on the piston, is made equal to the length, *O C*, of the crank, and if the centre line, *a C*, of the connecting-rod is extended so as to intersect a vertical line, *O K*, drawn through the centre, *O*, of the axle, that the distance, *O m*, will then represent the pressure exerted at right angles to the crank.* If, then, we MULTIPLY THE PRESSURE ON THE PISTON BY THE DISTANCE ($O\ m$ or $O\ n'$, fig. 301) FROM THE CENTRE OF THE AXLE, AT WHICH THE CENTRE LINE OF THE CONNECTING-ROD INTERSECTS, A VERTICAL LINE DRAWN THROUGH THE CENTRE OF THE AXLE, AND DIVIDE BY THE LENGTH OF THE CRANK, IT WILL GIVE THE ROTATIVE EFFECT. When the crank is back of the centre of the axle, as at C', it is not necessary to extend the centre line of the connecting-rod as it intersects the vertical line, as at n', without being extended.

QUESTION 436. *How may the rotative effect be shown for a whole revolution of the driving-wheel?*

Answer. To do this a circle, $L\ 1\ K\ B$, fig. 302, is drawn to represent the path of the centre of the crank-pin, and a horizontal centre line, $A\ B$, as described. Now divide the circle into 12 equal divisions—1 2 3 4, etc. From the dead-points, 1 and 7, with the length of the connecting-rod as a radius, mark 1′ and 7′ on $A\ B$; these will represent the two ends of the piston's stroke. Now, from 2 as a centre, and with the length of the connecting-rod, intersect $A\ B$, at 2′, with a short arc, and draw 2′ 2 m. Then 1′ 2′ will represent the distance that the piston has moved while the crank has turned from 1 to 2, or one-twelfth of its revolution. In a similar way 3 3′, 7 7′, 8 8′, 9 9′, can be laid down, which will give us the movement of the piston for successive twelfths of the first and third quarters of a

* It is not easy to prove this without the aid of mathematics. Those who know a little of geometry will be able to understand the following demonstration, those who do not must accept the conclusions without understanding the proof: In fig. 301, $e\ C$, which represents the pressure per square inch on the piston, has been made equal to the radius, $C\ O$, of the crank, and as explained above, $f\ C$ represents the pressure exerted through the connecting-rod on the crank. If the connecting-rod was infinitely long, the leverage with which it would act on the crank would be equal to the vertical distance, $C\ n$, of the centre of the crank-pin, from the line, $A\ B$, and the rotative effect would be equal to the pressure on the piston multiplied by $C\ n$. But owing to the angularity of the connecting-rod, the leverage through which it acts on the crank is equal to $O\ x$, a line drawn through the centre, O, of the axle and perpendicular, to $a\ C\ m$. So that if R, the length of the crank, is assumed to be equal to 1, the rotative effect is equal to the pressure, $f\ C$, exerted through the connecting-rod, multiplied by $O\ x$. As the two triangles, $C\ f\ e$ and $O\ x\ m$ are similar,

$$O\ x : O\ m :: C\ e : C\ f,$$

so that $O\ m \times C\ e = O\ x \times C\ f$.

As $C\ e$, which represents the horizontal pressure of the piston and reciprocating parts, has been made equal to $C\ O$ or R, the radius of the crank, we have

$$O\ m \times R = O\ x \times C\ f,$$

that is, the horizontal pressure of the piston and reciprocating parts multiplied by $O\ m$ is equal to the rotative effect. A similar demonstration will prove that $O\ n' \times R$ will be equal to the rotative effect when the crank-pin is in the position C'.

revolution. To avoid confusion in the diagram, the position of the connecting-rod has not been laid out for the second and fourth quarters of the revolution, and also because the positions of the crank-pin and piston are the same during the first and fourth and the second and third quarters of the revolution.

Next draw a horizontal line, *C D*, fig. 303, equal in length to the circumference of the driving-wheel, and subdivide this line into twelve equal divisions—1‴ 2‴ 3‴ 4‴ 5‴ 6‴, etc. From these points of division draw perpendiculars, 1‴ 1, 2‴ 2, 3‴ 3, etc. Draw the horizontal line, 1 *O*, above *C D*, so that 1 1‴ and *O* 0‴ are equal to half the diameter of the wheel. Then, from 1 as a centre, and with 1 1‴ as a radius, describe a circle, *A B C*, to represent the driving-wheel, and from 1 lay off the crank-pin, 1′, in the first position shown in fig. 302. As this is the dead-point, the pressure of the piston exerts no rotative effect on the crank. From 2 draw another circle and lay off the crank-pin, 2′, in the second position shown in fig. 302. As *C D* has been made equal in length to the circumference of the wheel, and it has been divided into twelve equal parts, 1‴ 2‴ is equal to one-twelfth of the circumference, so that the wheel, *A B C*, in turning one-twelfth of a revolution would roll from 1‴ to 2‴. From 2 as a centre, we then draw another circle to represent the wheel when it has turned one-twelfth of a turn and has rolled from 1 to 2. The crank is then in the position shown at 2′ in fig. 302, and the piston has moved $1\frac{13}{16}$ inches. By drawing 2′ *m* to represent the connecting-rod, we find that 2 *m* is equal to $6\frac{3}{4}$ inches. It will be supposed now that the engine is running at a speed of only four miles an hour, and that there is a uniform pressure of 140 lbs. on the piston, as shown by the diagram, fig. 285. At this slow speed the power required to accelerate and retard the reciprocating parts is so little that it may be disregarded.

To get the rotative effect for the position of the crank shown at 2 2′, fig. 303, we must then multiply $140 \times 6\frac{3}{4} = 945$, and divide by 12, which gives 78.7 as the rotative effect *in pounds pressure per square inch of the piston*. The spaces between the horizontal lines, below *C D*, are supposed each to represent 10 lbs. pressure per square inch, as indicated by the figures on the left hand side of fig. 303, and the pressure which has been calculated can be laid off from 2‴ to *E*. Proceeding in the same way for the third position, 3 3′, of the crank, we find that the piston has moved $6\frac{5}{8}$ inches, as shown in fig. 302, and 3 *m* is equal to $11\frac{1}{8}$ inches.

Therefore,
$$\frac{140 \times 11\frac{1}{8}}{12} = 129.8.$$

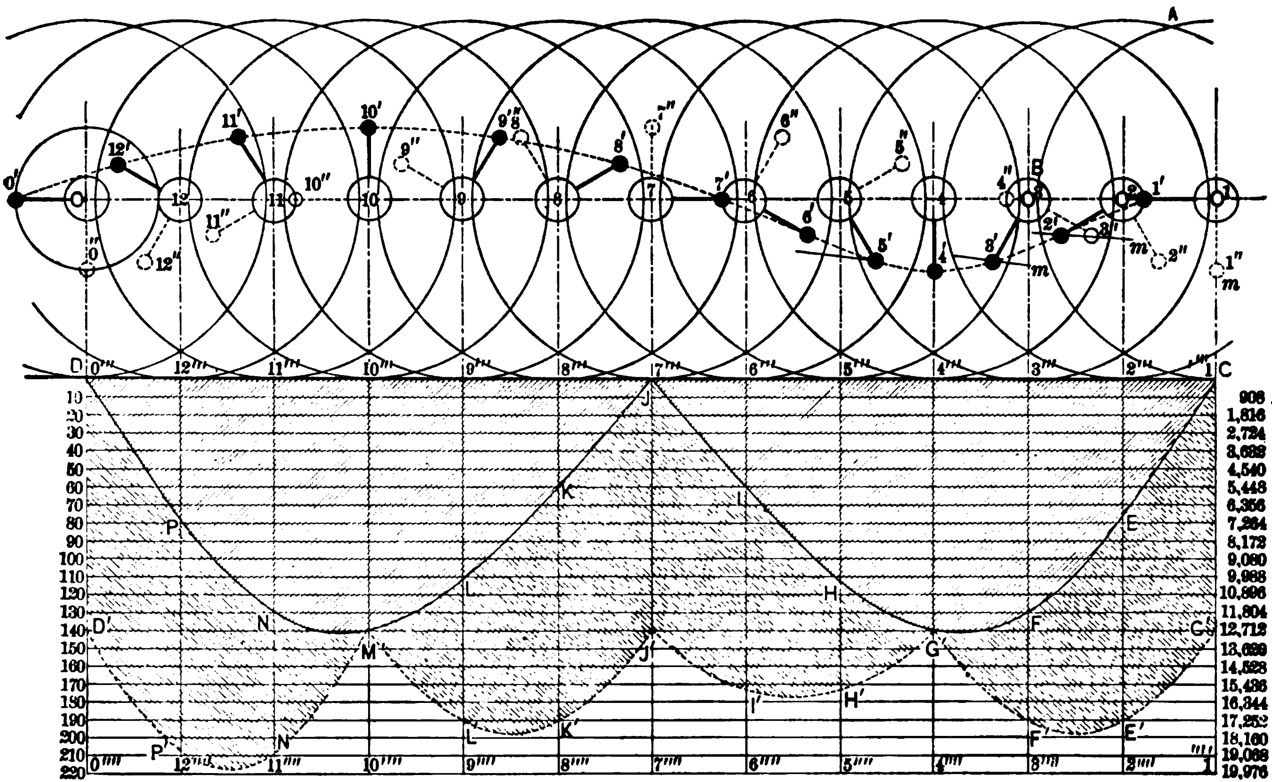


Fig. 308. Diagram Showing Rotative Effect on Crank-Pin. Scale ⅜ in. = 1 ft.

This pressure is laid off from the line, *C D*, fig. 303, on the perpendicular, 8‴ *F*. In the same way the rotative effect is calculated and laid down in fig. 303, for each of the successive positions, 4 5 6 7, etc., of the crank, shown in fig. 302, and curves, *C E F G′ H I J* and *J K L M′ N P D*, fig. 303, are drawn through the points laid down on the perpendicular lines. The vertical distance of these curves, below *C D*, then represents the rotative effect which is exerted by one crank at each point during a complete revolution of the driving-wheel.

But while the pressure on the piston on one side of the locomotive is acting on its crank, there is a simultaneous action on the other crank, which stands at right angles to the first one, and whose successive positions is shown by the dotted lines, 1 1″, 2 2″, 3 3″, etc. The rotative effect acting on the wheels is therefore equal to that exerted on each of the cranks added together. To show this combined effect, then, we must lay off other curves from those already drawn. Thus, the opposite crank, 1 1″, in the first position of the wheels stands at right angles to the centre line, 1 1′, and *O m*, is then equal to 12 inches, so that we have

$$\frac{140 \times 12}{12} = 140.$$

Therefore 140 is laid down from 1‴ to *C′* on the vertical line, 1‴ 1⁗. A similar calculation is made for the rotative effect of the crank, 2 2″, in the second position, and as the action of the opposite crank exerts additional rotative effect on the wheel, this force is added to that of the first crank by laying it off from *E* to *E′*. Proceeding in the same way for the other position of the crank, and laying off the distances, *F F′*, *H H′*, etc., and drawing the curve, *C′ E′ F′ G′ H′—D′*, through the points thus laid down, we have a curve whose distance below the line, *C D*, represents the combined rotative effect exerted by the pressure in the two cylinders during a whole revolution.

QUESTION 437. *What peculiarity may be observed in the form of this curve?*

Answer. It will be seen that the rotative effect varies very much at different points of the revolution. It is greatest when the wheel is midway between the positions 11 and 12, when the two cranks are in front of the axle and stand at angles of 45° with horizontal or perpendicular lines. When the wheel is between the 2 and 3 and 8 and 9 positions, or when the cranks both again stand at angles of 45° with a horizontal line, the rotative effect is equal, though somewhat less than it is when the cranks are both in front of the axle. Between the 5th and 6th positions of the wheel, when the cranks are both behind the axle and at the angles of 54° to a horizontal line, the rotative effect is less than at any of the other high points.

QUESTION 438. *How may this peculiarity of the variation in the rotative effect be explained?*

Answer. It is due to the fact that when both cranks are in front of the axle, the effect of the angularity of both connecting-rods is to increase the rotative effect. When one crank is in front and the other behind the axle, the one connecting-rod increases and the other diminishes the rotative effect, and when the two cranks are behind the axle, both rods diminish the rotative effect.

QUESTION 439. *At what points in a revolution is the least rotative effect exerted?*

Answer. When one of the two cranks is at a dead point, that is, in the 1st, 4th, 7th and 10th positions, shown in fig. 303. If the steam pressure is the same, the rotative effect is equal in each of these positions of the cranks.

QUESTION 440. *When the rotative effect is represented in pounds pressure per square inch of piston, as in fig. 303, how can we know the actual rotative effect or the tractive force exerted at the circumference of the wheel?*

Answer. This can be done by simply measuring the vertical distances of the curve with a different scale. Thus, in fig. 303, the spaces between the horizontal lines below *C D* have been supposed to represent 10 lbs. pressure on each square inch of the piston, as indicated by the figures on the left-hand side. If the piston is 17 inches in diameter, its area would be very nearly 227 square inches. Ten pounds' pressure would therefore exert a total pressure of 2,270 lbs. on the piston. If the wheel is 5 feet in diameter and the stroke 2 feet, the pressure on the piston would be exerted with a leverage of 2 to 5, so that the actual tractive force would be

$$\frac{2{,}270 \times 2}{5} = 908 \text{ lbs.}$$

for each ten pounds of pressure. If, then, we suppose the spaces between the horizontal lines each represent 908 lbs., as indicated by the figures on the right-hand side, we can measure the actual tractive force exerted at the circumference of the wheel.

QUESTION 441. *How can we lay off curves to represent the rotative*

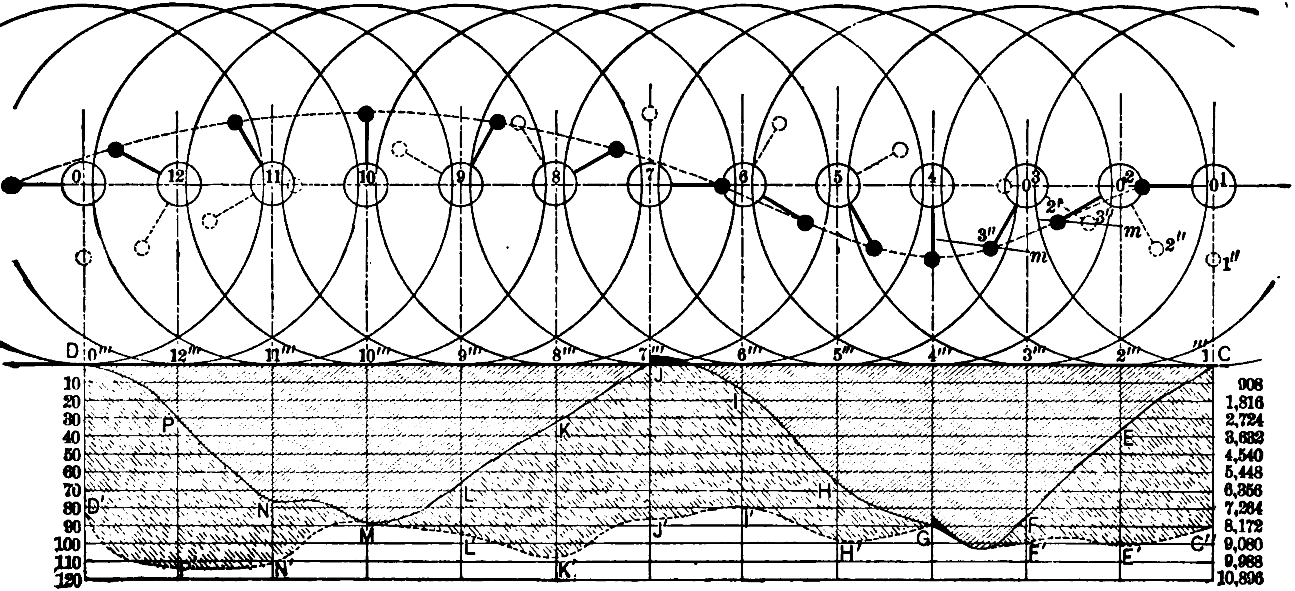


Fig. 804. Diagram Showing Rotative Effect on Crank-Pin. Scale ⅜ in.—1 ft.

effect when the pressure in the cylinder is not uniform during the stroke, and when the speed is so high that the acceleration and retardation of the reciprocating parts has an important influence on the action of the engine?

Answer. To do this a diagram, fig. 304, similar to fig. 303, should be laid down. For each position of the crank we must ascertain the movement of the piston. Then construct a diagram like that represented by fig. 300, and from that take the net horizontal pressure exerted on the crank when the piston is in the position indicated. Thus when the crank is in the second position represented in figs. 302 and 304, it has turned one-twelfth of a revolution, and the crank has moved $1\frac{1}{1}\frac{3}{6}$ inch. From the diagram, fig. 300, we find that the pressure at $1\frac{1}{1}\frac{3}{6}$ inch of the stroke measured above the line, EF, is 65 lbs. As $O\,m$ is equal to $6\frac{3}{4}$ inches, we have for the calculation,

$$\frac{65 \times 6\frac{3}{4}}{12} = 36.5.$$

We therefore lay off 36.5 from 2‴ to E, in fig. 304. In the third position of the crank the piston has moved $6\frac{5}{8}$ inches; the pressure is then 90 lbs., and $2\,m$ is equal to $11\frac{1}{8}$, so that the rotative effect is equal to 83.4 lbs., which distance is laid off from 3‴ to F. Similar calculations are made for other positions of the crank, the steam pressure being taken from fig. 300, and the curves, $C\ E\ F\ G—D$, and $C'\ E'\ F'\ G—D'$, are drawn in the manner described. The latter curve then represents the rotative effect when cutting off steam at one-third of the stroke and at a speed of 50 miles per hour.

QUESTION 442. *What is the effect of working steam expansively at high speeds?*

Answer. As already pointed out, the effect of cutting off steam early in the stroke, and the influence of the reciprocating parts tend to equalize the rotative effect during the whole revolution of the wheel. This is shown by the curve $C'\ E'\ F'\ G—D'$, which shows that the rotative effect on the crank-pin does not vary nearly as much as the corresponding curve in fig. 303 shows that it does when the steam is not expanded and when the reciprocating parts move slowly. There is also considerable irregularity in the curves in fig. 304, which is produced by the various and complicated causes which determine its form. The black areas, at G and J, represent the back pressure on the piston, shown also at F, in fig. 300. The curved dotted line drawn through the centres of the crank-pin, in figs. 303 and 304, show the path in which the pin moves during one revolution of the wheel.

CHAPTER XVIII.

ADHESION AND TRACTION.

QUESTION 443. *What is meant by the "adhesion" of a locomotive.*

Answer. It is the resistance which prevents or opposes the slipping of the driving-wheels on the rails, and is due to the friction of the former on the latter.

QUESTION 444. *On what does the amount of this friction depend?*

Answer. It depends upon the weight or pressure of the surfaces in contact, and consequently upon the load which rests on each wheel. It

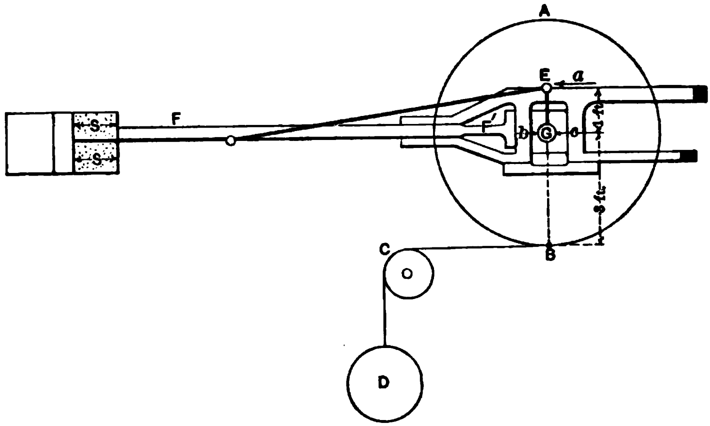


Fig. 305. Diagram Showing Adhesion of Locomotive. Scale ¼ in.—1 ft.

also depends upon the condition of the rails, and probably to some extent upon the material of which they and the tires on the wheels are made, and to the amount of surfaces in contact.

QUESTION 445. *How much force is required to make the driving-wheels of a locomotive slip on an ordinary railroad track?*

Answer. The force required to make them slip will, as already stated, vary very much with the condition of the rails. If they are quite dry and clean it will require a force equal to about one-fourth the weight on the wheels. That is, supposing we have a wheel, *A B*, fig. 305, attached to a frame which is fastened so that it cannot move, and that the wheel rests on a rail and is loaded with say 12,000 lbs., if now a rope or chain could be attached at a point, *B*, exactly at the tread of the wheel, and carried over a pulley, *C*, then it would require a weight, *D*, of about 3,000 lbs. attached to the end of the rope to make the wheel slip. If the rails were sanded, the adhesion would be somewhat greater, and if they were wet or muddy or greasy, considerably less. The proportion of the adhesion to the weight in the driving-wheels is about as follows:

ON DRY-SANDED RAILS IT IS EQUAL TO ONE-THIRD.

ON PERFECTLY DRY RAILS, WITHOUT SAND, IT IS ONE-FOURTH.

UNDER ORDINARY CONDITIONS, WITHOUT SAND, OR ON WET-SANDED RAILS, ONE-FIFTH.

ON WET OR FROSTY RAILS, ONE-SIXTH.

With snow or ice on the rails, the adhesion is still less.

Of course the total weight on all the driving-wheels must be taken in calculating the adhesion. Thus, if a locomotive has four driving-wheels, and each one of them bears a load of 12,000 lbs., then the total weight on the driving-wheels, or *adhesive weight*, as it is called, will be $12{,}000 \times 4 = 48{,}000$ lbs., and the adhesion will be

$$\frac{48{,}000}{5} = 9{,}600 \text{ lbs.}$$

QUESTION 446. *What is meant by the tractive power of a locomotive?*

Answer. It is the force with which the locomotive is urged in a horizontal direction by the pressure of the steam in the cylinders, and which therefore tends to move the locomotive and draw the load attached to it.

The tractive power is due to the effective pressure of steam on the pistons, and therefore its amount is dependent upon the average steam pressure in the cylinders on the area of the piston, and also on the distance through which the pressure is exerted, or, in other words, on the stroke of the piston and the size of the driving-wheels. Thus, if we have a cylinder 17 inchcs in diameter and 2 feet stroke, and an average steam pressure of 50 lbs. per square inch, then, as the area of such a piston would be 227 square inches, the average pressure on it would be $227 \times 50 = 11{,}350$ lbs., and as each piston moves through 4 feet during one revolution of the wheels, the number of foot-pounds of energy exerted by it would be 11,350 × 4=45,400, and for the two cylinders of a locomotive double that amount, or 90,800 foot-pounds. If the driving-wheels are 5 feet in diameter, their circumference will be 15.7 feet, and therefore the locomotive will move that distance on the rails during one revolution, if the wheels do not slip. The 90,800 foot-pounds of energy is therefore exerted through a distance of 15.7 feet, and therefore

$$\frac{90,800}{15.7} = 5,783 \text{ lbs.},$$

which is the force exerted at the circumference of the wheel as it revolves and the locomotive moves. If the wheels were only half the diameter, or 2½ feet, then their circumference would be 7.85 feet, and the tractive power would be

$$\frac{90,800}{7.85} = 11,566 \text{ lbs.},$$

or double what it was before. It will be seen, then, that the tractive force of a locomotive is dependent upon (1) the average steam pressure in the cylinders, (2) the area of the pistons, (3) the stroke of the pistons, and (4) the diameter of the driving-wheels.

QUESTION 447. *How is the tractive power of a locomotive calculated?*

Answer. BY MULTIPLYING TOGETHER THE AREA OF THE PISTON IN SQUARE INCHES, THE AVERAGE EFFECTIVE STEAM PRESSURE IN POUNDS PER SQUARE INCH ON THE PISTON DURING THE WHOLE STROKE, AND FOUR TIMES THE LENGTH OF THE STROKE OF THE PISTON,* AND DIVIDING THE PRODUCT BY THE CIRCUMFERENCE OF THE WHEELS. The result will be the tractive power exerted in pounds. The adhesion must, of course, always exceed the tractive force, otherwise the wheels will slip.

QUESTION 448. *How is the locomotive made to advance by causing the wheels to revolve?*

Answer. The pressure of steam in the cylinders is exerted in one direction against the piston, and in the opposite direction against the cylinder-head, as shown in fig. 305, in which the steam is represented by the dotted shading in the back end of the cylinder, and the direction of the pressure by the darts, *S S*. The pressure against the piston is communicated by the connecting-rod to the crank-pin, *E*, and that on the cylinder-head is exerted against the axle through the frame, *F F'*, and the direction of the two forces is indicated by the two darts, *a* and *b*. We may now regard

* This length may be taken in feet, inches, or any other measure, but in making the calculation the circumference of the wheels must be taken in the *same* measure as the stroke of the piston.

the spokes of the wheels as acting as levers, and assume that the fulcrum is either at the centre, *G*, of the axle, or at *B*, the point of contact of the wheel with the rail.* It may be assumed that it is at the centre, *G*, of the axle, and, for the sake of even figures, that the wheel is 6 feet in diameter, and cylinders have 2 feet stroke. It will also be supposed that the engine is supported, so that the wheels do not touch the rails, and that a chain or rope passing over a pulley, *C*, is attached to the wheels at *B* and with a weight at *D*. We now have a force, *a*, of say 10,000 lbs. exerted on the crank-pin, or at the end of the short arm, *E G*, of the lever, *E G B*. As *E G* is 1 foot and *G B* is 3 feet long, 10,000, at *E*, would be balanced by

$$\frac{10{,}000 \times 1}{3} = 3{,}333 \text{ lbs.}$$

at *B*. In other words, it would require 3,333 lbs. suspended from the chain, at *D*, to resist the strain at *E*. But when this is the case, the pressure of the axle at the fulcrum, in the direction of the dart, *c*, is equal to the pressure against the crank-pin, *E*, in the opposite direction, and indicated by the dart, *a*. We thus have two forces, one at $a = 10{,}000$ lbs., and another at $B = 3{,}333$ lbs., both in a forward direction. Then added together are equal to $10{,}000 + 3{,}333 = 13{,}333$ lbs.

As the pressure against the axle in the opposite direction, *b*, is only 10,000 lbs., there will be an unbalanced force of 3,333 lbs. acting in the direction of the dart, *c*, and tending to move it that way. As the axle is attached to the locomotive frame, this force will, of course, have a tendency to move the whole machine, and is really the tractive force of the engine.

If, on the other hand, we regard the point of contact, *B*, of the wheel with the rail as a fulcrum, we have a force of 10,000 lbs. acting, at *E*, against a lever, *E G B*, 4 feet long. The force which this would exert against the axle, *G*, would be calculated by multiplying 10,000 by the whole length of the lever, and dividing by its long arm, *G B*, so that we will have

$$\frac{10{,}000 \times 4}{3} = 13{,}333 \text{ lbs.}$$

* The question whether the centre of the axle or the point of contact with the rail is the fulcrum of the lever in this case has been the subject of much discussion and contention. As the word *fulcrum* means "a point about which a lever moves," it is believed that the dispute is due simply to a difference in the meaning assigned to the word fulcrum. If we regard the fulcrum as the point which is fixed in relation to the locomotive, then it is at the centre of the axle; but if we refer it to the surface of the earth, then it is at the top of the rail.

exerted at *G;* and as the pressure exerted by the steam in the cylinder in the direction of the dart, *b*. is only 10,000, there would be an unbalanced strain of 13,333 — 10,000=3,333 lbs. acting against the axle in the direction of the dart, *c*, or, in other words, there is 3,333 lbs. more of force pulling the axle forward than there is pushing it backward.

When the crank-pin is below the axle, in the position shown in fig. 306, then, if the centre of the axle is regarded as the fulcrum, we have a pressure of 10,000 lbs. pushing against the front cylinder-head, which is transferred to the axle by the frames, and acts on the axle in the direction of the dart, *c*, and we also have a pressure acting against the crank-pin, *E*, in the direction of the dart, *a*. If *G* is the fulcrum, the pressure which the

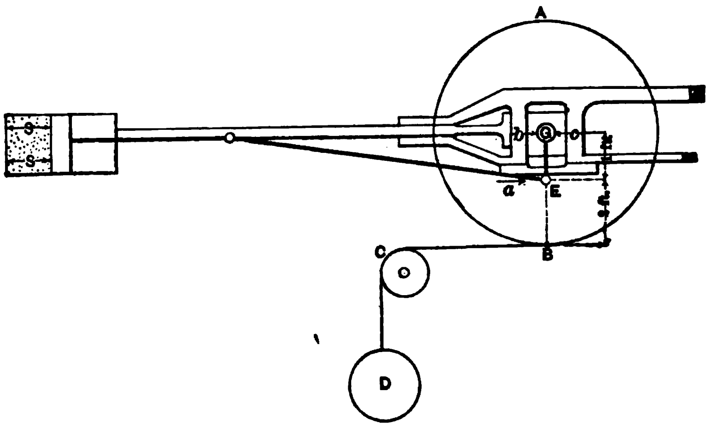


Fig. 306. Diagram Showing Traction Power of Locomotive. Scale ¼ in.=1 ft.

force a=10,000 lbs. would exert, at *B*, would be calculated by multiplying it by the short arm, *G E*, of the lever, and dividing, by *G B*, its whole length—that is,

$$\frac{10{,}000 \times 1}{3} = 3{,}333 \text{ lbs.},$$

which is the tractive force exerted at *B*.

If, on the other hand, *B* is the fulcrum, then the force exerted on the axle, *G*, by the pressure of the piston on the crank-pin would be calculated by multiplying it by the length, $E B$, of its long arm, and dividing by its whole length, $G B$, or

$$\frac{10{,}000 \times 2}{3} = 6{,}667 \text{ lbs.},$$

exerted at G in the direction of b. But the pressure on the cylinder-head pulls against the axle, G, in the direction, c, with a force of 10,000, so that the excess of strain in the direction, c, will be equal to 10,000 — 6,667 = 3,333 lbs.

It will be seen, then, that it is immaterial which point is regarded as the fulcrum, as the result of the calculations is exactly the same.

It must not, however, be hastily supposed from what has been said that the total pressure against the axle can be greater than its resistance to the pressure. As soon as the one exceeds the other, it will move. But supposing that it requires a force equal to 3,333 lbs. to draw a train coupled to the engine, as soon as the difference between the force exerted against the axle by the piston to move it forward and that which presses it back exceeds 3,333 lbs., the locomotive will move the train. If the force exerted continues to exceed the resistance, the speed of the train will be accelerated, and thus the resistance which holds the engine back and that which pushes it forward will always be equal.

QUESTION 449. *Does the fact that the piston is working from the end of a long lever, E G B, fig. 305, when the crank-pin is above the axle, enable the locomotive to start a heavier train than when the crank-pin is below the axle and the piston is working against a shorter lever, G E B, fig. 306?*

Answer. No; because as has already been shown, the pressure against the axle is the same in both cases. It is, in fact, only during the forward stroke that the pressure on the crank-pin moves the engine forward. The forward pressure which is exerted by the crank-pin at the axle is then greater than that exerted against the latter in the opposite direction by the cylinder-heads and frames. It is this excess of crank pressure which moves the engine and which is the tractive force during the forward stroke. During the backward stroke the piston is pushing the axle backward, and the pressure against the front cylinder-head is pulling it forward. The latter then exceeds the former, and the difference between the two is the force which moves the engine forward. As has been shown, the difference is the same in both positions of the crank, and therefore the locomotive cannot from this cause pull more when the crank is above the axle than when it is below.

CHAPTER XIX.

INTERNAL DISTURBING FORCES IN THE LOCOMOTIVE.

QUESTION 450. *What are the internal disturbing forces in a locomotive?*

Answer. They are: 1, those produced by unbalanced revolving parts; 2, the momentum of the parts which have a reciprocating motion; 3, those due to the varying pressure of the steam in the cylinder-heads; and 4, those caused by the upward or downward thrust of the connecting-rods against the guide bars.

QUESTION 451. *How does the disturbing effect of unbalanced weights in revolving mechanism manifest itself?*

Answer. In an ordinary machine, if a revolving shaft or wheel has more weight on one side of its centre than on the other—or is "out of balance," as it is called—the machine, unless it is very securely fastened, will shake when the shaft and wheel revolve rapidly, or if the revolving part is free to move laterally it will "wobble." This action is shown if we fasten a weight to one side of an ordinary spinning top, or, better still, if a small model of a pair of locomotive wheels, attached to an axle, is suspended from a journal-bearing by elastic, india-rubber bands, so that the wheels and axle can turn freely and also swing horizontally. The elastic bands will also allow the wheels and axle to vibrate vertically. A twine should then be wound around the axle and a weight attached to one end of it. This weight will cause the axle and wheels to revolve, and if the wheels and axle are balanced they will have very little horizontal or vertical movement; but if a weight is attached to one of the wheels, at some distance from its centre, and they are then made to revolve, they will vibrate violently both vertically and horizontally, owing to the effect of the centrifugal force of the weight.

QUESTION 452. *What is the cause of this disturbance in the movement of the wheels?*

Answer. It is due to the action of the unbalanced weight which exerts a centrifugal force, or a pull away from the axle, in the direction of a radius drawn through the centre of gravity of the weight and the centre of the axle.

QUESTION 453. *How may the disturbing action of the unbalanced weight be neutralized?*

Answer. By attaching an equal counterweight to the wheel on the opposite side of the axle, and at the same distance from it as the first weight. The centrifugal force of the counterweight will then be exerted in an opposite direction to that of the first weight, and the two will thus balance each other, and there will then be no disturbance to the motion of the wheels. If the weights balance each other accurately, the wheels will have very little or no lateral or vertical movement, showing that the effect of the centrifugal force of the one weight neutralizes that of the other.

QUESTION 454. *Is it essential that the two weights should be at the same distance from the centre of the axle?*

Answer. No. All that is needed is that one weight should balance the other. If the one is farther from the axle than the other, the first must be lighter, or if it is nearer it must be heavier than the other. It is essential for a perfect balance that if each weight is multiplied into the distance of its centre of gravity from the centre of the axle, that the products should be equal.

QUESTION 455. *What effect does an unbalanced weight on the crank-pin of a locomotive have?*

Answer. Its effect is similar to that of an unbalanced weight on any other revolving wheel or shaft. Thus, suppose that the large circles, *D*, *D* 4, *D* 8, *D* 12 and *D* 16, figs. 307–311, represent the circumference of a locomotive driving-wheel, *A*, its axle, and *C*, the crank-pin; and that a weight, *W*, is attached to the pin, and turns with it. When the wheel is revolving, and is in the position shown in fig. 307, the weight, *W*, will exert a centrifugal force against the pin in a direction away from the axle, as indicated by the dart below *d*. The effect of this is that a pressure is communicated to the axle which pushes against the driving-box and frame, and the force thus has a tendency to move that side of the engine ahead, if it is running in the direction indicated by the dart, *K*. When the crank-pin is in the position shown in fig. 309, the centrifugal force of the weight will push the crank-pin and wheel backwards; in the position shown in fig. 308, it pushes downward, and in that in fig. 310, upward, as indicated in each case by the darts, *d*. If the crank-pin was in the position represented by the dotted circle, *c*, in fig. 307, the centrifugal force would be exerted in a diagonal direction, as indicated by the dart, *c A*. When the crank-pin, *C*, on the nearest side of the engine, is in the position

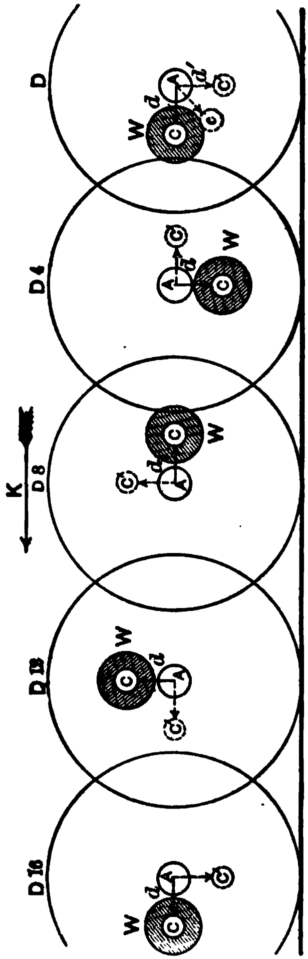


Fig. 307. Fig. 308. Fig. 309. Fig. 310. Fig. 311.

Diagrams Showing Effect of Centrifugal Force at the Crank-Pin. Scale ¼ in.—1 ft.

represented in fig. 307, the crank-pin on the opposite side is in the position represented by the dotted circle, *C′*. The centrifugal force of the revolving weight on this crank-pin is then exerted downward, or in the direction of the dart, *d′*. In fig. 308, the centrifugal force on the opposite pin pushes backward, in fig. 309 upward, and in fig. 310 forward. When centrifugal force is exerted either forward or backward on one side of a locomotive, the tendency is to produce what is called "nosing" or a horizontal movement of its front and back ends, around a vertical axis between them. When either of the crank-pins is above the axle, as in fig. 309 and fig. 310, the upward pressure on one side has a tendency to lift that side of the engine in that direction, and cause a rolling or rocking of the engine.

QUESTION 456. *How may the disturbing effect of a weight at the crank-pin of a locomotive be neutralized?*

Answer. This may be done in the same way that the effect of an unbalanced revolving weight on any other wheel or shaft is counteracted, that is, by attaching a counterweight opposite to the crank-pin. In other words the revolving parts may be balanced in ordinary locomotives so as to cause very little disturbance in the working of the engine, by simply putting a counterweight in each wheel opposite the crank-pin, as shown in fig. 339, whose weight, multiplied by the distance of its centre of gravity from the centre of the axle, will be equal to the weight at the crank-pin multiplied by the distance of its centre from that of the axle, or half the stroke. The revolving weights of each wheel consist of the crank-pin boss, crank-pin, one-half the coupling-rod or rods connected to the wheel. For each of the main driving-wheels, there must be added to these weights that of the back end of the main connecting-rod.

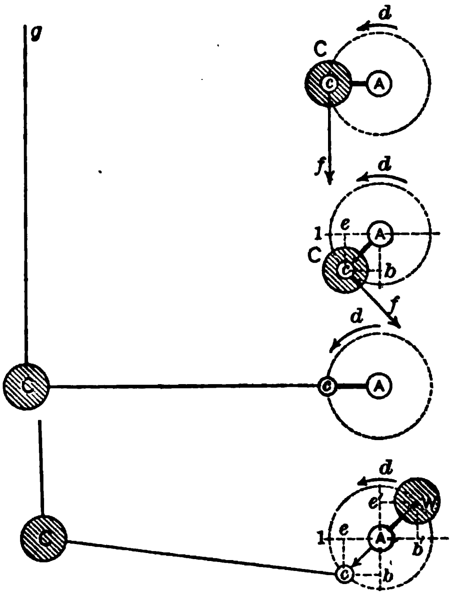
QUESTION 457. *Where are the counterweights of locomotive driving-wheels placed and how are they constructed?*

Answer. They are placed between the spokes of the wheels as shown at *A A*, fig. 339. They are sometimes made in two halves, and bolted to the wheels between the spokes, as shown in fig. 339. In other cases they are cast solid with the wheels, and in some instances, hollow spaces are made in the wheels which are filled with lead.

QUESTION 458. *How can the reciprocating parts of locomotives be balanced?*

Answer. To explain this it will be supposed that *c A*, fig. 312, is a crank on the shaft or axle, *A*, and revolving around it, and that *C* is a weight attached to the crank-pin, *c*. If the crank is revolving in the direction indicated by the dart, *d*, then the weight, if unconstrained, would move in a direction at right angles to *A c*, as indicated by the dart, *c f*. Instead of being free to move in that direction the crank pulls the weight toward the centre of the wheel and causes it to revolve in a circular path around the axle. As the weight resists this constraint, considerable pull must be exerted by the crank to draw the weight, *C*, from the path, *c f*, which it would take if it was detached from the crank when it reached *c*, into that of the dotted circle.

This pull is the centrifugal force of the revolving weight. When it reaches the position shown in fig. 313, if it was free to move, it would again take the direction, *c f*, at right angles to the crank, *c A*, but the crank continues to pull it toward the centre of the shaft, *A*, in the direction, *c A*, and



Diagrams Showing Action of Centrifugal Force at the Crank-Pin. Scale ¼ in.=1 ft.

compels the weight to revolve in a circular path. The centrifugal force exerted through the crank acts in a diagonal direction, *c A*. By the principle of the parallelogram of forces, if we let the radius, *c A*, of the crank represent the magnitude of the centrifugal force and construct a parallelogram, *e c b A*, whose sides are vertical and horizontal and drawn through the centres of the shaft, *A*, and crank-pin, *c*, then the horizontal side, *c b*, will represent the force required to move the weight, *C*, horizontally. If, instead of being attached to the crank, the weight, *C*, was suspended by a cord, *C g*, so that it could swing freely, as shown in fig. 314, and if it was connected to the crank by a rod, *C c*, then it is plain that as much pull must be exerted on this rod to move the weight horizontally as was exerted by the crank in fig. 312 to move it in the same direction. In other words, the resistance of the weight to horizontal movement, when the crank is at a dead-point, is just equal to the centrifugal force which would be exerted through the crank if the weight was attached to it. When the crank is in the position represented in fig. 313, it has been shown that the force required to move it horizontally is the horizontal component, *c b*, of the centrifugal force represented by *c A*. In fig. 315 the crank is represented in the same position as in fig. 313, and the weight, *C*, is again connected to *c*, by a rod or cord, *C c*. The force required to move *C* horizontally in this figure, is the same as that required to move *C* in fig. 313, excepting as it is influenced by the angle of the connecting-rod, *C c*, which may at present be disregarded. In other words, the force required to move *C* horizontally, is equal to the horizontal component of the centrifugal force of a weight equal to *C*, acting at the crank-pin. If now, we were to put a counterweight, *W*, fig. 315, equal to *C*, and opposite to the crank-pin, *c*, then the centrifugal force at *W*, would be equal to but would act in a direction, *A W*, opposite to that of *C*, in fig. 313. The horizontal component, *c′ W*, will be equal to but opposite to *c b*, in figs. 313 and 315. Therefore, *c′ W*, or the horizontal effect of the centrifugal force of the counterweight, *W*, will be equal to the horizontal force, *c b*, required to move *C*, and as they act in reverse directions they will balance each other.

When the crank-pin, *c*, is at the dead-point, as shown in fig. 314, the weight, *C*, is started from a state of rest, and its motion is accelerated until the crank has made a quarter turn, and its motion is then retarded to the end of the stroke, or until the crank reaches the back dead-point. During the second half of the crank's revolution, the movement of the weight, *C*, is again accelerated during the third quarter and retarded thereafter. The momentum of the weight, *C*, acquired during the first and third quarters of the revolution, if not otherwise resisted, will be exerted against the crank-pin and crank, and the reciprocating parts will thus be brought to a state of rest at the end of the stroke. This produces an unbalanced pressure of the crank on one side of the shaft, which has a tendency to push it in the direction in which the pressure is exerted. As the shaft is revolving such a pressure is exerted alternately forward and backward. If, however, there is a counterweight, *W*, opposite to the crank, the horizontal component of its centrifugal force, as has been shown, is just equal to, and is exerted in the opposite direction to the momentum of the reciprocating weight, *C*, and thus balances it, and relieves the shaft of the horizontal disturbances due to the motion of the reciprocating parts.

Now the relation of the weight, *C*, in figs. 314 and 315, to the crank is similar to that of the reciprocating parts of an engine, as shown in figs. 316 and 317, in which the cross-head, *H*, is connected to the crank-pin, *c*, by the rod, *H c*, and the piston-rod, *r*, and piston, *P*, are attached to the cross-head, and they are all moved together. When the crank is at the dead-point, as shown in fig. 316, the force required to move the recipro-

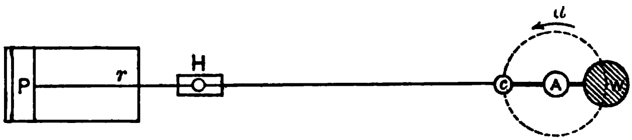


Fig. 316.

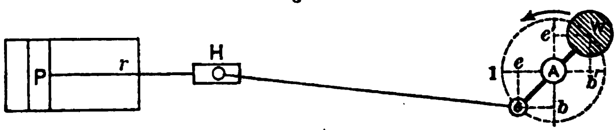


Fig. 317.

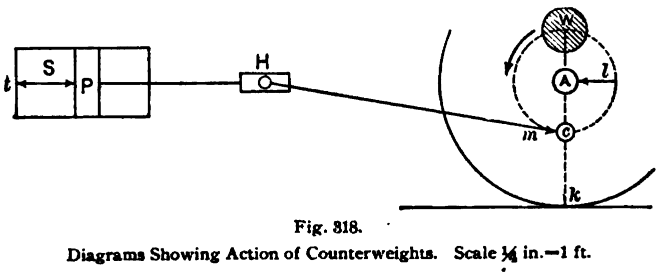


Fig. 318.

Diagrams Showing Action of Counterweights. Scale ¼ in.—1 ft.

cating parts horizontally is equal to the centrifugal force of a weight equal to these parts, acting at the crank-pin. Consequently, if we put a counter-weight, *W*, equal to the reciprocating parts opposite to the crank, its centrifugal force will be just equal to the resistance of these parts and will be exerted in an opposite direction, so that it will balance or counteract the horizontal resistance of the reciprocating parts. When the crank is in any other position, as in fig. 317, then the horizontal component, *e′ W*, of the centrifugal force of *W*, will always be equal to the horizontal resistance of the reciprocating parts, and they thus balance each other.

QUESTION 459. *What effect does the pressure of the steam in the cylinders have on the stability of a locomotive?*

Answer. This can be explained if it be supposed that we had an engine with a double crank and two cylinders located on opposite sides of the crank, as shown in fig. 319. If the crank should turn without steam in

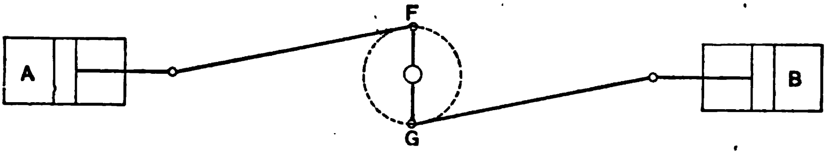


Fig. 319. Diagram Showing Action of Two Pistons. Scale ¼ in.—1 ft.

the cylinders, obviously the reciprocating parts of each would exactly balance each other. If steam was admitted to one of the cylinders so as to turn the crank at the same speed that it was turned without steam on, then it is plain that the movement of the reciprocating parts—their acceleration and retardation, their inertia and momentum—will be the same with steam on as they were without steam. As they balanced each other at the same speed without steam on, they will be in equilibrium when steam is admitted to one cylinder.

As it has been shown that a counterweight opposite the crank will balance the movement of the reciprocating parts, and as it is also obvious that one piston, etc., will balance another, we may disconnect one piston and substitute a counterweight to balance the other piston and its connected parts.

It is true that if steam is admitted into the front end, *S*, of the cylinder, fig. 318, that it will cause some disturbing effect, but it is not due to the motion of the reciprocating parts, but to the pressure of the steam. It would press equally on the cylinder-head, *t*, and on the piston, *P*, and these pressures would balance each other. The pressure on the cylinder-head is, however, communicated to the cylinder and frame, that on the piston to the crank-pin, wheel, and thence to the frame, as explained in the preceding chapter, so that they both act on the pressure in opposite directions. The only cause of disturbance is due to the fact that the pressure on the cylinder-head is communicated directly to the frame and thence to the axle, *A*, fig. 318, and that on the piston is communicated to the crank-pin, *c*. We will imagine the spoke, *A c k*, of the wheel to be a lever, and that the pressure on the cylinder-head is communicated through the frame and acts against the axle, as indicated by the dart, *l*, and that the pressure on the piston is exerted on the crank-pin at *m*. If *k*, the point of contact of the wheel with the rail, is regarded as the fulcrum of the lever, then one force acting on the end of the lever at *A*, and another equal force acting in the opposite direction at *c*, between the end, *A*, and the fulcrum, *k*, will push the upper end of the lever ahead. It is this action which propels the engine. As part of the force acting on the piston is exerted on the rail, at *k*, and the whole of that on the cylinder-head acts against the axle, we have an excess of pressure against *A*, which acts on the engine frame and tends to push one side of the engine ahead, and thus cause nosing, but other than that it has no disturbing effect on the action of the working parts. If we will imagine that the wheels are securely bolted fast so that they cannot turn, then the admission of steam into the cylinders would not disturb or affect their equilibrium, even if the engine was suspended so that it could swing freely.

QUESTION 460. *Will lead or compression, by admitting steam in front of the piston neutralize the momentum of the reciprocating parts?*

Answer. No; that they cannot have this effect will appear if we imagine that the piston should strike the cylinder-head at the end of each stroke. It would thus be brought to a state of rest by a violent blow. If a piece of india-rubber was interposed between the piston and cylinder-head the blow would be less violent, but the energy of the moving parts would still be communicated to the cylinder-head, as it would be if a cushion of steam was interposed, as it is when the engine has lead or compression, and the momentum would then be overcome in a less violent way than it is by a cushion of india-rubber.

QUESTION 461. *Is there any disturbing influence when the reciprocating parts of an engine are balanced by revolving parts?*

Answer. Yes; while the motion of reciprocating parts may be balanced by a revolving weight, the latter causes a disturbing effect on the machine, for the reason that the momentum and inertia of the reciprocating parts act in a horizontal direction only, whereas the revolving weight has vertical as well as horizontal movement. Thus, if the crank and counterweight are arranged, as shown in fig. 318, the counterweight, *W*, in order to balance the reciprocating parts, must be heavier than the weight concentrated at the crank-pin, *c*, consequently, the counterweight exerts more centrifugal force than the crank does, and when they are in the position represented the weight, *W*, would exert an upward pressure greater than the downard pressure at the crank. When they are at the dead-points, as shown in fig. 316, then if the counterweight, *W*, is equal to the weight of the revolving parts, at *c*, and the reciprocating parts, the centrifugal force of the former, and the momentum and inertia of the latter will be just equal to the centrifugal force of *W*. When the crank is between the dead-points and the two-quarters of its revolution, as shown in fig. 317, the centrifugal force of the counterweight is exerted in a diagonal or partly vertical and partly horizontal direction. Between the two dead-points, therefore, a counterweight which balanced the weight of both the revolving and the reciprocating parts creates a vertical disturbance, which is greatest at the two quarters of the revolution and increases from and diminishes towards each of the dead-points where it disappears entirely.

QUESTION 462. *How may the amount of this upward and downward force be determined?*

Answer. It is equal to the difference between the centrifugal force which is exerted vertically by the counterweight and the revolving weight at the crank-pin.

As an illustration of the method of calculating this upward and downward disturbance, and to show how it acts, we will take the case of an engine with four driving-wheels, 62 inches in diameter and 24 inches stroke, at a speed of 60 miles per hour. At that speed such wheels would revolve 325 times per minute. Let it be supposed that the following are the

WEIGHTS OF THE REVOLVING AND RECIPROCATING PARTS.

Revolving Parts.

Crank-pin, Boss, for each wheel	150 lbs.
Crank-Pin " "	110 "
Coupling-Rod " "	240 "
Back End of Main Connecting-Rod	190 "
Total Revolving Parts	690 lbs.

Reciprocating Parts.

Front End of Main Connecting-Rod	150 lbs.
Cross-Head	174 "
Piston and Piston-Rod	300 "
Total Reciprocating Parts	624 lbs.

It will be supposed, now, that the revolving weights connected to each wheel are perfectly balanced in the respective wheels. As has been explained, such balance weights will not cause any disturbance, and their effect may be disregarded here, But it will be supposed, further, that the weight of the reciprocating parts on each side is equally divided between the two wheels on that side. This will give 312 lbs. to each wheel which acts on the crank-pin 12 inches from the centre of the axle. Therefore, $312 \times 12 = 3{,}744$. If, then, the centre of gravity of the counterweight is 20 inches from the centre of the axle, the weight required to balance the reciprocating parts will be

$$\frac{3{,}744}{20} = 187.2.$$

By the rule given in answer to Question 167, it will be fonnd that the centrifugal force of each weight would be 11,205 lbs., and at 70 miles per hour—not an unusual speed for locomotives—it would be 15,318 lbs. This force, it will be observed, is greater than the weight which in many instances rests on a single wheel of a locomotive, and shows why less than the whole of the reciprocating weight should be counterbalanced.

The manner in which the force of the counterweight is exerted on the wheels while they are in motion is illustrated in fig. 320, in which a driving-wheel is represented, at *D*, with its crank-pin, *C*, at the forward dead-point. *c* is the centre of gravity of the counterweight, *W*. In this position its centrifugal force is exerted in a horizontal direction only, as indicated by the dart, *d*, whose length, *o c*, will be supposed to represent the magnitude of the force. *D* 4, *D* 8, *D* 12, and *D* 16, represent the position of the driving-wheel at the end of the first, second, third, and fourth quarters of a revolution, and the circles, 4, 8, 12, and 16, show the axle when the wheel is in these positions, and the dotted circles, 1, 2, 3-15, represent the intermediate positions of the axle during each sixteenth of a revolution. When the axle is in the position, 1, then the centre of gravity of the counterweight is at *c* 1, and its centrifugel force acts in the direction shown by the dart, *d* 1. Supposing, again, that the length, 1 *c* 1, of the dart, *d* 1, represents the magnitude of the centrifugal force, and that a parallelogram, *f*, *c* 1, *d* 1, is drawn whose sides are vertical and horizontal and of which *d* 1 is a diagonal, then by the principle of the parallelogram of forces, *c* 1, *d*, the vertical side will be equal to the vertical component or effect of the force, *d* 1. In the same way similar parallelograms could be drawn for the darts, *d* 2, *d* 3, etc.. but if the mag-

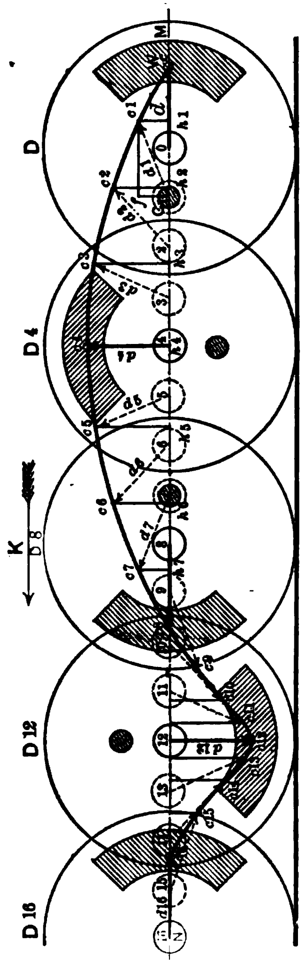


Fig. 320. Diagram Showing Effect of Centrifugal Force at the Crank-Pin. Scale ¼ in.—1 ft.

nitude of the centrifugal force is represented by the darts, *d* 2, *d* 3, etc., all that is needed to represent the vertical effect for each position of the wheel is to draw vertical lines, *c* 2 *h* 2, *c* 3 *h* 3, etc., from *c* 2, *c* 3, etc., the extremities of the darts to the horizontal line, *M N*, passing through the centres of the axle, and these lines will represent the vertical effect of the centrifugal force of the counterweight for each position, *c* 1, *c* 2, *c* 3, etc., of its centre of gravity. If we draw a curve, *c*, *c* 1, *c* 2–*c* 16 through each position of the centre of gravity of the counterweight during the whole revolution, its vertical distance above the centre line, *M N*, will represent the upward force exerted by the counterweight, and the distance of the curve below the line, *M N*, will represent the downward pressure of the counterweight, and the curve will represent to the eye the vertical strains exerted by the counterweight during a whole revolution of the wheel. It will be seen from the diagram that when the wheel is in the position indicated by *D*, as already explained, the centrifugal force is exerted in a backward direction—assuming that the engine is running from the right towards the left side, as shown by the dart, *K*. When the wheel has turned a quarter of a revolution, as shown at *D* 4, then the centrifugal force, *d* 4, is exerted upward; at *D* 12 it acts downward, and at *D* 16 it is again backward.

As the crank on the other end of the axle is at right angles to the one on this side, the centrifugal force of the counterweight on that side also acts at right angles to the one on this side, so that when the counterweight, *W*, exerts a backward horizontal pressure, the opposite one acts vertically either up or down, according to its position in relation to *W*. When *W* acts vertically, as at *D* 4, then its opposite exerts its force horizontally.

QUESTION 463. *How may the vertical disturbance of the counterweights be lessened?*

Answer. By balancing only a part of the weight of the reciprocating parts. When this is done there is more horizontal disturbance in the working of the engine than there would be if the whole of the reciprocating parts were balanced, but this is not considered so great an evil as the excessive vertical disturbance which necessarily results when the counterweight is sufficient to balance the whole of the horizontal momentum of the reciprocating parts. Whether a third, a half, two-thirds, or any other proportion of these parts should be balanced is a question which must be largely decided by experience and practical considerations. If a half is balanced it divides the vertical and horizontal disturbance equally, but there is still much difference of opinion with reference to which is the greater evil.

QUESTION 464. *To calculate the weight of a counterbalance what else must be known?*

Answer. We must know the position of its centre of gravity.

QUESTION 465. *How can the centre of gravity of a counterweight in one segment be found?*

Answer. BY CUTTING A WOODEN TEMPLET OF UNIFORM THICKNESS TO THE FORM OF THE SURFACE, AND FREELY SUSPENDING IT BY ONE OF THE CORNERS, *a*, AS IN FIG. 321; A PLUMMET-LINE, *a P*, DROPPED FROM

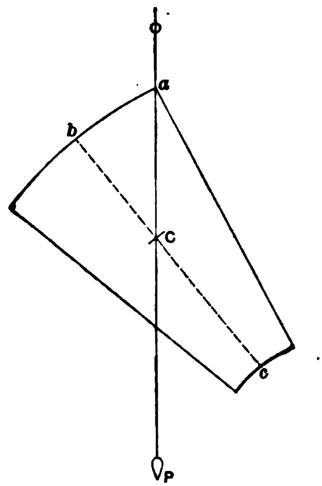


Fig. 321. Method of Finding Centre of Gravity of Counterweight.

THE SAME POINT OF SUSPENSION IN FRONT OF THE TEMPLET, WILL INTERSECT THE CENTRE LINE, *b c*, AT THE CENTRE OF GRAVITY, *C*.

QUESTION 466. *How can the centre of gravity of a counterweight in three segments be found?*

Answer. FIND THE CENTRE OF GRAVITY, *C*, FIG. 322, OF ONE OF THE COUNTERWEIGHTS, AS ABOVE; THROUGH *C* STRIKE AN ARC FROM THE CENTRE, *a*, OF THE WHEEL, CROSSING THE CENTRE LINES OF THE OTHER SEGMENTS AT THEIR CENTRES, *C′ C″*; DRAW *C′ C″* MEETING *A B* AT *D*, AND SET OFF *D E*, ONE-THIRD OF THE INTERVAL *D C*. THEN *E* IS THE COMMON CENTRE OF GRAVITY OF THE THREE SEGMENTS.

QUESTION 467. *How can the centre of gravity of a counterweight in two segments be found?*

Answer. This is required when the crank is opposite to a spoke, as in fig. 323. FIND THE CENTRE OF GRAVITY, C, OF ONE SEGMENT AS BEFORE, AND BY AN ARC FIND THE OTHER CENTRE, C'; DRAW C C', CUTTING A B at D, WHICH IS THE COMMON CENTRE OF GRAVITY.

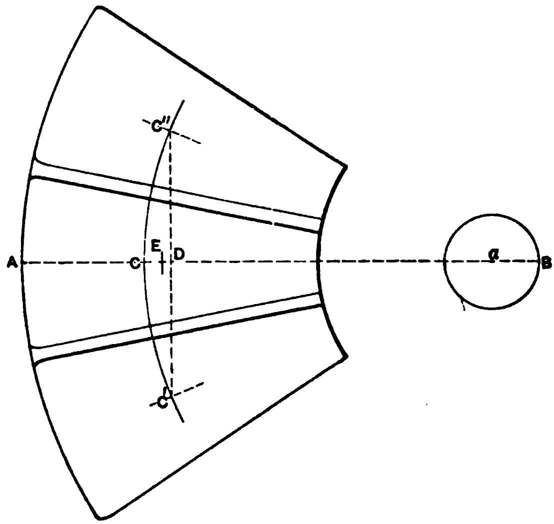


Fig. 322. Method of Finding Centre of Gravity of Three Counterweights.

QUESTION 468. *How can the centre of gravity of a counterweight in four segments be found?*

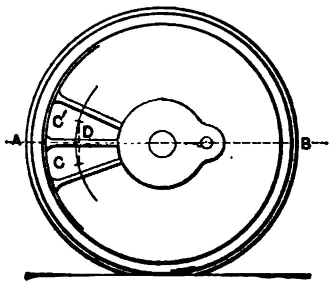


Fig. 323. Method of Finding Centre of Gravity of Two Counterweights.

Answer. FIND, AS BEFORE, THE CENTRES, C C' C'' C''', FIG. 324, OF

THE SEGMENTS; DRAW $C'' C'$ AND $C''' C$, CUTTING THE LINE $A B$; BISECT THE INTERVAL SO ENCLOSED AT E FOR THE COMMON CENTRE OF GRAVITY.*

QUESTION 469. *How may the counterweights be calculated?*

Answer. FIND THE SEPARATE REVOLVING WEIGHTS, IN POUNDS, OF CRANK-PIN, CRANK-PIN BOSS, COUPLING-RODS AND BACK END OF CON-

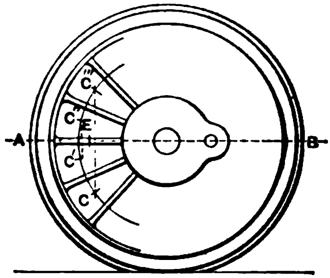


Fig. 324. Method of Finding Centre of Gravity of Four Counterweights.

NECTING-ROD, FOR EACH WHEEL; ALSO THE RECIPROCATING WEIGHT OF THE PISTON AND APPENDAGES, AND THE FRONT END OF CONNECTING-ROD; TAKE FIVE-EIGHTHS† OF THE RECIPROCATING WEIGHT AND DIVIDE IT EQUALLY BETWEEN THE COUPLED WHEELS, AND ADD THE PART, SO ALLOTTED, TO THE REVOLVING WEIGHT ON EACH WHEEL; THE SUMS SO OBTAINED ARE THE WEIGHTS TO BE BALANCED AT THE SEVERAL WHEELS; MULTIPLY THESE WEIGHTS BY THE LENGTH OF CRANK IN INCHES, AND DIVIDE BY THE DISTANCE IN INCHES OF THE CENTRE OF GRAVITY OF THE SPACE TO BE OCCUPIED BY THE COUNTERWEIGHT. THE RESULT WILL BE THE COUNTERWEIGHT IN POUNDS, TO BE PLACED DIAMETRICALLY OPPOSITE TO THE CRANK-PIN.

QUESTION 470. *What effect does the action of the connecting-rods have on the stability of a locomotive?*

Answer. When a locomotive is running forward, the pressure, in the guide-bars, due to the angle of the connecting-rod—excepting at the dead-points—is upward during both the forward and backward strokes of the piston. As this pressure is nearly at its maximum on one side when it ceases entirely on the other, its tendency is to cause the locomotive to roll.

* These rules and illustrations for ascertaining the centre of gravity of a counterweight are taken from D. E. Clark's Railway Machinery.

† As remarked before, from one-half to three-quarters of this weight may be taken in making the calculations.

CHAPTER XX.

THE RUNNING GEAR.

QUESTION 471. *What is meant by the running gear of a locomotive?*

Answer. It means those parts, such as the wheels, axles, and frames, which carry the other parts of the engine. As the Germans express it, it is the "*wagon*" of the locomotive.

QUESTION 472. *How may the wheels be classified?*

Answer. As *driving* and *carrying* or *truck wheels?*

QUESTION 473. *What service must the driving-wheels perform?*

Answer. The driving-wheels, as indicated by their name, "drive" or move the locomotive on the track, as was explained in answer to Questions 176, 177 and 178. As their adhesion depends upon the pressure with which they bear upon the rails, they must carry either a part or the whole of the weight of the engine.

QUESTION 474. *What is a "truck" of a locomotive?*

Answer. A *truck* consists of one or more pairs of wheels held in a separate frame, which is attached to the locomotive by a flexible connection—usually a *king-bolt* or *centre-pin*—somewhat as the front axle of an ordinary wagon or carriage is fastened to the body. The truck is not connected rigidly to the rest of the locomotive, but it can turn or oscillate about the king-bolt, so that the axles can assume positions which approximate to that of radii of the curves of the track. In Plates III, IV and V, 6 6 are the truck wheels, 75 the truck frame, and 98, Plate IV, the centre-pin, around which the truck frame turns.

QUESTION 475. *What service does the truck perform?*

Answer. It usually carries the weight of the front end of the locomotive, and also guides it into and around curves and *switches.** Sometimes a truck is placed under the back end of a locomotive to carry part of its weight.

QUESTION 476. *How does a truck guide a locomotive on a curved track?*

Answer. It does it very much in the same way as the front wheels of

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* A switch is a movable pair of rails by which a locomotive is enabled to run from one track to another.

an ordinary wagon enable it to turn around corners—that is, the truck wheels are attached to a separate frame, which is connected to the locomotive by a centre-pin, so that they can turn just as the front axle of an ordinary wagon can which is connected to the body by a king-bolt.

QUESTION 477. *Why are two pairs of wheels usually used on a locomotive truck instead of one, as on an ordinary wagon?*

Answer. Because it is necessary to have one pair of wheels guide the other. In a wagon the front axle is guided by the pole or shafts. Nearly every one knows the difficulty of moving such a vehicle when the pole or shafts are removed, especially if it be pushed from behind. The movement of the front axle is then uncontrolled, and it is impossible to direct its movement. The same thing would occur with a locomotive if a single

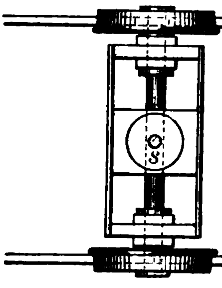


Fig. 325.

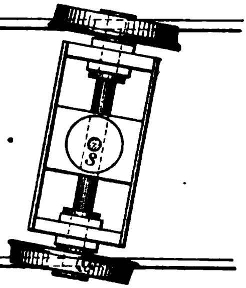


Fig. 326.

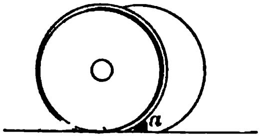


Fig. 327.

Action of Single Pair of Wheels on Track. Scale ¼ in.—1 ft.

pair of wheels were used and attached in the same way as the front axle of a wagon is. Thus, if a single pair of wheels was connected to a locomotive by a centre-pin, *s*, fig. 325, so that the axle would be free to move around this pin, then if one of the wheels should strike an obstruction, say a stone, *a*, fig. 327, there would be nothing to prevent the axle from being thrown into the position shown in fig. 326, and the wheels would be liable to leave the track. When two pairs of wheels are used, as shown in fig. 328, and both axles attached to the same frame, which is connected

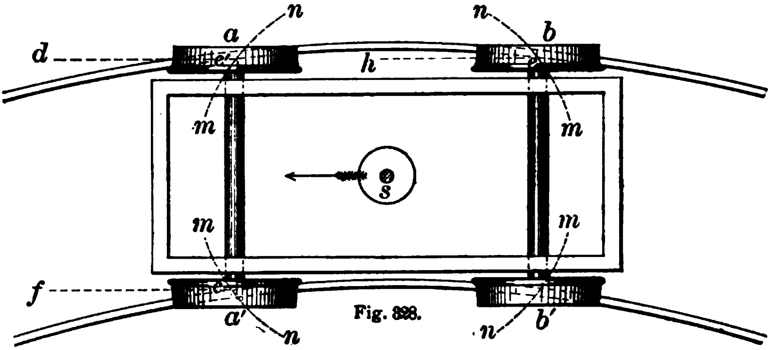


Fig. 328.

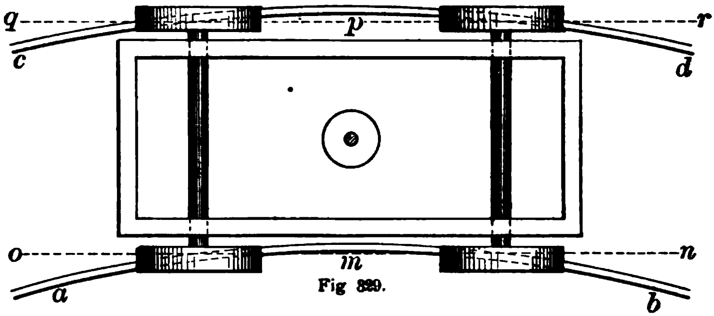


Fig 329.

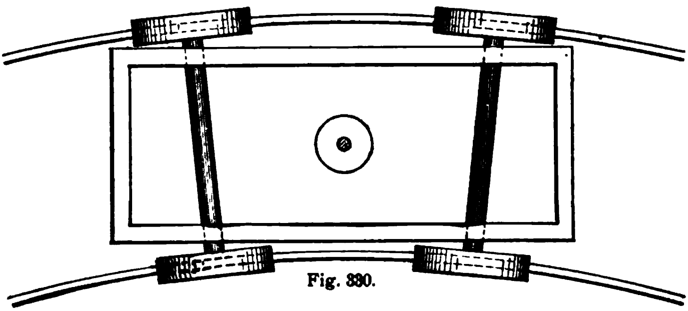


Fig. 330.

Action of Two Pairs of Wheels on Curve. Scale ¼ in.=1 ft.

to the engine by a centre-pin, *s*, between the two axles, then the wheels in moving round the centre-pin must move around it in arcs of circles, *m n*, *m n*, described from the centre, *s*. These arcs, it will be observed, cross the rails. Now, if the wheels should move in the direction indicated by the arcs, the flange of one of them would come in contact with the rail and prevent it from moving any farther. It is, therefore, evident that wheels arranged in that way can only move about the centre-pin as far as the curvature of the track will permit. Trucks are sometimes used with only one pair of wheels, but the centre-pin is then placed some distance behind the centre of the axle, or in the same relation to it that the centre, *s*, is to the axle, *a a'*, in fig. 328. It is evident, then, that if the frame for such a truck should turn around the centre-pin, the wheels must move across the track in the same way as represented by the arcs, *m n*, in fig. 328. The construction and operation of trucks with a single pair of wheels will be more fully explained hereafter.

QUESTION 478. *Why will a locomotive run around curves easier if the front axles are attached to a truck frame which is connected to the locomotive by a flexible connection.*

Answer. Because the truck axles can then assume positions which conform very nearly to the radii of the curves of the track, and it is well known that if two or more axles, each with a pair of wheels on it, are attached to a frame with their centre lines parallel with each other, as shown in fig. 329, they will roll in a straight line, but if the centre lines of the axles are inclined to each other, as shown in fig. 330, the tendency will be to roll in a curve, the radius of which will depend upon the degree of inclination of the axles to each other. In order to make the wheels, in fig. 329, roll on the curves, *c p d*, and *a m b*, it will be necessary to slide them laterally a distance equal to that between the curves and the straight lines, *q p r*, and *o m n*, and as the length of the outside curve is greater than the inside one, if the wheels are fastened to the axles so they cannot turn on them and roll on the curves, either the wheels on the inside or those on the outside must slip a distance equal to the difference in the length of the two rails. Considerable force will therefore be required to overcome the resistance due to the combined lateral and circumferential sliding of the wheels, so that more power will be needed to make them roll in a curve than is necessary to make them roll in a straight line. If, however, the axles are inclined to each other, then the wheels will naturally roll on a curved path, and it will not be necessary to slide them sideways to make them conform to such a path. But if the wheels are all attached to the axles, so that those on the same axle cannot turn independently of each other, and are all of the same diameter, then either the inside or the outside ones must slip, because the path in which the outside ones roll is longer than the inside curve, so that even if the axles are inclined to each other more power will be needed to roll the truck in a curved path than to roll the wheels, shown in fig. 329, in a straight line.

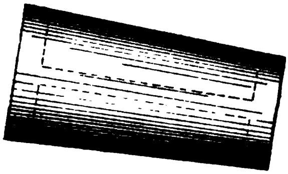


Fig. 331. Cone.

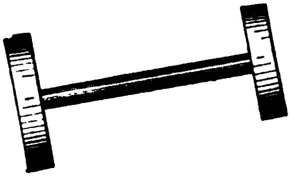


Fig. 332.

Action of Coned Wheels. Scale ¼ in. = 1 ft.

A cone or a portion of a cone, like that shown in fig. 331, will roll in a curved path. It will do the same if the middle is cut away, as indicated by the dotted lines in fig. 331, and as shown by full lines in fig. 332. If, now, the wheels are made so that their peripheries* form portions of a cone and the axles are inclined to each other, as shown in fig. 333, then there will be no slipping on the track, because the outside wheel, being larger in diameter than the inside one, advances further in the revolution than the latter does, and thus rolls on the longest path in the same time that the inside or smaller wheel does on the shorter one. When this is the case, such wheels will roll in a curve as easily as those in fig. 329 will in a straight line. The degree of inclination of the axles and of the sides of the cone must, however, vary with the radius of the curve. But if the axles are parallel to each other, and the wheels conical, as represented in

* The periphery is the outside surface on which the wheel rolls. This part of a wheel is usually called the "*tread*."

fig. 334, they will not roll either in a straight line or in a curve without great difficulty, because if they roll in a straight line, the wheels on one side being larger in diameter than those on the other, either the larger or

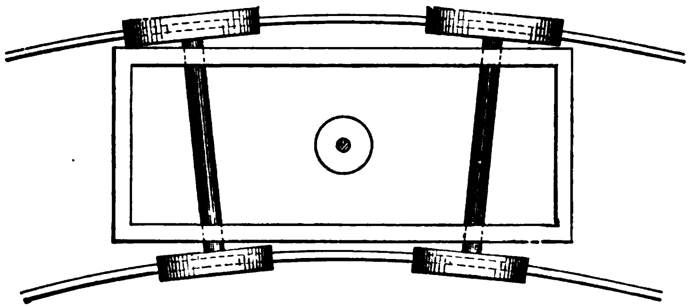


Fig. 333. Action of Two Pairs of Coned Wheels. Scale ¼ in.=1 ft.

the smaller ones must slip on the path in which they roll. If they roll on a curve, then each pair of wheels has a tendency to roll in a curve independent of the other, and therefore the wheels must slip laterally, if both pairs roll on the same track. Thus, suppose two pairs of wheels, *a a'* and *b b'*, fig. 334, to be made conical and attached to a frame so that their axles are parallel to each other; each pair of such wheels will then have a tendency to roll in circular paths, *a' i*, *a h*, and *b' k*, *b j*, the centres of which are at *m* and *n*, or at the apices of the cones of which their peripheries form a part. If they are made to roll in circular paths, *e f*, *c d*, described from a centre, *g*, then each pair of wheels must slip laterally over the space between the paths, *a' i* and *a h*, in which they would naturally roll and that in which they are made to roll. Thus, the wheel, *a*, would slide laterally the distance between the curve, *a h* and *a f*, and *a'* that between *a' i* and *a' d*; *b* would slide from *b j* to *b f*, and *b'* from *b' k* to *b' d*. It will thus be seen that in order that two pairs of wheels may roll with equal ease in a straight line and in curves, the wheels in the one case must be of equal diameters and the axles parallel, and in the other case the wheels must be of unequal diameters and their axles be *radial** to the curve. This is equally true of any number of pairs of wheels. If we have three, four, or any number of axles, with wheels all attached to the same frame, if their

* That is, that their centre lines incline toward each other, and if extended far enough would meet at the centre of the curve.

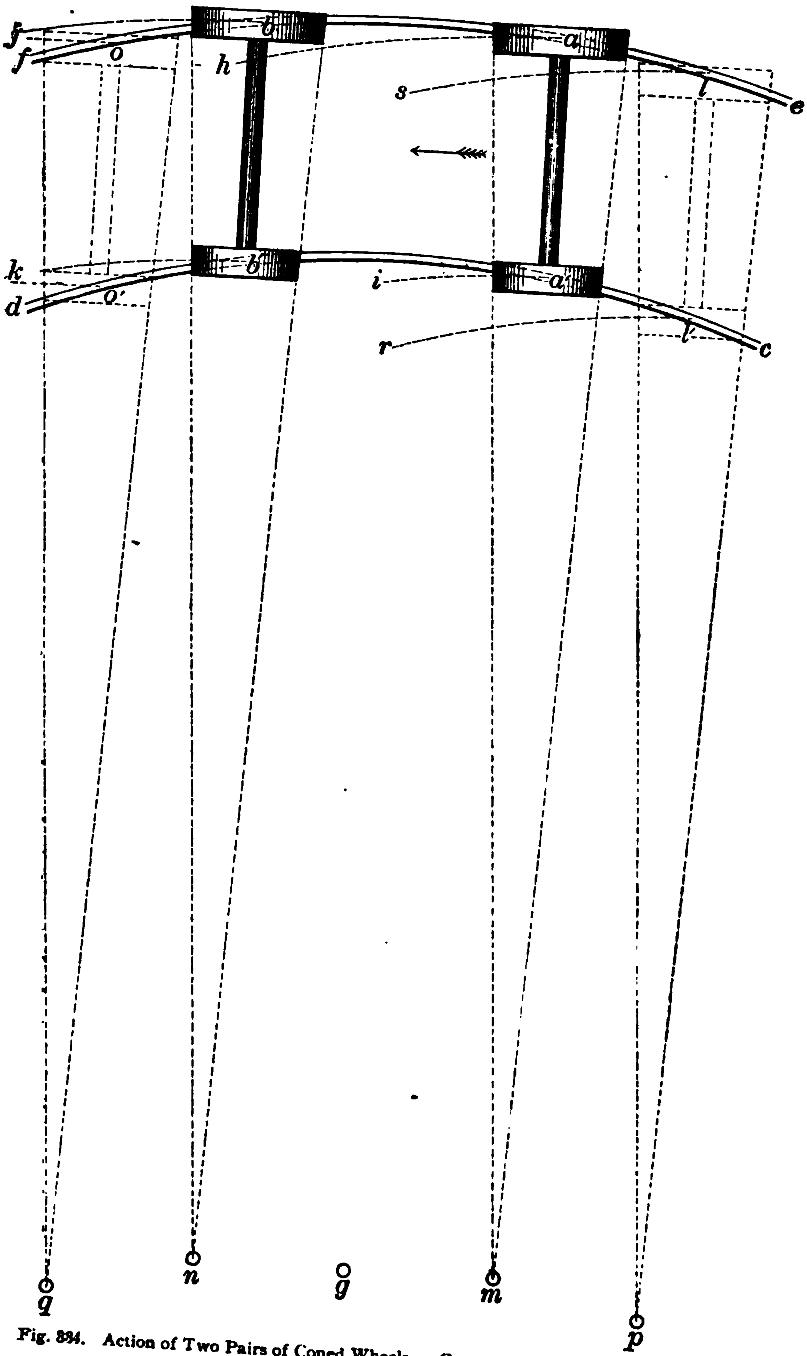


Fig. 834. Action of Two Pairs of Coned Wheels on C

axles are parallel, and the wheels of the same diameter, they will roll in a straight line; but if their wheels are conical and their axles radial, they will roll in a curve.

For the preceding reasons it is sufficiently obvious that if a locomotive is to run on both straight and curved tracks, on the former the wheels should be of the same diameter and the axles parallel, and on the latter the wheels should be conical and the axles radial.

QUESTION 479. *How are wheels made so that on curves they will act as though they were of the conical form described and on a straight truck all be of the same diameters?*

Answer. The periphery or tread of each wheel is made conical, but of the same size as the other, and with the small diameters of the cones outside, as shown in fig. 335. The flanges are then put closer together than

Fig. 335.

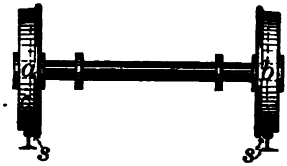
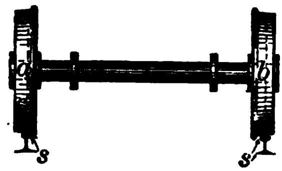


Fig. 336.



Action of Coned Wheels. Scale ¼ in.—1 ft.

the rails, so that there will be some space or end play, as it is called, between the flanges and the rails, as shown at *s s'*. On a straight track, if the position of the wheels on the rails is such that their two flanges are equally distant from the rails, as shown in fig. 335, then obviously at the points of contact with the rails or on the lines, *a* and *b*, the wheels are of the same diameter. But in running on a curved track the wheels, as has been shown, will roll toward the outer rail of the curve. The flange, *c*—supposing it to be on the outside of the curve—will therefore roll towards the rail, and consequently the outside wheel will rest on the rail at a point nearer the flange, as shown in fig. 336, where the diameter, *a*, is larger, and the inside wheel, *b*, will rest on the rail at a point farther from the flange where the diameter, *b*, is smaller than at *a* and *b*, in fig. 335; and consequently the action of the wheels is the same as though their peripheries were made of the form shown in fig. 332.

QUESTION 480. *Does the conical form of wheels have much influence on their action on curves?*

Answer. No; for the reason that while the conical form of the wheels will cause a single pair on one axle to roll in a curved path, if the axles of two pairs of such wheels are held parallel to each other, as they are in a locomotive or truck frame, the conical form has very little influence to act in that way. It has also been proved by experiment that when the axles are parallel to each other, the influence of the conical form of the wheels diminishes as the distance between the axles increases,* so that at the usual distance apart of the driving-axles of locomotives and of truck axles of locomotives and cars, the effect of the conical form of the wheels is almost, if not quite, inappreciable. Besides this, the conicity of the treads of wheels is rapidly worn away, so that it seems quite certain that the advantages resulting from coning-wheels are more imaginary than real.

QUESTION 481. *Is the resistance to rolling diminished by placing the truck axles nearer together?*

Answer. It is within certain limits. The nearer each other they are placed, the closer will the centre-pin of the truck be to the centre of the axles. The closer it is to the centre of the axles, the greater is the tendency of the wheels to become "slewed," or to assume a diagonal position to the rails, as represented in fig. 326, which increases the resistance and also the danger of running off the track. The increase of resistance from this cause, after the axles reach a certain distance from each other, is greater than the decrease from a closer approximation to the position of radii. In ordinary locomotives it is necessary to place the truck wheels from 5 ft. 6 in. to 6 ft. 6 in. apart, in order to get the cylinders between them in a horizontal position. This distance apart works very well in ordinary practice.

QUESTION 482. *What is meant by flange friction?*

Answer. It is the friction of the flanges of the wheels against the head of the rails. Thus if two pairs of wheels, *a a'*, *b b'*, fig. 328, be placed on

* This was shown in a paper read by the author at the annual convention of the Master Car Builders' Association, held in 1884, and which was published in the report of the proceedings of the convention of that year.

a curve and rolled in the direction indicated by the dart, *s*, the wheel, *a*, will roll toward the outside of the curve until the flange comes in contact with the rail. As already explained, if two axles are parallel to each other, no matter whether the wheels are conical or cylindrical, they must slip laterally in order to roll in the curved path into which the rail is bent. As the wheel offers considerable resistance to sliding laterally, there is a corresponding pressure of the flange against the rail, and consequently the revolutions of the wheel produce an abrasive action between the two. This action is obviously increased with the distance between the axles, because, as has been shown, the lateral slip of the wheels is then greater than when they are nearer together. It is also obvious that if the wheels are parallel with the rails, there will be no abrasive action of the flanges, but that the greater the angle at which the wheels stand to the rails the harder will the flanges rub against the rails, and the greater will be the flange friction. With the aid of geometry, it can very easily be proved that the farther apart two parallel axles are, the greater will be the angle of the wheels to the rails on a curved track, and, therefore, the greater will be their flange friction. It must, however, be remembered that if the wheels are so close together that they are liable to become "slewed," or assume a diagonal position across the rails, as shown in fig. 326, the angle of the wheels to the rails would thus be very much increased. It has, therefore, come to be a very generally recognized rule that the centres of axles should never be placed nearer together than the distance between the rails.

QUESTION 483. *Is the flange friction of all the wheels of a truck the same on any given curve?*

Answer. No; of the front wheels, *a* and *a'*, fig. 328, obviously only the flange of the one, *a*, on the outside of the curve comes in contact with the rail. As the centrifugal force of the engine presses the back pair of wheels toward the outside of the curve, the flange of the outside wheel, *b*, alone comes in contact with the rail. But as this wheel is constantly rolling *away* from the rail, as shown by the dotted line, *h e*, obviously the friction of its flange is less than that of the front outside wheel, *a*, which always rolls *toward* the rail. The flange of the back inside wheel, *b'*, is carried outward by the centrifugal force and also by the tendency of the outside wheel, *b*, to roll on its largest diameter on a curve, so that the flange of *b'* will not ordinarily touch the rail.

QUESTION 484. *How does a truck allow the axles of a locomotive to adjust themselves to the curvature of the track?*

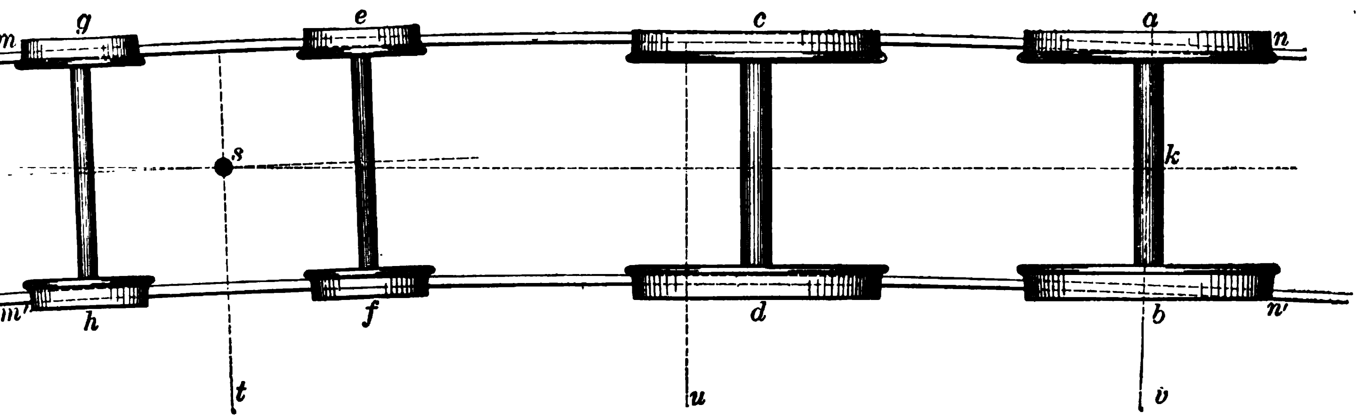


Fig. 887. Plan of Wheels of "American" Type of Locomotive. Scale ¼ in.—1 ft.

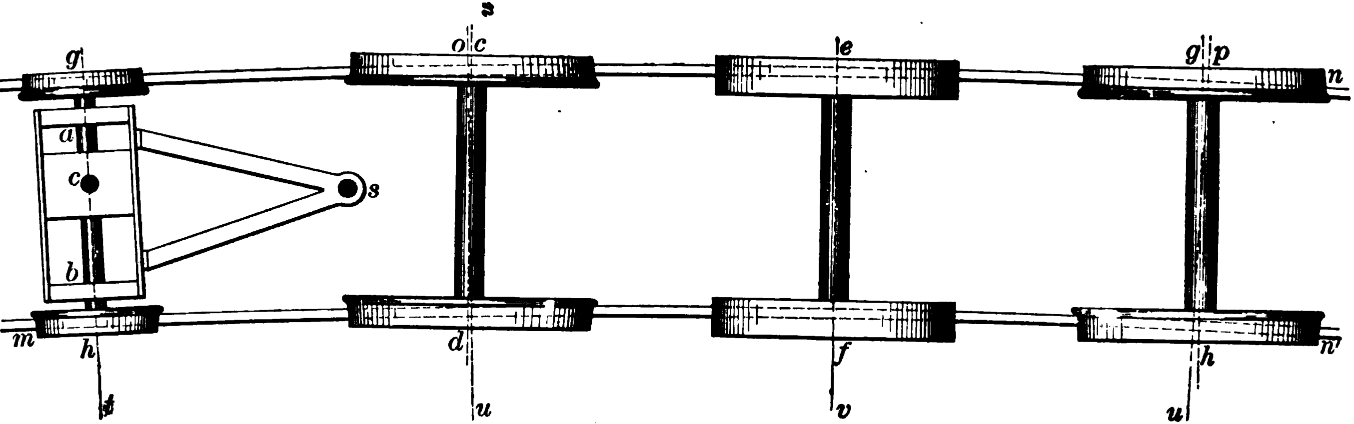


Fig. 338. Plan of Mogul Locomotive Wheels. Scale ¼ in. = 1 ft.

Answer. The truck is attached to the locomotive by a flexible connection or centre-pin, *s*, as shown in fig. 337 (which represents a plan of the wheels of an ordinary locomotive), from which it can be seen that the truck axles, *e f* and *g h*, instead of remaining parallel to the driving-axles, *a b* and *c d*, will, by turning around the centre-pin, *s*, adjust themselves to the curve so as to approximate as closely to radii as is possible for two axles which are that distance apart and are held parallel to each other. Of course, the farther apart they are the greater will be their divergence from the position of radii, and whether the tread of the wheels be cylindrical or conical, the farther apart their axles are the greater will be the divergence of the paths in which they would naturally roll from that of the curve of the track on which they must roll. Thus, if the axles were twice as far apart as they are represented in fig. 334, and were in the position shown in the dotted lines, *l l'* and *o o'*, the wheels, if they were conical, would then naturally roll in curves drawn from the centres, *p* and *q*. If the wheels are cylindrical, they would roll in straight lines. In either case the divergence of their paths, *l s* and *l' r*, from the curve of the track is greater than *a h* and *a' i*, the paths in which they would roll if their axles were nearer together. This divergence increases with the distance between the axles, and therefore the lateral slip of the wheels must be in the same proportion.

QUESTION 485. *How is a truck with a single pair of wheels arranged?*

Answer. The axle is attached to an A-shaped frame, shown at *a b s* in fig. 338, which is the plan of an engine with three pairs of driving-wheels and such a truck. The truck frame is connected to the engine with a pin, *s*, about which it can turn. and in this way the axle can adjust itself to the positions of the radii of the curve.

QUESTION 486. *Can the axles of driving-wheels assume positions radial to the track?*

Answer. In ordinary engines they cannot. Various plans have been devised for the purpose of enabling them to do so, but they have not met with much favor. It is, however, of less importance that the driving-axles, when they are behind the centre of the locomotive, should assume positions radial to a curved track than that the front wheels should. This is illustrated by a common road wagon, as all know the ease with which a vehicle can turn a corner if we run it with the front axle ahead, and the difficulty of doing so when the back axle is in front. In the case of a locomotive, the reason for it is very much the same as that which makes the flange friction of the back wheels of a truck less than that of the front ones. From fig. 337 it will be seen that the outside driving-wheels, *a* and *c*, when the engine is running with the truck in front, are rolling *from* the rail and not against it. As stated before, the centrifugal force of the engine when in motion has a tendency to throw the wheels toward the outside of the curve. It will also be noticed, from fig. 337, that the front driving-axle is near the centre of that portion of the curve which lies between the centre, *s*, of the truck and the centre, *k*, of the back axle. If it were in the middle, between them, it would be exactly radial to the curve; being near the middle, it approximates closely to that position, and therefore the flange friction of its wheels is very slight. It will be seen, too, that if the flange of the back or trailing-wheel, *b*, on the inside of the curve was not kept away from the rail, it would roll toward and impinge against it, and that the flange of the front driving-wheel, *d*, will come in contact with the inside rail before that on the back wheel can touch it. For this reason, and also on account of the effect of the centrifugal force exerted on the engine and the tendency of the wheels to roll on their largest diameters, the flange of the inside back wheel is kept out of contact with the rail, and as the back wheel, *a*, on the outside of the curve rolls away from the rail, there is very little friction of the flanges of the back driving-wheels.

It will also be observed from fig. 337, that if the radius of the curve is very short, the bend of the rails between the back pair of driving-wheels, *a b*, and the centre of the truck is so great that the inside rail will press hard against the flange of the front or main driving-wheel, *d*, next that rail. This, of course, produces a great deal of friction, and if the curve is excessively short the flange will mount on top of the rail, and the tread of the opposite wheel will fall off from its rail. For this reason the centre-pin of the truck is sometimes arranged so that it can move laterally—that is crosswise of the track. The front wheels of locomotives are also sometimes made with wide "flat" tires—that is, tires without flanges, so that there will be no friction against the one rail and no danger of falling off the other.

Another action also takes place which facilitates the motion of the driving-wheels of ordinary engines around curves. Every one knows how easily the direction in which the front wheels of a common wagon move can be controlled by taking hold of the end of the tongue or pole. With the leverage which it gives, the wheels and axle can easily be directed wherever it is desired. A similar action takes place in an ordinary locomotive. The front driving-axles are guided by the truck, which is attached to the locomotive frames 10 or 12 feet in front of the driving-axle, and thus the truck exerts a leverage to guide the movement of the driving-axles, just as a common wagon can be guided by the pole.

If the locomotive is run backward, then none of these advantages exist, and the flange friction of the back driving-wheels is excessive. From this cause engines, such as construction locomotives, which run backward as much as forward, wear out the flanges of the back wheels very rapidly on crooked roads.

QUESTION 487. *What is meant by the "spread" of the wheels or axles?*

Answer. It is the distance between the centres of the axles.

QUESTION 488. *What is the "wheel-base" of a locomotive?*

Answer. It is the distance between the centres of the front and back or trailing-wheels. On ordinary engines, such as that illustrated in Plate

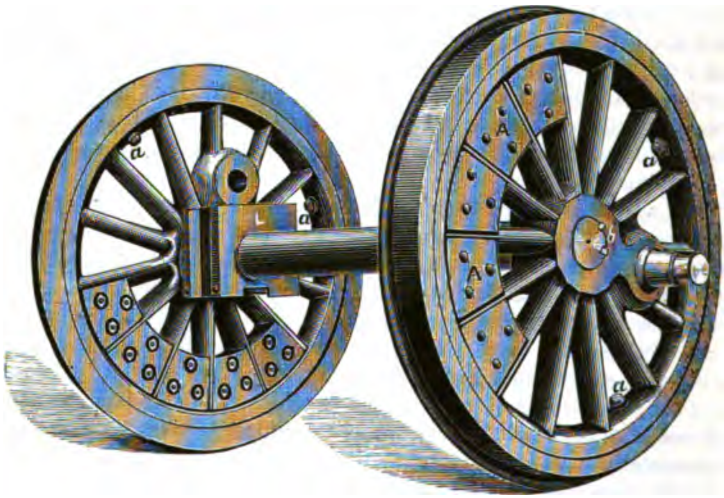


Fig. 339. Driving-Wheels.

III, it is usually measured from the centre of the front truck to the centre of the back driving-wheels.

QUESTION 489. *How are the driving-wheels of locomotives constructed?*

Answer. In this country they are made of cast iron with wrought-iron or steel tires around the outside. Fig. 339 represents a perspective view of a pair of locomotive wheels and axle. The central portion of the wheel

—that is, the hub, spokes, and rim, are cast in one piece. Usually the hub and the rim, and sometimes the spokes, are cast hollow. The central portion of the wheel—that is, the part which is made of cast iron, is called the *wheel-centre*. In Europe the wheel-centres are generally made of wrought-iron.

QUESTION 490. *How are the tires fastened on the wheel-centres?*

Answer. The insides of the tires are usually turned out somewhat smaller than the outside of the wheel-centre. The tire is then heated so that it will expand enough to go on the centre. It is then cooled off, and the contraction of the metal binds it firmly around the cast iron part of the wheel. As an additional security, bolts or set-screws, *a a*, fig. 339, are sometimes screwed through the rim and into the tire to prevent it from slipping off in case it becomes loose.

QUESTION 491. *How are tires held on the wheels in case the former break?*

Answer. In Europe, and on some railroads in this country, locomotive tires are fastened to the wheel-centres by what are called *retaining rings*. Fig. 340 represents a section of a tire, *A*, which is fastened in this way.

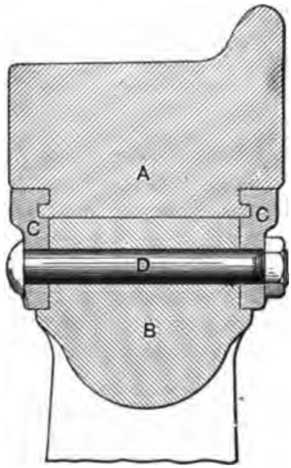


Fig. 340. Section of Tire with Retaining Rings. Scale ¼ in.=1 in.

The fastenings consist of flat rings, *C C*, which are placed on each side of the wheel and tire, and fastened to the wheel-centre, *B*, with bolts, *D*.

The rings have annular projections, at *C C*, which fit into corresponding grooves in the tires. In case the tire should break, these rings hold it in its position on the wheel and thus prevent an accident.

QUESTION 492. *Are there any standard sizes for the inside diameters of tires?*

Answer. Yes. To avoid the great inconvenience arising from a diversity in the *inside diameters* of tires, the American Railway Master Mechanics' Association has recommended standard dimensions for them and for the outside diameters of driving-wheel centres. These are given in the following table:

STANDARD DIMENSIONS FOR DRIVING-WHEEL CENTRES AND TIRES.

Outside Diameter of Wheel-Centres.	Allowance for Shrinkage of Tire.	Inside Diameter of Tires.
38 inches.	0.040 inch.	37.960 inches.
44 "	0.047 "	43.953 "
50 "	0.053 "	49.947 "
56 "	0.060 "	55.940 "
62 "	0.066 "	61.934 "
66 "	0.070 "	65.930 "

QUESTION 493. *How are the driving-wheels fastened on the axles?*

Answer. The hubs are accurately bored out to receive the axles, and the latter are turned off so as to fit the hole bored in the wheel. The axles are then forced into the wheel by a powerful pressure produced either with a hydraulic or screw press, made for the purpose. In order to prevent the strain upon the crank-pins from turning the wheels upon the axle, they are keyed fast with square keys driven into grooves cut in the axle and in the wheel to receive them. The ends of these keys are shown at *b*, fig. 339.

QUESTION 494. *How are the crank-pins made?*

Answer. They are made of wrought-iron or steel and accurately turned to the size required for the journals for the connecting-rods. Fig. 341 represents one of the main crank-pins, and fig. 342 a back pin for an American type of engine. The main pin has two journals, one, *A*, to which the main connecting-rod is attached, and the other, *B*, receiving the coupling-rod. The back pin has only one journal, *B*, for the coupling-rod. On some locomotives the main connecting-rod is attached to the outside journal, *B*, of fig. 341. The coupling-rod is then connected to journals next to the wheels.

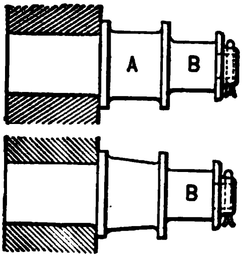
The collars on the crank-pins hold the rods on the pins.

QUESTION 495. *How are the crank-pins fastened to the wheel?*

Answer. They are turned so as to fit accurately into holes which are bored in the wheels. The holes are usually "straight" or cylindrical. The pins are then either driven in with blows from a heavy weight swung

Fig. 341.

Fig. 342.



Crank-Pins.

from the end of a rope, or else pressed in with a screw or hydraulic press. Sometimes the holes are bored tapered or conical and the pins turned to the same form. They are then ground in with emery and oil, so as to fit perfectly, and are secured by a large nut and key on the inside of the wheel.

QUESTION 496. *What are the pieces, A A, fig. 339, between the spokes of the wheels for?*

Answer. They are the *counterbalance weights*, or counter-weights, which are put in the wheels to balance the weight of the crank-pins, connecting-rods, and pistons, as explained in Chapter XIX.

QUESTION 497. *How are the truck wheels made?*

Answer. They are generally made of cast iron, usually in one piece. Figs. 343, 344, and 345 represent the most common form of cast iron wheels which is used for locomotive and car trucks. Fig. 343 is a view of the front or outside of a wheel, fig. 344 of the back side, and fig. 345 is a wheel with a part of it cut away, so as to show a section of it. It will be seen that the plates which form the centre of the wheel and the ribs on the back are curved in form. They are made in this shape so that when the wheel is cast and contracts in cooling, the plates and ribs can spring somewhat without being strained to a dangerous degree.

Fig. 343. Fig. 344.

Fig. 345.
Cast Iron Truck-Wheels.

The tread of the wheel is hardened by a process called *chilling*, This is done by pouring the melted cast iron into a mould of the form of the tread of the wheel. The mould for the tread is also made of cast iron, but being cold, cools the melted iron very suddently, and thus hardens it somewhat as steel is hardened when it is heated and plunged into cold water.*

QUESTION 498. *What other kinds of wheels are used for car and locomotive trucks?*

Answer. A variety of wheels with steel tires are used for locomotive and car trucks. The wheel-centres are made of cast iron or wrought-iron or compressed paper held between two wrought-iron plates. The tires are fastened to the centres—or they should be fastened—with some kind of retaining rings.

QUESTION 499. *What is the shape of the tread and flange of a car and locomotive wheel?*

Answer. Fig. 346 represents the standard form for the treads and flanges of car and locomotive wheels which has been adopted by the Master Car Builders' and the Master Mechanics' Associations.

* It is only certain kinds of cast iron which will be hardened in this way, or will "*chill*," as it is called. The cause to which this chilling property is due is not known.

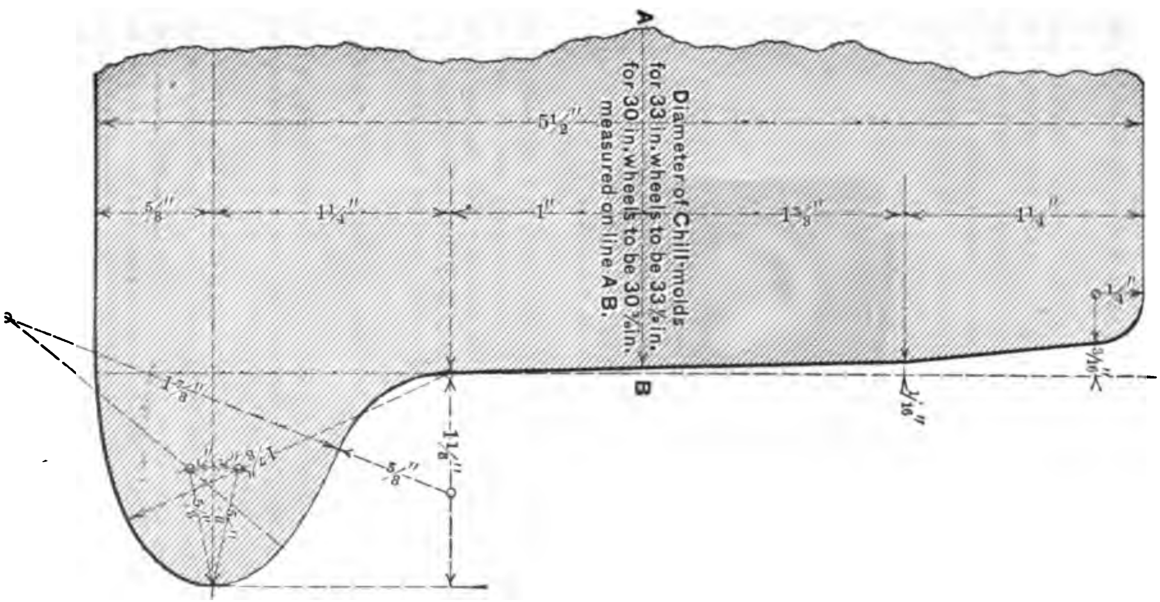


Fig. 846. Section of Standard Tread and Flange of Wheel. Full Size.

QUESTION 500. *On what part of the axle does the weight of the engine rest?*

Answer. It rests on what are called the *journals*, which are just inside of the wheels. These journals turn on brass bearings, called *journal-bearings*, which resist the friction of the revolving axle. The bearings are held in cast iron or cast steel boxes, called *journal-boxes*. One of these is shown at *L*, in fig. 339, and also separately, in fig. 347, in which *C* is the

Fig. 347. Driving Journal-Box.

journal-bearing and *d* the *oil-celler*. The latter is a receptacle underneath the axle which is filled with wool or cotton waste which is saturated with oil for the purpose of lubricating the journal. The oil-cellar is held in its position by two bolts, *f f*, which pass through it and the driving-box casting. By removing the bolts the oil-cellar can easily be removed, and the box can then be taken off the axle.

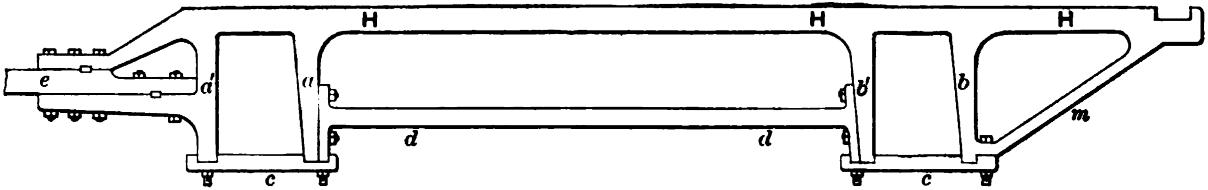
QUESTION 501. *How are the boxes, journals, and journal-bearings of the truck wheels made?*

Answer. They are very similar to those for the driving-wheels, their chief difference being that those for the truck wheels are smaller than those for the driving-wheels.

QUESTION 502. *How are the frames for locomotives constructed?*

Answer. The frames, 32 32 32, Plates III, IV and V. are made of bars of wrought-iron from three to four inches thick and about the same in width. Each frame is usually made in two parts, one at the back part of the engine, to which the driving-boxes and axles are attached, and the other at the front end to which the cylinders are bolted. The back part, or main frame, as it is called, is represented in figs. 348 and 349, and con-

Fig. 348.



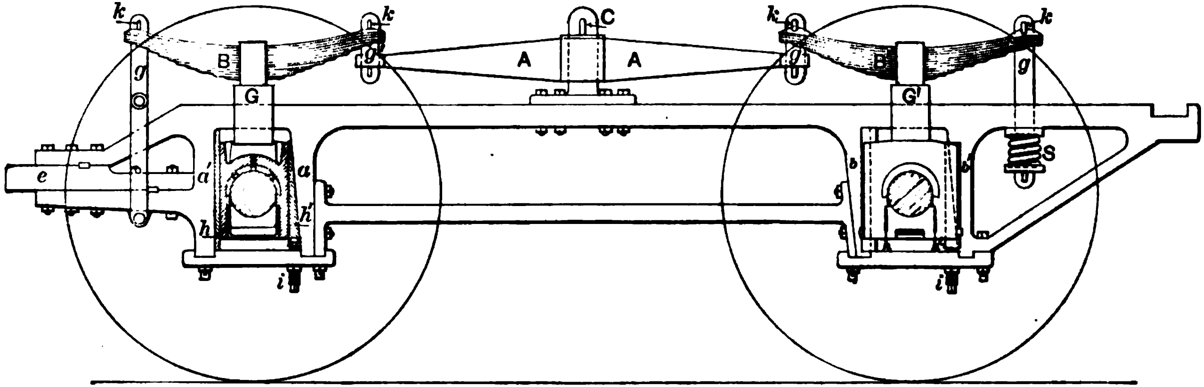


Fig. 349.
Frame, Springs and Driving-Boxes. Scale ⅝ in.—1 ft.

sists of a top bar, *H H*, to which pieces, *a*, *a'*, *b*, *b'*, called *frame-legs*, are welded. Two of these form what is called a *jaw*, which receives the axle-box, as shown in fig. 349. To the bottom of each jaw a *clamp*, *c*, fig. 348, is bolted to hold the two legs together. The two legs, *a* and *b'*. are united by a brace, *d d*, bolted to the legs. A brace, *m*, unites the back end of the frame with the leg, *b*, and is welded to each.

The front part of each frame consists of a single bar, *e*, which is bolted to the back end, as represented in figs. 348 and 349, which show the construction clearer than any description would. The front bar is shown plainly in Plates IV and V—the back end only is shown in figs. 348 and 349. These front bars extend forward to the front end of the engine, and a heavy timber, called a *bumper-timber*, extends across from one to the other and is bolted to each of them, as shown in Plates III, IV and V. This timber is intended to receive the shock or blow when the locomotive runs against any object, such as a car. The *cow-catcher* or *pilot*, 38 38, is fastened to this timber.

The front bar of the frames also has usually two lugs or projections on it, shown in Plate IV, between which the cylinders are attached. The latter are securely held in their positions by wedges, which are driven in between the lugs and the cylinder castings.

The frames, as already stated, are in this country made of wrought-iron forged bars, and are accurately planed off over their whole surface. In Europe they are made of rolled-iron plates.

QUESTION 503. *How are the frames fastened to the boiler?*

Answer. As already stated, they are fastened to the cylinders with wedges and bolts, and as the cylinders are bolted to the smoke-box, the frames are thus rigidly attached to the front end of the boiler. In order to strengthen those portions of the frames which extend beyond the front of the smoke-box and to which the bumper-timber is attached, diagonal braces, shown in Plates III, IV and V, are bolted both to the timber and to each of the frames at their lower ends. The upper ends are bolted to the smoke-box. Other braces are also fastened to the frames and to the barrel of the boiler. The frames are fastened to the fire-box by clamps, 10 10, Plate III, called *expansion clamps*. These clamps embrace the frames so that when the boiler is heated and expands the frames can slide through the clamps longitudinally. There are also usually two diagonal braces, shown in Plates III, IV and V, the upper ends of which are fastened to the back end of the shell of the fire-box at about the level of the crown-sheet, and the lower ends to the back ends of the frames.

Transverse braces are generally attached to the lower part of the frames, thus uniting the two together. The guide-yoke is also usually bolted to the frames and connected to the boiler.

QUESTION 504. *Why are the frames attached to the shell of the fire-box so as to slide longitudinally through the fastenings?*

Answer. Because when the boiler becomes heated it expands, and if it could not move independently of the frames, its expansion would create a great strain on both itself and the frames. The fastenings to the fire-box are therefore made so that the frames can move freely through them lengthwise, but in no other direction.

QUESTION 505. *How much more will a boiler expand than the frames in getting up steam?*

Answer. From $\frac{1}{4}$ to $\frac{5}{16}$ of an inch.

QUESTION 506. *Why is it necessary to support the engine on springs?*

Answer. Because,* however well a road may be kept up, there will always be shocks in running over it; these occur at the rail joints, and especially when the ballasting of the ties is not quite perfect. These shocks affect the wheels first, and by them are transferred through the axle-boxes to the frame, the engine and the boiler. The faster the locomotive runs, the more powerful do they become, and therefore the more destructive to the engine and road, and consequently the faster a locomotive has to run the more perfect should be the arrangement of the springs.

If we strike repeatedly with a hammer on a rail, the latter is soon destroyed, while it can bear without damage a much greater weight than the hammer lying quietly on it. The axles, axle-boxes and wheels strike like a hammer on the rails at each shock, while the shock of the rest of the parts of the engine first reaches and bends the springs, but on the rails has only the effect of a load greater than usual resting on them.

The way in which the springs lessen the injurious effects which the weight of the boiler, etc., exerts on the rails will be made plainer by another comparison.

A light blow with a hammer on a pane of glass is sufficient to shatter it. If, however, on the pane of glass is laid some elastic substance, such as india-rubber, and we strike on that, the force of the blow or the weight of the hammer must be considerably increased before producing the above-named effect. If the locomotive boiler is put in place of the hammer, the springs in place of the india-rubber, and the rails in place of

* This answer and much of the material referring to springs has been translated from "Die Schule des Locomotivführers," by Messrs. J. Brosius and R. Koch.

the glass, the comparison will agree with the case above. From this consideration it will be seen how important it is to make the weights of the axles, axle-boxes, and wheels as light as possible.

QUESTION 507. *How are the driving axle-boxes arranged so that the weight of the engine will rest on springs?*

Answer. They are arranged so as to slide up and down in the jaws. Springs, B B', fig. 349, are then placed over the axle-boxes and above the frames. These springs rest on ∩-shaped saddles, G G', which bear on the top of the axle-boxes. The frames are suspended to the ends of the springs by rods or bars, g, g', g, g', called *spring-hangers*. As the boiler and most of the other parts of the engine are fastened to the frames, their weight is suspended on the ends of the springs, which, being flexible, yield to the weight which they bear.

QUESTION 508. *How are the frames protected from the wear of the axle-boxes which results from their sliding up and down in the jaws?*

Answer. The insides of the legs, a, a', b, b', are protected with *shoes* or *wedges*, h, h', which are held stationary, and the boxes slide against the faces of the shoes, thus wearing the shoe or wedge, but not the frame.

QUESTION 509. *Why is one or both of the shoes made wedge-shaped?*

Answer. They are made in that way so that when they become worn, by moving one or both of them up in the jaws, the space between them is narrowed and the lost motion is taken up. They are moved by the screws, i, i. If the boxes should become loose from wear, it would cause the engine to thump at each revolution of the wheels or stroke of the piston.

QUESTION 510. *How are the springs for the driving-wheels made?*

Answer. They are made of steel plates, which are placed one on top of the other. These plates are of different lengths, as shown at B B, in fig. 349, and are from 3 to 4 inches wide, and $\frac{5}{16}$ to $\frac{7}{16}$ thick. The length of the springs measured from the centre of one hanger to the centre of the other is usually about 3 feet.

QUESTION 511. *What determines the amount which a spring will bend under a given load?*

Answer. The number of plates, their thickness, length and breadth. and of course the material of which they are made. This can be explained if we suppose we have a spring-plate of a uniform thickness, h, and a triangular form, of which fig. 350 is a side view and fig. 351 a plan, and that it is clamped fast at its base, b. It is a well-known mechanical law that any material of this form and under these conditions will have a uniform strength through its whole length to support any load, P, suspended at its end, and also that it will bend or deflect in the form of an arc of a circle.

QUESTION 512. *How are locomotive springs usually made?*

Answer. In locomotives the arrangement of springs is always such that they are either supported in the middle and moved at the two ends, or such that they are supported at the two ends and loaded in the middle;

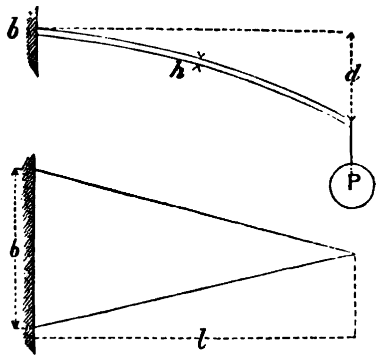


Fig. 350.

Fig. 351.

Diagrams Showing Action of Plate when Bent.

for our consideration it is indifferent which of the two kinds of springs is taken for the present illustration. That shown in plan and elevation in figs. 352 and 353, which is formed of a wide plate placed diagonally, and which in reality consists of two such triangular pieces as were represented in fig. 351, united at their bases, *m m*, fig. 353, and loaded at two opposite corners, *e* and *f*, would answer the requirements mentioned if the great breadth, *m m*, were not an obstacle. This breadth is obviated by cutting the spring into several strips, *a a, b b, c c, d d,* . . . . *i*, fig. 353, of equal width, and placing these not side by side, but one over the other, as shown in figs. 354 and 355.

In order that the separate strips and layers of the spring so made may not slip out of place, the strips *a a, b b,* etc., are made in one piece, and all the plates are enclosed with a metal strap, *F*, figs. 356, 357 and 358. The plates, instead of being cut from a piece like that represented in fig. 353, are, however, made out of steel of the proper width, and the ends, instead of being cut off pointed as represented, are sometimes drawn out thinner on the ends, like the point of a chisel, or oftener still cut off straight, as shown in fig. 358.

The band, *F*, which is put around the middle, is put on hot, and becomes tight by contracting as it cools. The centre of the spring has a hole drilled through it with a pin or rivet, *s*, fig. 357 (which shows a cross section

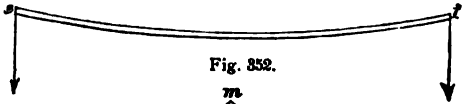


Fig. 352.

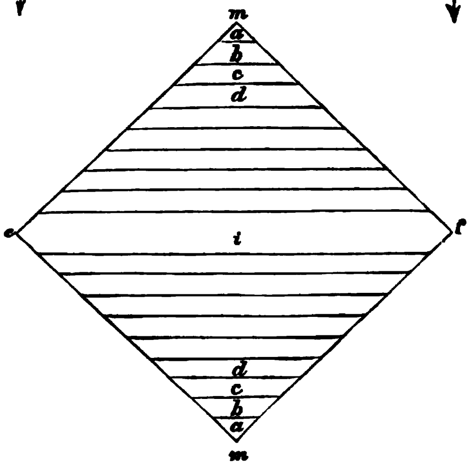


Fig. 353.
Diagrams Showing Action of Plate when Bent.

through the middle of a spring), to prevent the plates from sliding endwise. The plates at each end usually have a depression, *a*, fig. 359 (which is a cross section through the middle of a plate on a larger scale than the

Fig. 354.

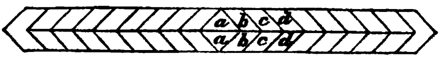


Fig. 355.
Springs.

preceding figure), made in them on one side, and a corresponding elevation, *b*, on the other. The elevation on one plate fits into the depression on the other, and thus prevents the plates from slipping sideways.

QUESTION 513. *How should springs be curved?*

Answer. Springs should be curved so that when they bear the greatest load which they must carry they will be straight. If they are curved too much they are subjected not only to a strain which bends the plates, but

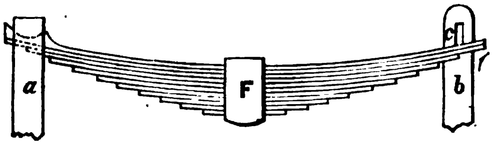


Fig. 356.

Fig. 357.

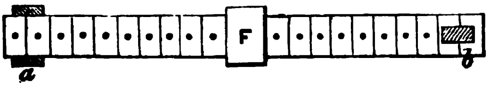


Fig. 358.

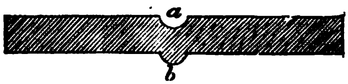


Fig. 359.

Driving-Springs. Scale ¾ in.—1 ft.

to one which has a tendency to compress them endwise. Thus, if a spring like that represented in fig. 360, is bent into a half-circle, it is obvious that

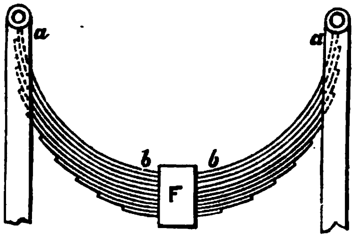


Fig. 360. Curved Spring.

the strain at the ends has no tendency at all to bend the plates, but only to compress them endwise. Near the middle the strain will, of course, bend the spring. In the one direction the spring is flexible and elastic, and in the other it is not; and as the strain of compression depends on the amount of curvature, the greater the latter is, the less flexibility and elasticity the spring will have.

Springs are often given a double curve, as shown in fig. 361. This is not to be recommended, because when a spring bends the plates must slide on each other. If they have but a single curve, they will do so and remain in contact through their whole length, but if they have two curves they will separate and therefore "gape," as it is called.

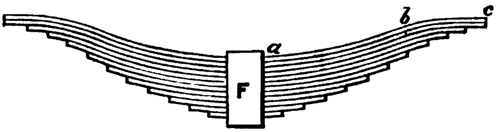


Fig. 361. Curved Spring.

QUESTION 514. *What is the shape of the band on the spring?*

Answer. The bands are usually made of the form shown in figs. 356 and 361, but recently they have been made* of the form shown in fig. 362

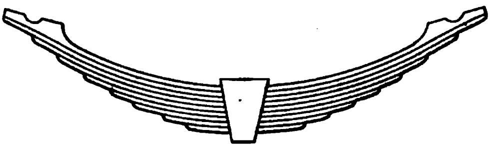


Fig. 362. Morris's Spring. Scale ¾ in.—1 ft.

—that is, narrower on the under side than on top. This allows the lower and shorter plates to bend more than they could if held by a wider band, and gives them greater elasticity.

QUESTION 515. *What is meant by the elasticity of a spring?*

Answer. It is the amount which a spring will deflect or bend under a given load without having its form permanently changed. If the bending is so great that the spring does not recover its original form when the load is removed, then the strain to which it is subjected is said to exceed *the limits of elasticity,* and if repeated often it will ultimately break the spring.

QUESTION 516. *What is meant by the elastic strength and the ultimate strength of a spring?*

Answer. The *elastic strength* is the strain it will bear without being

* This is the invention of George Morris, and is manufactured by the A. French Spring Company of Pittsburgh.

strained beyond the limits of elasticity, and the *ultimate strength* is the strain which will break it.

QUESTION 517. *What determines the strength of a spring?*

Answer. It depends (1) upon the material of which the spring is made; (2) its strength increases in proportion to the number of plates, and (3) to their width, and (4) in proportion to the square of their thickness, and (5) as the length diminishes.

Thus, if we wanted to double the strength of a spring like that shown in figs. 350 and 351, it could be done in either of the following ways: (1) by making it of material twice as strong; (2) by putting another plate just like it on top; (3) by doubling the width of the base, *b*, which would make the strength of the whole plate twice what it was before; (4) by making the whole plate about four-tenths thicker, which would increase its strength, as already stated, in proportion to the square of the thickness as $1.4 \times 1.4 = 2$ nearly; (5) by reducing the length to one-half what it is in fig. 350.

QUESTION 518. *What determines the elasticity of a spring?*

Answer. (1) The material of which it is made; with the same material the elasticity increases (2) as the number and (3) as the width of the plates diminishes, and (4) with the cube of the length, and (5) decreases with the cube of the thickness of plate.

Thus, supposing the plate in figs. 350 and 351 to be $\frac{3}{8}$ inch thick and the deflection, *d*, $2\frac{1}{2}$ inches, the latter would be only half as much, or $1\frac{1}{4}$ inches (1), if it were made of material twice as stiff, or (2) with two such plates, or (3) with one twice as wide at the base. If (4) the length were doubled, the deflection would be equal to $2 \times 2 \times 2 = 8$ times what it was before, or in proportion to the cube of the length. If (5) the thickness were doubled the deflection would be *reduced* in the same proportion, and would be only one-eighth of $2\frac{1}{2}$ inches or $\frac{5}{16}$ inch.

QUESTION 519. *What should be the proportion of the plates of a spring in relation to each other?*

Answer. The lower plates should diminish regularly in their lengths. The reason for this will be apparent from the fact which has already been stated, that if a triangular plate of uniform thickness is clamped fast at its base, it will, if loaded at the end, be of uniform strength throughout its whole length. It is immaterial what the length of the base of such a triangle is; if the two sides are of equal length and the thickness of the plate is uniform, not only its strength, but the amount of deflection or bending from any load will be equal all through its length. If, therefore, we make a spring by cutting a plate formed of two such triangular pieces united at their bases into strips, as has already been explained, evidently the spring made of them will have a uniform strength throughout its whole length. As the strips thus made diminish in length regularly, it is evident that if the spring plates are made of steel rolled of the requisite width, their length should be the same as that of those cut from the plate referred to above. When this is the case, the lower outline, *a b b a*, fig. 363, of the spring will, when the spring is not bent, be straight lines.

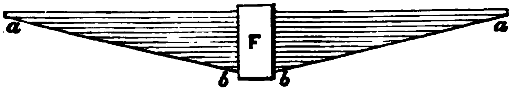


Fig. 363.

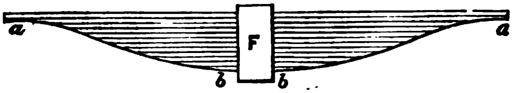


Fig. 364.

Springs.

Sometimes the lower outline of springs is made curved, as shown in fig. 364. This gives too much stiffness between the middle, *b b*, and the ends, *a*, *a*. In drawing springs, therefore, it is best to lay them out with the plates straight, as shown in fig. 363, and after determining the thickness, drawing a straight line from a point near the strap to the end of the longest plate will give the best form of the spring and the length of each of the plates. It is necessary, however, to put a sufficient number of long plates in each spring to give it the required strength next to the attachment of the hanger. Sometimes one or more of these long plates are made thicker than the rest. The evil of this method of construction will be apparent, if it is remembered that the greatest permissible deflection up to the breaking of the spring, decreases with the *cube* of the thickness of the plate, and its strength increases with the *square* of the thickness. Now, if we have a spring with say ten plates $\frac{3}{8}$ inch thick and one on top $\frac{3}{4}$ inch thick, the thick plate will have a strength *four* times that of the thin plates, but its elasticity will be only one-eighth that of the thin plates, and therefore it will require eight times as much load to bend it any given distance as is needed to bend the thinner plates the same distance. But its strength is only four times that of the thin plates, so that for any given amount of elasticity the thick plate must bear twice as much load as it has strength to carry. This shows what a great mistake is committed if some of the plates are made thicker than others, a conclusion which is supported by practical experience, as it is found that if the top plates are made thicker than others, the thick ones break most frequently, which is the necessary result of the supposed strengthening by increasing the thickness of the top plates.

QUESTION 520. **How can we find by calculation the elasticity or deflection of a given steel spring?*

Answer. BY MULTIPLYING THE BREADTH OF THE PLATES IN INCHES BY THE CUBE OF THEIR THICKNESS IN SIXTEENTHS, AND BY THE NUMBER OF PLATES: DIVIDE THE CUBE OF THE SPAN† IN INCHES BY THE PRODUCT SO FOUND, AND MULTIPLY BY 1.66. THE RESULT IS THE ELASTICITY IN SIXTEENTHS OF AN INCH PER TON OF LOAD.

QUESTION 521. *How can we find the span due to a given elasticity and number and size of plate?*

Answer. BY MULTIPLYING THE ELASTICITY IN SIXTEENTHS PER TON BY THE BREADTH OF PLATE IN INCHES, AND BY THE CUBE OF THE THICKNESS IN SIXTEENTHS, AND BY THE NUMBER OF PLATES: DIVIDE BY 1.66, AND FIND THE CUBE ROOT OF THE QUOTIENT. THE RESULT IS THE SPAN IN INCHES.

QUESTION 522. *How can we find the number of plates due to a given elasticity, span, and size of plate?*

Answer. BY MULTIPLYING THE CUBE OF THE SPAN IN INCHES BY 1.66; THEN MULTIPLYING THE ELASTICITY IN SIXTEENTHS BY THE BREADTH OF PLATE IN INCHES, AND BY THE CUBE OF THE THICKNESS IN SIXTEENTHS: DIVIDE THE FORMER PRODUCT BY THE LATTER. THE QUOTIENT IS THE NUMBER OF PLATES.

QUESTION 523. *How can we find the working strength—that is, the greatest weight it should bear in practice, of a given steel-plate spring?*

Answer. BY MULTIPLYING THE BREADTH OF PLATES IN INCHES BY THE SQUARE OF THE THICKNESS IN SIXTEENTHS, AND BY THE NUMBER OF PLATES; MULTIPLY, ALSO, THE WORKING SPAN IN INCHES BY 11.3: DIVIDE THE FORMER PRODUCT BY THE LATTER. THE RESULT IS THE WORKING STRENGTH IN TONS (OF 2,240 POUNDS) BURDEN.

QUESTION 524. *How can we find the span due to a given strength and number and size of plate?*

* The following rules for calculating the proportion and strength of steel springs are from Clark's Railway Machinery.

† The span is the distance between the centres of the spring-hangers when the spring is loaded.

Answer. BY MULTIPLYING THE BREADTH OF PLATE IN INCHES BY THE SQUARE OF THE THICKNESS IN SIXTEENTHS, AND BY THE NUMBER OF PLATES; MULTIPLY, ALSO, THE STRENGTH IN TONS BY 11.3: DIVIDE THE FORMER PRODUCT BY THE LATTER. THE RESULT IS THE WORKING SPAN IN INCHES.

QUESTION 525. *How can we find the number of plates due to a given strength, span and size of plates?*

Answer. BY MULTIPLYING THE STRENGTH IN TONS BY THE SPAN IN INCHES, AND BY 11.3; MULTIPLY, ALSO, THE BREADTH OF PLATE IN INCHES BY THE SQUARE OF THE THICKNESS IN SIXTEENTHS: DIVIDE THE FORMER PRODUCT BY THE LATTER. THE RESULT IS THE NUMBER OF PLATES.

QUESTION 526. *How can we find the required amount of curvature or set of the spring before it is loaded?*

Answer. BY MULTIPLYING THE ELASTICITY, PER TON, IN INCHES, BY THE WORKING STRENGTH IN TONS; ADD THE PRODUCT TO THE DESIRED WORKING COMPASS. THE SUM IS THE WHOLE ORIGINAL SET, TO WHICH AN ALLOWANCE OF $\frac{1}{8}$ TO $\frac{3}{8}$ INCH SHOULD BE ADDED TO THE PERMANENT SETTING OF THE SPRING.

QUESTION 527. *How are the spring-hangers attached to the ends of the springs?*

Answer. A great variety of methods have been used. The most common ones are those shown in fig. 349, in which the hangers consist of single bars which pass through openings or *eyes* in the ends of the springs, and have keys, *k k*, which bear on top of the springs. Sometimes the hangers are made to embrace the ends of the springs, as shown at *a a*, figs. 356 and 358.

The springs have projections forged on their ends to receive the keys in the upper end of the hangers, which are made to fit the grooves formed between the projections.

QUESTION 528. *How are the lower ends of the hangers held?*

Answer. The front hanger, *g*, fig. 349, of the front spring, and the back hanger, *g*, of the back spring are attached to the frame as shown. Sometimes a coiled or rubber spring, *S*, is interposed between the hanger and the frame to give more elasticity. The hangers, g' g', are attached to the ends of a lever, *A A*.

QUESTION 529. *Why are the ends, g' g', of the springs attached to the lever,* A A?*

* This lever is called an *equalizing lever* or *beam*, or, more briefly, an *equalizer*.

Answer. Because if there is a spring for every axle and the hangers are fastened to the frames, then evidently the locomotive has as many points of support as it has axle-boxes. Every shock from the rails is transferred through the wheel and the axle to the nearest axle-box and the spring belonging to it, and the latter must be made strong enough to receive and dispose of the whole of it. If the adjacent hangers, g' g', fig. 349, of the adjoining springs, B and B', are connected by an equalizing lever, A A, which turns on the fixed point, C, then the shock which affects one wheel will be transferred first to the spring, B, over it. From this spring a part of the shock will be transferred to the frame by the hanger, g, and a part by the hanger, g', to the equalizer, A, which will transfer the pressure to the adjoining spring, B'. If, by some uneveness of the road or a powerful oscillation of the locomotive, a spring is momentarily burdened, the equalizer thus causes the next wheel to receive part of this load.

The advantages of this arrangement are evident: since the springs have to receive only a part of the shocks, they can be made less strong and therefore more flexible. The danger of running off the track and that of breaking axles, springs and hangers, is therefore reduced by the use of equalizing levers.

QUESTION 530. *How are the equalizing levers constructed?*

Answer. They are made of wrought-iron, and are supported in the centre by a fulcrum, C, fig. 349, which is fastened to the frame or boiler or both. The spring hangers, g' g', are usually attached to the levers by eyes and keys. Sometimes eyes are made in the lever, as shown in fig. 349, and the hanger is inserted into the eye and held either with a key, as shown, or else with projections which are forged on the hanger below the lever. In other cases the hangers are made with an eye which embraces the end of the lever, as explained in answer to Question 527.

QUESTION 531. *How is the distribution of weight of the engine affected by the equalizing levers?*

Answer. The effect of the equalizing levers is to distribute the weight equally on all of the driving-wheels. This will be apparent if it is observed that the weight suspended from each of the spring-hangers of each spring in fig. 348 must be the same; for if the weights in the two hangers, g' and g', were unequal, then the end of the spring which supports the heaviest weight would be drawn down until the pressure was equalized. If the weights suspended from the two hangers, g' and g', attached to the equalizing lever were unequal, then the one supporting the greatest load would draw up its end of the equalizer until the weights were again in equilibrium.

Another effect of equalizing levers is that each side of the locomotive is supported in such a way that the action is the same as it would be if it was supported on one point. If, for example, we have a heavy beam, say a piece of timber like that shown by *A B*, fig. 365, suspended at one point

Fig. 365.

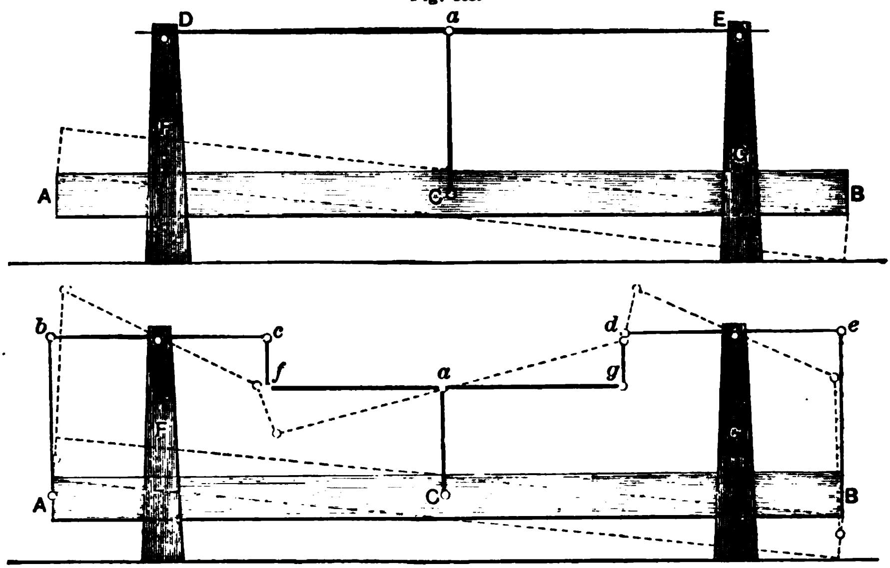


Fig. 366.
Diagram Showing Action of Equalizing Levers. Scale ⅜ in.—1 ft.

C, in its centre, to the middle, *a*, of a long spring, *D E*, the ends of which rest on two supports, *F* and *G*, it is evident that if the point of suspension is at the middle, *C*, of the beam, and *a* of the spring, the weight of the beam will rest equally on the two supports, *F* and *G*, and that the ends of the beam can move up or down or vibrate about the point of suspension, *C*, without affecting the distribution of weight on the supports, *F* and *G*. If, now, the timber is suspended from three points, its middle, *C*, and two ends, *A* and *B*, as shown in fig. 366, the ends, *A* and *B*, being attached to the ends of the springs, *b c* and *d e*, the latter resting on the supports, *F* and *G*, and connected at their opposite ends to an equalizer, *f g*, whose fulcrum is at *a*, it is evident that each of the end hangers, *b A* and *e B*, must support one-half of that part of the weight of the timber between it and the middle, *C*, and that the centre hanger, *a C*, must support one-half the weight between the middle and each of the two ends. Thus, the hanger, *b A*, must support one-half the weight of the timber between *A* and *C*, and *e B* must support one-half of that between *B* and *C*; in other words the end hangers would each sustain one-fourth of the weight of the timber and the middle one-half of its weight. If the weight of the timber is 1,000 lbs., the end hangers would each sustain 250 and the middle one 500 lbs. The weight of the middle of the timber is hung on the equalizer, *f g*, and one-half, or 250 lbs., of it is thus transferred to each of its ends, *f* and *g*, and thence to the hangers, *f c* and *g d*, and thus to the springs, so that the ends, *c* and *d*, of the springs each sustain a weight of 250 lbs.; therefore, as the opposite ends also sustain the same weight, it is evident that each of the springs bears a total load of 500 lbs., or one-half of the weight of the timber. If the ends of a timber supported as shown in fig. 366, are moved up or down about the centre point of suspension, it is evident that the distribution of weight would not be affected any more than it was in fig. 365 by a similar movement, because if the ends of the timber move as shown by the dotted lines around the centre point of suspension, *C*, the end, *A*, will ascend as much as *B* descends. The same thing is true of the ends, *b* and *e*, of the springs and of their opposite ends, *c* and *d*, and also of the ends of the equalizer, so that when the timber, springs and equalizer are in the position shown by the dotted lines, it is in equilibrium, just as it was when the timber was horizontal; and therefore the weight on the supports is the same in both cases, thus showing that the load, *A B*, can move about the centre of suspension when supported as shown in fig. 366, as freely as it can if arranged as shown in fig. 365. It therefore follows that in the distribution of the weight of each side of the locomotive on the wheels and on the track, it may be regarded the same as though it was supported at one point, which is the fulcrum of the equalizing-lever.

QUESTION 582. *What advantage results from supporting the weight of the back part of the locomotive on two points?*

Answer. If the back part of the locomotive rests on only two points and the front end on the centre of the truck, then the whole weight of the engine will be sustained on three points. Now it is a well-known fact that any tripod, like that on which an engineer's level is mounted, or a three-legged stool, will adjust itself to any surface, however uneven, and stand firmly in any position; whereas if there are more than three points of support, as a four-legged stool, if they are all in the same plane, the surface on which they rest must be a plane, otherwise some of them will not touch. All railroad tracks have inequalities of surface, and therefore it is of the utmost importance that a locomotive should be able to adjust itself on its points of support to any unevenness of the track on which it must run. This is possible only when the weight rests on three points of support.

QUESTION 533. *How is the truck constructed?*

Answer. As has already been explained, trucks usually have two pairs of wheels.* These are attached to a frame, 75 75, Plates III, IV and V. The axles have boxes, called *truck-boxes*, and brass bearings similar to those used on the driving-axles. These boxes work in jaws, also similar to those on the main engine frame, excepting that they have no attachment to prevent them from being worn by the motion of the boxes up and down in the jaws. Fig. 367 is a longitudinal section, fig. 368 a plan, and fig. 369 a transverse section† of a truck. The frame, *C D E F*, fig. 368, shown also at *h' h'*, figs. 367 and 369, is of rectangular form, and is forged in one piece. The legs, *f f*, which form the jaws for the boxes are bolted to the frame as shown in fig. 367. To the lower end of these legs a brace, *g g g*, is bolted, which ties them together. On each side of the truck one spring, *M M*, is placed under the frame and in the reverse or inverted position to that of the driving-springs shown in fig. 349. A pair of equalizing levers, *G G*, is placed on each side of the truck, one lever on the inside of the frame and the other on the outside, as shown in the plan. Referring to fig. 367, and it will be seen that the ends of these equalizers rest on the top of the truck-boxes, and the springs are attached to the levers, at *i i*, by the hangers, *j j*. The truck-frame rests on the top of the spring-strap, *N*. It is evident that this arrangement of spring and equalizer operates in the same way as that employed for the driving-wheels in distributing the weight on each of the wheels, and that the truck-frame is supported on two points, *k k*, figs. 368 and 369. The weight of the front end of the engine rests on a cast iron *centre-plate, H*. This is sometimes bolted rigidly to transverse bars, *m m, m m*, figs. 368 and 369, which are fastened to the sides of the truck-frame. The engravings show

* In some rare cases three pairs of wheels are employed for locomotive trucks. Six-wheeled trucks are very commonly used under passenger cars.

† The sections are both shown through the centre of the truck.

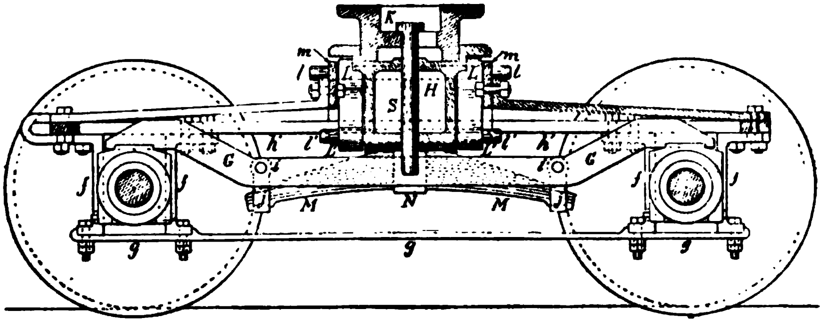


Fig. 367.

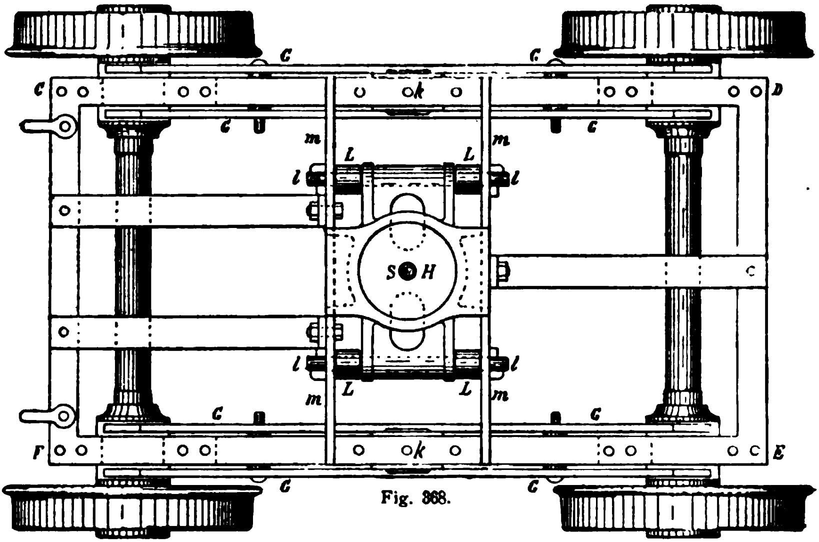


Fig. 368.

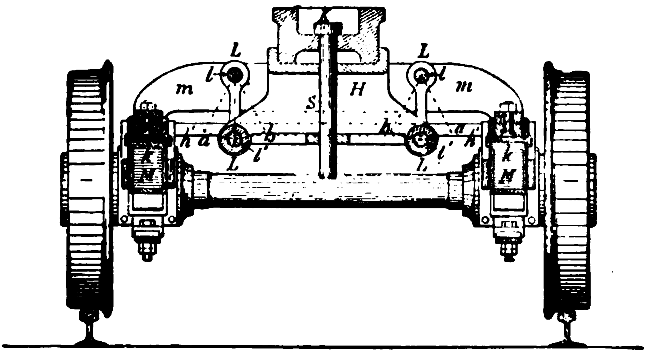


Fig. 369.

Four-Wheeled Truck. Scale ¼ in. = 1 ft.

what is called a ***swing-motion*** truck. In this the centre-plate is suspended from the transverse bars by links, *L L, L L*, so that it can swing or oscillate transversely to the *rails*. These links are suspended from the pins, *l l, l l*, which pass through the bars, *m m, m m*, and the centre casting or centre-plate, *H*, rests on other pins, *l′ l′*, which pass through the lower ends of the links. The dotted lines, *L a, L b*, and the arcs, *a b, a b*, show how the centre-plate, *H*, swings on the links. The centre-pin, *S*, sometimes has a key underneath the centre-plate. This key is intended to prevent the engine from "jumping" off of the truck on a rough track or in case of accident. The annular cavity in the top of the centre-plate and the projection which fits into it are intended to receive the strain which otherwise would bear against the centre-pin and would be liable to break or bend it.

From this description it will be seen that while the truck-frame rests on two points, *k* and *k*, the weight of the engine is supported by the centre-plate of the truck. As the back part of the engine rests on substantially the centres of the two equalizers, this distribution of the weight fulfills the conditions of the tripod, or, as it has been called, the "***three-legged principle***."

QUESTION 534. *How are "pony" or Bissell* trucks with a single pair of wheels constructed?*

Answer. A plan of such a truck, *g s h*, with its details omitted, is shown in fig. 338. Figs. 370, 371 and 372 represent a truck of this kind with all its parts; 370 is a longitudinal section, 371 a plan, and 372 transverse section. It consists of a rectangular frame, *C D E F*, fig. 371, to which the axles are attached. As explained in answer to Question 485, it also has an **A**-shaped frame, which is bolted to the back part of the rectangular frame. The apex of this **A**-shaped part is connected to the main frame of the locomotive by a pin, *s*, about which the truck can turn. The **A**-shaped portion of the frame is indicated by the letters, *r s t*. Such trucks have swing-bolsters, *H*, similar to those used on four-wheeled trucks. They are suspended from links, *L L*, whose ends swing in arcs of circles indicated by the dotted lines, *a b*.

QUESTION 535. *How are the king-bolts of pony-trucks arranged?*

Answer. The front king-bolt, *K K*, figs. 370 and 372, is held in a casting, *B B*, which is bolted to the engine frame. The king-bolt bears on the swing-bolster, *H*. In some pony-trucks this king-bolt is a solid bolt or pin, like that shown in figs. 367 and 368. In other cases it has been

* So named after the inventor, Louis Bissell.

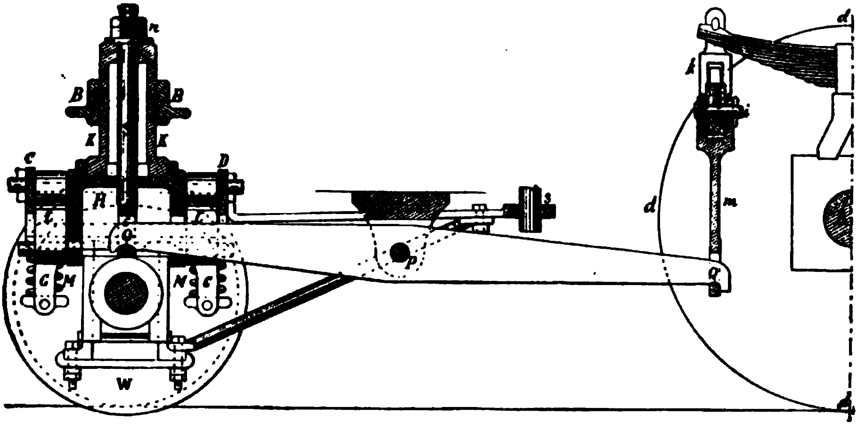


Fig. 370.

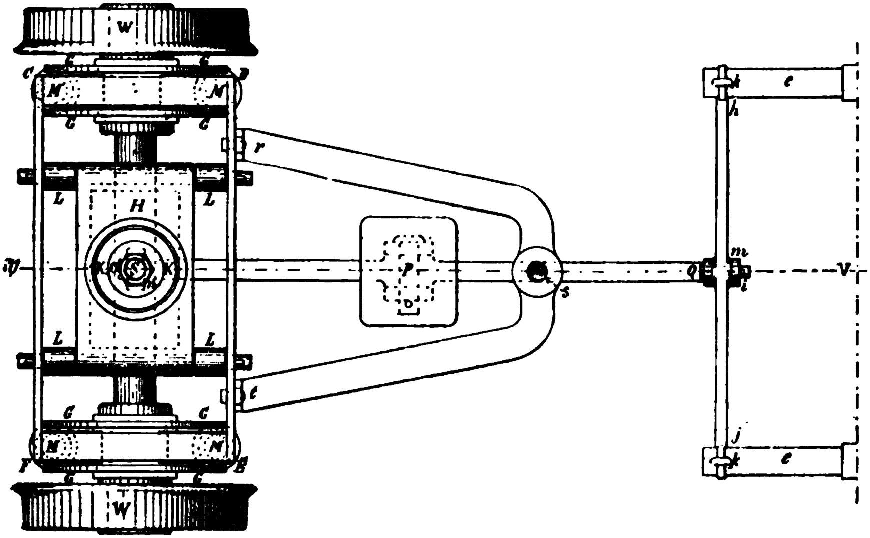


Fig. 371.
Bissell or Pony Truck. Scale ½ in. = 1 ft.

found desirable to connect trucks of this kind with the front driving-wheels by an equalizing lever, and the king-bolt is then made hollow, as shown in figs. 370, 371 and 372.

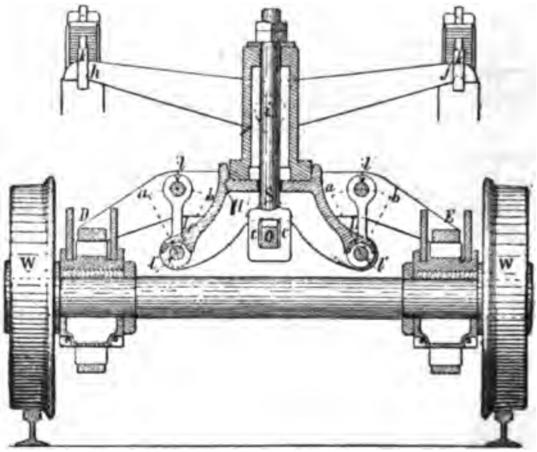


Fig. 372. Bissell or Pony Truck. Scale ⅛ in.—1 ft.

QUESTION 536. *Why are pony trucks connected to the driving-wheels by equalizing-levers?*

Answer. This is done for very much the same reason that driving-wheels are connected together in this way, as was explained in answer to Question 529. The connection of a pony truck with the driving-wheels of a locomotive is the invention of the late William S. Hudson, who patented the plan in 1864. In his specification he said that "in practice irregularities more or less serious occur at nearly every joint or junction of the ends of the rails, and at certain points in a railroad track, as in passing switches and across tracks, and especially in passing over small obstacles or defects in the road, the inequality in the load which is thrown upon the several wheels becomes very great unless, in addition to the rise of the springs, provision is made by introducing equalizing-levers in some manner to induce a unity of action between each pair of wheels and some other pair."

QUESTION 537. *How are equalizing-levers arranged to connect pony trucks with the driving-axles of locomotives?*

Answer. Usually one equalizing-lever, *O P Q*, figs. 370 and 371, is placed in the middle of the engine instead of one on each side, as is the ordinary practice with driving-wheels. This lever has a fulcrum at *P*, which is attached to the engine frame. The front end, *O*, of the lever is supported in an eye, *c c* (shown clearly in fig. 370), which is formed in the lower end of the centre-pin, *S*. This pin passes through the hollow king-bolt, *K K*, and is supported by a pair of nuts screwed on the upper end, and which bear on top of the king-bolt. The king-bolt can slide vertically in the casting, *B B*. *A* is the front driving-axle, and *d d d* represents one-half of the periphery of one of the front driving-wheels, and *e e* one-half of the driving-wheel springs. A transverse equalizing-lever, *h j*, figs. 371 and 372, is suspended by hangers, *k k*, to the front ends of the driving-wheel springs, and the back end, *Q*, of the lever, *O P Q*, is suspended to the centre, *i*, of the lever, *h i j*, by a hanger, *m*. It is obvious that if one or both of the front driving-wheels should roll over any object, or a high place in the track, so as to be raised up and thus compress one or both of the springs, *e e*, that this action would produce an upward tension on the transverse lever, *h i j*, the hanger, *m*, and the back end, *Q*, of the lever, *O P Q*, and this would exert a downward pressure on the front end, *O*, which would be transferred by the centre-pin, *S*, to the top of the king-bolt, *K K*, and by it to the bolster, *H*, which is suspended by links, *L L*, to the truck frame. Any undue weight resting on one or both of the driving-wheels would thus be transmitted to the truck, and a reverse action will occur if the truck wheels, *W W*, bear any undue weight.

QUESTION 538. *How does such a truck adjust itself to the curvature of the track?*

Answer. The two centre-pins, *S* and *s*, are both attached to the locomotive on its centre-line, represented by *U V*, fig. 371, and they cannot move away from that line. If the truck wheels, *W W*, encounter a curve they must move sideways in relation to the engine. This they are enabled to do by reason of the bolster, *H*, being suspended from the truck frames by the links, *L L*, fig. 372. The lower ends of these links can swing in relation to the upper ones, as indicated by the arcs, *a b* and *b a*, in fig. 369, or the upper ends can move in relation to the lower ones, as shown in fig. 372. When the front end of the locomotive enters a curve, the truck wheels and the frame move laterally and carry the upper ends of the links toward *a a* or *b b*, fig. 372, according to the direction of inclination of the curve, and the bolster, *H*, centre-pin, *S*, and king-bolt, *K K*, all retain their central position in relation to the engine. When the truck wheels move laterally their axle, instead of being parallel to the driving-axle, becomes inclined to it, as shown by the dotted centre lines, *g t* and *c d*, fig. 338, and on a curve the position of the centre line of the truck-axle approximates to that of a radius of a curve on which the engine is moving or standing.

QUESTION 539. *How are the springs of a pony truck arranged?*

Answer. In the truck shown by figs. 370, 371 and 372, spiral springs, *M M*, are used. These are placed underneath the frames, as shown, and ∩-shaped yokes, *G G, G G*, rest on top of the axle-boxes, and are coupled to a cup-shaped casting under the springs, and on which they rest. The form of these yokes is shown partly by dotted lines in fig. 370.

QUESTION 540. *What advantage does the use of a pony truck give over one with four wheels?*

Answer. It permits of the front driving-wheels being placed closer to the cylinders than is possible when one pair of the truck wheels is behind the cylinders, as it usually is when a four-wheeled truck is used. If the driving-wheels are located nearer to the cylinders they will bear a larger proportion of the weight of the engine than they do if they are further back.

CHAPTER XXI.

MISCELLANEOUS.

QUESTION 541. *What is a sand-box of a locomotive, and how is it constructed?*

Answer. A sand-box, 39, Plates III and IV, is usually a cylindrical receptacle which is made of sheet iron with a cast iron base and top. It is generally placed on top of the boiler and is intended to carry a supply of dry sand, which is scattered on the rails in front of the driving-wheels when the latter are liable to slip. This is done by pipes, 40, Plate III, one on each side of the engine. They lead from the sand-box to within a few inches of the rail. At the upper end and inside the sand-box they each have a valve which is operated by a lever connected to the cab by a rod so that the locomotive runner can open or close the valve at pleasure. The sand-box has an opening on top through which the sand is supplied to the box. This opening has a loose cover to exclude rain and dirt from the sand.

QUESTION 542. *What is the bell,* 41, *Plates III and IV, for?*

Answer. It is used for giving signals of the starting or approach of the engine. It also is located on top of the boiler and is usually hung on a cast iron frame and rung with a rope, shown in Plate III, connecting it with the cab. Locomotive bells usually weigh from 50 to 100 lbs.

QUESTION 543. *What is the signal-gong?*

Answer. It is a gong-bell with a hammer or clapper attached to it, and fastened usually to the under side of the roof of the cab. The train bell-cord is connected to the hammer, by which the bell can be rung from any part of the train to signal to the engineer to start or stop the engine.

QUESTION 544. *What is a locomotive head-light?*

Answer. It is a large lamp, 35, Plates III and IV, placed in front of the locomotive to signal its approach at night and also to illuminate the track for the locomotive runner.

QUESTION 545. *How is a head-light constructed?*

Answer. The lamp has what is called an Argand burner; that is, a burner with a hollow cylindrical wick through the centre of which a current of air circulates which thus supplies the flame with a larger quantity of air than is possible if the air can come in contact with the burner only on the outside. The result is that the combustion of an Argand burner is much more brilliant than that of ordinary burners. In order to throw all the light on the track the burner is placed inside of a concave reflector, *a b c*, fig. 373, which is of a *parabolic* form. One of the peculiarities of

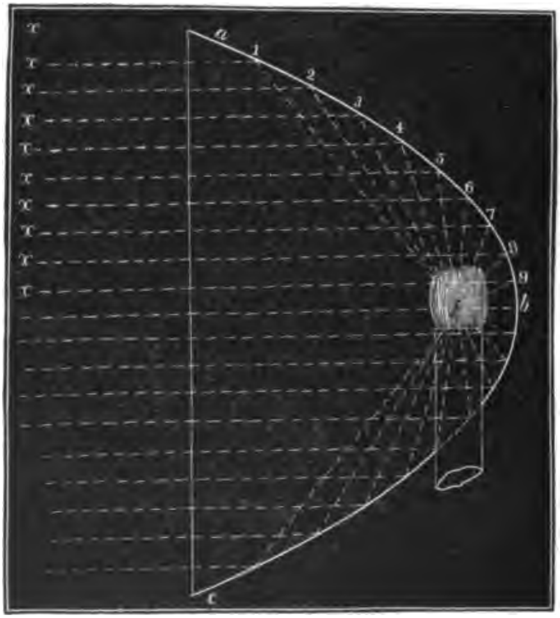


Fig. 373. Head-Light Reflector.

this form of reflector is that if a light is placed in its focus, *f*, the rays will be reflected from its surface in parallel lines. Thus, let *a b c*, fig. 373, represent a section of such a reflector. Now, if a light be placed in the focus, *f*, the rays will strike against the reflector in the direction of the dotted lines, *f* 1, *f* 2 . . . *f* 9, etc., and be reflected in straight horizontal lines, 1 *x*, 2 *x*, 3 *x*, etc., and thus be thrown directly in front of the engine. The reflectors are usually made of copper and plated with silver.

The lamps and reflectors for head-lights are enclosed in a rectangular case which is placed on top of the smoke-box, or is supported on two brackets bolted to the front of it. On these brackets a wooden shelf is fastened on which the head-light rests.

QUESTION 546. *What are the running-boards and hand-rails?*

Answer. The *running-boards* are narrow platforms, made of wood or iron, 56 56, Plate III, placed on each side of the boiler to enable the locomotive runner or fireman to go from the cab to the front end of the engine when it is running. The hand-rails, 57 57, are brass or iron pipes attached to the top of the boiler and extending from the cab to the smoke-box, and are placed there, as their name indicates, for persons on the running-board to take hold of.

QUESTION 547. *What provision is made for removing from the track obstacles such as cattle, fallen rocks, etc., which may be in front of locomotives?*

Answer. What is called a *cow-catcher* or *pilot*, 38, Plates III and IV, is attached to the front of the locomotive. This is usually made of wood, and consists of a triangular frame at the bottom, which is supported so that it is a few inches above the tops of the rails. Straight pieces of wood of about 2½ × 4 inches section are fastened to this frame and also to a horizontal piece which is bolted to the bumper-timber. These pieces when arranged in this way, and only a few inches apart, give to the cow-catcher a peculiar curved form—somewhat resembling that of the mould-board of a plow—which is very well adapted for throwing any obstacles from the track. Sometimes these pieces are placed horizontally instead of being inclined up and down. Cow-catchers are also in some cases made of round iron bars or angle iron. They are always bolted securely to the bumper-timber and strengthened by strong iron braces attached to the bottom frame at the front and back. These braces are usually fastened at the other end to the bumper-timber, but are sometimes attached to the bed-plates of the cylinders.

There is also usually a strong *pushing-bar*, 79, Plate 4, attached with a bolt and hinged joint to the bumper-timber. This is shown in Plates IV and V in the position it occupies when not in use. It is used in pushing cars, as very often there is not room for the pilot under the end of the car. In using it, it is raised up, and the front end is then coupled to the draw-head of the car.

Iron plates and scrapers are often attached to the pilots in winter to remove snow from the track.

QUESTION 548. *What is the foot-board or foot-plate of a locomotive?*

Answer. It is a wrought or cast iron plate, 95, Plate IV, which extends across and rests upon the two frames at the back part of the locomotive and behind the boiler, and on which the locomotive engineer and fireman stand. It also unites the two frames very securely, and furnishes an attachment for the draw-bar.

QUESTION 549. *What other purpose is the foot-board sometimes made to serve?*

Answer. It is sometimes made much heavier than is necessary for strength in order to increase the weight, and thus the adhesion, on the driving-wheels. It is a fact often not suspected that any weight placed on the back end of an ordinary locomotive will increase the load on the driving-wheels by an amount considerably greater than that of the weight itself. The reason of this is that the locomotive rests on the centre of the truck and the centres of the equalizers, and therefore the weight, if applied to the back end of the engine, gains considerable leverage. This will be clear if we take a beam, *A B*, and rest it on two supports, *m* and *n*. fig.

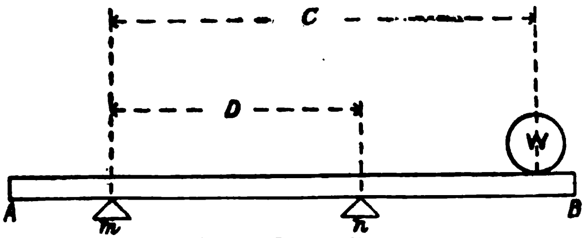


Fig. 374. Diagram Showing Effect of Weight on Foot-Boards.

374. If, now, we put a weight, *W*, on the end, overhanging the point of support, the weight which will rest on *n* will be equal to that of *W* multiplied by its distance, *C*, from *m* and divided by the distance, *D*, between *m* and *n*. Thus, if a foot-board weighs 1,000 lbs., and its centre of gravity is 5½ feet behind the centre of the equalizer, and the latter 14 feet from the centre of the truck, then the weight thrown on the driving-wheels will be equal to

$$\frac{1,000 \times 19\frac{1}{2}}{14} = 1,393 \text{ lbs.}$$

The same thing is, of course, true of any other weight placed on the back end of the engine.

QUESTION 550. *What are the "wheel-guards" of a locomotive?*

Answer. They are sheet iron covers, 61 61, Plate III, over the upper half of the periphery or tread of the wheels, and are placed there to protect the engine from the dirt and mud which adhere to the wheels, and are then thrown off on the machinery by the centrifugal force.

QUESTION 551. *What are "check" or "safety chains"?*

Answer. There are two kinds of such chains, the one, 78, Plates III and IV, attached to the trucks and frames of the locomotive and the tender. The object of these chains is to prevent the trucks from turning around and getting crosswise of the track if they should leave the rails. The other kind of safety chains, 50, Plates III and IV, connect the engine to the tender, so that in case the draw-bar or coupling-pins should break, the engine and tender will not separate. Great care should be exercised to attach the truck chains so that the fastenings will be strong enough to resist the strains to which they will be subjected in case the trucks run off the track. The grossest carelessness and ignorance are often shown in the construction of these parts.

QUESTION 552. *Where should steps be placed on locomotives?*

Answer. Steps should be attached to the back end of the locomotive, as shown by 101, Plates III, IV and V, to enable the men to get on and off the foot-board. Such steps are usually made too small, so that those who use them are liable to miss their foothold, especially at night. To guard against this they should be made of more liberal size than they usually are made. Steps should also be attached to the pilots of locomotives for men to stand on in coupling the locomotives to cars. Without such steps men must often be exposed to great danger in coupling cars to the front end of an engine.

CHAPTER XXII.

FRICTION AND LUBRICATION.

QUESTION 553. *What is meant by friction?*

Answer. Friction is the resistance between two bodies in contact which opposes the sliding of the one on the other. Thus, if a brick is placed on a board with a slight inclination, it will not slide because the friction between them, or the resistance opposed to motion, is greater than the force exerted by the weight of the brick to move it downward. If, however, the inclination of the board is increased sufficiently so that a larger proportion of the weight of the brick urges it downward, then the friction will be overcome, and it will slide. When the brake-blocks of a car are pressed against the wheels, they produce friction, which resists the revolving motion of the wheels, and if the resistance of this friction is greater than the propelling force, the car will ultimately stop; and when the weight of an engine is supported on the driving-wheels and they rest on the rails, the friction between them and the rails, as has already been pointed out, resists their slipping on each other, and thus enables a locomotive to exert tractive force. Friction also resists the turning of an axle on its journal, which is overcome by the tractive power of the locomotive.

QUESTION 554. *On what does the amount of friction depend?*

Answer. The amount of friction of two bodies in contact depends (1) UPON THE PRESSURE OF THE ONE ON THE OTHER, AND SO FAR AS THE FRICTION OF MOST OF THE PARTS OF RAILROAD MACHINERY IS CONCERNED MAY IN PRACTICE BE REGARDED AS INDEPENDENT OF THE AREA OF THE SURFACES IN CONTACT; (2) ON THE NATURE OF THE MATERIALS IN CONTACT; (3) ON THE NATURE OF THE SUBSTANCE, SUCH AS OIL OR OTHER LUBRICANT, WHICH IS INTERPOSED BETWEEN THEM; (4) ON THE SPEED; (5) ON THE TEMPERATURE. Thus, a brick will slide down an inclined board as easily if it is laid on its broadest side as it will if placed edgewise; and if a cast iron plate, say 10 inches square, is planed and scraped, so as to be as nearly a perfect plane surface as it is possible to make it, it will, if loaded with, say a hundred pounds' weight, slide on a similar true surface as easily as another plate with half as much area and loaded with the same weight. A shaft resting against a long bearing will require no more power to turn it than would be needed if the bearing was short.*

QUESTION 555. *What is meant by the "co-efficient of friction"?*

Answer. It is the proportion which the resistance to sliding motion bears to the force pressing the surfaces together. Thus, a smooth, clean, and dry cast iron plate loaded with 100 lbs. will require a force of about 15 ibs. or fifteen one-hundredths of the weight or pressure of the plates, to slide them on each other. The *co-efficient of friction* is therefore said to be 0.15, and with any other weight or pressure on the plates we could determine the force required to slide them on each other by multiplying the pressure by the co-efficient of friction. Thus, if the plates were loaded with 250 lbs., the force required to slide the one on the other would be equal to $250 \times 0.15 = 37.5$ lbs. The co-efficient of friction, however, varies for different materials. Thus, while it is 0.15 between two pieces of smooth, clean, and dry cast iron, the co-efficient of a piece of brass on cast iron, under similar conditions, is 0.22, and of two pieces of wood about 0.4.

QUESTION 556. *What is the effect of introducing some unguent or lubricating material, such as oil, between the surfaces in contact?*

Answer. The co-efficient of friction is very much reduced thereby. Thus the co-efficient of the cast iron plates, if their surfaces are greased with tallow, is 0.1; if lubricated with lard, 0.07, with olive oil, 0.064, and with lard and plumbago, 0.055, thus showing that the amount of friction depends very much upon the nature of the lubricant which is used, as well as on that of the material in contact.

QUESTION 557. *What effect on the amount of friction has the manner of applying the lubricating material to the surfaces in contact?*

Answer. The more perfect the lubrication the less will be the co-efficient of friction It has, for example, been found by experiments made with cast iron shafts turning on bearings of the same material that when the lubricating material was applied so that the surfaces were only "unctuous," that is, slightly greasy, the co-efficient of friction was very little less than when they were dry, that is, when there was no lubricating substance between them, and that when they were greased "from time to time" the co-efficient was reduced to 0.07 and 0.08; but when they were continually oiled it averaged 0.05, and sometimes fell as low as 0.025, showing that with the best lubrication the friction was only one-sixth

* Ordinarily somewhat less power is required to turn it if the bearing is long than if it is short, the reasons for which will be explained hereafter.

what it was when the surfaces were only "unctuous." Between these two limits there is every degree of frictional resistance, according to the condition of lubrication. This shows how important it is that the oiling fixtures of a locomotive should be kept in the most perfect condition and the utmost care be exercised in keeping every part of it which is subjected to friction thoroughly lubricated.

QUESTION 558. *What effect does the pressure per square inch of the surfaces in contact have upon the lubrication?*

Answer. The tendency is, when this pressure becomes excessive, to press out the lubricant which is between the two surfaces, and ordinary experience proves that the greater the weight or the force per square inch with which two bodies are pressed together, the greater is the difficulty of keeping them perfectly lubricated.

Thus, it is easier to keep the journals of a car well lubricated when it is empty than when it is heavily loaded, and the guide-bars of a locomotive are more liable to be abraded when the engine is pulling a heavy load than with a light one.

QUESTION 559. *What effect has the velocity of the surfaces in contact on the friction and lubrication?*

Answer. With the surfaces in the same condition, the friction is nearly independent of the velocity of the motion of the surfaces against each other, but perfect lubrication becomes more difficult as the velocity increases, so that an increase of velocity will often increase indirectly the amount of friction. Thus, taking our previous illustrations, it is more difficult to keep the journals of a car or engine well lubricated when running fast than when running slow, and the same thing is true of the guide-bars and other parts.

QUESTION 560. *What considerations should govern the proportions of frictional bearings for locomotives and other machines?*

Answer. The dimensions to be given them should not be determined from a consideration solely of their resistance to rupture,* but they should be made so large that the pressure they must bear will be distributed over so much surface that the proportion borne by each square inch will be comparatively small, thus making good lubrication much less difficult, and consequently reducing the co-efficient of friction.

QUESTION 561. *Is not the amount of energy required to overcome the friction on a journal of large diameter greater than would be required if the journal was smaller?*

* Morin's Mechanics.

Answer. If the co-efficient of friction in the two cases is the same, undoubtedly the large journal will require the greatest expenditure of energy to turn it, because its periphery moves further than that of the small one; but the advantage attributed to large journals is that they can be lubricated more perfectly, because their surfaces being larger the pressure is not so great per square inch, and thus the gain from the reduction of the co-efficient of friction is greater than the loss attributable to the increase of the diameter of the journal. Thus, if a car journal is 3¼ inches in diameter × 5½ inches long, the available surface exposed to friction is equal to that of a longitudinal section of the journal, or 3¼ × 5½ = 17.875 square inches.* Supposing now that the journal is loaded with 5,000 lbs., and the average co-efficient of friction is 0.085. In one revolution of the wheel the journal will move 0.85 of a foot, and therefore 5,000 × .085 × .85 = 361¼ foot-pounds of work. If, now, the journal is made, as has been proposed, 3¾ × 7 inches, then its effective surface will be equal to 26¼ square inches, but the journal will move 0.98 of a foot in one revolution. If, however, the lubrication is improved by the increased area of the journal so that the co-efficient of friction is reduced from 0.085 to 0.07, then the energy consumed in one revolution will be equal to 5,000 × 0.07 × .98 = 343 foot-pounds, or less than was consumed with the small journals. The co-efficient of friction is assumed, and could only be determined by experiment, but the assumption shows how the resistance of the large journals may be less than that of the small ones. Of course it would be better to give the increased bearing surface by adding to the length of the journal, but nearly all locomotives and car journals must be increased in diameter, as well as in length, when they are enlarged, in order to have the requisite strength to carry the loads they must bear.

QUESTION 562. *Is the law that* FRICTION IS IN PROPORTION TO THE PRESSURE ON EACH OTHER AND INDEPENDENT OF THE AREA OF THE SURFACES OF CONTACT *true under all circumstances?*

Answer. Probably not. The exact law of the variation of friction which is due to change of pressure when the surfaces are thoroughly lubricated, or change of area when they are not lubricated, and the pressures become excessive, is not thoroughly understood. It seems probable, at least, that with surfaces thoroughly well lubricated, that friction is, to

* The reason for this is that the effective surface of the journal which resists the pressure of the bearing, is equivalent only to the horizontal area just as the surface which resists the pressure inside of a boiler is equivalent to the diameter multiplied by its length, as was explained in answer to Question 241.

some extent at least, independent of speed and pressure, and also that with excessive pressure—as of the driving-wheels of a locomotive on the rails without lubrication—that the friction increases with the area of the surfaces in contact, and not in proportion to the weight on them alone.

QUESTION 563. *What effect has the nature of the materials in contact on the friction?*

Answer. The amount of friction and also the lubrication is very much influenced by the nature of the bearing surface, and also by the material used as a lubricant. Some metals, such as brass and other alloys, are much less liable to abrasion, and seem to retain lubricants on their surfaces better than other metals, and are therefore much used for journal and other bearings. Some substances, especially oils, are good lubricants, while other materials of apparently similar nature are not. The reason why these materials possess these properties while others are without them is not known, and the value of any material as a lubricant, or the degree to which another will resist friction without abrasion, can only be tested by experiment.

QUESTION 564. *How are the journals of the axles of locomotives lubricated?*

Answer. The driving and engine truck axle boxes have oil-holes and receptacles on top, which are filled with cotton or woolen waste, into which the oil is poured when the engine is standing still. The tender axle boxes have receptacles below the journals, which are filled with waste and saturated with oil, as explained in answer to Question 599.

QUESTION 565. *How are the crank-pins and cross-head guides lubricated?*

Answer. The guides and the connecting-rods have oil or lubricating cups attached to them above the bearings. Such cups are shown in Plate III, on top of the guide-bars, 62, and above the crank-pins, 5 5. Fig. 375 is an outside and fig. 376 a sectional view of an oil-cup for locomotive guides.* It consists of an internal glass-cup, *a a*, which is enclosed in a brass case, *b*, which has round openings on its four sides, shown at *a*, fig. 375, so that it can be seen how much oil the cup contains. The glass cup is held in place by a cap, *c*, which is screwed on the case, *b*. India-rubber washers are placed above and below the glass cup, to make tight joints when the cap is screwed down. The oil is poured into the cavity, *d*, in the cap, *c*, and runs down into the glass cup, *a*, through openings not shown in the engraving. From *a* it flows to the bearings through the

* Manufactured by the Nathan Manufacturing Company of New York.

opening, *e*. The rate of flow is regulated by a conical screw-plug, *f*, which can be adjusted so as to increase or diminish the flow of oil to the bearings. The lower part, *g*, of the cup is screwed into the guide-bars. The

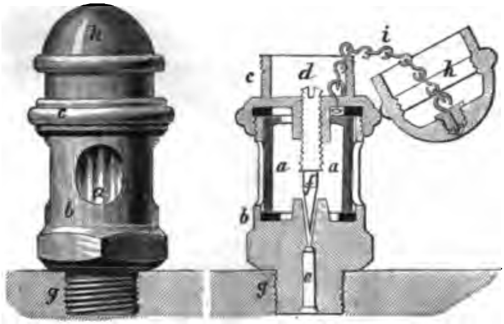


Fig. 875. Fig. 876.
Oil-Cup for Locomotive Guide-Bars.

cap, *c*, has a loose cover, *h*, to exclude dirt from the cup. It is held by a chain, *i*, to prevent its being lost.

Fig. 877 is an external view of a similar oil-cup for connecting-rods.

Fig. 877. Oil-Cup for Connecting-Rods.

The cap is screwed on the case, and the flow of oil is adjusted by a small rod or pin, the lower end of which rests on the surface of the crank-pin.

There is a great variety of oil-cups in use, and much ingenuity has been exercised in devising appliances to regulate the supply of oil.

QUESTION 566. *How are the slide-valves and pistons of a locomotive lubricated?*

Answer. The method which was formerly employed was to attach an oil-cup to the top of the steam-chest, by which oil was supplied to the valve below when the steam was shut off. To do this the fireman had to

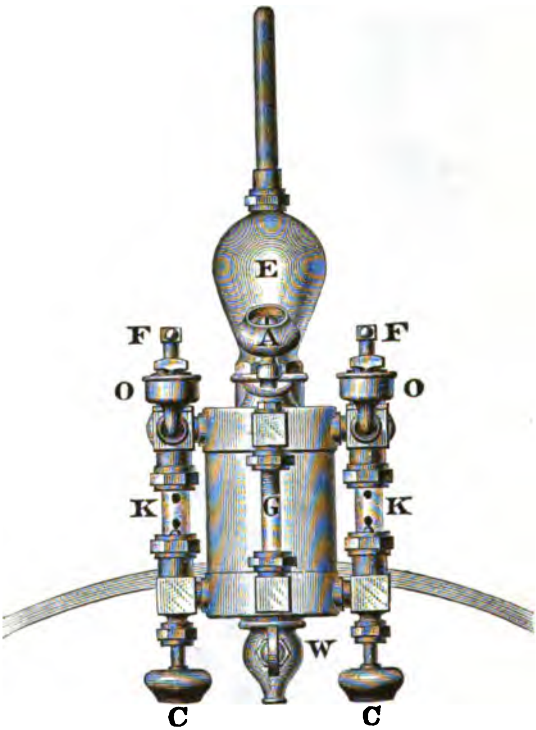


Fig. 378. Sight-Feed Lubricator.

go to the front end of the engine. To avoid this pipes were connected to the steam-chests, and extended back to the cab with oil-cups in the cab, so that the valves could be oiled from the cab without going out to the front of the engine. Of late years what are called "*sight-feed lubricators*."

which supply oil continuously to the cylinders, are used. These are placed in the cab, and are connected to the steam-chests by pipes. Fig. 378 represents an end view, fig. 379 a sectional view on a plane parallel to that of fig. 378,* and fig. 379 a side view of such a lubricator. In this class of lubricators the weight of a column of water displaces the oil in the cup, and causes it to flow *upward*, drop by drop, through water in glass-tubes to the pipes, which are connected to the steam-chests.

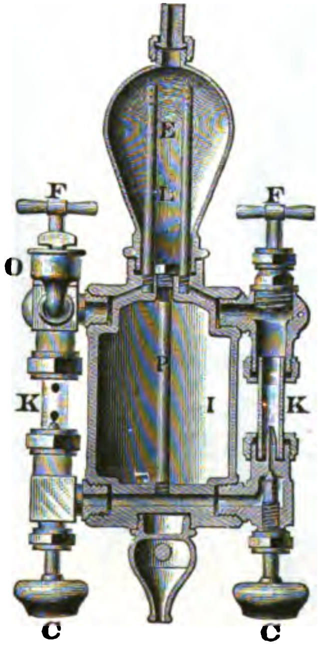


Fig. 379. Sight-Feed Lubricator.

In fig. 379, *I* is the reservoir for holding the oil, which is filled through the plug, *A*, figs. 378 and 380. *E* is a condenser, to which steam is conducted by a pipe on top connected to the boiler, as shown in fig. 380. As the steam is condensed in *E*, fig. 379, the water of condensation flows down into the

* Manufactured by the Nathan Manufacturing Company, of 92 Liberty Street, New York.

reservoir, *I*, by a pipe not shown in the engraving, and the water being heavier than the oil, the former sinks to the bottom of *I*, and the oil floats on top. If the reservoir is half full of water, and is then entirely filled with oil, the water as it condenses in *E* will flow down to the bottom of *I*, and cause the oil to flow slowly into the top of the pipe, *P*, and from

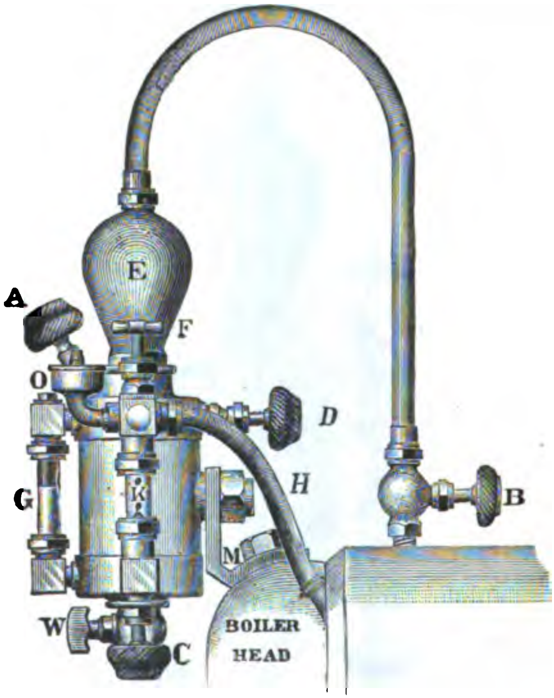


Fig. 380. Sight-Feed Lubricator.

there down into the channel, *J*, below *I*, and thence to the glass tubes, *K K'*, which are filled with water by the condensation of steam. This flows into them through the pipes, *L*. The oil then passes upward, drop by drop, through the water in the tubes, *K K'*, as shown on the left-hand side of fig. 379, and it then passes by an opening above the tubes to the pipes, *H*, one of which is shown in fig. 380, and through them to the steam-chests. The flow of oil is thus constantly in sight, and it can, therefore, be known whether the lubrication is continuous and regular. The pipes, *L*, inside of the reservoir conduct a small quantity of steam and water to the pipes, *H*, after the glass tubes, *K K*, are filled, and in this way the oil, when it reaches the surface of the water in the tubes, *K K*, mingles with the current of steam, which thus forms a steam lubricant that is said to reach and oils all parts of the valves and cylinders.

The quantity of oil entering the sight-feed glasses, *K K*, can be regulated by the valves, *C C*.

The two sides of the lubricator form two distinct and entirely separate oilers, which work independently for each cylinder. The feed is regular and continuous, whether steaming or with steam shut off, going up or down grade.

Each side is provided with an independent "hand" or auxiliary oiler, *O O*, to be used in case any of the glass tubes should break. The auxiliary oilers communicate directly with the pipes, *H*, and can be used as simple oilers in case of need. In case one of the glass tubes should be broken, the valve, *F*, above it should be closed, which will prevent the escape of steam from the broken tube.

Another glass tube, *G*, forms a gauge to show the quantity of oil and water in the reservoir, *I*, and a cock, *W*, is used to drain the reservoir, *I*, before refilling it.

The valve, *D*, opens or closes the opening which communicates from the condenser, *E*, to the reservoir, *I*. This valve should be closed when the engine has completed its run. If it, the valves, *C C*, and the steam-valve, *B*, are left open, oil will continue to feed into the cylinders so long as there is any steam in the boiler.

The following directions have been given by the manufacturers for the care of the sight-feed lubricators:

DIRECTIONS FOR USING THE NATHAN SIGHT-FEED LUBRICATOR.

"Fill the cup with clean, strained oil, through the filling plug, *A*, then open the water-valve, *D*.

"To start: Open the steam-valve, *B*, wait until the sight-feed glasses have filled with condensed water, then regulate the feed by the valves, *C C*. To stop: Close the valves, *C C*.

"To renew the supply of oil: Close the valves, *C* and *D*, and draw off the water at the waste-cock, *E*; then fill the cup and start again as before, always opening the valve, *D*, first.

"The valves, *F F*, must be always kept open, except when one of the glasses breaks. In such case close the valves, *F D* and *B*, to shut off the cup, and use the auxiliary oilers, *O O*, as common cab oilers.

"The valve, *D*, must be closed or opened in advance of the valve, *B*, whenever this latter is closed or opened.

"Once in two weeks, at least, blow out the cup with steam, opening the valves wide, with the exception of the filling plug, *A*, which should remain closed."

CHAPTER XXIII.

SCREW-THREADS, BOLTS AND NUTS.

QUESTION 567. *How must the screws of bolts and nuts be made, in order to fit each other?*

Answer. Each size of screw must be made of exactly the same diameter, and the threads must be of the same form and proportions and *pitch*.

QUESTION 568. *What is meant by the "pitch" of a thread?*

Answer. It is the distance the thread progresses lengthwise of the screw in one revolution. Thus, if a single-threaded screw has $\frac{1}{8}$ of an inch pitch, it means that the threads are $\frac{1}{8}$ of an inch apart, measured from the centre of one thread to the centre of that next to it, and therefore there are eight threads to each inch in length of the screw.

QUESTION 569. *What is meant by a "single-threaded" screw?*

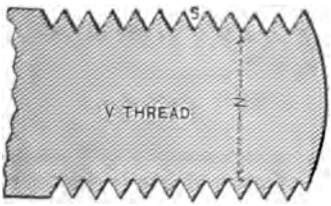


Fig. 381. Full Size.

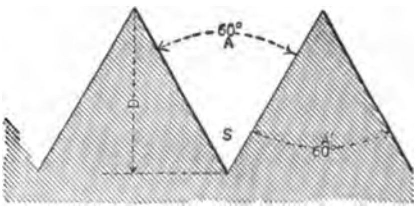


Fig. 382. Eight Times Full Size.

Sections of Screw-Threads.

Answer. It means a screw with but one thread instead of two or more. Thus, if we take a string and wind it around a pencil, it will represent a single-threaded screw, and if we take two or three strings and wind them parallel to each other, they will represent double or treble-threaded screws. The latter kinds are seldom or never used on locomotives, so that in the following discussion only single-threaded screws will be referred to.

QUESTION 570. *What is the usual form of the threads of screws?*

Answer. Until a few years ago the most common form was what is called the V-thread, represented in fig. 381 (and on an exaggerated scale in fig. 382), which was made sharp at both the top and bottom. It is evident that if such a thread for one screw is made very pointed, and that for another is blunt, that the nut for the one will not fit the other accurately, and also that if a nut has eight threads to the inch, it will not fit on a bolt with nine. Owing to the fact that, for a long time, no common standard had been agreed upon for the form, proportions or pitch of screws, there was a very great diversity in these respects in the screws which have been used in the construction of locomotives and other machinery. In 1864 the inconvenience and confusion from this cause became so great that it attracted the attention of the Franklin Institute, of Philadelphia, and a committee was appointed by that association to investigate and report on the subject. That committee recommended the adoption of the Sellers system of screw-threads and bolts, which was devised by Mr. William Sellers, of Philadelphia. This same system was subsequently adopted as the standard by both the Army and Navy Departments of the United States, and then by the Master Mechanics' and Master Car Builders' Associations, so that it may now be regarded, and in fact is called, the United States standard, but the design is due to Mr. Sellers, and the system should be designated by his name.

QUESTION 571. *In establishing a standard system of screws and threads, what is the first thing which must be determined?*

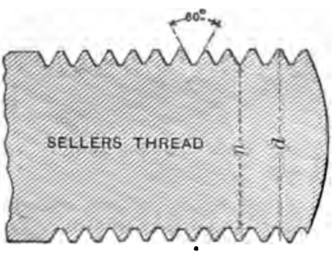


Fig. 383. Full Size.

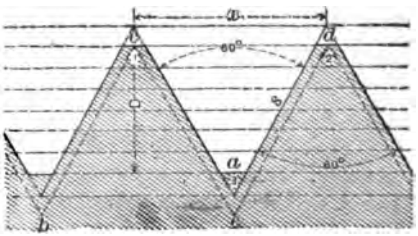


Fig. 384. Eight Times Full Size.

Sections of Sellers' Screw-Threads.

Answer. The number of threads to the inch, or the pitch of the threads for screws of different diameters.

QUESTION 572. *What is the standard for the number of threads to the inch for the different sized screws of the Sellers system?*

Answer. The number of threads with their other proportion is given in the table on page 454.

QUESTION 573. *What is the form of the thread of this standard?*

Answer. The form is shown in fig. 383, and on an exaggerated scale by fig. 384. It is similar to the V-thread, excepting that it is flattened at the top and bottom.

QUESTION 574. *What advantages has the Sellers form of screw-threads over the old V-form?*

Answer. The flattened point or edge makes the thread less liable to injury by being battered, and the diameter—and consequently the strength—of a screw with the Sellers thread at *n*, fig. 384, at the root of the thread, is considerably greater than a thread of the V-form.

QUESTION 575. *What other reasons are there for the adoption of this form of thread?*

Answer. It has already been pointed out that if a screw is made with a "blunt" thread it will not fit a nut with very acute or "sharp" thread; or, if the thread of the bolt is acute and that in the nut obtuse, they will fit imperfectly. It is, therefore, necessary in a standard system to fix upon the angle which the sides of the thread shall bear to each other. In the Sellers standard system this angle was made 60 degrees, because that is easily laid off without special instruments,* and is, perhaps, as good as or better than any other form for the threads.

It is obvious that if a tool is ground with its sides at an angle of 60 degrees to each other, if the point is made sharp, after a very little use it will be worn more or less so that the bottom of the thread will not be cut perfectly sharp, and therefore it will be difficult to make bolts and nuts with threads of this form to fit each other accurately.

It will also be impossible to measure the diameter of the screw at the bottom of the thread if it is made sharp, as its depth will vary as the point of the tool wears, and it is almost impossible to measure the diameter of such a screw precisely with ordinary calipers. To obviate these evils the standard threads are made flat on the top, and it is evident—as has been pointed out—that a similar shape at the bottom will give increased strength to the bolt as well as conform to and fit the thread in the nut.

* This can be done by drawing a circle of any diameter, and subdividing the circumference into six equal parts with the radius. Lines drawn from the points of division to the centre will have an inclination of 60 degrees to each other.

Screw-Threads.				Nuts.				Bolt Heads.			
Diameter of screw.	Threads per inch.	Diameter at root of thread.	Width of flat.	Short diameter rough.	Short diameter finish.	Thickness rough.	Thickness finish.	Short diameter rough.	Short diameter finish.	Thickness rough.	Thickness finish.
1/4	20	.185	.0062	1/2	7/16	1/4	3/16	1/2	7/16	1/4	3/16
5/16	18	.240	.0074	19/32	17/32	5/16	1/4	19/32	17/32	19/64	1/4
3/8	16	.294	.0078	11/16	5/8	3/8	5/16	11/16	5/8	11/32	5/16
7/16	14	.344	.0089	25/32	23/32	7/16	3/8	25/32	23/32	25/64	3/8
1/2	13	.400	.0096	7/8	13/16	1/2	7/16	7/8	13/16	7/16	7/16
9/16	12	.454	.0104	31/32	29/32	9/16	1/2	31/32	29/32	31/64	1/2
5/8	11	.507	.0113	1 1/16	1	5/8	9/16	1 1/16	1	17/32	9/16
3/4	10	.620	.0125	1 1/4	1 3/16	3/4	11/16	1 1/4	1 3/16	5/8	11/16
7/8	9	.731	.0138	1 7/16	1 3/8	7/8	13/16	1 7/16	1 3/8	23/32	13/16
1	8	.837	.0156	1 5/8	1 9/16	1	15/16	1 5/8	1 9/16	13/16	15/16
1 1/8	7	.940	.0178	1 13/16	1 3/4	1 1/8	1 1/16	1 13/16	1 3/4	29/32	1 1/16
1 1/4	7	1.065	.0178	2	1 15/16	1 1/4	1 3/16	2	1 15/16	1	1 3/16
1 3/8	6	1.160	.0208	2 3/16	2 1/8	1 3/8	1 5/16	2 3/16	2 1/8	1 3/32	1 5/16
1 1/2	6	1.284	.0208	2 3/8	2 5/16	1 1/2	1 7/16	2 3/8	2 5/16	1 3/16	1 7/16
1 5/8	5 1/2	1.389	.0227	2 9/16	2 1/2	1 5/8	1 9/16	2 9/16	2 1/2	1 9/32	1 9/16
1 3/4	5	1.491	.0250	2 3/4	2 11/16	1 3/4	1 11/16	2 3/4	2 11/16	1 3/8	1 11/16
1 7/8	5	1.616	.0250	2 15/16	2 7/8	1 7/8	1 13/16	2 15/16	2 7/8	1 15/32	1 13/16
2	4 1/2	1.712	.0277	3 1/8	3 1/16	2	1 15/16	3 1/8	3 1/16	1 9/16	1 15/16

To give this form requires only that the point of the cutting tool shall be taken off, and it is evident that then this form of thread can be cut in a lathe with the same tool and in the same manner as the sharp thread.

The advantage of the Sellers form of thread, in the matter of strength, will be apparent if the form of a V thread of the same diameter as the Sellers thread is laid off, in fig. 384, as shown by the dotted lines, *b c e d*. It is plain from this that the small triangular portion of the top of the V thread, between the two horizontal dotted lines, at 1 and 2, has less strength than the corresponding part of the Sellers thread between these lines; and it is also plain that if the sides, *c e* and *e d* of the V thread are made of the same angle as the Sellers thread, that the former must be cut deeper than the latter by a distance equal to *a e*, and that the bolt will be weakened in proportion to the amount of metal thus cut away at the root of the thread.

QUESTION 576. *What are the proportions of the standard threads?*

Answer. The rule given by Mr. Sellers for proportioning the thread is as follows: "DIVIDE THE PITCH, OR, WHAT IS THE SAME THING, THE SIDE OF THE THREAD (*c* 3, fig. 384), INTO EIGHT EQUAL PARTS; TAKE OFF ONE PART (*c*) FROM THE TOP AND FILL IN ONE PART (3) IN THE BOTTOM OF THE THREAD: THEN THE FLAT TOP (below *c*) AND BOTTOM (below *a*) WILL EQUAL ONE-EIGHTH OF THE PITCH, THE WEARING SURFACE (*s*) WILL BE THREE-QUARTERS OF THE PITCH, AND THE DIAMETER OF SCREW (*n*, fig. 383) AT BOTTOM OF THE THREAD WILL BE GIVEN IF WE DIVIDE 1.002 BY THE NUMBER OF THREADS PER INCH AND DEDUCT THE QUOTIENT FROM THE OUTSIDE DIAMETER (*d* fig. 383) OF THE SCREW."

The form and proportions of the thread are shown in fig. 384, which has been drawn eight times the size of a thread for a bolt one inch in diameter, so as to represent the different parts clearly; *x* represents the pitch, and *D* the depth of the thread; *d*, fig. 383, represents the outside diameter of the screw, and *n* the diameter at the bottom or root of the thread. The width of the flat part of the thread at the top and bottom of the threads is shown at *c*, *d*, and *a*, fig. 384, and *s* indicates the length of the side or wearing surface of the thread.

For practical use in the shop a gauge like that shown in fig. 385 will be found convenient for grinding the tools to the proper form for making the standard screws. With this gauge the screw cutting-tool can first be ground to the proper angle by fitting it to the deepest notch, and the requisite quantity should then be taken off the point by fitting it to the notch representing the form of thread for the sized bolt or number of threads to the inch which it is intended to cut.

QUESTION 577. *What other precaution must be taken to secure interchangeability of screw bolts and nuts?*

Answer. Great care must be taken that the diameters of the screws are accurately maintained to the standard sizes. The diameters of the standard sizes of screws are given in the table on page 454. It has been a common practice to make screws somewhat larger than these sizes because iron is often rolled larger in diameter than its nominal size, and then the superfluous metal must be cut away to reduce the screw to the

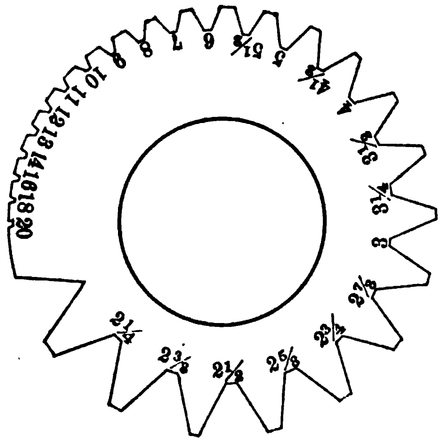


Fig. 385. Screw Thread-Gauge. Full Size.

standard size. It should be distinctly known that there are no standard screws for bolts and nuts which are a small fraction of an inch larger or smaller than the diameters given in the table, and that a screw slightly larger or smaller in diameter than the sizes given does not conform to the standard.

Whenever this standard for threads is used, if any pretense at all is made to accuracy of workmanship, careful attention should be given to the form and proportion of the threads as well as to the number to the inch.

It is impossible, however, with the ordinary tools and appliances in use in machine shops, to make taps and dies with sufficient amount of precision, so that the bolts and nuts cut with them will always be interchangeable. Such tools are now made in establishments provided with special machinery, appliances, and workmen required to secure and maintain exact uniformity and the necessary degree of precision to insure interchangeability.

QUESTION 578. *What has been done to secure uniformity in the diameters of screws?*

Answer. The Master Mechanics' and Master Car Builders' Associations have adopted limits for the diameters of round bar iron. It has been specified by these Associations that such iron shall not vary from its nominal size more than the amount given in the following table:

LIMITS OF SIZE OF ROUND ROLLED IRON.

Nominal Diameter of Iron. Inches.	Maximum or + Size. Inches.	Minimum or — Size. Inches.	Total Variation. Inches.
¼	.2550	.2450	.010
5/16	.3180	.3070	.011
⅜	.3810	.3690	.012
7/16	.4440	.4310	.013
½	.5070	.4930	.014
9/16	.5700	.5550	.015
⅝	.6330	.6170	.016
¾	.7585	.7415	.017
⅞	.8840	.8660	.018
1	1.0095	.9905	.019
1⅛	1.1350	1.1150	.020
1¼	1.2605	1.2395	.021

Caliper limit gauges, like that shown in fig. 386, are made by the Pratt-Whitney Company, of Hartford, Conn., for measuring bar iron. The two ends of the gauges are made of the maximum and minimum dimensions given in the table, and the Associations already referred to have recommended that round iron of the nominal standard sizes be made of such diameter that each size *will* enter the large or + end of the gauge intended for it, *in any way*, and will *not* enter the small or — end *in any* *way*. Fig. 387 is a reference gauge which is used for testing the caliper gauges shown in fig. 386.

In buying taps and dies the purchaser should see that they conform in every respect to the standard, and in making specifications for new work similar care should be exercised to secure the true standard, form and proportion of screws. In many shops the workman who have the care of

Fig. 386. Caliper Limit Gauge for Round Iron.

Fig. 387. Reference Gauges for Round Iron.

those tools are entirely ignorant of the peculiarities of the Sellers system, and have only the vague idea that so long as they get the proper number of threads to the inch they are doing all that is necessary to secure uniformity. Unless, therefore, some care is exercised to insure accuracy of workmanship in this department, the adoption of a "standard" for screws will not insure the advantages which would result from uniformity of screws and threads.

QUESTION 579. *What is the usual shape of nuts?*

Answer. The most common shape is square or hexagonal, as shown in figs. 388–391, but they are sometimes made cylindrical, as shown in figs. 392 and 393, with grooves cut on the outside to hold a wrench.

QUESTION 580. *Why is it often essential to adopt some means to prevent nuts from turning or unscrewing?*

Answer. When bolts and nuts are exposed to vibration, it is found that a slackening is very liable to occur, so that the excessive vibration on locomotives requires that many of the nuts should be locked in some way.

QUESTION 581. *How are nuts prevented from turning?*

Answer. The simplest plan, and the one which is most frequently employed, is that shown in figs. 394 and 395, which is simply a second or "*lock nut*" screwed on over the first and tightened down upon it. Lock nuts are usually made thinner than the main nut, and when that is the case, it is argued that the thinnest nut should be screwed on the bolt first,

Fig. 388 Fig. 390. Fig. 392. Fig. 394.

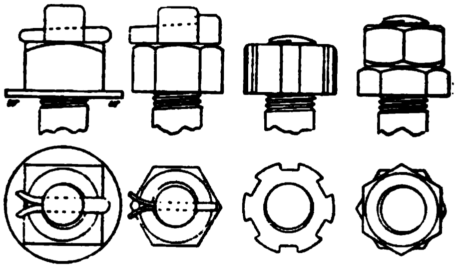


Fig. 389. Fig. 391. Fig. 393. Fig. 395.

Different Forms of Nuts. Scale ¼ in.—1 in.

because if the second nut is screwed down hard on the first one, the strain on the bolt is borne by the one last screwed on.

When lock nuts are used, if the total thickness of the two nuts is equal to about one-half more than the ordinary proportion for the thickness of nuts, it will be found that sufficient has been done to insure a perfect locking.

When the object is merely to prevent nuts from unscrewing and being lost, what are called *split keys* or *cotters* are used. These are sometimes round, tapered pins, shown in figs. 388 and 389, which are divided or split so that the two parts can be bent into the form shown in fig. 389. In other cases they are made of flat pieces of metal, as shown in figs. 390 and 391, which are bent as shown in fig. 391.

QUESTION 582. *What are the shapes of bolt-heads?*

Answer. They are made in a variety of forms according to their use, but usually they are either square or hexagonal, the same as nuts.

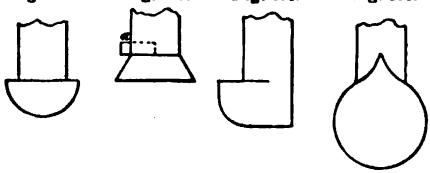
QUESTION 583. *In what other forms are bolt-heads made?*

Answer. Fig. 396 represents a bolt with a hemispherical head, and fig. 397 one with a countersunk head. The latter form is used when a projecting head would be in the way of something else. To prevent the bolt from turning when a hemispherical or countersunk head is used, a hole is sometimes drilled into the side of the bolt and a pin, *a*, fig. 397, is fitted into it. This pin rests in a corresponding cavity cut in the side of the hole in which the bolt fits.

Fig. 398 represents a hook-headed bolt, which is sometimes used to fasten tires on wheel centres. Fig. 399 is the form of bolt-head used to move the wedges which form the wearing surface for driving-axle boxes.

QUESTION 584. *Are there any standard sizes for bolt-heads and nuts?*

Fig. 396. Fig. 397. Fig. 398. Fig. 399.



Different Forms of Bolt-Heads. Scale ¼ in.—1 in.

Answer. Yes; proportions were devised by Mr. Sellers and were adopted by the associations already referred to. These are given in the table on page 454.

QUESTION 585. *What is a washer?*

Answer. A washer, shown at *w w*, fig. 388 and in fig. 389, is a ring of metal or other material, which is put under a bolt-head or nut to give it a fair bearing. Washers are also put between bolt-heads or nuts when they bear on wood or other yielding material to increase the area of their bearing.

QUESTION 586. *What is a stud?*

Answer. A stud is a bolt with a nut in place of a head. Studs are screwed into their place and are provided with nuts instead of heads, so that the stud need not be unscrewed to loosen or remove the parts which it secures or fastens. Studs are generally used to make attachments to cast iron, such as the cylinder-heads and steam chests of locomotives, because a thread cut in cast iron is liable to be injured by often screwing and unscrewing a bolt into and from it.

CHAPTER XXIV.

TENDERS.

QUESTION 587. *What are locomotive tenders for?*

Answer. They carry a supply of fuel and water for locomotives while they are running.

QUESTION 588. *How are they constructed?*

Answer. The construction of a locomotive tender is shown by figs. 400 to 404. Fig. 400 is a side view, fig. 401 a plan, fig. 402 a longitudinal section, fig. 403 an inverted plan, and fig. 404 a front view with the forward truck omitted. The tender has a rectangular frame, *A A A A*, made of either iron or wood. The frame shown in the engravings is made of iron channel bars, which are rolled bars whose section is somewhat similar in form to a letter E with the middle member omitted. Tender frames are, however, often made of wooden timbers. The frame is mounted on a pair of trucks, *B B*, figs. 400 and 402. The top of the frame is covered with planks, *C C C*, which form the floor of the tender. On top of this floor a sheet iron tank, *D D*, is placed, which carries the supply of water. This tank is made somewhat in the form of a letter ⊃, as shown in the plan. It is made in this way so that the space, *B'*, fig. 401, between the two branches, *D D*, or "*legs*," as they are called, will give room for fuel. Around the upper edge of the tank a sheet iron rim, *E E*, is riveted, so as to prevent the fuel from falling off when it is filled up above the top of the tank.

QUESTION 589. *How are tender tanks filled with water?*

Answer. They are usually filled at water stations with leather or canvas hose connected to a pipe or tank which furnishes a supply of water. The appliances for doing this are described in Chapter XXV. The tank has an opening, *F*, on top called a "man-hole" or "filling funnel" into which the hose is inserted, and a stream of water is then allowed to flow through the hose into the tank of the tender. The tank which supplies water to the tender is located higher than the tender, and the water is usually pumped into this tank so that it will run into the tender.

QUESTION 590. *What other way is there of filling tenders with water?*

Answer. To avoid frequent stops for water, express passenger locomotives are sometimes provided with what is called a "water-scoop" for taking water while the engine is running. This consists of a bent tube, *G G G*, figs. 400 to 404, which is attached to the under side of the tank, and extends up inside of it to the top. A long trough, *H H H*, figs. 402 and 404, is laid between the rails and filled with water. The lower end of

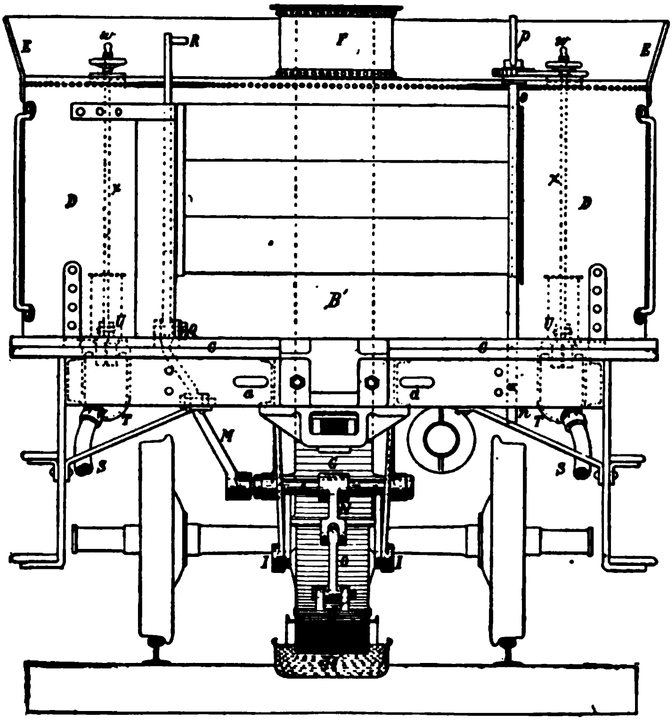


Fig. 404. Front End View of Tender. Scale ⅜ in.—1 ft.

the bent tube or scoop has a joint or hinge at *I*, so that it can be lowered into the trough, and the lower end, *J*, of the scoop will then dip a few inches into the water. The motion of the engine forces the water up the tube, *G G G G*, and it is discharged into the tank at *K*, fig. 402.

QUESTION 591. *How is the end of the scoop lowered into the water?*

Answer. A shaft, *L*, with two arms, *M* and *N*, is located above the lower end of the scoop. One of these arms, *N*, is connected by a link, *O*, to the movable part of the scoop, and the other arm, *M*, is connected by a rod, *M P* (shown by dotted lines in fig. 402), to a lever, *P Q R*. The fulcrum of this lever is at *Q*, and it has a handle, *R*, at the top. By moving the upper end of the lever backward the scoop is lowered, and by moving it forward the scoop is raised.

QUESTION 592. *How is the water conducted from the tender to the engine?*

Answer. To each side of the front end of the tank, a piece of rubber hose, *S*, is attached, which is connected at the other end to the pipe on the engine which supplies the pump or injector with water. In some cases this hose is connected directly to the tender tank, but in others small cast iron cisterns, *T T*, are attached to the bottom of the tank, and the hose is counected to them. A cistern of this kind is shown on a larger scale in figs. 406 and 407. The purpose of these cisterns is to prevent air being drawn into the hose when the tank is nearly empty, which would interfere with the working of the pumps or injectors.

QUESTION 593. *How is communication opened and closed between the hose and the tank so as to "turn on" and "shut off" water from the hose?*

Answer. This is done by valves, *U U*, fig. 402 in the bottom of the tank. A section of one of these valves, with the appliances for opening and closing it, and the cistern, already referred to, is shown on an enlarged scale by figs. 405, 406 and 407. *C* is the cistern and *V* the valve, which is operated by means of a rod, *R R*. This rod has a screw on its upper end, which is screwed into a casting, *A*, that is riveted to the top of the tank. The screw is turned by a crank and handle, *H*, on its upper end. When it is turned in one direction the valve is raised, and if turned the opposite way it is lowered. The wheel, *W*, is also screwed on the rod, *R*, and acts as a check or lock nut to hold the rod and valve in any desired position. The valve is covered with a hood or strainer, *B*, perforated with small holes, which is intended to prevent dirt from entering the hose and thus getting into and obstructing the pump or injector. The hose is connected to the cistern and to the supply pipe by a screw-coupling, *D*, similar to that used with ordinary fire-engine hose.

QUESTION 594. *How are the flat sides of the tank strengthened so as to resist the pressure and weight of the water?*

Answer. They are sometimes braced or stayed with rods or bars, *V V* and *W W* figs. 400, 401 and 402, extending from one side to the other, and from the top to the bottom, and angle or T-iron is also riveted to the sides to stiffen them.

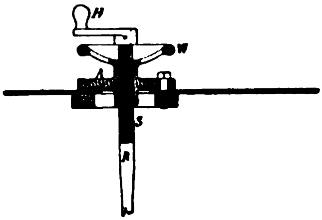


Fig. 405

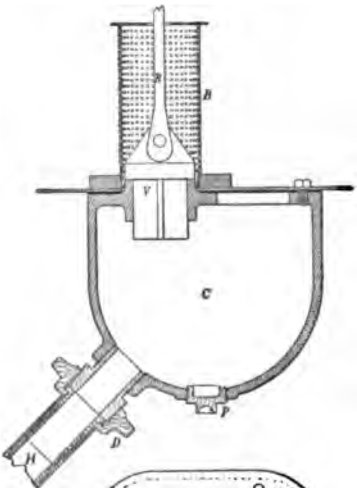


Fig. 406.

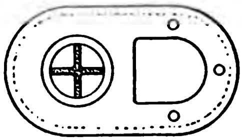


Fig. 407

Tender, Valve and Cistern. Scale 1 in.=1 ft.

QUESTION 595. *How is the violent motion or swash of the water in the tank prevented?*

Answer. Transverse plates, *X X X*, called "swash-plates," are placed in the tank to resist the movement of the water when the tender stops or starts suddenly.

QUESTION 596. *How is the tender connected to the engine?*

Answer. By the draw-bar, *Y*, and coupling-pin, *Z*, fig. 402, and also by the safety chains, 50, Plate IV, which are connected to the eyes, *a a*, figs. 403 and 404.

QUESTION 597. *In what respect do the tender trucks differ from the engine truck?*

Answer. Chiefly in having the journal-bearings and frames outside of the wheels.

QUESTION 598. *Why are the bearings placed outside instead of between the wheels?*

Answer. Because if they are outside they are then more accessible than if they are between the wheels, and the oil-boxes on the axles can be entirely closed over the ends of the axles, so that no oil can leak out at that end, whereas if the boxes are inside, they must be left open at both ends. When the boxes are on the outside, they can be oiled, or a journal-bearing can be removed and a new one put in its place, with much less difficulty than if the boxes are on the inside of the wheels. The only reason why the bearings of engine truck-axles are placed inside the wheels is because they would be in the way of the cylinders if they were outside.

QUESTION 599. *How are the axle-boxes for the tender axle constructed?*

Answer. Their construction is similar to that of a car axle-box, a standard form of which is represented in figs. 408, 409, and 410. Fig. 408 is a section lengthwise of the axle, fig. 409 a sectional plan, and fig. 410 a section crosswise of the axle. *A* is the journal of the axle, which is enclosed by a cast iron box, *K K*, which is open in front and at the back. The front has a cover, *H*, which is either fastened by a spring, as shown in the illustrations, or is bolted to the box. The axle enters the box from the back, *I*, and has either a wood or leather packing, *J J*, called a *dust-guard*, to keep the dust from getting in and the oil from leaking out of the box. *D* is a brass journal-bearing which rests against a cast iron bearing piece or *key*, *E*, which is put in so that by removing it through the opening, *F*, the brass bearing can be raised up high enough to clear the collar, *G*, on the end of the axle and thus be removed in the same way. The lower portion, *L*, of the box under the axle is usually filled with cotton or woolen waste saturated with oil. This constantly presses against the axle, and thus keeps it oiled.

QUESTION 600. *How are the tender trucks constructed?*

Answer. They are made of various patterns, some of which have wooden frames, but they are now usually made of iron. The truck illustrated in figs. 400, 402 and 403 is made of iron, and is very similar to the four-wheeled engine truck which has been illustrated, excepting as pointed out, that the frames and journal-bearings are outside the wheels instead of between them.

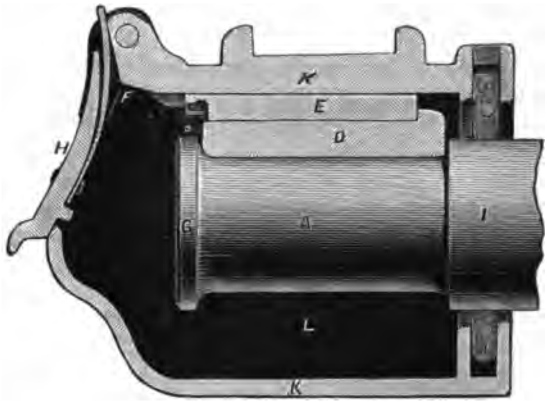


Fig. 408.

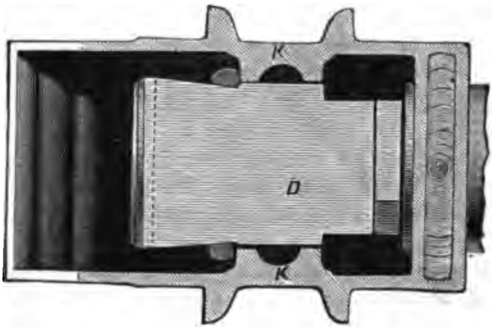


Fig. 409.
Tender Truck Journal-Box.

QUESTION 601. *How are the tenders supported on the trucks?*

Answer. Usually they rest on the centre-plate, *b*, fig. 402, of the front truck and on bearings, *c*, fig. 400, on the frames on each side of the back truck. This arrangement gives three bearing points, the advantages of which have been explained in Chapter XX. A truck which supports the load which it carries in the centre is said to be *centre-bearing*, and if the load is carried on each side, *side-bearing*.

QUESTION 602. *How are the brakes applied to the tender?*

Answer. They are often applied to one truck alone, but both trucks should always have brakes attached to them.

QUESTION 603. *What are the chains, c' c' c' c', fig. 400 for?*

Answer. These chains are fastened by one end to the corners of the truck frames and to the tender frames by the other, so as to hold the trucks parallel with the track in case they should get off the rails.

QUESTION 604. *What are the brakes for and how are they constructed?*

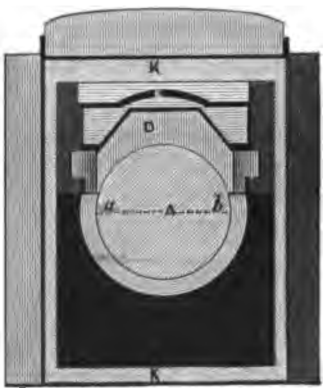


Fig. 410. Tender Truck Journal-Box.

Answer. The brakes are for the purpose of stopping the locomotive and tender quickly. They consist of cast iron blocks, *d d*, figs. 400, 402 and 403, called brake-blocks or brake-shoes, which are attached to transverse wooden or iron beams, *e e*, called *brake-beams*. These beams are suspended from the truck frame by the links or hangers, *f f*, called "*brake-hangers*." Levers, *g g g g*, called "*brake-levers*," are attached to the middle of these beams by pivoted fulcrums. The two levers on each truck are connected together by rods, *h* and *h*. The upper end of one of each pair of these levers is held fast by a pin, at *i*, and the upper ends, *k k'*, of the other lever are connected together by a rod, *l l'*, fig. 400; *l'* is connected by a rod and chain, *m*, to a shaft, *n o*. The chain is wound on the shaft, which is turned by a crank, *p*, on the upper end. By this means the upper ends, *k k'*, of the levers are drawn toward the shaft, which forces the brake blocks against the wheels. A piston in the cylinder, *r*, is also connected with one of the brake-levers. The piston is operated by compressed air, the action of which is fully explained in Chapter XXVI on air brakes.

CHAPTER XXV.

WATER-TANKS AND TURN-TABLES.

QUESTION 605. *How are locomotive tenders or tanks supplied with water?*

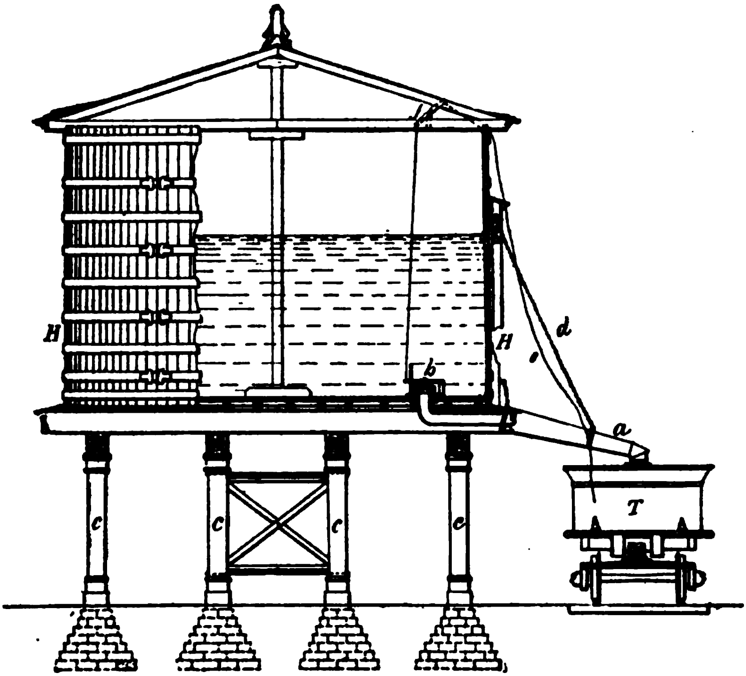


Fig. 411. Water-Tank. Scale $\frac{1}{16}$ in.=1 ft.

Answer. At suitable places, called *water stations*, along the line of the road, large tanks or reservoirs, *H H*, fig. 411, are located. These are filled either from natural streams which are higher than the tanks and thus flow into the latter, or else the water is pumped in, either by hand or by horse, wind, water, or steam power. When there is room for them, these tanks are usually located near the track, as shown in fig. 411, so that the water can be conducted by a spout, *a*, direct from the tank to the man-hole of the tender, *T*. Communication to and from this spout is opened and closed by a valve, *b*, inside of the tank, which is moved from the tender by a rope, *e*, connected to a lever, *f*, and to the valve, *b*. The spout is usually attached to the tank by a hinged joint, so that it can be lowered to the tender and then raised up out of the way of the engine and train. It is generally balanced by a counterweight, suspended to one end of a rope, *d*, which passes over a pulley and is fastened to the spout at the other end. The tanks are now generally made of wooden staves like a tub or pail, and supported on a heavy frame, *c c c*, made of wood as shown in the engraving, or on stone or brick masonry.

When there is no room for the tank or reservoir near the track, it is placed in any convenient position at some distance from it, and the water is then conveyed by an underground pipe to the place where the locomotive must take water. At the end of this pipe what is called a *stand-pipe* or *water-crane*, fig. 412,* is located. This consists of a vertical pipe, *A*, with a horizontal arm, *B*, which is made so as to swing around over the man-hole of the tender when the latter is to be filled with water. In some cases the horizontal arm alone swings around, but in others the vertical pipe turns with the horizontal one in a joint, *C*, underneath the surface of the ground. The latter plan is thought to be preferable to the first, as the pipe is less liable to freeze fast in the joint when the latter is underground than when it is exposed above. A suitable valve, *D*, is also attached to the pipe below ground, so that the stream of water can be turned off or on at pleasure by the lever, *E*, which is connected by rods to the valve.

QUESTION 606. *What effect does the use of impure water have on a locomotive boiler?*

Answer. The use of impure water, or that which contains a considerable amount of mud or solid matter mixed with it, or in suspension, as it is called, or has lime or other mineral substances chemically combined with it, will very soon coat the inside of the boiler with a covering of scale, which is a very bad conductor of heat, and consequently the boiler is much less efficient, and much more heat is wasted than if the heating surfaces were clear. Besides this loss of efficiency, when boiler-plates are

* The engraving illustrates a stand-pipe made by the Sheffield Velocipede Car Co., of Three Rivers, Mich.

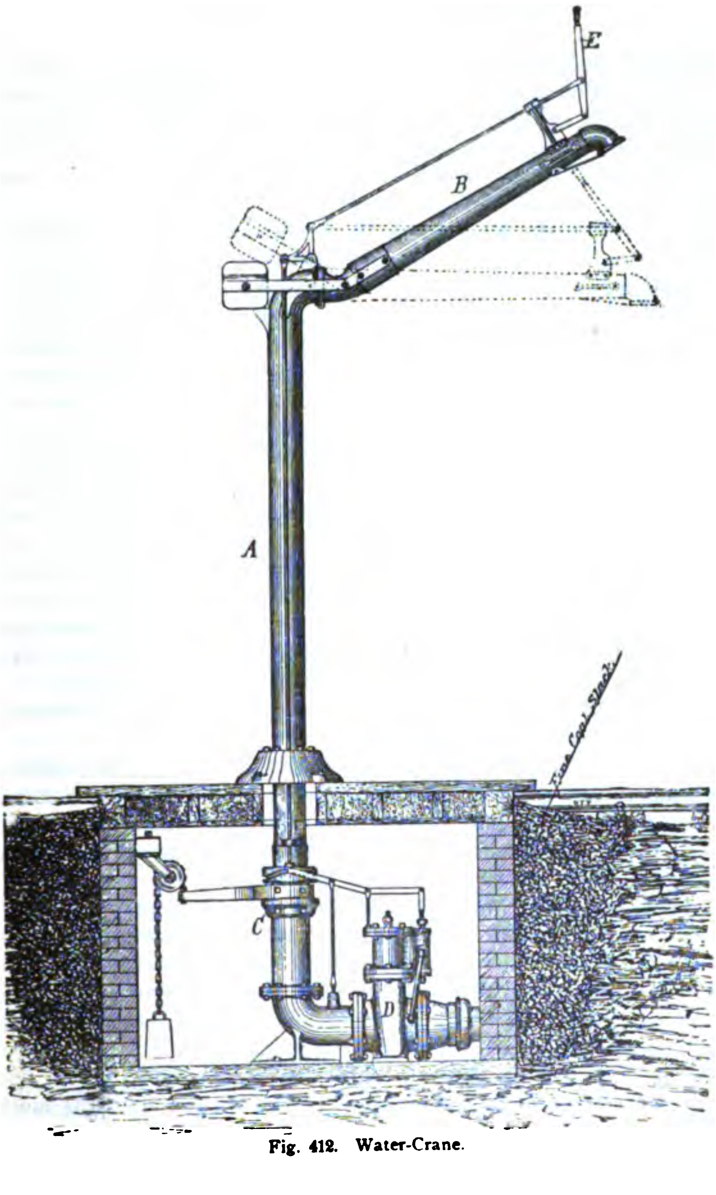


Fig. 412. Water-Crane.

covered with non-conducting scale, they are much more liable to be injured by the action of the fire than when the water comes directly in contact with the metal of the plates. Some water, too, has a corroding effect on the metal of the boiler which is very destructive.

QUESTION 607. *What considerations should determine the source from which a supply of water should be drawn?*

Answer. The first must of course be its convenience to the point where the water is to be used; but more attention should be given to the quality of the water than it ordinarily receives. The location where a water-tank must be having been decided upon, every possible available source of supply should be sampled, and analysis made of each of the samples and the corrosive substance which it contains, and the solid residue which is left after the water is evaporated should be determined. This having been done, the source which contains the least corrosive or scale-making material should be chosen. In general running streams are much better than any other sources. Wells very rarely are good sources of supply. Much expense can be saved in boiler repairs and in the fuel account by a little judicious expenditure of money to secure a supply of good water. On many of the older railroads an examination of all possible sources of water-supply is now being made, with a view to abandoning a large number of the old sources, and securing others near by which contain much less scale-making material. If this had been done when the roads were first located, much extra cost for fuel and repairs would have been saved.

QUESTION 608. *How can the relative amount of incrustating substances in different kinds of water be determined?*

Answer. The relative quantity of solid matter or mud which is held in suspension can be at least approximately determined by simply filling vessels, say large clear glass bottles, with different kinds of water and adding a few drops of water of ammonia, and letting them stand for some time until the solid matter settles to the bottom.

A comparison of one water with another, as to its scale-making properties, may readily be obtained by having samples of the different waters in some small bottles of the same size, adding to them water of ammonia until each is distinctly alkaline, and then a little phosphate of soda. This causes a precipitation of the iron, alumina, lime and magnesia in the water as phosphates, and the bulk of the precipitate indicates the relative amount of scale-making material. This test is, of course, crude, and would hardly take the place of a good chemical analysis, but it is much better than nothing.

When the water of ammonia cannot easily be procured, an experiment may be tried in the same way, by dissolving common white soap, or other pure soap, in a goblet of pure water, and then stirring into the glasses of water to be tested a few teaspoonfuls of this solution. The comparative amount of scale-making material in the water will be shown by the amount of coagulated matter which will be thrown down.

QUESTION 609. *What are the most commonly occurring corrosive materials in waters used in boilers?*

Answer. The most commonly occurring corrosive materials are sulphates of iron and alumina and chloride of magnesium. The former are universal constituents of mine drainage. The latter occurs most frequently along the sea-shore. In addition to this many waters which drain from mines contain large amounts of free sulphuric acid. If any mine drainage gets into the water-supply at any place, the use of that water should be abandoned if possible. Also in wells along the sea-shore, or on the banks of rivers affected by the tides, chloride of magnesium is a frequent constituent, and often causes serious corrosion of boilers.*

QUESTION 610. *How are locomotive tenders supplied with coal?*

Answer. This is done in a variety of ways. Sometimes the coal is shoveled from cars alongside of the tender, but this is a slow and laborious method. In other cases iron buckets are filled with coal at stations and then are hoisted by cranes and swung over the tenders. They are then either tipped or a door in the bottom is opened and the contents are emptied into the tender. In still other cases, small cars are loaded with coal and are run on platforms which are high enough, so that the contents of the cars can be dumped into the tender. Fig. 413 represents a side view and fig. 414 a transverse section of what is called a *coal chute*.† It consists of an inclined track, *A A*, which leads to an elevated level track, *B B*, which extends through a building, *H H*. On one or both sides of this track the building has receptacles or "pockets," as they are called, *F*, fig. 414, to receive the coal from the cars. These pockets have inclined floors, *G*, and are closed by doors, *D D*, figs. 413 and 414. Each pocket also has a spout or "*apron*," *E*, which can be extended out over the tender, as shown in fig. 414. These aprons are hinged at *I*, and can be folded up out of the way when not in use. The pockets are filled with coal, and

* The above information about water was furnished by C. B. Dudley, Chemist, of the Pennsylvania Railroad Company.

† The figures represent a coal chute made and patented by Messrs. Williams, White & Co., of Moline, Ill.

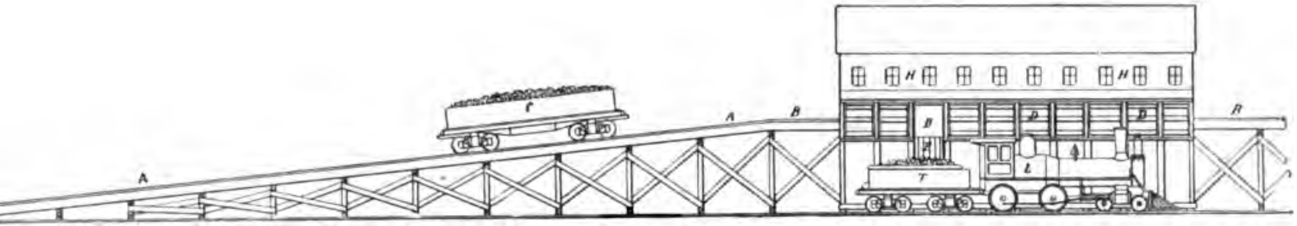


Fig. 413.

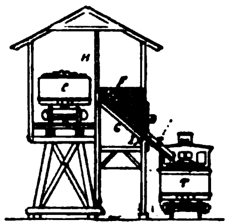


Fig. 414.
Coaling Station with Coal Chutes.

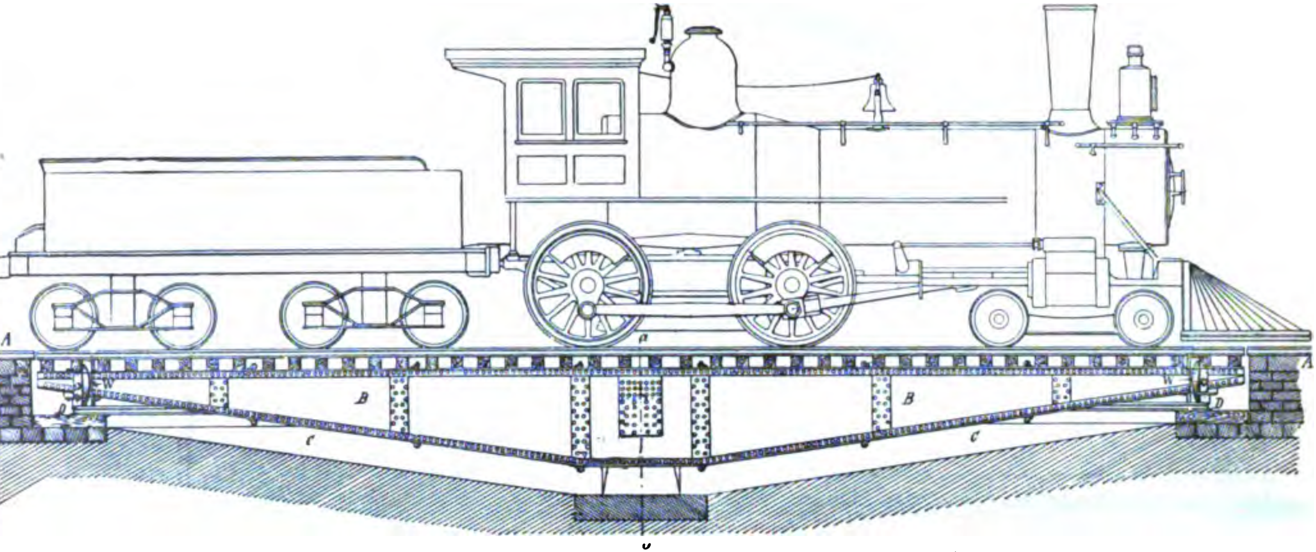


Fig. 415. Wrought-Iron Turn-Table. Scale ⅛ in. — 1 ft.

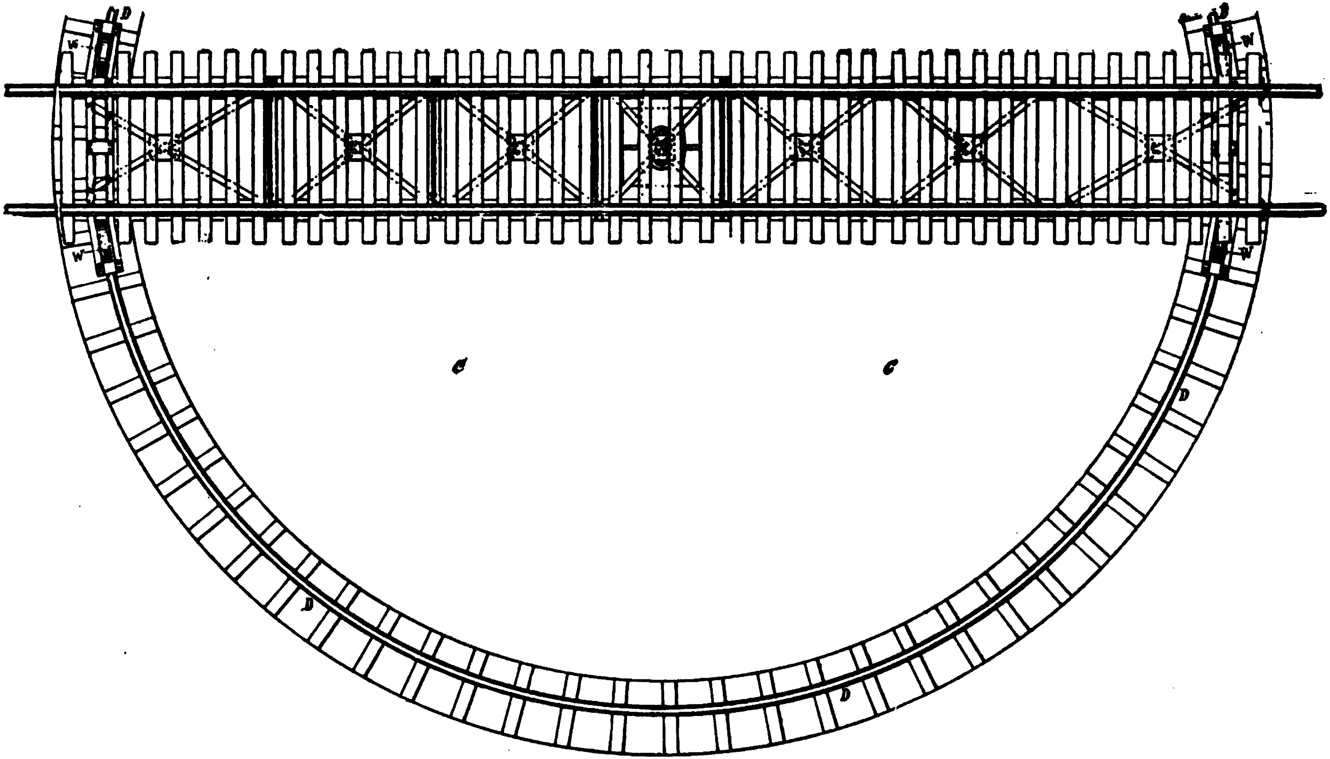


Fig. 416. Plan of Turn-Table. Scale ⅛ in.—1 ft.

when a tender, *T*, is to be supplied it is run on a track alongside of the coal chute opposite to one of the pockets. The apron, *E*, is then lowered and the door, *D*, opened, and the contents of the pocket are emptied into the tender in a few seconds.

In some cases coal chutes are furnished with scales for weighing the coal supplied to tenders.

QUESTION 611. *How are locomotives turned around on the track?*

Answer. The most common means employed for that purpose is a *turn-table*, of which fig. 415 is a side elevation, fig. 416 a plan, and fig. 417 a cross-section through the centre on the line, *a b*.* It consists of two heavy beams or girders made of wood, cast or wrought-iron, placed side by side, and resting on a pivot, *P*, fig. 417, in the centre, on which they

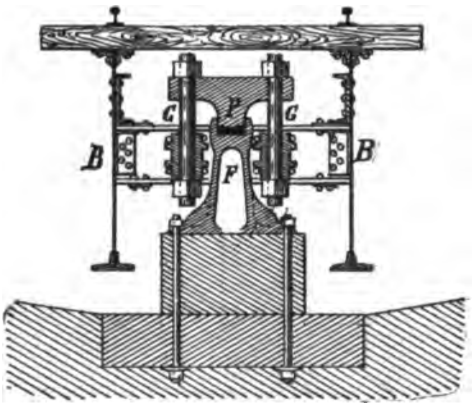


Fig. 417. Section of Centre of Turn-Table. Scale ¼ in. = 1 ft.

turn. They are placed in a circular pit, *C C* (part of which is omitted in the plan), below the level of the track, *A A*, so that when rails are laid in the ordinary way on top of the girders they will be exactly level with the track which leads up to the pit. By turning the girders on the central pivot so that the rails will come exactly in line with the permanent track which leads up to the pit, the locomotive can be run on the turn-table, which is then revolved a half-revolution, which of course reverses the position of the locomotive and brings it opposite the permanent track so that it can be run off from the table. In order to prevent the girders from

* Designed by A. P. Boller, C. E., 71 Broadway, New York.

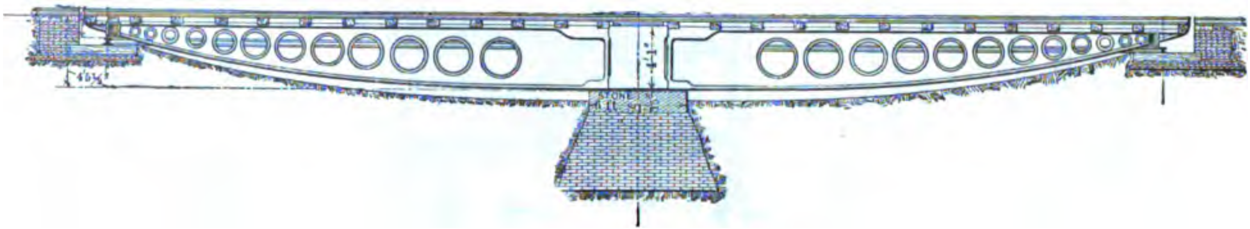


Fig. 418. Wm. Sellers & Co.'s Cast Iron Turn-Table.

tipping down when the engine first runs on or off of the turn-table, wheels, *W W*, are placed at their outer ends which run on a circular track, *D D*, and they bear any inequality of weight that may be thrown on either end of the turn-table if the locomotive is not equally balanced on the central pivot.

Fig. 418 represents a cast iron turn-table, manufactured by Messrs. Wm. Sellers & Co., of Philadelphia.

QUESTION 612. *How are the central pivots of turn-tables constructed?*

Answer. They usually consist of a vertical post, *F* (shown in fig. 417, which is a transverse section through the centre of the turn-table, fig. 415), the end of which has a hard cast iron or steel bearing. In some cases, the weight rests on conical steel rollers, which revolve in a circular path formed in the top plates, as shown at *a a*, in fig. 419, which is a longitudinal section through the central point of Messrs. Wm. Sellers & Co.'s

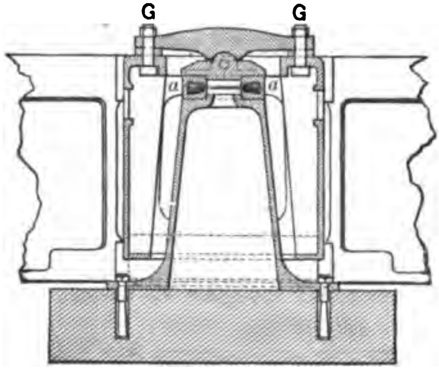


Fig. 419. Longitudinal Section.

turn-table. Sometimes turn-tables are fitted with gearing and cranks, but if they are made so that the whole weight rests on the centre, and if they are of sufficient length so that an engine and tender can be moved on them sufficiently to be balanced over the centre, gearing will not be needed; but a simple lever fastened to the turn-table will be all that will be required to turn the table and the engine and tender on it. The tables should be of such a diameter or length across the centre as will enable the class of engine in use on any road to be balanced. With light engines a table 50 feet in diameter is large enough; with the long, heavy engines now used on the great trunk lines, an engine and tender quite fill up the entire length of 50 feet, leaving no margin for adjustment. In such cases a table 60 feet in diameter should be employed. These large tables are also made heavier in proportion. When the engine and tender is balanced over the centre pivot, one man can turn the loaded table with ease.

In setting up turn-tables it is necessary that the foundation at the centre, upon which the pivot rests, should be of the most substantial character, so as not to be liable to settle. The circular track, which may be made of light rails, which weigh about 28 or 30 lbs. to the yard, should be level, and the table should be so adjusted as to swing clear of the circular track when loaded. The pit required is quite shallow near the edge and deepens toward the centre, and should be properly drained to prevent water from standing in it. Provision is made for covering the entire pit by a platform turning with the table, but this should be avoided whenever possible, as the best constructed cover does offer some resistance in turning. Even in roundhouses, where a covered pit might be considered preferable as presenting a smooth floor for crossing in any direction, it has been found advisable, in view of the greatest ease in turning and the facility offered by the open pit for cleaning, to dispense with the cover. The centre of the table must be kept clean and well oiled, say with best sperm or lard oil and tallow of such a consistency as not to harden in cold weather. The top cap at the centre is held in place by bolts, *G G*, figs. 417 and 419. These bolts take the entire weight of the table and load; by slacking off the bolts the table can be lowered on the wheels on the circular track and the cap lifted off to gain access to the bearings. This should be opened, examined and cleaned at least once every three months.

QUESTION 613. *Is there any other method of turning locomotives?*

Answer. Yes; what is called a Y is sometimes used. This consists of a system of tracks laid somewhat in the form of the letter Y, as shown in fig. 420, in which *A B* is the main track with two curves, *A a C* and *B b C*, laid as shown. If it is desired to turn a locomotive which is standing in the position of the dart, *A*, it is run on the curve, *A a C*, to the position of the darts, *a* and *C*. It is then run backward from *C* on the curve, *C b B*, as represented by the dart, *b*, and when it reaches the main track in the position of the dart, *B*, it is evident that its position will be reversed from that in which it was, at *A*, as is shown if we compare the direction of the dart, *A*, with that of *B*.

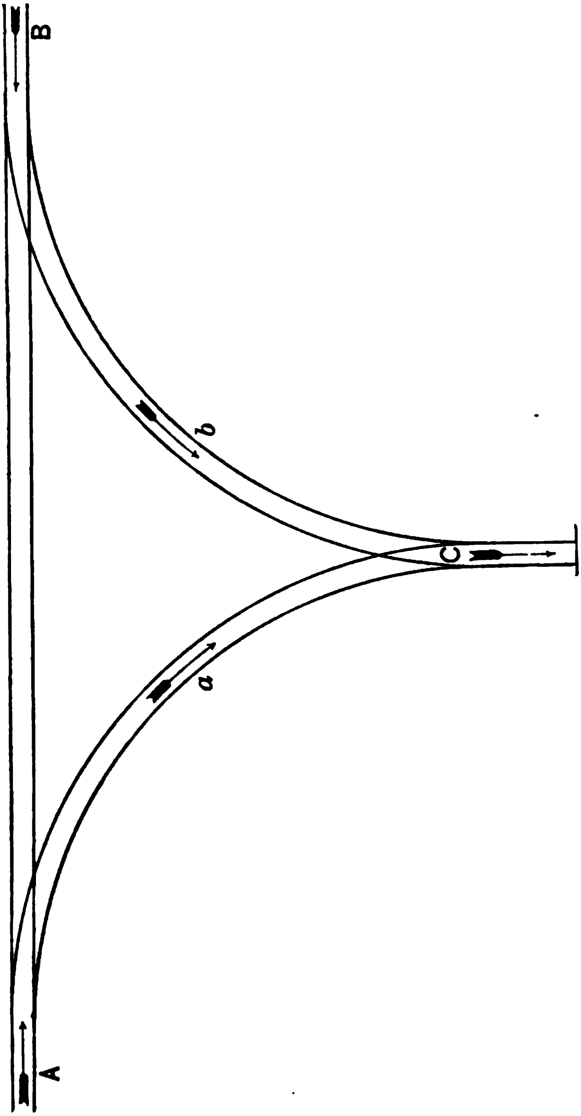


Fig. 490. The Y System for Turning Locomotives.

CHAPTER XXVI.

THE WESTINGHOUSE AIR-BRAKE.

QUESTION 614. *What are the brakes on locomotives, tenders, and cars for?*

Answer. The brakes are for the purpose of reducing the speed of such vehicles, or stopping them quickly when they are moving.

QUESTION 615. *How are brakes usually constructed and operated?*

Answer. The brakes which are most commonly used on railroads consist of metal or sometimes wooden shoes, which are attached to transverse beams, and suspended so that the shoes can bear or rub against the treads of the wheels. The beams are connected to levers, and the levers are connected together by rods and by a chain to a windlass, which is wound up by a crank or hand wheel, and the brake-shoes are thus pressed against the treads of the wheels, and the friction which is produced resists the motion of the vehicle and causes it to run slower or stops it.

QUESTION 616. *What difficulty is encountered in using brakes of this kind which are applied by hand?*

Answer. In cases of danger it takes too much time to apply them. If a fast-running train encounters any obstacle or obstruction on the track the brakes cannot be applied quickly enough to stop the train in time to avoid an accident.

QUESTION 617. *What was the air-brake designed for?*

Answer. It was designed to apply brakes quickly by means of compressed air instead of hand power, and also to place the control of the brakes in the hands of the locomotive engineer.

QUESTION 618. *How were the first air-brakes constructed?*

Answer. The first air-brake designed by Mr. Westinghouse consisted of an air-pump on the locomotive, driven by steam, for compressing the air, and a reservoir on the locomotive or tender for holding the compressed air. The tender and each car had a cylinder and piston underneath its body, the pistons being connected to the brake-levers. Each car had a pipe, called a *brake-pipe*, extending its whole length and connected to the brake-cylinder, the pipes on adjoining cars and the tender being connected together by flexible hose. The brake-pipe under the tender was connected to the air reservoir and had a valve, by which communication could be opened or closed between the pipe and the reservoir. The latter was pumped full of air of a pressure of about 45 lbs. per square inch. When it was desired to apply the brakes, communication was opened between the air reservoir and the train-pipe. The compressed air in the reservoir then flowed through the train-pipes to the cylinders and forced the pistons outward. The force exerted on the pistons was communicated to the brake-levers, thus pressing the brake-shoes against the wheels. This form of brake has been named the "*straight*" air-brake by the men who used it.

QUESTION 619. *What difficulty was encountered in using this form of brake?*

Answer. If the train consisted of more than a few cars, considerable time was required for the air to flow from the reservoir through the brake-pipes to the cylinders. When danger is imminent a very small fraction of time is of the utmost importance. It was therefore found that this form of air-brake would not act quickly enough in case of danger, and it was also found that in the event of the bursting of a coupling hose or brake-pipe, the supply of air to the cars behind the rupture was cut off and the air in the reservoir escaped, and the brakes would not work. As such ruptures were liable to occur at times when the brakes were most needed, it was a serious defect.

The couplings of the hose between the cars had check-valves, which closed when they were uncoupled, but when a train broke in two the brakes could be applied to the front end of it only and would stop it, whereas they had no control over the back portion, which was liable to run into the front part and thus cause a dangerous collision.

QUESTION 620. *How were these difficulties overcome?*

Answer. To meet these difficulties, Mr. George Westinghouse, Jr., devised and in 1872 patented what is called the Automatic Air-Brake, and which is now generally used on passenger and to some extent on freight trains in this country.

QUESTION 621. *How is the automatic air-brake constructed?*

Answer. Its general arrangement is shown in Plate VI, which represents a side view and plan of a locomotive, tender, and car, and a view looking at the back end of the locomotive. The pipes and reservoirs are colored blue, and the other parts of the brake are colored red. In fig. *A* the running gear of the tender and car are shown in section; fig. *B* is an end view looking at the back end of the engine, and in fig. *C* the bodies of the tender and car are supposed to be removed and are indicated by dotted lines only.

The automatic brake consists of the same parts as the first or "straight" air-brake had—that is, an air-pump, 1, figs. *A*, *B* and *C*; a main reservoir, 2, a brake-pipe, 3 3, 3′ 3′, 3″ 3″, for conveying air from the main reservoir to the tender and each car behind it; cylinders and pistons, 4, 4′, 4″, on each vehicle of the train, which are connected to the brake-levers and brake-beams as shown, and as will be more fully explained further on. The brake-pipe has a flexible hose connection, 5 5′ 5″, between adjoining vehicles which have suitable couplings for connecting and disconnecting the hose. Instead of having but one air reservoir on the engine or tender for holding compressed air, the automatic brake has besides separate or auxiliary reservoirs, 6 6′ 6″, on the locomotive, the tender, and each car. The air pump is connected to the main reservoir by a pipe, 7 7. The main reservoir is connected by another pipe, 8 8 8, to the engineer's brake-valve, 9. The brake-pipe, 3 3′ 3″, is connected to the engineer's valve and extends back under the tender and cars, and, as already explained, is connected together between the different vehicles by hose, 5 5′ 5″, and to the auxiliary reservoirs by pipes, 10 10′ 10″, and the auxiliary reservoirs are connected to the brake cylinders by other pipes, 11 11′ 11″. The pipes, 10 10′ 10″ and 11 11′ 11″, communicate with the auxiliary reservoirs through valves, 12 12′ 12″, called triple-valves, whose construction and operation will be explained further on.

The cylinders, 4 4′ 4″, have pistons which are connected to a system of brake-levers shown in the engravings. These levers are connected to the brake-beams, 13′ 13″, which have shoes, 15 15′ 15″, on their ends that bear against the treads of the wheels.

QUESTION 622. *How does the automatic air-brake operate?*

Answer. Its operation is as follows: Before the train starts steam is let on to the air-pump, which then pumps or compresses air which passes into the main reservoir, 2, through the pipe, 7 7. Communication is then opened by means of the engineer's valve, 9, between the pipe, 8 8, which is connected to the main reservoir and the brake-pipe, 3 3′ 3″.

The compressed air then flows from the main reservoir through the pipe, 8 8, engineer's valve, 9, and brake-pipe, 3 3′ 3″, thence through the branch pipes, 10 10′ 10″, and triple-valves, 12 12′ 12″, to the auxiliary reservoirs, 6 6′ 6″. When the reservoirs and brake-pipe are filled with compressed air of about 70 lbs. pressure per square inch, the train is ready to start.

The triple-valves are constructed so that as long as the brake-pipe is filled with compressed air communication between the auxiliary reservoirs, 6 6′ 6″, and the brake-cylinders, 4 4′ 4″, is closed, but as soon as the pressure in the brake-pipe is reduced the triple-valves open communication between the auxiliary reservoirs, 6 6′ 6″, and the brake-cylinders, 4 4′ 4″, through the pipes, 11 11′ 11″. If some of the compressed air in the brake-pipe is allowed to escape, and the pressure in it is thus reduced, the triple-valves will open, so that the air can flow from the auxiliary reservoirs into the brake cylinders, which will then force out the pistons and apply the brakes. The engineer's valve is constructed so that by turning a handle shown at 9, figs. *B* and *C*, it allows the air in the brake-pipe to escape, which reduces the pressure in the pipe. To apply the brakes, then, all that the engineer must do is to turn the handle of the valve, 9.

QUESTION 623. *After the brakes have been applied, how are they released?*

Answer. The handle of the engineer's valve, 9, is turned so that it closes the opening for the escape of the air from the brake-pipe, and at the same time it opens communication between the main reservoir, 2, and the brake-pipe. The compressed air stored in the main reservoir then flows into the brake-pipe, which closes the triple-valves, 12, 12′, 12″, and at the same time they allow the air in the cylinders, 4, 4′, 4″, to escape, and springs in the cylinders force the pistons inward and thus release the brakes.

QUESTION 624. *In practice what is essential in applying automatic brakes?*

Answer. In case of danger it is essential that the brakes should be applied as quickly as possible, and it is also important that the engineer should be able to apply them either gradually or as rapidly as circumstances may require—in other words, that he should be able to regulate the pressure on the brake-shoes to stop slowly or quickly, or to increase or release it at pleasure.

QUESTION 625. *What is meant by the automatic action of the brakes?*

Answer. It has been explained that when the pressure of the air in the brake-pipe is reduced, that the triple-valves open communication between the auxiliary reservoirs and the brake cylinders so that the compressed air in the reservoirs then flows into the cylinders and applies the brakes. If, therefore, a coupling hose should burst or a train brake in two, or any other accident should occur so that the compressed air in the brake-pipe would escape, the brakes would go on of themselves, or be applied *automatically*.

QUESTION 626. *On what does the automatic action of the brakes depend?*

Answer. Chiefly on the triple-valves and their connections with the auxiliary reservoirs and the brake cylinders. Fig. 421 is a perspective

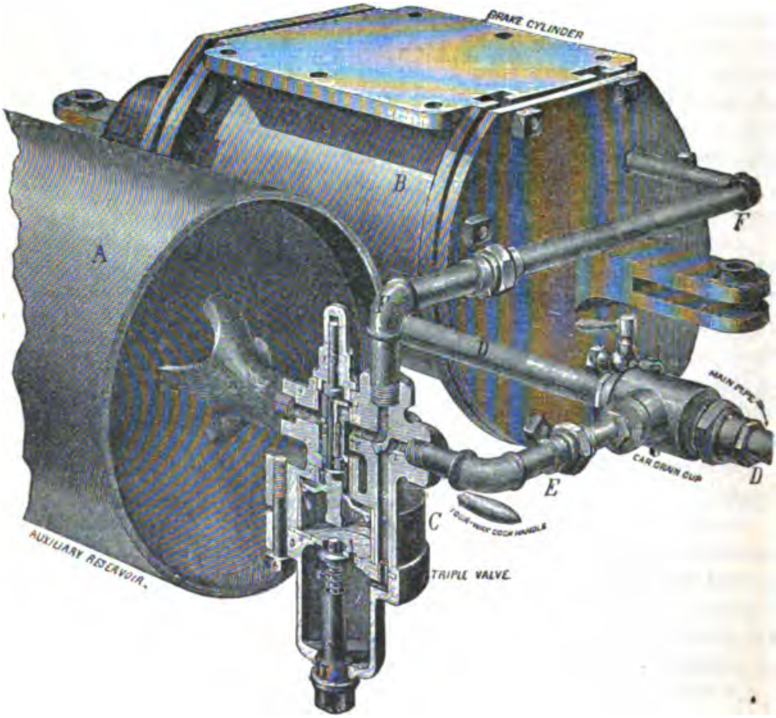


Fig. 421. Brake Cylinder, Auxiliary Reservoir and Triple-Valve.

view, and shows one end of the auxiliary reservoir *A*, the cylinder *B*, with the triple-valve, *C*, shown in section. *D D* is the brake-pipe, to which the triple-valve is connected by the pipe, *E*. The triple-valve is also connected to the cylinder, *B*, by the pipe, *F F*, and to the auxiliary reservoir by the connection, 2.

QUESTION 627. *How is the triple-valve constructed, and what is its operation?*

Answer. Its construction is shown in fig. 422, which represents a section of the valve. It consists of a piston, 5, which works in a cylindrical chamber, *B*. The rod or stem of this piston engages with a slide-valve, 6.

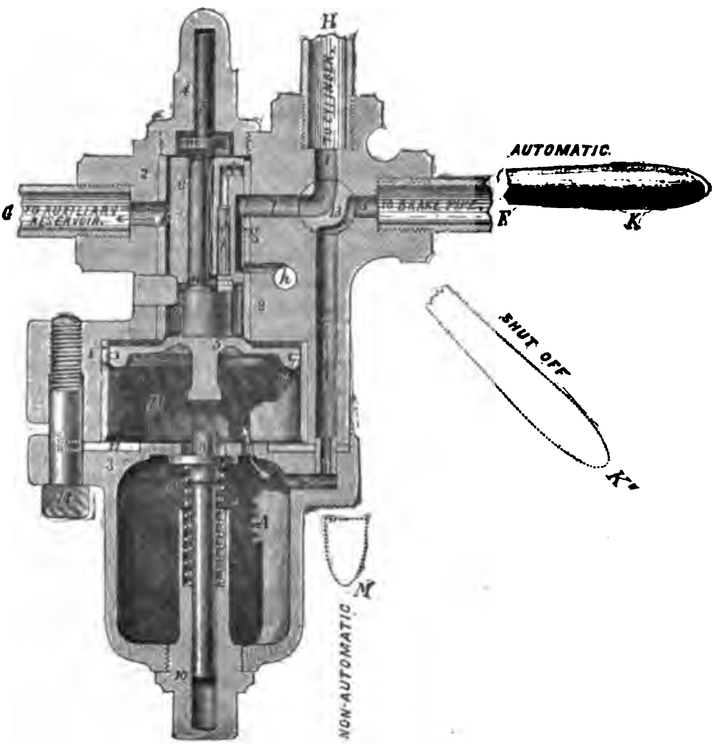


Fig. 422. Triple-Valve.

When the engineer's valve is turned so that there is communication from the main reservoir through the valve to the brake-pipe, the air from the reservoir enters the triple-valve at *F*, passes through the four-way cock, 13, by passages, *a b c*, and drain-cup, *A*, to the cylinder, *B*, forcing the piston, 5, into its normal position, as shown in the engraving. The air then flows through a small groove—shown at *i*, on the left-hand side of the piston—past the piston into the valve chamber, *C*, above it, and through the passage, *C k*, and pipe, *G*, into the auxiliary reservoir, while at the same time there is an open communication from the brake-cylinder to the atmosphere through the pipe, *H*, and passages, *d e f g h*. Air will thus continue to flow into the auxiliary reservoir until it is filled with air of the same pressure as that in the brake-pipe.

If, now, the air in the main brake-pipe, *F*, is allowed to escape by means of the engineer's valve, or through accident, such as the bursting of a hose, the pressure of the air in the brake-pipe, *F*, and chamber, *B*, below the piston, 5, will be reduced, whereupon the greater pressure in the auxiliary reservoir and above the piston, 5, will force it downward past the groove, at *i*, and close it. As the piston descends it moves the slide-valve, 6, with it and uncovers the passage, *f*, so as to permit air to flow directly from the auxiliary reservoir through the pipe, *G*, passages, *k f e d*, and pipe, *H*, into the brake-cylinder, which applies the brake.

To release the brakes, air from the main reservoir must be admitted, by means of the engineer's brake-valve, 9, Plate IV, into the main brake-pipe, *F*, fig. 422, from the main reservoir. As the pressure in the main reservoir is greater than that in the auxiliary reservoirs, it forces the piston, 5, and slide-valve, 6, upward and back to the position shown in the engraving, which allows the air in the brake-cylinder to escape through the pipe, *H*, and passage, *d e f g h*.

To apply the brakes gently, a slight reduction is made in the pressure in the main brake-pipe, *F*, which moves the piston down slowly. The slide-valve, 6, has a conical valve, 7, called a *graduating valve*, which closes the passage, *l*. A pin, *n*, in the piston-rod engages with the valve, 7, so that when the piston first begins to move downward it pulls the valve, 7, with it and opens the passage, *l*. As the piston moves further the collar, *m*, engages with the slide-valve and carries it downward with it until the port, *l*, is over the passage, *f*, and the piston, 5, comes in contact with the graduating stem, 8, and spring, 9. Air from the auxiliary reservoir then flows through holes (shown by dotted lines above 7), in the slide-valve, and then passes by the passages, *l f e d*, to the brake-cylinder. When the pressure in the auxiliary reservoir and in the cavity, *C*, above the piston has been reduced, by expanding into the brake-cylinder, until the air is of the same pressure as that in the main brake-pipe, the piston then pushes it up far enough to close the small valve, 7, and thus cuts off the air supply to the brake-cylinder, and causes whatever pressure there is in the brake-cylinder to be retained there, thus applying the brakes with a force proportionate to the reduction of pressure in the brake-pipe. If the pressure in the brake-pipe be again slightly reduced by the engineer's valve, the valve, 7, will again be opened by the piston, 5, and in this way, by repeated applications, the brakes can be applied gradually up to their full force. It will thus be seen that it is important to be able to regulate and control the pressure in the main brake-pipe. This is done by means of the engineer's brake and equalizing discharge valve which will be described farther on. For making a quick stop, a large volume of air may be let out of the train-pipe which causes the piston, 5, to descend its entire distance, compressing the graduating spring, 9, until it strikes the leather joint, 11. The upper edge of the slide valve, 6, now completely uncovers port, *f*, permitting a direct flow of the air from the reservoir to the brake-cylinder, through ports, *f e d*, applying the brakes to their full force.

QUESTION 628. *What is the four-way cock 13, fig. 422, for?*

Answer. This cock is used to shut off communication with the brake-cylinder and auxiliary reservoir with which it is connected, if from any cause it is desirable to have the brake on any particular car inoperative. To do this the handle *K*, which is connected to the plug, 13, of the cock is turned from a horizontal position, *K*, to an intermediate one, shown by the dotted lines at *K''*. This leaves the main brake-pipe unobstructed to supply air to the other vehicles in the train. If the handle, *K*, of the cock is turned down to the position indicated by the dotted lines at *M*, there will then be a direct communication from the main brake-pipe to the brake-cylinder through a channel, *a e d*, and pipe, *H*—the triple-valve and auxiliary reservoir being cut out—and the apparatus can be worked as a non-automatic brake by admitting air into the main brake-pipe and brake-cylinder to apply the brakes.

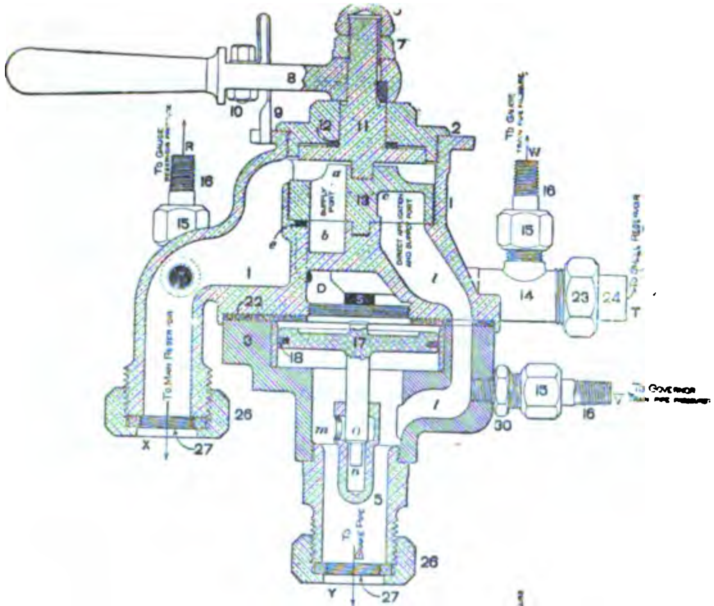
QUESTION 629. *What is the lower chamber, A, for?*

Answer. This is called a *drain-cup*, and its object is to collect any water which may accumulate in the pipes. The water can be removed by unscrewing the plug, 10, in the bottom of the cup.

QUESTION 630. *Why is it absolutely essential to have an excess of pressure in the main reservoir over that in the main pipe and auxiliary reservoirs?*

Auswer. When the brakes are applied, as has been explained, the piston, 5, in the triple-valve, fig. 422, is forced down in the cylinder, *B*. To release the brakes this piston must be forced up in the cylinder to the

Fig. 423.



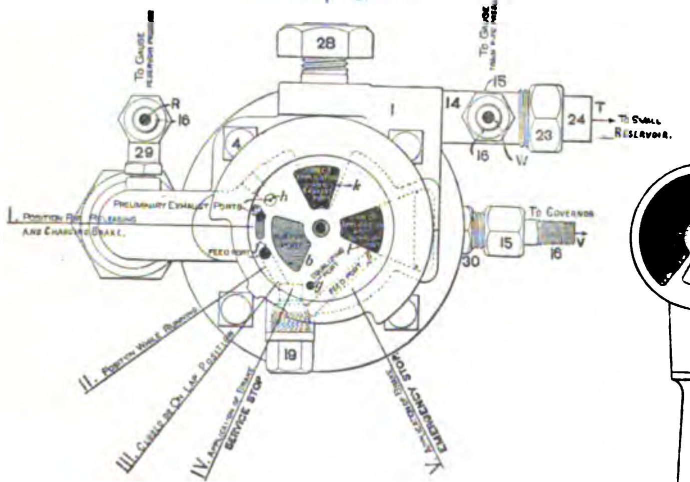


Fig. 424.

Engineer's Brake-Valve. Scale ¼ in.—1 in.

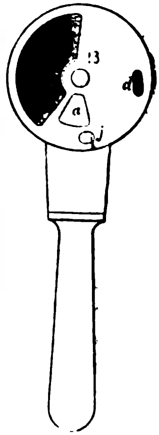


Fig. 425.

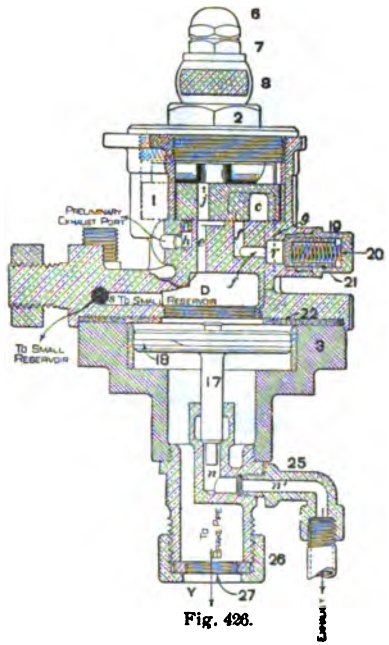


Fig. 426.

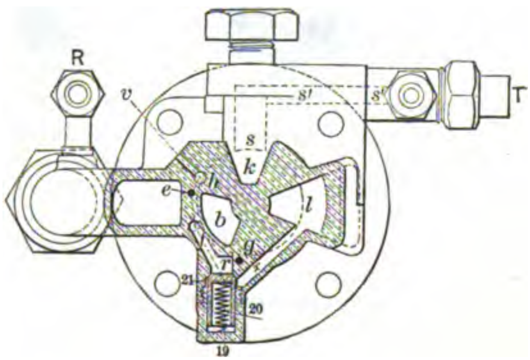


Fig. 427.
Engineer's Brake-Valve. Scale ¼ in.—1 in.

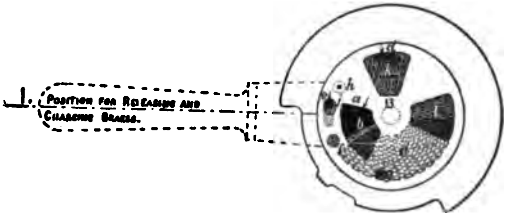


Fig. 428.

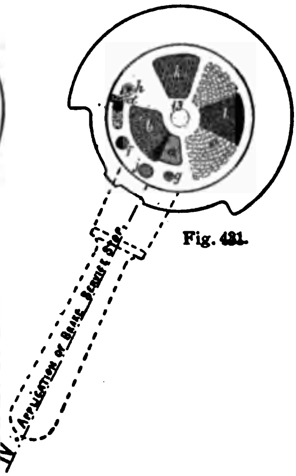


Fig. 431.

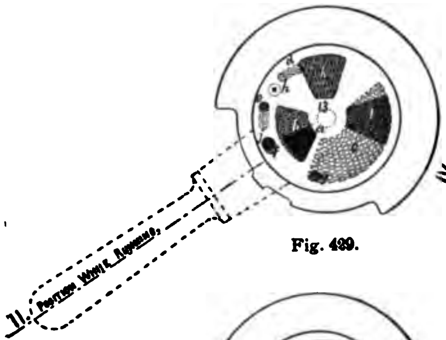


Fig. 429.

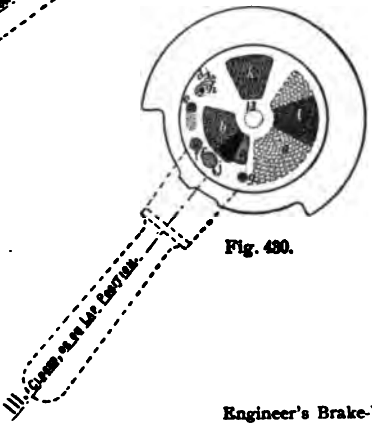


Fig. 430.

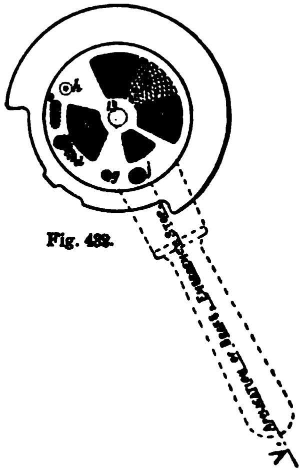


Fig. 432.

Engineer's Brake-Valve.

position shown in the engraving. To do this promptly and with certainty *it is absolutely essential* in long trains, and *is of great importance* in short ones, to have an *excess* of pressure in the main reservoir, so that when air is admitted to the brake-pipe the pressure below the pistons in the triple-valves will be considerably greater than that above it. If it is not considerably greater it may not be sufficient to raise the pistons into the position they must occupy to release the brakes. The method of increasing the pressure in the main reservoir will be explained further on.

QUESTION 631. *How is the engineer's brake and equalizing discharge valve constructed, and how does it operate?*

Answer. The construction of this valve is shown in figs. 423 to 432, fig. 423 being a vertical section on the line, *I V*, of fig. 424, the latter being a plan with the valve, 13, removed, and fig. 426 is a similar section on the irregular line, *v h e f r* 19, of fig. 427; fig. 427 is a horizontal section just below the valve, 13, of 423. The pipe, *X*, fig. 423, connects with the main reservoir, and *Y* with the brake-pipe. Fig. 425 is an inverted plan of the rotary valve, 13. This valve has an opening or "*supply port*," *a* (shown also in fig. 423), and a cavity, *c*, in its under side analogous to the exhaust cavity in an ordinary locomotive slide-valve. This cavity is represented by shade lines in the plan, and by dotted shade lines in figs. 428 to 432. The valve has another small port, *j*, which passes entirely through it—as shown in fig. 426—and a small cavity, *d*, fig. 425, also indicated by dotted shade lines in the various plans.

Fig. 428 represents a plan of the rotary valve, 13, on its seat, in the position it would be placed to release the brakes, and where it would be left when the engine has completed its run. To prepare for another run, steam is turned on and the air-pump is started, which forces air into the main reservoir, which is connected to the engineer's valve by the pipe, *X*, fig. 423. When the rotary valve is in the position shown in fig. 428, the *supply-port*, *a*, in the valve is over the cavity, *b*, in the valve-seat. This cavity is also shown in figs. 423 and 424, and in figs. 428 to 432 the part which is uncovered by the port, *a*, is represented by black shading, and that which is covered by the valve is shaded with white dotted lines. When the valve is in the position shown in fig. 428, the cavity, *c*, in its under side is over the supply cavity, *b*, and also over the port, *l*, which is connected with the main brake-pipe, *Y*, as shown in fig. 423. When the valve is in the position shown, air can flow from the main reservoir up through the pipe, *X*, fig. 423, into the supply port, *a*, in the valve, and into the cavity, *b*, in the valve-seat, then up into the cavity, *c*, in the under side of the valve, and from there down into the *direct application and supply port*, *l l*, which communicates with the main brake-pipe, *Y*, from which it passes to the triple-valves and through them to the auxiliary reservoirs. When the rotary valve is in this position, the port, *j*, in the valve, fig. 428, is over the port, *e*, figs. 423 and 424, in the seat, which is connected with the chamber, *D*, as shown by dotted lines in fig. 423. Air from the main reservoir can therefore flow into the chamber, *D*, above the piston, 17, and thence through the port, *s*, which communicates with the pipe, *T* (as shown by dotted lines, *s s' s'*, fig. 427), and thence to a small reservoir, 16, Plate VI, called the "*engineer's brake-valve reservoir*," which is usually suspended under the running-board of the engine. The purpose of this reservoir is to add to the volume of the chamber, *D*.

When the auxiliary reservoirs are filled with compressed air the rotary valve is then turned to the II, or "*while running*" position, indicated by the line II, in fig. 424, and as represented in 429. In this position the valve has moved so far that there is no longer communication between the supply port, *b*, in the valve-seat, the cavity, *c*, in the valve and the port, *l*, in its seat. A small hole, *j*, in the valve then comes over the small feed-port, *f*, in the seat, which is connected to the cavity, *r*, under the "*feed-valve*," 21, as shown in figs. 426 and 427, so that the air can then flow from the main reservoir through the brake-pipe, *X*, port, *j*, and passage, *f*, into the cavity, *r*, fig. 427. The feed-valve, 21, is pressed down on its seat by a spiral spring, 20, which has a resistance equivalent to a pressure of air of about 20 lbs. per square inch. When this additional pressure is accumulated in the main reservoir, the feed-valve is forced open, and the air which escapes passes through the "*feed-port*" or channel, *x*, fig. 427, to the port, *l*, and thence to the brake-pipe, *Y*, fig. 423. At the same time air can pass from the port, *l*, see fig. 429, into the cavity, *c*, under the valve, and thence down through the "*equalizing port*," *g*, in the valve-seat, which, as shown, by dotted lines, in fig. 426, communicates with the cavity, *D*, above the piston, 17. The same pressure is therefore maintained in the chamber, *D*, that exists in the feed-port, *x*, so that the pressure above and below the piston is thus equalized. The stem, *o*, of the piston, fig. 423, forms a small conical valve which is seated above the passage, *n*, and closes it when down. The area of the opening below the valve is reduced by a teat attached to the stem, so as to regulate the escape of air from the train pipe to the atmosphere, through the passages, *m n*. The passage, *n*, communicates with the atmosphere—see fig. 426—so that if the piston is moved upward and opens the valve, *n*, it allows air in the brake-pipe to escape. It will thus be seen that when the rotary-valve is in position II, fig. 429, that the same pressure is maintained in the chamber, *D*, fig. 423, that exists in the brake-pipe. When the rotary valve, 13, is in this position no air can pass from the main reservoir to the brake-pipe until the pressure in the main reservoir is sufficient to open the feed-valve, 21, which requires a pressure of 20 lbs. per square inch. As the pressure in the brake-pipe is exerted against the opposite side of the valve, 21, it will require an excess of pressure of 20 lbs. in the main reservoir over that in the brake-pipe before the valve, 21, will be opened, and when it does open, air from the main reservoir will flow from the pipe, *X* (see figs. 424 and 427), port, *j*, passage, *f*, into the cavity, *r*, and thence through the feed-port, *x*, into the cavity, *l l*, and brake-pipe, *Y*. Consequently, when the rotary-valve is in the position II, the pump will fill the main reservoir with air of a pressure 20 lbs. greater than that in the brake-pipe, the object of which has already been explained, and which is very essential in the operation of the brakes.

To apply the brakes for making ordinary stops at stations, or service stops, as they are called, the handle, 8, fig. 423, of the rotary-valve is turned into position III, figs. 424 and 430. When in this position all communication through the valve and its seat is closed. The valve handle should then be moved to the IV position, or that for the "application of brakes for service stop," shown in fig. 431. The small exhaust cavity, *d*, figs. 425 and 431, on the under side of the rotary-valve, 13, then establishes communication between the two "*preliminary exhaust-ports*," *e* and *h*, figs. 424 and 431, in the valve-seat. The first of these, *e*, connects with the chamber, *D*, as shown in fig. 426, and the second, *h*, leads to the atmosphere (see fig. 427). Air can therefore escape up from the chamber, *D*, see fig. 423, through the passage, *e*, cavity, *d*, and down the passage, *h*, to the atmosphere. It will be remembered that the chamber, *D*, is connected by the passage, *s*, *s'*, and pipe, *T*, figs. 423 and 427, with the engineer's brake-valve reservoir, 16, Plate VI. A pressure-gauge, 21, Plate VI, is connected by a pipe to the branch, *W*, fig. 423, which communicates with the chamber, *D*, through passage, *s s'*.

The gauge, 21, has two sets of works in it, one of them connected as described, and the other connected by a pipe to the one which leads to the main reservoir. The two hands of the gauge thus indicate the pressure in the main reservoir and also in the chamber, *D*, in the engineer's brake-valve, fig. 423.

In making an ordinary stop, after the pressure in *D* has been reduced about 8 lbs., the handle of the engineer's valve should be restored to the III, or closed position. This reduction of pressure in *D* will cause the air below the piston, 17, fig. 423, to force it and its stem upward, which will open the valve at *n*, and allow air in the brake-pipe, *Y*, to escape to the atmosphere through the ports, *m*, and passage, *n'*, thus applying the brakes gently. This discharge of air continues after the valve-handle is carried to the III, or "closed" position—which allows the pressure in the brake-pipe to gradually equalize itself through the whole length of the train—and the escape of air from the brake-pipe does not cease until the pressure in it has been reduced slightly lower than that yet remaining in the chamber, *D*, above the piston. The latter is then forced downward, which closes the outlet at *n*, and prevents the further escape of air, until the operation is repeated, which may be necessary to apply the brakes with the desired force.

QUESTION 632. *What difficulty in the application of brakes is the feature of the engineer's brake and equalizing valve, which has been described last, intended to overcome?*

Answer. In applying the brakes, especially on long trains, if the engineer, instead of allowing the air to escape slowly from the brake-pipes, allows a considerable amount of air to escape in a short time and then closes the valve suddenly, the air is exhausted from the front end of the brake-pipe which applies the brakes on the front cars before the pressure in the pipe has equalized itself. The air in the back end of the pipe then rushes forward, and if the valve has been closed suddenly this rush of air acts on the triple-valves and is liable to release the brakes on the front cars. To avoid this difficulty, the opening of the passage, *h*, figs. 424 and 426, in the valve-face is made extremely small, so that the pressure in the chamber, *D*, will not be reduced too rapidly, and the chamber, *D*, is connected with the brake-valve reservoir, 16, Plate VI, so that the volume of air which must be discharged before the brakes are applied is much greater than that contained in the chamber, *D*. As soon as the pressure above the piston, 17, fig. 423, is reduced lower than that below it and in the brake-pipe, *Y*, the piston moves upward slowly and opens the valve, *o*, which permits the air in the brake-pipe to escape through the passage, *n'*, fig. 426. This discharge of air continues after the rotary-valve, 13, has closed the opening, *h*, for the escape of air from the chamber, *D*, and does not cease so long as there is any difference in the pressure above and below the piston, and until the pressure in the brake-pipe has been equalized and reduced slightly lower than that yet remaining above the piston.

So long as there is more pressure below the piston than above it the valve, *o*, remains open, and is closed very gradually as the pressure in the brake-pipes is reduced. This, as has been explained, permits the pressure in the brake-pipe to become equalized, and secures a uniform application of the brakes through the whole length of the train.

When the pressure in the brake-pipe is reduced a little below that above the piston the latter is forced down, and closes the valve, *o*, which prevents the further escape of air until the rotary-valve handle is again moved to the IV position, fig. 431, and the operation is repeated.

QUESTION 633. *How are the brakes released?*

Answer. The rotary-valve handle, 8, fig. 423, is turned back to the I position, or that "for releasing brakes," shown in fig. 428. This, as already described, allows air from the main reservoir to flow up through the pipe, *X*, fig. 423, down through the port, *a*, in the rotary-valve, into the cavity, *b*, in the valve-seat, and from there up into the cavity, *c*, in the under side of the valve, and thence down into the passage, *l l*, and to the brake-pipe, *Y*. The pressure in the latter, as has been explained, acts on the triple-valve, which closes communication between the auxiliary reservoirs and brake-cylinders, and allows the air in the brake-cylinders to escape.

QUESTION 634. *In case of imminent danger or any emergency, how is the brake operated?*

Answer. In such an event it is, of course, essential to apply the brakes as quickly and as forcibly as possible. To do this the handle of the rotary-valve is moved to the V or "emergency stop position," figs. 424 and 432. The chamber, *c*, in the under side of the rotary-valve then comes over the port, *l*, in the seat, which connects with the brake-pipe and also over the port, *k*, which communicates with the atmosphere. This establishes direct communication between the brake-pipe and the open air, and permits the air in the brake-pipe to escape quickly through the large openings of the ports referred to.

QUESTION 635. *Where is the air pump for operating the brakes usually located?*

Answer. It is generally attached to the right-hand side of the fire-box or further forward on the boiler. See 1, Plate VI.

QUESTION 636. *How is the air pump constructed?*

Answer. Fig. 433, which represents a vertical section of such a pump, shows its construction. It consists of a steam cylinder, 3, and an air cylinder, 5. Both of these cylinders have pistons, 11 and 14, which are connected together by a piston-rod, 11. Steam taken from the locomotive

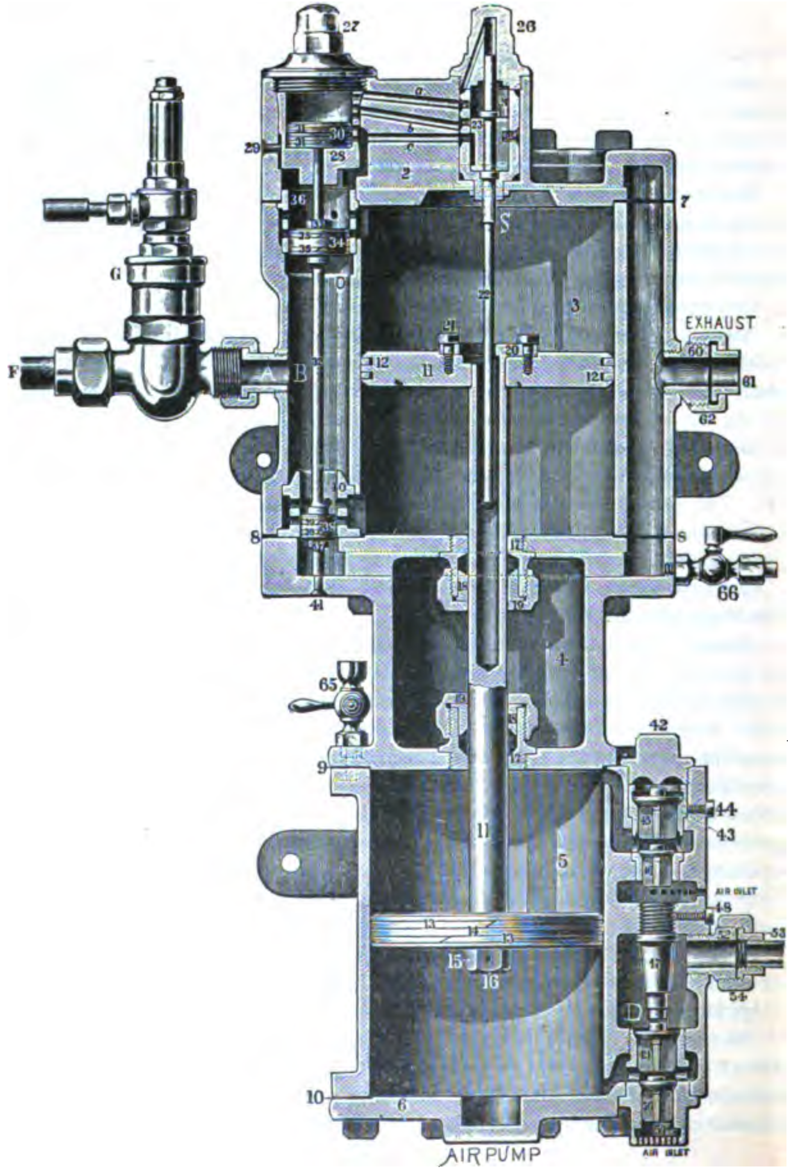


Fig. 433. Brake Air Pump.

boiler is admitted to the upper cylinder by a pipe, *F*, and passage, *A*. The upper piston, 11, is operated by the steam pressure in the cylinder, 3, and moves the lower one, 14, which compresses the air in cylinder, 5. The steam from the boiler enters the cylinder, *B*, between the two small piston-valves, 34 and 38. The upper piston, 34 being of greater diameter than the lower one, the tendency of the pressure is to raise the pistons, unless they are held down by the pressure of a third piston, 30, of still greater diameter, which works in a cylinder directly above, 34, and bears on the rod, 32. The pressure on this third piston is regulated by the small slide-valve, 23, which works in the central chamber, 24, on the top cylinder-head. This valve receives its motion from a small rod, 22, which is connected to the valve, 23, and extends into the hollow piston rod, 11. The small rod has a knob on its lower end and a shoulder, *S*, just below the top cylinder-head. A steam passage connects the valve chamber, 24, with the steam space, *B*, between the pistons, 34 and 38. The steam acting on the third piston, 30, holds the piston-valves, 34 and 38, down and at the same time steam enters the cylinder, 3, through the openings at 40 and pushes the main piston, 11, up in its cylinder. As the main piston approaches the upper end of the cylinder, the shoulder, 20, on the piston strikes the shoulder, *S*, on the rod, 22, and pushes it and the valve, 23, upward. This allows the steam in the cylinder, *C*, to escape, and relieves the pressure above the piston, 30. The steam pressure below the piston-valve, 34, then pushes it and the valve, 38, upward, which admits steam into the upper end of the cylinder, 3, through the openings in the cylinder, 36, and also allows that in the lower end to escape through the openings at 38. The piston, 11, is thus forced down in the cylinder until the shoulder, 20, comes in contact with the knob on the end of the rod, 22, which moves the slide-valve, 23, and again admits steam into the cylinder above the piston, 30, and the action is repeated. The exhaust chambers at 36 and below 38, communicate with the pipe, 61, through which steam is exhausted. This pipe is indicated by 25, in Plate VI.

QUESTION 637. *How is the air cylinder of the air pump constructed?*

Answer. It has air inlets at 48 and 51 and conical valves, 45, 46, 49, and 50, above and below these inlets. When the piston, 14, descends it compresses the air below it, which closes valve 50 and raises and opens 49, so that the compressed air passes into the chamber, *D*, and through the pipe, 53—indicated by 7, in Plate VI—into the main reservoir. At the same time a partial vacuum is produced above the piston, which causes the atmospheric pressure below valve 46 to raise it, thus allowing air to flow into the cylinder through the air inlets at 48. The chamber above 45 is connected with the chamber, *D*, and main reservoir, so that when the pressure in them is greater than that below the valve, 45, it is forced down on its seat and closed. The reverse action takes place when the piston, 14, ascends—that is, valve 50 opens to admit air below the piston and 49 is closed by the pressure above it. At the same time 46 is closed and 45 opens, so that the air which is compressed above the piston flows through the valve, 45, to the chamber, *D*, and thence into the main reservoir.

QUESTION 638. *How is the action of the air pump regulated?*

Answer. By means of what is called a pump governor, indicated by 22, in Plate VI, and by *G*, in fig. 433, on the left-hand side of the pipe connection, at *A*, and shown in a vertical section in fig. 434.

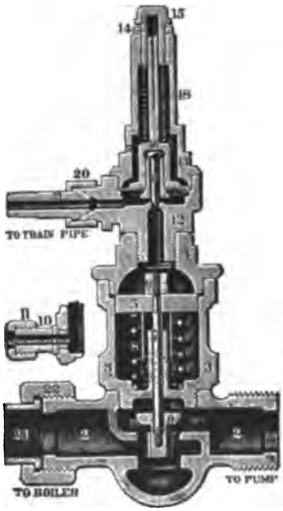


Fig. 434. Brake-Pump Governor.

QUESTION 639. *What is the construction and action of the pump governor?*

Answer. One end, 23, of the horizontal pipe, 2 2, is connected to the boiler and the other end to the pump. The chamber, 2 2, has a division and a valve, 9, between the two ends. The valve is connected by a stem, 7, to a piston, 5, which bears on a spiral spring, 8. 19 is a diaphragm which is pressed down by another spiral spring, 18, which resists a pressure under the diaphragm of about 70 lbs. per square inch. A small conical valve, 17, is connected to the diaphragm, and opens and closes an opening below it and above the piston, 5. The space below the diaphragm is connected by a pipe, 21, to the brake-pipe. When the air pressure below the diaphragm exceeds 70 lbs. it raises it and opens the valve, 17, which admits compressed air above the piston, 5, which is forced down, thus closing the valve, 9, and shutting off steam from the pump. The air in the chamber above the piston then leaks past the piston, 5, and escapes from it into the open air, through an opening represented by dotted lines. When the pressure in the brake-pipe, 21, is reduced, the spring, 18, closes the valve, 17, so that the action of the spring, 8, and the pressure below the valve, 9, opens it and admits steam to the pump.

QUESTION 640. *How are the brake-cylinders and pistons constructed?*

Answer. The construction of a brake-cylinder is shown in section by fig. 435. It is a simple cylinder with a piston, 8, which has leather pack-

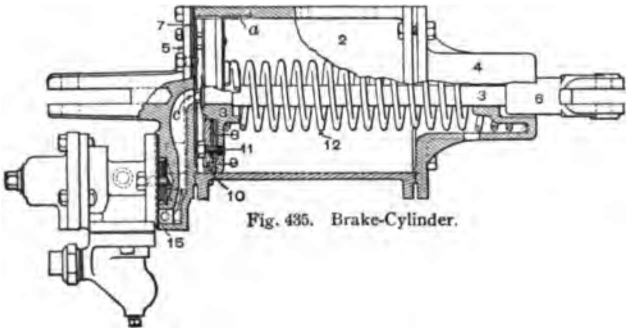


Fig. 435. Brake-Cylinder.

ing, 9, and a piston-rod, 3. The piston-rod, after being driven out by compressed air, is forced back again, when the air is released, by a spiral spring, 12, which is wound around the piston-rod.

To prevent the application of the brakes from a slight reduction of pressure, caused by leakage in the brake-pipe, an oval groove $\frac{3}{64}$ inch wide, and $\frac{5}{64}$ inch deep, and 3 inches long—shown at *a*, at the top of the piston, in fig. 435—is cut in the body of the brake-cylinder, of such a length that the piston must travel 3 inches before the groove is covered by the packing leather. A small quantity of air, such as results from a leak, passing from the triple-valve into the cylinder, has the effect of moving the piston slightly forward, but not sufficiently to close the groove. This permits the air to flow out past the piston. If, however, the brakes are applied in the usual manner, the piston will be moved forward beyond the groove, notwithstanding the slight leak.

QUESTION 641. *How are the brake-pipes on the locomotive tender and cars connected together?*

Answer. By flexible hose, 5 5′ 5″, Plate VI, between the different vehicles in the train. The hose are attached at one end to the brake-pipes and are connected together between the different vehicles in the train by couplings, shown by figs. 436 and 437. Cocks, 29′ 29″, Plate VI,

Fig. 436.

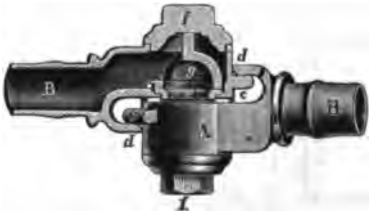


Fig. 437.
Hose Connections.

are attached to the ends of the brake-pipes on each car and at the back end of the tender. The end of the pipe which comes at the end of the train can thus be closed to prevent the air in the brake-pipe from escaping.

QUESTION 642. *What arrangement is made for applying the brakes from the inside of the cars?*

Answer. A vertical pipe with a cock or valve, 28″, Plate VI—called a "*conductor's valve*"—on the upper end is connected to the brake-pipe on each car. By opening this valve the air in the brake-pipe can escape which applies the brakes. A cord which extends the whole length of the car is usually connected to this valve, so that it can be pulled from any part of the car.

QUESTION 643. *How is the moisture which condenses in the inside of the pipes and reservoirs removed?*

Answer. A cup, called a drip-cup, is connected to the brake-pipes below the tender, from which the water that collects in it is drawn by means of a cock in the bottom of the cup. There are also cocks, 20′ 20″, Plate VI, attached to each auxiliary reservoir, and when they are opened, if there is any water in the reservoirs it can escape.

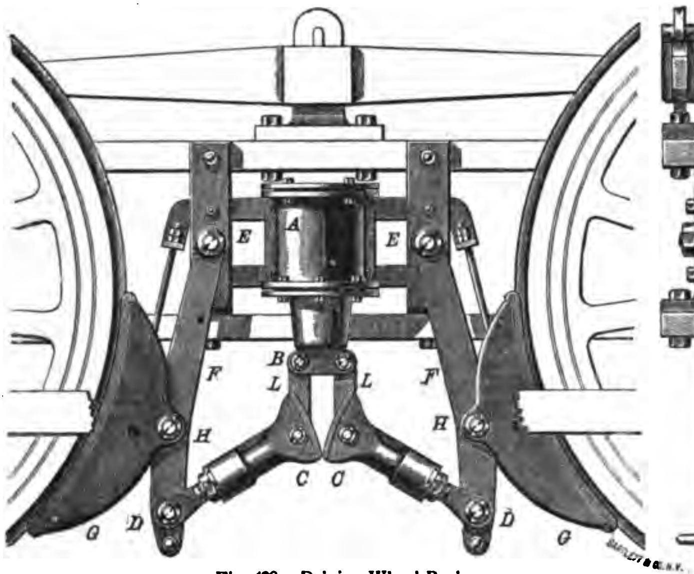


Fig. 438. Driving-Wheel Brake.

Fig. 439.

QUESTION 644. *How are the air-brakes on the locomotives arranged?*

Answer. The brake-shoes, 15 15, are usually applied to the driving-wheels, and are located between these wheels, as shown in Plate VI and fig. 438, which is a side view, and fig. 439 an end view, showing the arrangement of the brakes in relation to the wheels. A brake-cylinder, *A*, is placed on each side of the engine, the piston-rods of which work through the lower head. The rods have cross or T-heads, *B*, on their lower ends, which are connected by links, *L L*, to the cams, *C C*. These cams are connected to the levers, *F F* at *D D*. The levers have break-blocks, *G G*, attached to them by pins at *H H*. The surfaces of the two cams which are in contact with each other are eccentric to the centre of the pins, *D D*, and when they are pressed down by the piston, they force their lower ends, *D D*, and levers, *F F*, outward, which presses the brake-blocks against the wheels. 6, Plate VI, is the auxiliary reservoir for the engine or "*driver-brakes*," as they are called, and 12 is the triple-valve by which the brake on the engine is operated. 11 is the pipe which supplies the driver-brake reservoir with compressed air, and 10 is the pipe by which it is conveyed from the triple-valve to the break-cylinders, 4 4.

QUESTION 645. *What is meant by the term "straight air-brake?"*

Answer. As explained in answer to Question 618, this term is used to designate the first form of the Westinghouse air-brake, in which there were no auxiliary reservoirs under the cars, the compressed air being stored in a main reservoir on the engine or tender, from which it flowed direct through the brake-pipe to the brake-cylinders under the different vehicles. The brakes were released when communication was closed between the main reservoir and the brake-pipe, and opened from the brake-pipe to the atmosphere by means of the engineer's valve. When "straight air" is applied it flows direct through the brake-pipe to the brake-cylinders, and the auxiliary reservoirs, triple-valves, and pressure-retaining valves are not used, and the brake has no automatic action.

QUESTION 646. *How can the automatic brake be used as a straight air-brake?*

Answer. The old form of automatic brake can be converted into a straight air-brake by simply turning the handle, *K*, fig. 422, of the four-way cock on the triple-valve downward to *K'''*, so as to stand in a vertical (|) position; the cock then opens direct communication from the brake-pipe to the brake-cylinders through the channels, *a e d*. With the new quick-acting triple-valve, which will be described further on, the automatic brake cannot be converted into a straight air-brake.

QUESTION 647. *When should the automatic brake be used as a straight air-brake?*

Answer. In case of serious leakage of pipes, or other defect which prevents the use of the automatic brake, the handle of the four-way cocks of all the triple-valves, excepting those on vehicles on which the brakes are

cut out, should be turned downward, and the train can then be run with "straight air" to the terminus. It is better to do this than to depend upon the use of the hand-brakes; but all the brakes which are in use (that

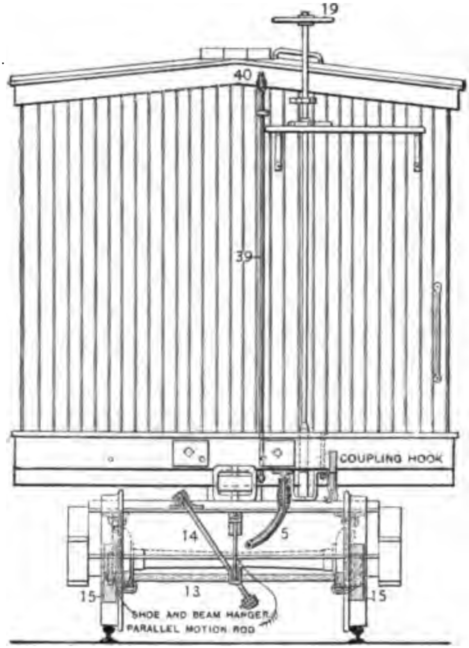


Fig. 442.

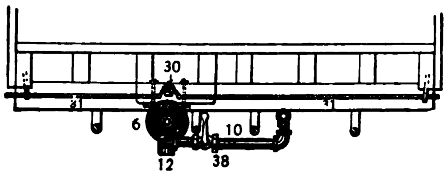


Fig. 443.
Freight Car Brake. Scale ¼ in.=1 ft.

is, that are not cut out) on a train must be operated either by "straight air" or automatically, as the two systems will not work together on the same train.

QUESTION 648. *How do the air-brakes for freight trains operate, and how are they constructed?*

Answer. The action of brakes on freight trains is the same as on passenger trains, although the form of construction is somewhat different. Fig. 440 is a side elevation, and fig. 441 an inverted plan, fig. 442 an end view, and fig. 443 a transverse section of a freight car with brake attached, and fig. 444 is a section of the cylinder and auxiliary reservoir. The construction of the cylinder is substantially the same as that used on passenger trains. The auxiliary reservoir, 10, is, however, made of cast iron, and is attached to the brake-cylinder head, 14, as shown in fig. 444.

QUESTION 649. *What provision is made on freight train brakes for descending long grades?*

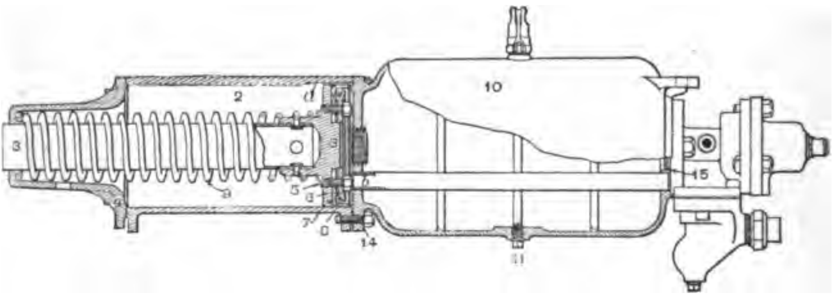


Fig. 444. Brake Cylinder and Auxiliary Reservoir.

Answer. What is called a "*pressure-retaining valve,*" 40, figs. 440 and and 442, is connected by a pipe, 39 39, with the discharge port of the triple-valve, 12. An enlarged section of this valve is shown by fig. 445. 5 is the valve which opens and closes the passage or pipe, *b b*. The valve has a weight, 3, which presses it down. A pressure of about 15 lbs. in the pipe, *b b*, is sufficient to raise this weight and allow the air to escape at the opening, *c*. 4 4 is a three-way cock which, in the position shown—with the handle horizontal—closes the opening, *a*, so that the air can escape only under the valve, 5, and opening, *c*. As the valve is weighted, no air can escape until its pressure is sufficient to raise the weight, 3. Consequently, if the handle of the cock is turned to a horizontal position in descending long grades, a pressure of about 15 lbs. is retained in the brake-cylinder, which keeps the train under control when otherwise the brakes would be released to recharge the reservoirs. On slight grades or a level the handle of the cock should be turned down, which opens communication between the pipe, *b*, and opening, *a*, which allows the air to escape freely from the discharge port, *a*, of the pressure-retaining-valve.

QUESTION 650. *What difficulty was encountered in operating air-brakes on long freight trains?*

Fig. 445. Pressure-Retaining Valve.

Answer. In some tests made with long freight trains it was found that the triple-valve, shown in fig. 422, and which has been described, in answer to Question 627, would not apply the brakes as quickly as was considered desirable. For that reason the quick acting triple-valve represented in section, in fig. 446, was designed by Mr. Westinghouse.

QUESTION 651. *How is this valve constructed and how does it act in ordinary braking?*

*Answer.** The outside shell or casing of this valve has three openings, *R*, *S*, and *T*. *R* is connected to the auxiliary reservoir, *S*, to the brake-cylinder, and *T* to the brake-pipe. The latter branch communicates by means of the passages, *Q D D'*, and openings, *l l*, with a cylinder, B, in which the triple-valve piston, 5, works. The chamber, *C*, on the opposite side of this piston contains a slide-valve, 6, and is in direct connection with the auxiliary reservoir through the branch, *R*, and when the piston is

* Much of the following description was taken from one which originally appeared in *Engineering*.

in the position shown in the engraving, compressed air from the brake-pipe, *T*, can flow through the chanels, *Q D D' l*, and through a groove, *E*, in the cylinder past the piston, 5, until the pressure in *C* and in the auxiliary reservoir is equal to that in the train-pipe. At the same time

Fig. 447.

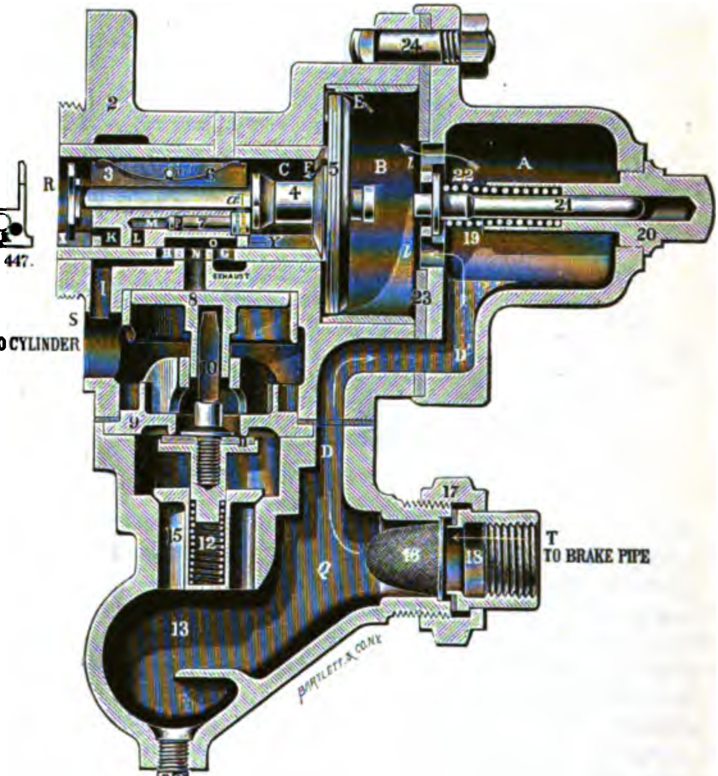


Fig. 446.
Quick Acting Triple-Valve.

the branch, S, and the brake-cylinder are connected to the atmosphere through the passage, *I*, the port, *H*, the cavity, *O*, in the slide-valve, 6, and the port, *G*, which communicates with the open air. Fig. 449 represents a plan of the valve face with a sectional plan of the valve on it in the same position as it is shown in fig. 446. The section of the valve is drawn on the line *X Y*, of fig. 446. If, now, when the slide-valve is in the position, shown in figs. 446 and 449, the pressure in the train-pipe, *T*, is slightly reduced by opening the engineer's valve, the pressure in the cylinder, *B*, will also be reduced, and the piston, 5, will be moved to the right, as shown in fig. 450 * by the expansion of the air in the auxiliary reservoir. Under ordinary circumstances, however, the piston will be moved through only half of its available travel, in consequence of the pressure in the reservoir being reduced to that in the train-pipe by a part of the air flowing into the brake-cylinder in the following way: The stem, 4 4′, of the piston passes through the slide-valve, 6—the connection between the two being so made that the piston can move a small distance without moving the valve. The slide-valve contains a small conical valve, 7, called a "*graduating valve*," which is seated in a cavity in the valve, and is shown in figs. 446, 450, and also in the horizontal section of the slide-valve, fig. 448, which is drawn on the centre line of the valve, 7. This conical valve is connected to the slide-valve stem, 4, 4′, by a pin, *a*, shown by dotted lines on figs. 446 and 450, so that when the piston moves, it first carries with it and opens the valve, 7. This allows air which enters through the passages, *P P*, figs. 448 and 450, to flow into the passage, *M*. The continued movement of the piston carries the slide-valve, 6, to the right into the position shown in fig. 450, and also in fig. 451 —the latter again represents a plan of the valve face with a horizontal section of the valve drawn on the line, *X Y*, of fig. 450, and it is shown in the same position in 451 as in fig. 450. By comparing figs. 446 and 449 with 450 and 451 it will be seen that the movement of the valve to the position shown in figs. 450 and 451 first closes the connection of the port, *H*, with the atmosphere through the cavity, *O*, and then brings the port, *L*, in the valve over the port, *H*, in the valve seat. The air can then flow from the chamber, *C*, and auxiliary reservoir through the openings, *P*, passage, *M*, port, *L*, port, *H*, and passage, *I*, into the brake-cylinder, when it acts on the piston, and thus applies the brakes. As soon as the pressure in *C* has fallen slightly below that in the brake-pipe, the pressure on the opposite side, *B*, of the piston, 5, moves the latter slightly back and closes the valve, 7, and cuts off the air supply to the brake-cylinder. If, now, the

* In drawing the sections of the valve and its seat, some liberty has been exercised in order to show how the valve acts. The sections are not strictly correct, but they thus show the operation of the valve more plainly than they would if they represented the valve exactly.

Fig. 448.

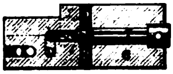


Fig. 449.

Fig. 450.

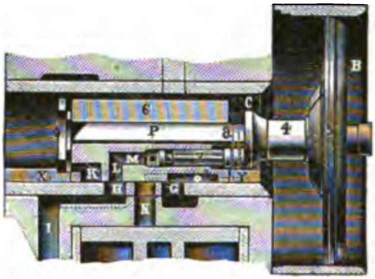


Fig. 451.

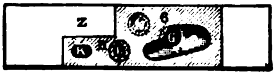


Fig. 452.

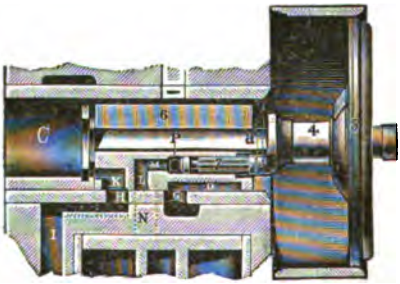
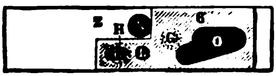


Fig. 453.



Quick Acting Triple-Valve.

pressure in the brake-pipe be again slightly reduced by the engineer's valve, the valve, 7, will again be opened by the piston, 5, and in this way by repeated applications the brakes can be applied gradually up to the maximum force which would be possible when the pressure is equalized in the cylinders and auxiliary reservoirs.

QUESTION 652. *How does the triple-valve, shown in fig. 446, act in making an emergency stop in case of danger?*

Answer. If the locomotive runner opens the brake-valve wide the pressure in the brake-pipe will be so far reduced that the piston, 5, will move to the extreme limit of its travel, and will seat itself against the leather ring, 23, fig. 446, this opens the valve, 7, and moves the slide-valve, 6, to the position shown in fig. 452 and fig. 453, and brings the port, *K*, over *H*.

From the end view, fig. 447, and sectional plan, fig. 453 of the slide-valve, 6, it will be seen that one corner of it, at *Z*, is cut away diagonally. Consequently when the valve reaches the position, shown in figs. 452 and 453, it uncovers the port, *N*. Air from the chamber, *C*, and auxiliary reservoir then flows down through the passage, *N*, and acts on the piston, 8, fig. 446, forcing it down, which opens the valve, 11. As soon as this occurs the pressure in the chamber, *Q*, and brake-pipe, *T*, below the check-valve, 15, raises it, and there is then a clear passage from the brake-pipe, *T*, to the pipe, *S*, and into the brake-cylinder. There is also a passage from the auxiliary reservoir through the port, *K*, fig. 452, and passages, *H* and *I*, into the brake-cylinder, but as the area of the cross sections of these passages, compared with that through the valves, 11 and 15, is relatively small, the air in the brake-pipe has time to discharge into the brake-cylinder before the pressure in the latter has been increased much by that which enters from the reservoir, through *K* and *I*. The air in the brake-pipe has thus time to discharge into the cylinder and thus relieve the pressure in the pipe *before* the air in the auxiliary reservoir has increased the pressure above the check-valve, 15, sufficiently to close it, thus preventing the air above it from flowing back into the brake-pipe. By this means the air in the brake-pipe under each vehicle is discharged into the brake-cylinder, thus utilizing it for applying the brakes and effecting a quicker discharge of air from the brake-pipe and more prompt application of the brakes than is possible if the air in the brake-pipe must all escape through the engineer's valve.

After the engineer has accomplished his object, the brakes are released in the usual way, by opening communication between the main reservoir

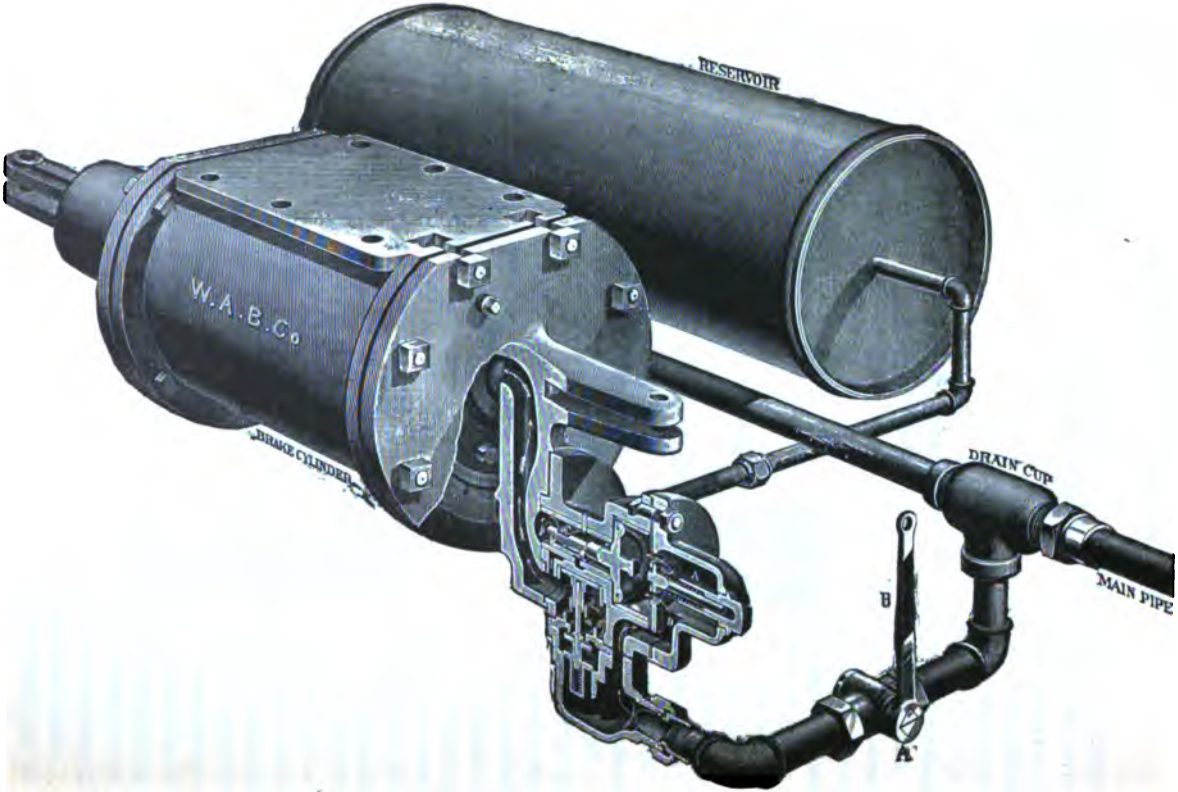


Fig. 454. Brake-Cylinder, Auxiliary Reservoir, and Triple-Valve.

and the brake-pipe through the engineer's valve on the engine. The pressure in the brake-pipe, *T*, fig. 446, then flows through the passages, *Q D D' l l*, and moves the piston, 5, back into the position shown. The cavity, *O*, in the valve then connects the passage, *N*, with the atmosphere, which relieves the pressure above the piston, 8, which is raised by the pressure under it, and the valve, 11, is closed by the spring, 12, below it. The air in the brake-cylinder then exhausts through the passage, *I*, port, *H*, cavity, *O*, in the valve and passage, *G*, into the open air, and the springs in the brake-cylinder return the brake-pistons and take off the brake-blocks from the wheels, and the auxiliary reservoirs are again recharged through the groove, *E*.

QUESTION 653. *How is the quick acting triple-valve applied to the brake-cylinders?*

Answer. On passenger trains it is attached to the end of the brake-cylinder, as shown in fig. 454, which is a perspective view of a brake-cylinder, auxiliary reservoir, and triple-valve—the latter shown in section—with their connections. On freight trains the brake-cylinder is bolted to the end of the auxiliary reservoirs and the triple-valve is bolted to the end of the reservoir with a pipe, *a*, running through the latter, for conveying the compressed air to and from the triple-valve and cylinder, as shown in fig. 444, which represents a section of these parts. A screw plug, 26, fig. 446, is provided in the bottom of the air chamber, 13, for removing any dirt which may accumulate there.

QUESTION 654. *With how much force should the brake-blocks be pressed against the wheels?*

Answer. The friction between the brake-blocks and the wheels, and between the wheels and the rails, or the "adhesion" of the wheels, is very nearly the same with equal pressures. Therefore, if the force with which the brakes are pressed against any of the wheels should be greater than the weight on the rails under those wheels, the friction of the brake-blocks would exceed the adhesion of the wheels to the rails, and the wheels would slide. For this reason the pressure of the brakes on any pair of wheels should never exceed the weight on the rails under those wheels. Experience has shown that the wheels of passenger cars are liable to slide if the brake pressure on any of the wheels exceeds 90 per cent. of the weight on the rails under them, and if they do slide they are liable to have flat spots worn on the treads. For this reason the pressure of the brake on any wheel of a passenger car is limited to 90 per cent. of the weight on the rail under it when the car is empty or light, and the pressure on freight cars is limited to 70 per cent. of the light weight. Practical experience has shown that 75 per cent. of the weight on driving-wheels can be safely used as a braking force without harm to the structural parts of the engine, but it is not advisable in any case to have a pressure of over 12,500 lbs. on any one wheel, because a greater pressure causes excessive wear of tires.

Fig. 455.

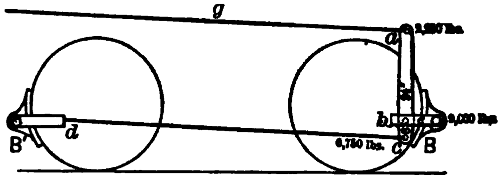


Fig. 456.

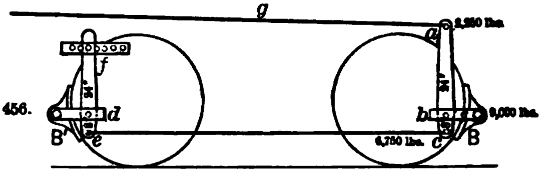


Fig. 457.

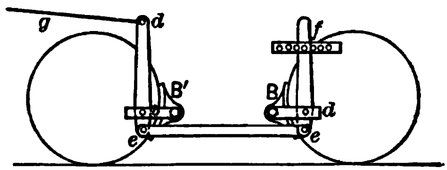
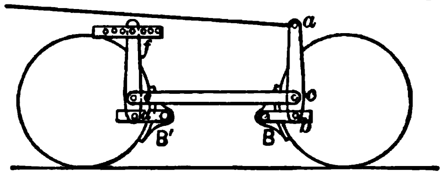


Fig. 458.



Arrangement of Brake-Levers.

QUESTION 655. *How is the pressure applied to the brake-shoes?*

Answer. By means of levers, 14 14′ 14″, Plate VI, connected to the brake-beams to which the brake-shoes are attached.

QUESTION 656. *How are the brake-levers arranged in relation to the wheels?*

Answer. The levers which are connected to the brake-beams are arranged in several different ways. Fig. 455 shows the simplest arrangement in use for hand-brakes, with the brake-blocks or shoes, *B B'*, outside of the wheels. It consists of a single lever, *a b c*, which is connected to the brake-beam, *e*, by a fulcrum, *b*. The lower end, *c*, of the lever is connected by a rod, *c d*, to the brake-beam, *d*. The upper end, *a*, of the lever is connected by a rod, *g*, to the brake-windlass. This arrangement is open to the objection that the pressure on the brake-blocks, *B*, is greater than that on *B'*, and therefore this plan is now seldom used.

Fig. 456 represents an arrangement with double levers which are attached to the brake-beams in the same way as the lever, *a b c*, shown in fig. 455. The brake-blocks are also outside of the wheels, and the lower ends of the levers are connected together by a rod, *c e*. The upper end of the lever, *e d f*, is held by an adjustable stop at *f*. With this arrangement, the rod, *c e*, is in tension when the brakes are applied by the brake-windlass.

Fig. 457 represents an arrangement with two levers and the brake-blocks, *B B'*, between the wheels. The upper end, *d*, of the lever, *d b e*, is connected to the brake-windlass, and *f d e* is held by an adjustable stop, *f*. The rod, *e e*, is in compression when the brakes are applied.

Fig. 458 shows another arrangement similar to fig. 457, excepting that the rod, *e e*, is above instead of below the brake-beams.

QUESTION 657. *How are the air-brake cylinders connected to the brake-levers?*

Answer. Two systems, the Stevens and the Hodge, shown by figs. 459 and 460, are used. The brake-cylinders are usually placed between the two trucks and have two levers, *g i* and *g' i'*; one of these, *g' i'*, is connected to the brake-piston at *i'*, and the other, *g i*, to the brake-cylinder at *i*. They are connected together by a tie-rod, *h h'*, and in the Hodge brake, fig. 460, by rods, *g l* and *g' l'*, to the floating levers, *k m* and *k' m'*. In the Stevens system, fig. 459, the cylinder levers are connected directly to the brake-beam levers, *a c* and *a' c'*. With this arrangement, it is only necessary to give the levers the right proportion to get the proper pressure of the brakes on the wheels.

QUESTION 658. *How can the pressure which should be exerted by the brake-shoes on the wheels be calculated?*

Answer. The first thing to do is to ascertain the minimum weight on the rails under each pair of wheels of the car or other vehicle to which the brakes are applied. This is done by taking the total weight of the car when empty and dividing it by the number of its pairs of wheels. Then for passenger cars take 90 per cent. and in the case of freight cars 70 per

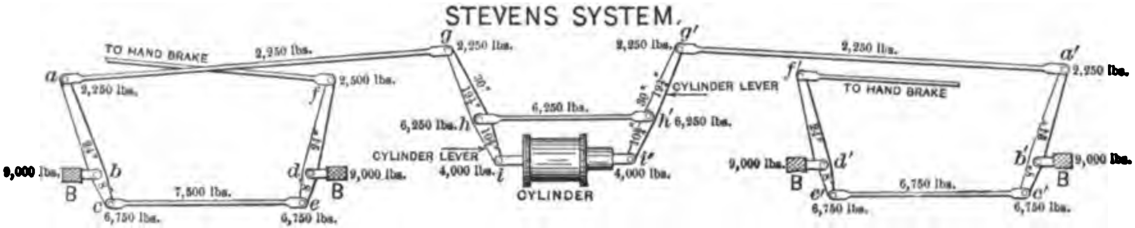


Fig. 459.

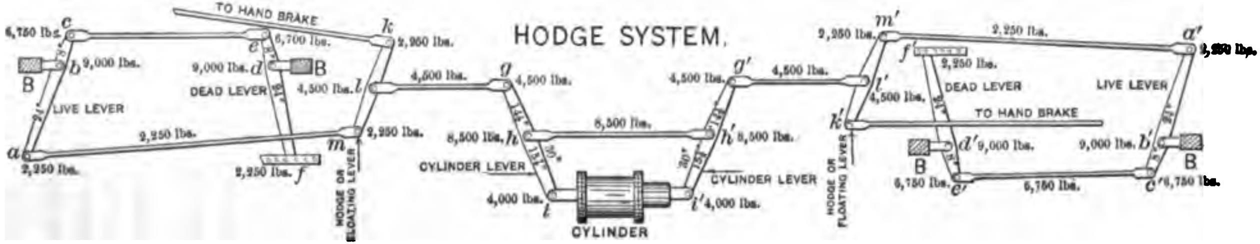


Fig. 460.

Arrangement of Stevens' and Hodge's System of Brake-Levers.

cent. of the weight on each pair of wheels, when the car is empty, which will be the pressure which should be exerted on each brake-beam.

Thus suppose we have an eight-wheel passenger car which weighs 40,000 lbs. empty. It would have 10,000 lbs. of weight to each pair of wheels, 90 per cent. of which would be 9,000 lbs., which is the pressure that should be exerted on each brake-beam.

In the case of six-wheeled trucks on which the brakes are not usually applied to the middle pair of wheels, the calculation is made in the same way, the only difference being that the brakes are omitted on the middle pair of wheels if the brakes are not applied to them.

QUESTION 659. *What should be the pressure in the brake-cylinders?*

Answer. Experience has shown that a pressure of 50 lbs. per square inch in the cylinders of the old automatic, and 60 lbs. with the new quick-acting brake, is the best that can be used. The size of the cylinders and the brake-levers should then be so proportioned that this air pressure will exert the required force on the brake-beams.

QUESTION 660. *How can the proportion of the brake-levers be calculated?*

Answer. Their proportions are calculated from the principle of the lever which was explained in Chapter III.

To illustrate how this can be done, the arrangement of lever shown in fig. 455 will be taken first. It will be supposed that the pressure on the brake-shoe is to be 9,000 lbs., and that the lower end of the lever is 8, and the upper one 24 inches long; what force must be exerted at *a?* In this case the pressure on the brake-shoe is the counter-force, and that at *a* the minor-force; by the rule given in answer to Question 48, we will have $9{,}000 \times 8 \div 32 = 2{,}250$ lbs.=the force which must be exerted at *a*. To get the major-force exerted at *c*, on the rod, *c d*, and brake-shoes, *B'*, we have by the rule given in answer to Question 48, $9{,}000 \times 24 \div 32 = 6{,}750$. This explains what has already been pointed out, that with this arrangement of brakes the pressure on the shoe, *B'*, is less than that on *B*.

If we want to calculate the pressure which a force at *a*, of 2,250 lbs. would exert on the brake-shoe, by the rule, in answer to Question 47, we will have $24 + 8 = 32 \times 2{,}250 \div 8 = 9{,}000$=pressure on *B*.

The calculations are similar for the leverages in figs. 456, 457 and 458. In fig. 456, with a force of 2,250 lbs. at *a*, we would again have 9,000 at *b*, and 6,750 at *c*, and as this is exerted on the rod, *c e*, it would be the major-force acting on the lever, *f d e*. To get the pressure exerted on the brake-shoe, *B'*, by the rule in answer to Question 47, we would have

$8 + 24 = 32 \times 6{,}750 \div 24 = 9{,}000$ lbs., showing that with this arrangement of levers the pressure on the two brake-shoes is equal.

It happens in applying air-brakes to cars that the proportions of the brake-beam levers, *a b c* and *f d e*, figs. 459 and 460, are nearly always established; therefore the problem usually is to proportion the cylinder-levers, *g h i* and *g' h' i'*, to produce a given pressure on the brake-beams with some given dimensions of brake-beam levers.

QUESTION 661. *How are the proportions of the cylinder-levers calculated?*

Answer. As an example, we will take the dimensions and pressures referred to in the answer to the previous question, and represented in fig. 456. With the proportions of levers given to exert a force of 9,000 lbs. on the brake-beams, there must be a pull of 2,250 lbs, on the rods, *a g* and *a' g'*, fig. 459. These rods are connected to the cylinder-levers, *g h i* and *g' h' i'*. One of these levers is connected to the cylinder at *i*, and the other to the piston-rod at *i'*, and they are connected together by the rod, *h h'*. Consequently, when the piston-rod is forced out it exerts a pull on the rods, *h h'*, *g a* and *g' a'*, which is communicated to the levers, *a b c* and *a' b' c'*. If the cylinder is 10 inches in diameter—a usual size for passenger cars—the area of its piston will be 78.5 square inches, which, multiplied by a pressure of 50 lbs. per square inch, will give a total pressure on the piston of 3,925 lbs., which for even figures will be taken at 4,000 lbs. The total length of the cylinder-levers, *g h i* and *g' h' i'*, will be assumed to be 30 inches, and it has been shown that a pull of 2,250 lbs. is required on the rods, *a g* and *g' a'*, to produce the required pressure on the brake-beams. The problem, then, is to determine the length of the two ends of the cylinder-levers so that a pressure of 4,000 lbs. exerted by the piston at *i'*, will pull with a force of 2,250 lbs. at *g* and *g'*. We have, then, the major and the minor-forces and the total length of the lever, so that by the rule in answer to Question 49, we would have $2{,}250 + 4{,}000 = 6{,}250$ = the counter-force at *h* and *h'*. $4{,}000 \times 30 \div 6{,}250 = 19.2$ inches = long end of lever. The length of the short end of the lever is, of course, equal to its whole length less the length of the long end, or $30 - 19.2 = 10.8$ inches.

Some care should be taken not to get the position of the ends of these levers reversed from what they should be. *The short end should always be next to the major-force and the long end next to the minor-force.*

QUESTION 662. *What different arrangement of levers is used in applying the air-brake?*

Answer. As explained in answer to Question 657, two systems are commonly used, the Stevens', fig. 459, and the Hodge's, shown in fig. 460. In the latter, what are called floating-levers, *k l m* and *k' l' m'*, are used. One end, *m* and *m'*, of each of these levers is connected to the brake-beam levers, *a b c* and *a' b' c'*, by rods, *m a* and *m' a'*; the other ends, *k* and *k'*, of the floating-levers are connected to the hand-brakes, and the cylinder-levers, *g h i*, *g' h' i'*, are connected to the middle of the floating-levers by rods, *g l* and *g' l'*. It is obvious that with this arrangement, if the two ends of the floating-levers are of equal length, one-half of the pull which is exerted by the cylinder-levers, through the rods, *g l* and *g' l'*, is transmitted to the hand-brakes, and the other half to the levers, *a b c* and *a' b' c*. Consequently, with this arrangement the cylinder-levers must be so proportioned that they will exert a pull through the rods, *g l* and *g' l'*, equal to double that which must act on the ends, *a* and *a'*, of the "*live*" brake-beam levers, *a b c* and *a' b' c'*. In this case, then, the levers must be proportioned so that for the conditions which have been assumed, a pressure of 4,000 lbs. on the piston at *i'*, will exert a force of 4,500 lbs. at *g* and *g'*. The calculation for the length of the long end of the lever would therefore be 4,500 + 4,000 = 8,500 = the counter-force at *h* and *h'*. 4,500 × 30 ÷ 8,500 = 15⅞ = long end of lever. It will be noticed that in figs. 459 and 460 the relative position of the long and short ends of the cylinder-levers is reversed; in fig. 459 the short end is next to the cylinder, whereas in fig. 460 the long end is in that position. The force exerted on the rod, *h h'*, fig. 460, will be equal to the counter-force, or 4,000 + 4,500 = 8,500 lbs. By calculating the effect of this, it will be found that the same force is exerted on the rods, *g l* and *g' l'*, showing that the brakes are applied equally on both trucks.

QUESTION 663. *How may the rules for calculating the length of brake-levers be summarized?*

Answer. The following are the essential rules to be used for such calculations:

I. *To get the pressure on the brake-piston:* MULTIPLY THE AREA OF THE BRAKE-PISTON IN SQUARE INCHES BY THE AIR PRESSURE PER SQUARE INCH, IN LBS., IN THE CYLINDER (usually 50 lbs.).

II. *To get the pressure on each brake-beam:* FOR PASSENGER CARS TAKE 90 PER CENT. OF THE WEIGHT (when empty), IN LBS., ON THE RAILS BELOW THE WHEELS TO WHICH THE BRAKES ARE APPLIED AND DIVIDE BY THE NUMBER OF BRAKE-BEAMS.

III. *To get the force which must be exerted at the upper end of each brake-beam lever:* If the brake-beam is attached to the lever between its two ends (as in figs. 456 and 457), MULTIPLY THE PRESSURE ON THE BEAM, IN LBS., BY THE LENGTH IN INCHES OF THE SHORT END OF THE LEVER,* AND DIVIDE BY ITS WHOLE LENGTH. If the brake-beam is attached to the end of the lever (as in fig. 458), MULTIPLY THE PRESSURE ON IT, IN LBS., BY THE LENGTH IN INCHES OF THE SHORT END OF THE LEVER, AND DIVIDE BY THE LENGTH IN INCHES OF THE LONG END.

IV. *To get the proportions of the brake-cylinder levers:* If floating-levers are not used (as in fig. 459): TAKE THE FORCE, IN LBS., EXERTED AT THE TOP OF EACH LIVE BRAKE-BEAM LEVER; if floating-levers are used (as in fig. 460,) TAKE DOUBLE THIS FORCE AND ADD IT TO THE PRESSURE, IN POUNDS, EXERTED ON THE BRAKE-PISTON. THEN TO GET THE LENGTH OF THE END OF THE CYLINDER LEVER NEXT TO THE CYLINDER, MULTIPLY ITS WHOLE LENGTH BY THE FORCE EXERTED, IN LBS., ON THE OPPOSITE END OF THE LEVER, AND DIVIDE THE PRODUCT BY THE SUM OF THE FORCES EXERTED AT THE TWO ENDS OF THE LEVER. The length of the other end of the lever could be obtained by multiplying its whole length by the pressure exerted on the piston and dividing by the sum of the forces as before.

QUESTION 664. *In what distance can trains be stopped at different speeds with a quick-acting automatic brake?*

Answer. This to some extent depends upon the number of wheels in the train to which the brakes are applied. If all the wheels in a train, excepting the truck wheels of the locomotive, have brakes, it can be stopped quicker than is possible if the driving-wheels have no brakes, or if the cars have six-wheeled trucks on which brakes are seldom applied to the middle pair of wheels. Under the most favorable conditions, with all the cars empty, trains can be stopped in about the following distances:

At 20	miles	an hour	120 feet.
" 30	"	"	270 "
" 40	"	"	480 "
" 50	"	"	750 "
" 60	"	"	1,080 "

If the cars are loaded, these distances would be increased in the proportion that the loads bear to the whole weight of the train.

* The length of a lever should always be measured from the centres of the pins by which it is connected to the other parts.

CHAPTER XXVII.

THE CARE AND USE OF THE WESTINGHOUSE AIR-BRAKE.*

QUESTION 665. *How should the brake gear be adjusted?*

Answer. It should be adjusted so that when the brakes are full on the pistons in the brake-cylinders of cars will not have travelled less than 7 inches nor more than 9 inches. This will allow for wear of shoes, stretching of rods, springing of brake-beams, etc. Great care must be exercised, when taking up the slack in the brake connections, to have the levers and pistons pushed back to their proper places, and the slack taken up by the pins and holes at the top of the dead levers or in the under connections, 23′ 23″, Plate VI, of the levers.

The driving-wheel brakes should be adjusted so that when they are fully applied the piston will run out about 3 inches, and to be kept adjusted so as not to take up the entire stroke of the pistons.

QUESTION 666. *Before leaving the engine-house what should the engineer observe?*

Answer. He should know whether the engineer's brake-valve, the air-pump, and the other parts of the brake on the engine and tender are in perfect working order, and if not the defects should be promptly reported.

QUESTION 667. *Before coupling to a train what should the engineer do?*

Answer. He should know that the steam-cylinder of the air-pump was properly lubricated with locomotive cylinder oil, and that the air-cylinder is sparingly lubricated with a small quantity of good mineral lubricating oil. Tallow and lard oils should not be used in the air-cylinders.

The air-pump should be started slowly to allow the water which accumulates in the steam-cylinder, from the condensation of the steam, to escape gradually; it should not be forced out by running the pump with full steam pressure. After the pump has made a few strokes put about a teaspoonful of West Virginia mineral oil into the oil-cup of the air-cylinder.

* In the answers to the questions in this chapter, free use has been made of the instruction book by the Westinghouse Air-Brake Company, and of other similar books issued by some of the railroad companies.

Before coupling to the train, the main reservoirs should be pumped full of air of the maximum pressure of 90 lbs., to insure the release of the brakes on the train, and also to be able to charge the auxiliary reservoirs quickly after the engine is coupled to the train.

After being connected to the train the handle of the engineer's valve should be turned to the I, or "*charging position*," figs. 424 and 428, until the pressure gauge indicates that the pressure in the train-pipe is equal to 70 lbs. The handle should then be turned to the II, or "*while running position*," fig. 429, in order to accumulate an extra pressure of 20 lbs. in the main reservoir.

The air-gauges which are now supplied for the new automatic brake, as already explained, have two sets of works and two hands—a black and a red one. The black one indicates the pressure in the brake-pipe and the red one that in the main reservoir. The difference of pressure indicated by these hands represents the excess of pressure which is accumulated in the main reservoir over that in the brake-pipe, to aid in releasing the brakes quickly and for recharging the brake-pipe and auxiliary reservoirs. This excess of pressure is accumulated when the handle of the engineer's valve is placed in the II, or "*running position*," and should be about 20 to 25 lbs. As the pressure in the train-pipe should be 70 lbs., that in the main reservoir should be 90 lbs. The importance of having an *excess* of pressure in the main reservoir cannot be emphasized too strongly.

QUESTION 668. *In making up trains what should be done?*

Answer. All the hose couplings between the different vehicles should be connected together so that the brakes will be applied throughout the whole train. No brake in any car must be "cut out" unless it is defective. The coupling of the hose at the rear of the last car and at the front of the engine (if there is a hose there) should be attached to the coupling-hook. If for any reason the hose between two vehicles are not used for connecting the brakes they should be attached to their coupling-hooks.

In coupling the hose, place the coupling shoulders, near the stop-pin, firmly together, then twist the heads into place as if they turned on a pivot, firmly pressing the heads toward each other until both heads strike the stop-pins.

All the brake-pipe cocks, 29′ 29″, Plate VI, should be opened by turning their handles *down or at right angles to the brake-pipe*,* excepting that of the cock at the rear end of the train, which should be closed by turn-

* On the old brake the plugs of these cocks are horizontal, on the new quick-acting brake they stand vertical.

ing its handle so as to stand parallel with the train-pipe. If the brake-pipe is extended to the front of the engine, to connect with another engine, the cock at the front end of the train should also be closed. The hose at the front (if there is one at the front) and rear ends of the train should be attached to their coupling-hooks.

The handles, *K*, fig. 422, of the four-way cocks on the triple-valve of the old brake, and the handles of the cocks under the auxiliary reservoirs should also be turned horizontal.

The new or quick acting triple-valve has no four-way cock attached to it, but has a stop-cock, *A*, fig. 454, on the pipe which connects the triple-valve with the brake-pipe. This stop-cock should be opened by turning its handle, *B*, at right angles to the pipe to which it is attached, as shown in fig. 454. When the cock is closed the handle stands horizontal. This same arrangement is used on the new freight car brakes.

It is very important to the successful action of the brake, and to avoid detentions, that the handles of the cocks should be placed in their proper position before starting.

QUESTION 669. *How should the brakes be inspected before starting?*

Answer. Before leaving terminal stations, or wherever there has been any change in the make-up of the train, after all the couplings are made, the engineer should turn the handle of the engineer's valve, 9, Plate VI, to the I, or "*release and charging position*" (see figs. 424 and 428), and charge the auxiliary reservoirs with air of not exceeding 70 lbs. pressure per square inch. After the reservoirs are charged, he should bring the handle to the III, or "*lap position*," fig. 430, leaving it in this position for a few moments and observing whether there is any leakage, which will be indicated by a gradual falling off in pressure, as shown by the air-gauge. If there is a leakage it should be found and the defect remedied. The pipes and joints of the brakes must be kept tight, and when leaks are discovered, if the defect is a serious one, the car should not be used until it is repaired.

A person whose duty it shall be to inspect the brakes and *know* that they are in proper order, should then see that all the hand-brakes are released, and then ask the engineer to apply the brakes. The inspector should then walk to the rear of the train, examining the brakes of each car, and see whether they have been applied. If he finds them set all right, he should signal "off brakes" from the rear of the train. The engineer should reply by two light blasts of the whistle or other signal and immediately release the brakes. The inspector should then return to the engine and notice whether the brakes are released on every car. If any are found which are still set he should release them by opening the small cock, 20, Plate VI, attached to the under side of the auxiliary reservoir or cylinder, which is called "bleeding" the brake. The inspector should then observe whether there is the full air pressure—90 lbs.—in the main reservoir. If not it should be pumped up to full pressure and the brakes applied again by the engineer. If those which were not released on to the first test "stick" again, they should first be released by "bleeding" and then cut out. If all the other brakes are released, the brakemen will report all right; if any of them are not released, they should be cut out if they do not release on the second trial. After the inspection it should be observed that all the cocks in the auxiliary reservoir or cylinder are closed.

It should be understood that if cars which have different air pressures in the brake-pipes and auxiliary reservoirs are coupled together, air from the brake-pipe having the higher pressure escapes into the pipe having the lower pressure, and thus applies the brakes on the car which has the greatest pressure. In such cases by "bleeding" the cars, with over-pressure, until the brakes commence to release, the time required to equalize the pressure by pumping on the engine will be saved.

The valves for the application of the brakes from the inside of the car should also be examined when the brakes are inspected, and it should be observed whether all their connections are tight and in good condition.

The discovery of a defect in the brake apparatus affecting its working, either before or during a trip, should at once be made known to all trainmen and to the engineer, so that there may be a proper understanding of it, and measures should be taken to insure safety in running the train.

After making up or adding to a train, or after a change of engines, the rear brakeman should ascertain whether the brake is connected throughout the train. The engineer must, under these circumstances, always test the brakes, to insure their being properly coupled and in order for use.

QUESTION 670. *How should the air-pump be worked?*

Answer. While the locomotive is in service it should be run constantly, but not faster than is necessary to maintain the required air pressure in the reservoirs. The pump governor being connected to the train-pipe should constantly be used and should be set to maintain a pressure of 70 lbs. therein, as shown by the air-pressure gauge.

While running the handle of the engineer's valve should be kept in the II, or "*running position*," figs. 424 and 429. This allows the brake-pipe and auxiliary reservoirs to be charged with air and an excess of pressure to be accumulated in the main reservoir.

QUESTION 671. *How should the brakes be applied to make ordinary stops?*

Answer. The brakes, as has been explained, are applied when the pressure in the brake-pipe is suddenly reduced, and released when the pressure is restored.

It is of very great importance that every engineer should bear in mind that the air pressure may sometimes reduce slowly, owing to the steam pressure getting low, or from the stopping of the pump, or from a leakage in some of the pipes when one or more cars are detached for switching purposes, and that in consequence it has been found absolutely necessary to provide each cylinder with what is called a leakage groove, which permits a slight pressure to escape without moving the piston, thus preventing the application of the brakes when the pressure is slowly reduced, as would result from any of the above causes.

This provision against the accidental application of the brakes must be taken into consideration, or else it will sometimes happen that all of the brakes will not be applied when such is the intention, simply because the air has been discharged so slowly from the brake-pipe that it only represents a considerable leakage, and thus allows the air under some cars to be wasted.

It is thus very essential to discharge enough air in the first instance, and with sufficient rapidity, to cause all of the leakage grooves to be closed, which will remain closed until the brakes have been released. In no case should the reduction in the brake-pipe for closing the leakage grooves be less than 8 to 10 lbs., which will move all pistons out so that the brake-shoes will be only slightly bearing against the wheels. After this first reduction the pressure can be reduced to suit the circumstances.

On the other hand, locomotive runners should be careful not to use too much force in making ordinary stops. By applying the brakes at a fair distance from the station, with moderate force, the train may be stopped gently and without inconvenience to the passengers, while if the brakes are put on with two much force, the train is jerked in a manner that is extremely disagreeable, and may be dangerous to the passengers. To avoid this in making a stop, the handle of the engineer's valve should not be turned beyond the IV position; "*for service stops,*" see figs. 424 and 431. With a train of two or three cars the handle should be kept in that position for a few seconds only and should then be closed gently by moving the handle to the III position, when the pressure in the brake-pipe has been reduced from 8 to 10 lbs., as indicated by the gauge. The brakes are fully applied when the pressure in the brake-pipe, as shown by the gauge, has been reduced about 20 lbs. *Any further reduction is a waste of air.* The brakes should be applied far enough away from the station so that the train may be controlled and stopped without moving the handle beyond the IV position. As the brakes on the train are applied from the auxiliary reservoirs, frequent use of the brakes reduces the pressure, and consequently the power of the brakes, for while applying the brakes the supply of air to the reservoirs through the brake-pipe is cut off. Therefore, after each application the handle of the engineer's valve should be turned to the extreme left until the maximum pressure is obtained, after which it should be moved to the II position, where it should remain while running. It is bad practice to apply and release the brakes more than once or twice at the most in service stops, unless time is given between application for recharging the train reservoirs, as it reduces the pressure too much on the train.

The most satisfactory stops are made by applying the brakes, lightly at first, at sufficient distance away, and increasing the pressure as the train draws nearer the station until it is almost stopped, then, excepting on heavy grades, releasing the brake, by turning the handle to the I position, to avoid jerking the train. After the air has been released from the brake-pipe of long trains, by placing the handle of the brake-valve in the IV, or "*service stop*" position, and is then moved back to the III, or "*closed*" position, air will continue to escape through the valve, as explained in answer to Question 681, until the pressure has been reduced uniformly throughout the brake-pipe by an amount indicated by the black pointer of the gauge. This is the equalizing feature of this valve which is of great importance in the operation of the brakes, especially on long trains.

A reduction of pressure in train-pipe of about

7	lbs.	will	give	about	4	lbs.	per square	inch	in brake-cylinder.
9	"	"	"	"	19	"	"	"	"
11	"	"	"	"	26	"	"	"	"
13	"	"	"	"	40	"	"	"	"
15	"	"	"	"	46	"	"	"	"
17	"	"	"	"	50	"	"	"	"

QUESTION 672. *How should the air-brake be used in case of danger?*

Answer. In case of danger the object, of course, is to stop as quickly as possible without reference to the comfort of any one. In such cases the handle of the engineer's valve should be turned to the V, or "*emergency position*," figs. 424 and 432. Stops should not be made in this way any oftener than is necessary, as they are liable to slide and flatten wheels of the train.

QUESTION 673. *What must be done to release the brakes?*

Answer. The handle of the engineer's valve must be turned to the extreme left, or to the I, or "*release position*," quite against the stop, and should be kept there until the brakes are fully released and the pressure in the train-pipe is restored, and then moved back to the II position against the intermediate stop, which is the feed position, and is where it should remain while the train is running. This course is necessary so as to be always ready with an excess of pressure in the main reservoir to release the brakes, thus avoiding the necessity of "bleeding." The handle should never be left midway between these two positions, as this will nearly, if not quite, close the passage leading to the brake-pipe.

If the air-gauge, while running, shows too much excess of pressure, the excess pressure-valve, 21, figs. 426 and 427, may have become obstructed. After coming to a full stop at a station, move the valve-handle to the V, or "*emergency position*," and accumulate a high pressure in the main reservoir; then move the handle back from the V, or "*emergency position*," to the II, or "*running position*," so that the full reservoir pressure is brought upon the excess pressure-valve, to blow out any obstruction. If the difficulty is thus removed the black hand of the gauge should move up to within 20 lbs. of the red one; if it does not, the valve should be examined and cleaned.

Where two or more engines are coupled in the same train, the cock, 8, fig. B, Plate VI, should be closed upon all but the head engine of the train, in order to permit this engine to handle the train-brakes without interference from the other engines.

Engineers of all trains should avoid making exhibition stops, and should never, excepting on a heavy grade, or in case of necessity, hold the brakes fully applied until the train comes to a full stop, as this causes a reaction in the motion of the train which is very disagreeable to passengers, and in case of a long freight or stock train, is damaging when there is much slack in the couplings. This can be avoided ordinarily, on passenger trains, as already explained, by releasing the brakes gradually before coming to a full stop, so that all the air will be off at the moment the stop is made.

On long down grades it is important to be able to control the speed of the train, and at the same time to maintain good working pressure. This is easily accomplished by running the pump at a good speed, so that the main reservoir will accumulate a high pressure while the brakes are on. When, after using the brakes some time, the pressure has been reduced to 60 lbs., the train-pipes and reservoirs should be recharged as much as possible before the speed has increased to the maximum allowed. A greater time for recharging is obtained by considerably reducing the speed of the train just before recharging and by taking advantage of the variation of the grades.

To release the brakes with certainty, it is important to have a higher pressure in the main reservoir than in the main pipe. If the engineer feels that some of the brakes are not off, it is best to turn the handle of the engineer's brake-valve to the III, or "*on lap position*," just far enough to shut off the main reservoir, and then pump up 15 or 20 lbs. extra, which will help to release the brakes, all of which can be done while the train is in motion.

QUESTION 674. *If, while the train is moving, the brakes are applied from some cause unknown to the engineer, what should he do?*

Answer. Whenever the brakes are applied from any cause, it is important to maintain an excess of pressure in the main reservoir, in order to be able to release them promptly thereafter. If there is but a slight reduction of pressure in the train-pipes, indicating that the brakes have been applied by leakage, he should at once move the handle of the brake-valve to the I position in order to release them; but if the brakes should be applied at once and the air-gauge show that all the air in the train-pipe has escaped, he will know that a pipe or hose has burst, a coupling has been broken, or that a conductor's valve has been opened, and he should aid in stopping the train by turning the handle to the V, or "*emergency position*," to stop as quickly as possible, and also to prevent the escape of air from the main reservoir. When the train is stopped he can release the brakes and await the signal from the conductor to proceed. If the brakes are not released by turning the handle to the I, or "*release*" position, it should put on the III, or "*closed*" position, until the pressure in the main reservoir has been increased 10 or 15 lbs., and the handle should then be turned to the I, or "*release*" position. If this does not accomplish the desired end, the brakes should be applied quickly and then released. If the engineer is not able to release the brakes, he should signal the fact to the trainmen, who will then assist in releasing them by "bleeding."

QUESTION 675. *How are the brakes applied from the inside of the cars?*

Answer. This can be done in three different ways: First, by opening the conductor's valve, by pulling on its cord and *holding it down* until the train is stopped. The new form of conductor's valve has no spring, and is open when the handle is up, and will remain so without holding it; second, by disconnecting the hose couplings; third, by opening the cock, 29″, Plate VI, on the brake-pipe on the rear end of the train. These methods should be used only in cases of emergency.

QUESTION 676. *In running trains up or down steep grades exceeding 100 feet per mile and a half mile in length, what should be observed?*

Answer. The engineer should first assure himself that the brake apparatus is in good working condition. Before going down such grades he should examine the valve-gear of the locomotive carefully, to see that it will be efficient if the engine is reversed.

QUESTION 677. *Why is the train-pipe carried to the front end of the locomotive?*

Answer. This is done so that the brakes on the locomotives can be coupled together, in case two are used on the front of the same train —called a "double header"—or so that the brakes can be coupled to the rear car in case the locomotive is used as a pusher at the back end of a train.

QUESTION 678. *How are the air-brakes operated on a "double header," or when two engines are coupled together?*

Answer. When two or more engines equipped with air-brakes are coupled to a train, *the forward engine should control the air-brake,* but all the engines should be connected to the brake-pipe. When the train is in motion, the stop-cock, 8, fig. B, Plate VI, should be closed upon all but the leading engine, and the leading engineer should do all the braking. Otherwise the brakes may all be pumped off, by the rear engineer, very soon after the brakes are applied by the first engineer, and this will render the brakes useless. Hence, the leading engine must control the train brakes entirely and absolutely, except in case of accident to the air of leading engine, and until a proper signal is given by the first engineer for the second engineer to assume control of the air-brakes on the train, for which contingency the second engineer must at every moment be *prepared to act instantly on a mountain grade.*

If from any cause the supply of air or any part of the brake on the leading engine has failed, and it is desired to give up the control of the brakes to the second engineer, a signal (usually two short and one long blast of the whistle — — ———) should be given by the first engineer, and the second one by repeating it should signify that he understands it and has control of the air-brakes. The second engineer having assumed control of the brakes, should retain entire charge of them to the end of the trip, unless it may be necessary to again put them in charge of the first one. On heavy grades the aim of the engineer should always be *to keep control of the train. Descending at high speed must not be practiced with any train*, for there may come a time when some part of the machinery may fail, and *while it may be practicable to control speed by hand-brakes at* 8 *to* 10 *miles per hour, it may be impossible at* 20 *to* 30 *miles per hour to regain its control.**

The driver brakes should not be used too freely on mountain grades, as it heats the tires of driving-wheels, expands and may loosen them on the wheel centres, and thus not only destroy their brake efficiency, but may make the engine useless for draft purposes also.

QUESTION 679. *How can the brakes be released if they are applied on a car which is not coupled to an engine, or if from other cause they cannot be released by the locomotive runner?*

Answer. On passenger cars this is done by turning down the handle of the release cock, 20, Plate VI—below the auxiliary reservoir—which opens it and allows the air in the reservoir to escape; which—in railroad parlance—"bleeds" the reservoir and the brake-cylinder.

QUESTION 680. *How can the brakes be released when they have been applied by a burst hose?*

Answer. By closing the brake-pipe cock directly in front of the burst hose; the brakes ahead of it can then be released by the locomotive runner, and those behind it, as has been described in answer to the previous question.

QUESTION 681. *What is meant by "cutting out" the brakes on a car?*

Answer. It means that the compressed air in the brake-pipe is shut off from the triple-valve, auxiliary reservoir, and brake cylinder, so that they do not operate, but the air can still pass through the brake-pipe to the cars behind.

QUESTION 682. *How can the brakes on a car be cut out?*

Answer. With the old form of automatic brake, the handle, *K*, fig. 422, of the four-way cock attached to the triple-valve should be turned down to the half-way position, *K*," and the release cock below the auxiliary reservoir, should be opened. When the quick-acting triple-valve is used,

* From the Code of Rules Governing Engineers and other Employees in the use of the Westinghouse Air-Brakes on the Northern Pacific Railroad.

the handle, *B*, of the cock shown in fig. 454 should be turned to the horizontal position to cut out the brakes on that car.

QUESTION 683. *What must be done if a car or the engine is detached from the train?*

Answer. When any of the vehicles in a train must be uncoupled, trainmen should not close the brake-pipe cocks, by turning their handles at right angles to the brake-pipe, or disconnect the hose until the brakes have first been released by the engineer. Before engines or cars are uncoupled, the brakes should be fully released on the whole train. Neglecting this precaution, or setting the brakes by opening a valve or cock when the engine is detached, may cause serious inconvenience in switching.

The cocks, 29′ 29″, Plate VI, before and behind the hose couplings to be separated should then be closed—by turning their handles at right angles to the brake-pipe—to prevent the application of the brakes on the cars which are uncoupled. The hose couplings should then be disconnected. *This must always be done by hand*, and the couplings should then be hung on their coupling-hooks.

QUESTION 684. *What is essential in taking care of the brake-cylinders and other parts of the brakes?*

Answer. The brake-cylinders must always be kept clean and free from gum, so that they will readily release when the air has been discharged, and should be oiled once in three months with suitable oil furnished for that purpose. The last date of oiling should be marked on the cylinders with chalk. The pistons should be taken out once a year and cleaned, at which time the brake rigging should have a general overhauling and be tested. The date of this general overhauling and testing should be stencilled in white lead on the cylinder.

All parts of the brakes should be kept clean and in good condition, and the pipe connections tight.

QUESTION 685. *How should the air-pumps be taken care of?*

Answer. The steam-cylinder should be lubricated with a small quantity of engine oil, and the air-cylinder should be sparingly lubricated with a small quantity of 32° gravity West Virginia mineral oil (tallow or lard oil should not be used in the air-cylinder).

In case the air-pump gets hot in operation on the road, use a small amount of valve oil, *not tallow*, to overcome the difficulty temporarily. Head-light oils will cut the gum out, but except it is very thoroughly cleaned out will cause heating worse than before, and is bad oil to use on this account.

The best means for cleaning out the air-pump thoroughly, and it should be done at the shops, is to disconnect the discharge pipe and pump through a few quarts of weak lye, discharging it into a proper vessel and pumping it through again until all passages are thoroughly cleaned. After the lye use clean warm water, to thoroughly clean out all the passages, then remove the lower head, shove the piston to the upper head, and oil the cylinder bore with oily waste.

QUESTION 686. *How should the triple-valves be taken care of?*

Answer. In cold or damp weather they should be drained frequently to let out any water that may have collected. This can be done by slacking the nut or the plug in the bottom of the triple-valve, and thus letting the water escape; the plug should then be screwed up again. The water in the drain-cup on the tender should be drained out daily in cold or damp weather by the cock under it. The valves for the application of the brakes from the inside of the car should be kept tight.

QUESTION 687. *What should be observed with reference to the main reservoir?*

Answer. The water should be drained out of it ordinarily once a week, and in winter or damp weather daily. If the pump is not kept well packed considerable water will accumulate in the main reservoir.

QUESTION 688. *What should be done in case a train breaks in two?*

Answer. In case a train breaks in two, the *brakeman should close the stop-cock on the rear car* of the part of the train remaining attached to the engine, when he reaches it, and then give the engineer a signal to let the brakes off.

When cars are again properly coupled up, *before opening the air into the rear end of the train*, the brakeman should give the engineer a signal to set the brakes, which should be done strong, and be left on until the brakeman opens the air-cocks into the rear section of the train. When this is done the engineer will have regained the same control of the air in the entire train as he had before the break in two. This action will save valuable time, which otherwise may be spent in releasing the air on each car by hand.

QUESTION 689. *What should be done in case hose couplings are frozen, so that they cannot be uncoupled, or leak?*

Answer. They should be thawed with a lighted torch, care being taken not to heat them so hot as to injure the packing or rubber of which the hose is made.

QUESTION 690. *How does the automatic freight train brake operate?*

Answer. The construction and operation of the freight train brake is substantially the same as that of the passenger train brake. The parts of the freight brake are, however, lighter and are arranged more compactly. They are shown in figs. 440–445.

QUESTION 691. *When and how is the pressure-retaining valve used on freight cars?*

Answer. As explained in answer to Question 649. In going down long grades it becomes necessary for the engineer to recharge the reservoirs with air, and to do so he is obliged to release the brakes. When the handle of the pressure-retaining valve, 40, fig. 440, which is located at the end of the car near the brake-wheel, is turned horizontal, as shown in fig. 445, an air pressure of 15 lbs. is retained in the brake-cylinder after the brake is released by the engineer. When the valve-handle points down, the valve allows the air to exhaust freely from the brake-cylinder when the brakes are released. The retaining feature of this valve should only be used on long grades; at all other times the valve-handles should be turned to point down.

QUESTION 692. *What precaution should be taken in cases when only a part of the cars, or the engine and tender only are equipped with air-brakes?*

Answer. After shutting off steam from the engine, engineers should allow the slack of the train to close in against the engine before applying the brakes. This, to a great extent, will prevent concussions of cars against each other in the rear portion of the train, which are not provided with air-brakes.

CHAPTER XXVIII.

THE EAMES VACUUM DRIVING-WHEEL BRAKE.

QUESTION 693. *What difference is there in the principle of working of vacuum and air-brakes?*

Answer. In air-brakes the force which applies the brakes is exerted by air of a pressure considerably greater than that of the atmosphere, whereas in vacuum brakes the force is exerted by ordinary atmospheric pressure.

QUESTION 694. *By what means is the atmospheric pressure exerted to apply the brakes?*

Answer. The air is exhausted from a cylinder or other vessel, so that the pressure of the atmosphere acts on the opposite side of a piston or diaphragm, and thus exerts the requisite force to apply the brakes.

QUESTION 695. *How is the air exhausted?*

Answer. Usually by means of an instrument called an "ejector."

QUESTION 696. *How is an ejector constructed and how does it operate?*

Answer. It consists of a tube, *A*, fig. 461, to which a current of steam is admitted by the pipe, *B*. As indicated by the darts, the steam enters the tube through the annular space around the internal nozzle, *D*. This produces what is called an "induced current" of air through the tube, *D*, or, in other words, the steam escaping into *A*, draws the air in *D* after it, and thus produces a partial vacuum above the valve, *E*, the air pressure below raises the valve, the air is then exhausted from the space, *F*, below it from the pipe, *G*, and from a diaphragm vessel, with which the pipe, *G*, is connected.

QUESTION 697. *How is the diaphragm arranged and how does it operate?*

Answer. Fig. 463 represents the diaphragm vessel, *H*, the lower portion being shown in section. It has a wide open mouth, with a flange, *b b*, around it. This open mouth is covered by an india-rubber diaphragm, *d d*, which is attached to the flange, *b b*, by a ring below it and bolts shown in the engraving. The diaphragm has two metal plates, *e* and *f*, in the

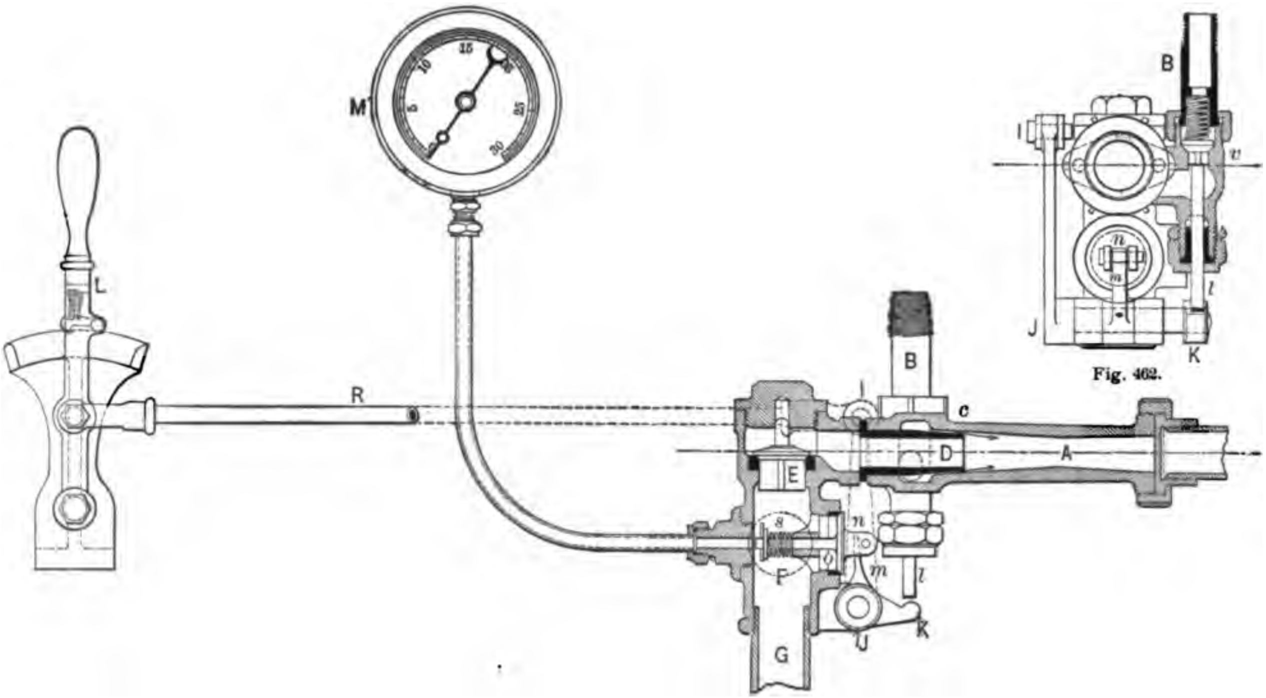


Fig. 462.

Fig. 461.
Ejector and Arrangements for Eames' Vacuum Brake. Scale 2 in.—1 ft.

middle, with a bolt and eye, *g*, fastened to them by a nut, which holds the plates and diaphragm together.

QUESTION 698. *How do the ejector and diaphragm operate to apply the brakes?*

Answer. The ejector is placed in any convenient position on the engine—usually on the side of the fire-box, as shown at *E*, fig. 464. The pipe, *G G*, of the ejector is connected to the diaphragm vessel, *H*, and the eye, *g*, on the diaphragm is connected by a rod, *g h*, to the arm, *h i*, which is attached to a shaft, *i*. This shaft has a short arm, *i j*, which is connected to the brake-shoes by a rod. *k*. *L* is the vacuum-lever located inside of the cab, and shown on an enlarged scale in fig. 461. Steam is admitted to the ejector by a valve, *v*, fig. 462, which is attached to the stem, *l*. This valve is operated by means of the vacuum-lever, *L*, fig. 461, which is connected by a rod, *R*, to an arm, *I J*, shown by dotted lines in fig. 461. This arm is attached to a shaft, *J*, fig. 462, which has a short arm or toe, *K*, connected to it. When the lever, *L*, is moved backward or toward the left-hand side of the engraving, the toe, *K*, lifts the spindle, *l*, and valve, *v*, fig. 462, which admits steam to the annular space around *D* in the

Fig. 463. Diaphragm Vessel for Vacuum-Brake.

ejector, and its escape produces a partial vacuum in the pipe, *G*, and diaphragm vessel, *H*, fig. 464, as has been explained. When this occurs the air below the india-rubber diaphragm presses it upward, and this pressure is communicated to the brake-shoes through the connections, *g h i j* and *k*, fig. 464. When the brakes have been applied sufficiently, the lever, *L*, fig, 461, is moved forward, or toward the right in the engraving, to the middle position in which it is shown. This lowers the toe, *K*, and allows the steam-valve, *v*, to close. When the current of steam is shut off the air flows into the pipe, *A*, and nozzle, *D*, and its pressure on

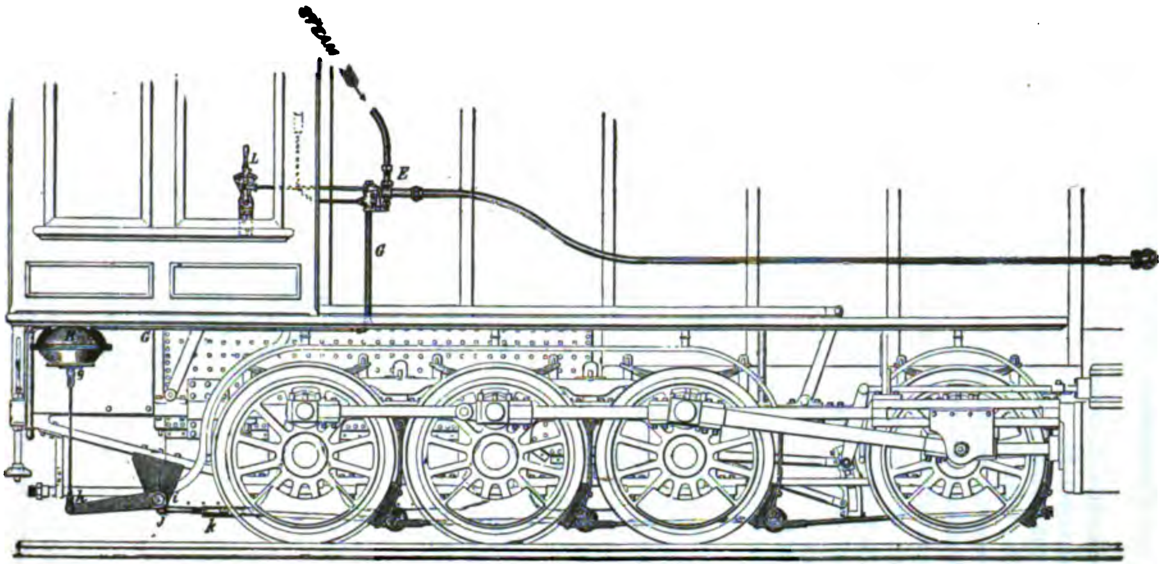


Fig. 464. Eames' Vacuum Driving-Wheel Brake.

top of the check-valve, *E*, closes it, and retains the vacuum in the pipe, *G*, and diaphragm vessel, *H*.

QUESTION 699. *How is the brake released?*

Answer. The lever, *L*, is moved still farther forward, or toward the right hand side of the engraving, from the position in which it is shown in fig. 461. This moves the shaft, *J*, which has an arm, *m*, that engages with a pin, *n*, attached to a release-valve, *o*, and this action opens the valve. The air then flows into the ejector, *F*, pipe, *G*, and diaphragm vessel, *H*, fig. 464, and equalizes the pressure above and below the diaphragm and releases the brakes. The release-valve, *o*, has a spring, *s*, on its spindle, to close it when the lever, *L*, is moved back to the position shown in fig. 461.

M is a pressure gauge to show how much the pressure has been reduced in the ejector.

QUESTION 700. *How much pressure can be exerted on the brakes by the ejector and diaphragm?*

Answer. This depends upon the size and number of the diaphragms. The manufacturers of this brake recommend that for driving-wheels—for which purpose it is chiefly used—that a pressure upon the brake-shoes equal to about 65 per cent. of the weight on the wheels should be employed.

QUESTION 701. *How is the pressure on the brake-shoes of the different wheels equalized?*

Answer. The rod, *k*, fig. 464, is connected to a circular disc, *E*, fig. 465,

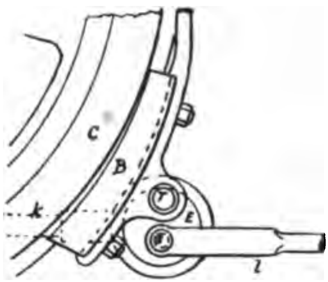


Fig. 465. Brake-Shoe for Eames' Brake.

which has two shafts or spindles, *s* and *T*, which are located eccentrically or on each side of the true centre of the disc. When a strain of tension is exerted on the rod, *k*, it draws the brake-shoe, *B*, against the wheel, *C*, but at the same time it exerts a tension on the rod, *l*, which is communicated to the shoe on the next wheel, and to as many more as have the brakes applied to them.

QUESTION 702. *For what service is the vacuum-brake most used?*

Answer. It is now applied chiefly to the driving-wheels of locomotives, but is also used on short trains which make frequent stops, as on the elevated railroads of New York.

CHAPTER XXIX.

PROPORTIONS OF LOCOMOTIVES.

QUESTION 703. *In proportioning a locomotive to any given kind of work, what are the first facts which should be known?*

Answer. We should first know the weight of the train which the locomotive must draw; second, the speed at which it must run; and third, the steepest grades and the shortest curves of the road on which it must work. From these data the resistance of the train which the locomotive must overcome can be at least approximately determined.

QUESTION 704. *When the greatest resistance of a train is known, what is the next thing to be determined?*

Answer. As was stated in answer to Question 178, if the wheels revolve and their adhesion is greater than the resistance opposed to the movement of the locomotive, the latter will overcome the resistance; but if the latter is greater than the friction, the wheels will slip. It therefore follows that the adhesion must be somewhat greater than the resistance. As the adhesion is equal to about one-fifth * of the adhesive weight or pressure of the driving-wheels on the rails, obviously this weight should be five times the resistance. Thus, if we have a train weighing 400 tons which we want to take up a grade of 40 feet per mile at a speed of 20 miles per hour, its resistance, calculated from the table given in Chapter XXXI, would be 9,360 lbs. Therefore, 9,360 × 5=46,800 lbs.=the required adhesive weight.

QUESTION 705. *What considerations determine the manner of distributing this weight on the wheels?*

Answer. It is found by experience that if too much weight is placed upon one wheel, the material of which the rails are made is partly crushed and injured, and they then wear out much more rapidly than they would if the weight was distributed on more wheels, and thus a smaller amount of weight rested on each point of contact with the rails. The amount of weight which can be carried on a single wheel depends upon the material

* See answer to Question 444.

of which the rails are made, and to some extent on their form and size, or as the latter is usually expressed, on their weight per yard.

QUESTION 706. *When the adhesive weight and the number of driving-wheels are known, how is the size of the latter determined?*

Answer. The size of the wheels will, to a certain extent, depend upon the speed, because the larger the wheels, the further will the locomotive move in one revolution; but no exact rule can be given for their size. At present there is still a great diversity of opinion among engineers regarding the best sizes of wheels for any given service. Probably the safest plan will be to consult the best practice, and in the absence of any better reasons be guided by that.

QUESTION 707. *What requirement determines the size of the cylinders?*

Answer. The cylinders must be large enough so that with the maximum steam pressure in the boiler, they can always turn the driving-wheels when the locomotive is starting, but their size should not be much greater than is needed to turn the wheels, because if they are the pressure on the pistons is liable to cause the wheels to slip on the rails.

QUESTION 708. *How much force must be exerted to turn the driving-wheels?*

Answer. The maximum force which must be exerted to turn the wheels is that required to overcome their friction or adhesion to the rails, and make them slip. The adhesion, as explained in Chapter X, varies from one-third to one-sixth of the weight bearing on the rails. The cylinders should, therefore, be so proportioned that the greatest tractive force which will be exerted by the pistons will be equal to the maximum adhesion. As it is only under very favorable conditions that the adhesion of the driving-wheels is equal to a third of the weight on them, in calculating the size of the cylinders the adhesion may be assumed to be one-fourth the weight on the wheels.

With an ordinary slide valve and link motion working in full gear, the greatest average pressure in the cylinders at a slow speed is about 90 per cent. of the boiler pressure. From this the greatest mean tractive force may be calculated by the rule given in answer to Question 447.* As the

* A committee of the Master Mechanics' Association appointed to report on this subject have recommended that the pressure in the cylinders be taken at 85 per cent. of the boiler pressure; but in order to have the cylinders as nearly of the right size as possible during all conditions of the tires, they based their calculations on the diameter of the tires when half worn out. As this introduces an element of confusion in comparing the dimensions of different engines, it has been preferred to base the calculations on a somewhat higher percentage of boiler pressure and on the original diameter of the tires, which gives nearly the same results and avoids the confusion referred to.

stroke of the pistons is usually known, the problem generally is to determine the diameter of the cylinders, which with an average pressure of 90 per cent. of the maximum boiler pressure, will give a tractive force equal to the adhesion of the wheels, assuming that to be equal to one-fourth the weight on them. Having the adhesion and knowing the boiler pressure, the tractive force for different sized cylinders can be calculated until the diameter is found which will be of the right size. But as this would be tedious, the following rule which gives the right diameter with one calculation, will be found convenient:

TO GET THE AREA OF THE PISTONS OF A LOCOMOTIVE.

MULTIPLY ONE-FOURTH OF THE WHOLE WEIGHT (IN POUNDS) WHICH RESTS ON THE RAILS UNDER THE DRIVING-WHEELS BY THE CIRCUMFERENCE (IN INCHES) OF THOSE WHEELS. THEN MULTIPLY 90 PER CENT. OF THE MAXIMUM BOILER PRESSURE (IN POUNDS PER SQUARE INCH) BY FOUR TIMES THE STROKE OF THE PISTONS (IN INCHES), AND DIVIDE THE FIRST PRODUCT BY THE SECOND. THE QUOTIENT WILL BE THE AREA OF EACH PISTON IN SQUARE INCHES.*

To apply this rule to an actual example, an engine with pistons 18 inches in diameter and 24 inches stroke, and with driving-wheels 5½ feet=66 inches in diameter, loaded with 64,000 lbs.=32 tons and a maximum boiler pressure of 150 lbs. per square inch, will be taken. The circum-

* This rule has been worked out algebraically as follows:

Let A = Area of one piston (in square inches).
P = Maximum boiler pressure (per square inch).
p = Mean pressure (per square inch) in the cylinder.
S = Stroke of piston (in inches).
C = Circumference of driving-wheels (in inches).
W = Total weight on rails below all the driving-wheels (in pounds).

As p is assumed to be = .90 P the tractive force, by the rule given in answer to Question 406, will be = $\frac{A \times .90 P \times 4 S}{C}$.

The adhesion has been assumed to be equal to ¼ W, and as the tractive force and the adhesion should be equal, we have

$$\frac{A \times .90 P \times 4 S}{C} = \tfrac{1}{4} W,$$

from which we have

$$A = \frac{\tfrac{1}{4} W \times C}{.90 P \times 4 S}.$$

It is not easy to give a demonstration of this rule without the use of algebra, and those not acquainted with that branch of mathematics must accept the rule on faith.

ference of these wheels will be 207.3 inches, so that by the rule we will have:

$$\frac{64,000}{4} = 16,000 \times 207.3 = 3,316,800,$$

and
$$150 \times .90 \times 4 \times 24 = 12,960,$$

and
$$\frac{3,316,800}{12,960} = 255.9 = \text{area of cylinder.}$$

Having the area the diameter can readily be ascertained by calculation, or from a table of diameters and areas. In this case the diameter is 18 inches very nearly.

QUESTION 709. *What are the three elements which determine the size of the cylinders?*

Answer. From what has been said it will be seen that the size of the cylinders is governed by, first, the weight on the driving-wheels; second, the diameter of those wheels; and, third, the steam pressure.

QUESTION 710. *Are the sizes of cylinders generally determined by these considerations?*

Answer. No; many locomotive superintendents regard the expansive action of the steam in the cylinders as of more importance in determining their size than any other consideration, and therefore they make the cylinders larger than the above rule would indicate they should be. In other cases cylinders are made of considerably smaller sizes than would be given by the rule. Caprice, prejudice and accident, seem to have had considerable influence in determining the proportions of cylinders.

QUESTION 711. *In what way can we compare the relative sizes of cylinders, taking into account the weight on the driving-wheels, their size, and the steam pressure?*

Answer. The method of doing this can be best explained by taking, as an example, a standard passenger locomotive with cylinders 18 inches diameter and 24 inches stroke, driving-wheels 5½ feet=66 inches diameter, and with 64,000 lbs. of load on these wheels. The circumference of such wheels is 207.3 inches, and if they do not slip the locomotive will move that distance on the rails while the wheels revolve once. At the same time each piston will sweep through its cylinder twice, and therefore during one revolution of the wheels four times one cylinder full of steam is used. The cubical space that a piston 18 inches diameter and 24 inches stroke sweeps through in moving from one end of the cylinder to the other is equal to 6,107 cubic inches, so that in one revolution of the wheels $6{,}107 \times 4 = 24{,}428$ cubic inches of steam are used. If, then, we divide 24,428 by 207.3 inches, the distance that the locomotive moves during one revolution of its driving-wheels, it will give us the amount of steam used to move the locomotive and train one inch. That is, $24{,}428 \div 207.3 = 117.8$. It will thus be seen that a locomotive of the dimensions given, and with 64,000 lbs. or 32 tons (of 2,000 lbs.) of adhesive weight, has 117.8 cubic inches of cylinder capacity* to move it one inch. If the locomotive had only half as much weight on the driving-wheels, it would have only half as much adhesion and could pull only half as much load, and would therefore require only half as much steam, and consequently need only half the cylinder capacity of the other locomotive. If there was three-quarters or a third as much adhesive weight, the cylinder capacity should also be three-quarters or a third. In other words, the cylinder capacity should be proportioned to the adhesive weight. If, then, we divide the number of cubic inches of steam consumed while the engine moves one inch by the number of tons (of 2,000 lbs.) of adhesive weight, it will give us the number of cubic inches of cylinder capacity per ton of adhesive weight. Applying this to the preceding example, $117.8 \div 32 = 3.68$ cubic inches will be the cylinder capacity per ton of adhesive weight and per inch of the circumference of its driving-wheels. This quantity has been named the *modulus of propulsion*, which can be calculated by the following rule:

MULTIPLY THE AREA OF ONE PISTON (IN SQUARE INCHES) BY THE STROKE (IN INCHES) AND THE PRODUCT BY FOUR. DIVIDE THIS PRODUCT BY THE CIRCUMFERENCE OF THE DRIVING-WHEELS (IN INCHES) AND BY THE WEIGHT (IN TONS OF 2,000 LBS.) ON ALL THE DRIVING-WHEELS. THE QUOTIENT WILL BE THE MODULUS OF PROPULSION.

This modulus varies considerably in different locomotives. Thus in some consolidation engines built for the Denver & Rio Grande Railroad, the cylinders were 20 inches diameter and 24 inches stroke, the wheels 46 inches diameter with 103,000 lbs. of weight on them. The modulus of propulsion on these engines is 4.05, whereas some ten-wheeled passenger engines on the Michigan Central Railroad, have cylinders 19×24 inches, wheels 68 inches diameter, with 96,000 lbs. on the driving-wheels, and, consequently, have a modulus of propulsion of only 2.65.

To get a measure of the cylinder capacity which will also take the

* The cylinder capacity is the space swept through by the two pistons. In the above illustrations what is meant is, that the average space in the cylinder swept through by the piston is 117.8 cubic inches for each inch that the locomotive advances.

steam pressure into account, we should multiply the modulus of propulsion by the maximum boiler pressure per square inch. This product has been named the *modulus of traction*. Thus in the first example the boiler pressure was assumed to be 150 lbs., and therefore $3.68 \times 150 = 552$, in the second it was 140 lbs., so that $4.05 \times 140 = 567$. Experience seems to indicate that a modulus of traction of about 550 will give very good results in practice.

It should be remarked here that it is unimportant, so far as the power of the locomotive is concerned, whether the cylinders have a large diameter and a short stroke or a small diameter and a long stroke, provided the cubical contents are the same. Thus, cylinders 17½ inches in diameter and with 20 inches stroke would have almost exactly the same capacity, and the same power would be exerted with them as with cylinders 16×24 inches; the only difference would be that with the cylinder of the largest diameter the pressure on the piston, and consequently on the crank-pin journal, and the strain on the parts would be greater than with the smaller cylinder. The difference in pressure would, however, be exactly compensated by the loss or gain in the leverage exerted through the driving-wheels on the rails.

QUESTION 712. *What circumstances should determine the size of locomotive boilers?*

Answer. They should be proportioned to the amount of adhesive weight, and to the speed at which the locomotive is intended to work. Thus, a locomotive with a great deal of weight on the driving-wheels could pull a heavier load, and would, by the above rule for proportioning the cylinders, have a greater cylinder capacity than one with little adhesive weight, and would therefore consume more steam, and therefore should have a larger boiler. It is also obvious that if a locomotive like that shown in Plate III should have a boiler just large enough to furnish steam when running at the rate of 20 miles an hour, it would be too small if the locomotive ran 40 miles an hour, the train resistance being the same in both cases. Driving-wheels 5 feet in diameter would at 20 miles per hour make 112 revolutions per minute, and would therefore consume 448 cylinders full of steam. At 40 miles per hour double the number of revolutions would be made, and consequently twice the quantity of steam would be used, and therefore the boiler should have twice the steam-producing capacity. If, therefore, we know the size of a boiler required for a given amount of adhesive weight and a given speed, we can easily calculate the boiler capacity for any other weight and speed.

QUESTION 713. *What circumstances usually determine the size and proportion of locomotive boilers?*

Answer. The weight and dimensions of locomotive boilers are in nearly all cases determined by the limits of weight and space to which they are necessarily confined. It may be stated generally that *within these limits a locomotive boiler cannot be made too large*. In other words, boilers should always be made as large as is possible under the conditions that determine the weight and dimensions of the locomotives.

QUESTION 714. *On what does the steam-generating capacity of a boiler depend?*

Answer. First, upon the size of its grate and fire-box, because more fuel can be burned in a large fireplace than in a small one; second, on the amount of heating surface to which the products of combustion are exposed; and, third, on the draft produced by the blast or exhaust steam. Of course the amount of steam generated is also dependent upon a great variety of other circumstances, such as the nature of the combustion, the firing, the arrangement of the fire-box, grates, exhaust-pipes, smoke-box, etc., and the condition of the heating surfaces; but these have nothing to do with the size of the boiler.

QUESTION 715. *What are the proportions of boilers used in locomotives like that which is represented in Plates III-V?*

Answer. The area of the grate is usually about 18 square feet, and the total heating surface about 1,600 square feet.

QUESTION 716. *At what speed are such engines usually run?*

Answer. The speed varies so much under different circumstances, that it is impossible to give even approximately the average speed of such engines.

QUESTION 717. *In what respects is the operation of locomotive boilers different from that of nearly all other steam boilers?*

Answer. The amount of steam generated in proportion to the amount of heating surface is much greater in locomotive boilers than in any other kind. To produce combustion which will be sufficiently active to generate the requisite quantity of steam, the fire must be stimulated by the blast created by the exhaust steam to a degree unknown in other kinds of boilers. So rapid is the movement of the products of combustion that a smaller proportion of the heat is imparted to the water contained in the boiler, and consequently a less amount of water is evaporated in proportion to any given amount of fuel than in boilers in which combustion is less violent. The combustion is often less complete, because the strong draft does not allow time for a perfect combination of the gases which produce combustion.

The supply of steam which a locomotive boiler must furnish is also much more irregular than the demands made upon any other kind of boiler. At one time the fire must be urged to the greatest possible intensity, in order to furnish steam enough to pull a train up a steep grade. When the top is reached the demand ceases, and the boiler can be cooled. The load which a locomotive can pull over a given line of road is usually limited by the utmost capacity of the boiler to supply steam at these critical periods.

QUESTION 718. *What relation is there between this irregular action and the size of the boiler?*

Answer. The smaller the boiler, or rather the larger the amount of steam which must be generated in a given time in proportion to the heating surface, the more must the fire be urged; and, therefore, the smaller the boiler in proportion to the work it must do, the less will be its economy. In order to produce a rapid combustion in a small boiler, it is necessary to contract the exhaust nozzles in order to create a draft strong enough. In doing this the back pressure on the pistons is very much increased, and when the blast becomes very violent a great deal of solid coal is carried through the tubes and escapes at the smoke-stack unconsumed. At the same time large quantities of unconsumed gases escape, because there is not time for combustion to take place in the fire-box. The fact that with a violent draft the flame and smoke are in contact with the heating surface for a sensibly shorter period of time also has its influence, as less heat will be imparted to the water if the products of combustion are only $\frac{1}{100}$ of a second instead of $\frac{2}{100}$ in passing through the tubes.

There is another consideration which should be taken into account in this connection, which is, that if a boiler is so small that it is worked nearly up to its maximum capacity at all times, it will be impossible to accumulate any reserve power in it in the form of water heated to a high temperature to be used as occasion may require. With a boiler having a great amount of heating surface and capacity for carrying a large quantity of water, the latter can be heated at times when the engine is not working hard, and the heat thus stored up in the water can then be used when it is most needed. Thus we will suppose that to pull a train of cars on a level 250 lbs. of steam are consumed per mile. On a grade of 80 feet per mile the resistance will be three times what it is on a level, and therefore three times the quantity of steam will be consumed, so that the boiler must then evaporate 750 lbs. of water per mile. Now, to convert 250 lbs. of water heated up to a temperature due to 130 lbs. of effective pressure, or 355.6 degrees, into steam of that pressure will require 216,575 units of heat. If at the same time that this steam is being consumed, we pump into the boiler 250 lbs. of water of a temperature of 60 degrees, 73,900 more units of heat will be needed to raise the water to the temperature due to 130 lbs. effective pressure, so that on the level part of the road it would be necessary to transmit to the water in the boiler 216,575 + 73,900 = 290,475 units of heat in a mile. If there is no room in the boiler for storing a surplus quantity of hot water, it will be necessary on a grade as fast as the steam is consumed to feed an equivalent amount of cold water to take the place of that which was converted into steam, so that on a 80 feet grade it would be necessary to convert at the rate of 750 lbs. of hot water into steam in a mile, which would require 649,725 units of heat, and at the same time an equal amount of cold water must be heated to a temperature due to the pressure of the steam, which would require 221,700 more units. So that it will be necessary to transmit at the rate of 871,425 units of heat to the water per mile. Now, if the boiler was so large that more water could be pumped into it and heated than was used on the level portion of the road, and could be stored up in the boiler for future use, the pumps might be either partly or entirely shut off when the engine was working the hardest on the grade. In this way, instead of being obliged to convert hot water into steam, and at the same time heat an equivalent amount of cold feed-water, there would be a surplus of hot water stored up already heated. It would therefore only be necessary to convert this hot water into steam, which will require a transmission of heat to the water at the rate of 649,725 units of heat instead of 871,425. It must be remembered that on nearly all roads there are certain difficult places which practically limit the capacity of the locomotives on that line. If, therefore, the capacity of the engines can be increased at those points, their capacity over the whole line is increased. It will be seen by the above illustration that by having a large boiler it is necessary for it to do very much less work at the critical period, when, as every locomotive engineer knows, it is often of the utmost importance to make use of every possible available means in order to pull the train. It is true that on a very long grade the supply of surplus hot water would soon be exhausted, but even in such cases there is usually one place, owing to a curve or other cause, which is more difficult to surmount than any other, and then it will be necessary to use more steam for a short time than the locomotive can generate if the boiler is fed continuously. For such occasions a surplus of water can be used. But even if the resistance is equal over the whole length of the incline, still the large boiler will have the advantage, because it can at all times generate more steam than a smaller one. It may, therefore, we think, safely be assumed that locomotive boilers should always be made as large as the weight of the locomotive will permit.

QUESTION 719. *What effect does the size of the driving-wheels have upon the combustion and evaporation of locomotive boilers?*

Answer. As small wheels make more revolutions in running a given distance than large ones, there will be more strokes of the piston with the former than with the latter, if the locomotive in both cases runs at the same speed. As smaller cylinders can be used with small wheels, the blast up the chimney is then composed of a larger number of discharges of steam, but each one is of a less quantity of steam than when larger wheels and cylinders are employed. In the one case the "puffs" of steam are many and small, and in the latter few and large. If the cylinders are proportioned by the rule which has been given for that purpose, the amount of steam discharged in running any given distance will be the same with engines of the same weight having large and those with small wheels, the only difference being that it will be subdivided into a greater number of discharges in the one case than in the other. Now, it is found that the draft of engines is much more effective on the fire when the blast is thus subdivided, that is when small wheels and cylinders are used, than it is with large ones, and therefore more steam is generated with the former than with the latter.

QUESTION 720. *What relation is there between the size of the wheels and that of the boiler?*

Answer. As has been explained, the size of the boiler is limited by the weight of the locomotive. The boiler and its attachments of an American type of locomotive, when the former is filled with water, weigh about half as much as the locomotive; therefore, unless we increase the weight of the latter or decrease the weight of the machinery, we cannot increase the size of the boiler. Now, large wheels are heavier than small ones; they require larger cylinders, stronger connections, heavier frames, and in fact nearly all the parts of the machinery used with large wheels must be heavier than are required when small wheels are used. Therefore, by decreasing the size of the wheels all the other parts of the engine proper can be made lighter than is possible if large wheels are used, and thus the size and weight of the boiler can be increased without increasing the whole weight of the locomotive. There is, of course, a practical limit below which the size of the wheels cannot be reduced, because the speed of the piston would become so great as to be injurious to the machinery. By reducing the stroke, however, with the diameter of the wheels, the evil referred to may be obviated to a great extent. Cylinders with a large diameter and comparatively small stroke have also the advantage that there is less surface exposed to radiation of heat than there is in cylinders in which these proportions are reversed.

CHAPTER XXX.

COMBUSTION.

QUESTION 721. *What is meant by combustion?*

Answer. By combustion is meant the phenomenon ordinarily called burning, as when a piece of wood or coal or a candle is burned. In reality combustion is a union of one of the "*chemical elements,*" oxygen, of which the atmosphere is composed, with the elements which constitute the fuel.

QUESTION 722. *What is meant by the term "chemical element?"*

Answer. The science of chemistry has demonstrated that nearly all substances by which we are surrounded are composed of certain other substances, which latter, as far as is now known, are not compounds, and are therefore called *elementary substances, or chemical elements.* Thus, the air by which we are surrounded is composed of two gases, called nitrogen and oxygen; water is composed of hydrogen and oxygen, and coal chiefly of carbon and hydrogen. There are now over sixty of these elementary substances known. From no one of them have chemists been able to extract any material excepting the substance itself. These elementary substances will combine with others so as to form what is apparently a new material, but on weighing it, it will be found that the weight of the new material is greater than the original elementary substance, showing that something was added to it which effected the change.*

QUESTION 723. *To what fact is this combination or combustion of elementary substances due?*

Answer. It is owing to the fact—the exact reason for which is, perhaps, not yet understood fully—that the atoms of the elementary substances of which fuel is composed, that is, hydrogen and carbon, and the atoms of oxygen, which forms part of the atmosphere by which we are surrounded, attract each other with great energy when they are excited into activity by the application of heat.

QUESTION 724. *What phenomenon always attends chemical combination of substances?*

Answer. Such combination always gives out heat, whereas their separation absorbs heat. It has further been proved by actual experiment that

* "The New Chemistry," by J. P. Cooke, Jr.

the amount of heat liberated by the chemical union of the same quantity or number of atoms of two or more substances is always the same, and that when, by any cause, the atoms thus joined are separated, exactly the same amount of heat is absorbed.*

QUESTION 725. *In what proportions do the elementary substances combine with each other?*

Answer. It is a law of chemistry that each of the elementary substances combines with the others in certain definite proportions only. These proportions vary for the different elements, and have been determined with great accuracy by chemists. Thus, 8 parts by weight of oxygen will combine with nitrogen and form atmospheric air, or the same proportion of oxygen will combine with hydrogen and form water, or with carbon and form carbonic acid, which is the deadly gas which accumulates at the bottom of wells.

Oxygen always combines with other substances in the proportion of 8 parts by weight, or by *some simple multiple of* 8, that is, $8 \times 2 = 16$ parts, or $8 \times 3 = 24$ parts, etc. Each of the other elementary substances also has a certain fixed proportion in which it combines with others, and this proportion, which is usually given by weight, is represented by a number called its *chemical equivalent*. Thus 8 is the chemical equivalent of oxygen. Carbon combines with other elements in proportions of 6, and nitrogen in proportions of 14, so that 6 and 14 are the chemical equivalents of carbon and nitrogen. Now 8 parts by weight of oxygen can be made to combine with 14 parts of nitrogen, or $8 \times 2 = 16$ parts of oxygen will combine with 14 of nitrogen, but it is impossible to make, say 12 parts of oxygen combine with 14 parts of nitrogen. We can combine $14 \times 2 = 28$ parts of nitrogen with 8 parts of oxygen, but no chemical process can make, say 10 or 20 parts of nitrogen combine with 8 parts of oxygen. If 20 parts of nitrogen are mixed with 8 parts of oxygen, then the latter will combine with 14 parts of the former, but 6 parts of nitrogen will be left, and chemical combination will then cease.

The following table will give the chemical equivalents of the principal elements which enter into the process of combustion of the fuel used in locomotives:

	Chemical equivalent by weight.
Oxygen	8
Nitrogen	14
Hydrogen	1
Carbon	6
Sulphur	16

* "The New Chemistry," by J. P. Cooke, Jr.

QUESTION 726. *What effect do the proportions in which elements are combined have upon the substances which are produced by the combination?*

Answer. A change in the proportions in which the elements are combined usually alters the entire nature of the substance, so far at least as it affects our senses. For instance, oxygen unites chemically with nitrogen in different proportions, forming five distinct substances, each essentially different from the others, thus:

14	parts of	Nitrogen	with	8	of Oxygen	forms	Nitrous Oxide.
14	"	"	"	16	"	"	Nitric Oxide.
14	"	"	"	24	"	"	Hyponitrous Acid.
14	"	"	"	32	"	"	Nitrous Acid.
14	"	"	"	40	"	"	Nitric Acid.

We here find the elements of the air we breathe, by a mere change in the *proportions* in which they are united, forming distinct substances, which differ from each other as much as *laughing gas* (nitrous oxide) does from that most destructive agent, *nitric acid*, commonly called *aqua-fortis*.*

QUESTION 727. *What occurs when a fresh supply of bituminous coal is thrown on a bright fire in a fire-box of a locomotive?*

Answer. The fresh coal is first heated by the fire, and if a sufficient quantity is thrown in to prevent the immediate formation of flame,† a volume of gas or vapor, usually of a dark yellow or brown color, is given off. The quantity evolved will be greatest when the coal is very small. This gas or vapor is commonly called smoke, but it does not deposit soot, and in reality is not true smoke. If a sheet of white paper be held over the vapor as it escapes from the coal and there is no flame, the sheet will become slowly coated with a sticky matter of brown color difficult to remove, and having a strong tarry or sulphurous smell; whereas, if a sheet of paper is held over smoke it will quickly be covered with black soot. The color and smell left on the paper in the first case are due to the tarry matter, sulphur, and other ingredients in the gas. Deprived of the coloring matters, the vapor is a chemical mixture of 2 parts of hydrogen and 6 parts of carbon, and is called carburetted hydrogen, and is nearly the same as the colorless gas by which our houses are lighted.‡ A similar gas is generated at the wick of a burning candle or lamp, and is consumed in

* "Combustion of Coal and the Prevention of Smoke," by C. Wye Williams.

† Usually if more than two or three shovels full are thrown in, there will be no immediate formation of flame.

‡ "A Treatise on Steam Boilers," by Robert Wilson.

the flame. Before the gas is expelled from the fresh coal, the latter must be heated to a temperature of about 1,200°, so that if 100 lbs. at a temperature of 50° is put on the fire, 23,000 units of heat will be absorbed to heat the coal.* Nor is this all, as has been explained in answer to Question 106, when any substance is vaporized a certain amount of heat apparently disappears, which has been called the *heat of evaporation* or *of gasification*. Average bituminous coal contains about 80 per cent. of carbon, 5 per cent. of hydrogen, and 15 per cent. of other substances usually regarded as impurities. When the coal is heated up to about 1,200°, the 5 per cent. of hydrogen unites with three times its weight of carbon, and thus 20 per cent. of the coal is converted into the gas described. In this process a large amount of heat is absorbed or becomes latent, as it does when water or any other substance is converted into vapor. It will therefore be seen that the first effect of putting fresh coal on the fire *is to cool the fire*. This fact has an important bearing on the question of combustion and will be referred to hereafter.

QUESTION 728. *How can the process of the combustion of the gas generated from the coal be best explained?*

Answer. As this gas is substantially the same as ordinary illuminating gas, the manner in which it burns can, perhaps, be made clearer by examining the combustion of an ordinary gas-light. As stated before, combustion is a chemical union of the oxygen which forms one of the elements of the air with the hydrogen and carbon of the fuel, which, in this case, form gas. It should be clearly kept in mind that combustion is the result of this union, and that the oxygen is as essential to combustion as coal or gas, and, in fact, is the fuel of combustion, just as much as coal or gas is. If we were to conduct a pipe from the external air into a vessel filled with coal gas we could *light the air* and it would burn in the gas as the gas burns in the air.

It will be noticed, however, that before either the gas or the air will burn, they must be lighted. Air and gas, even if mixed together in the same vessel, will not burn unless they are lighted. This can be done by the flame of any burning material, or with a piece of metal heated to a very high temperature, or by an electric spark. In other words it may be said that the atoms of the two gases must be excited into activity by the application of heat, that is, what is called an *igniting temperature* must be communicated to them before chemical combination will begin. The

* The quantity of heat required to heat coal is only about one-fifth that needed to heat the same weight of water to the same temperature.

chief feature which distinguishes combustion from other chemical union is the circumstance that the heat generated during the combination is sufficient to maintain an igniting temperature, and the necessity of doing so in order to continue the process is of very great importance in the combustion of coal in locomotive boilers, as will be shown hereafter.

QUESTION 729. *How does an ordinary gas-light burn after it is lighted?*

Answer. Under ordinary conditions the hydrogen, which is the most combustible of the two elements of which coal gas is formed, is the first to burn. This part of the combustion forms the lower bluish part of the flame. The combustion of the hydrogen thus separates it from the carbon, which is then set free; and as carbon is never found in a gaseous condition when uncombined with other substances, it at once assumes the form of fine soot when the hydrogen is burned away from it. This fine soot, or pulverized carbon, is, however, intensely heated by the combustion of the hydrogen. Now carbon, when heated to an igniting temperature will, if brought into contact with a sufficient quantity of oxygen, combine with it or be burned. Each particle of carbon thus becomes a glowing centre of radiation, throwing out its luminous rays in every direction. The sparks last, however, but an instant, for the next moment they are consumed by the oxygen, which is aroused to full activity by the heat, and only a transparent gas rises from the flame. But the same process continues; other particles succeed, which become heated and ignited in their turn, and it is to this combustion of the solid particles of carbon that the light which is given out by a gas-burner or candle is due.*

QUESTION 730. *Why does a gas-burner, candle or other flame sometimes smoke?*

Answer. Because the supply of oxygen is then insufficient to consume the particles of solid carbon which are set free and which then assume the form of soot. This can be illustrated if we cut a hole in a card, *d d*, fig. 466, so as to fit over an ordinary gas-burner, *b*. If we then light the gas and place a glass chimney, *a a*, over the burner and let it rest on the card, it will be found that the flame will at once begin to smoke, because very little air can then come in contact with the flame, and therefore when the fine particles of carbon are set free by the combustion of the hydrogen, instead of being burned, as they would be if the air with its supply of oxygen were not excluded from the flame by the chimney, they escape unconsumed in the form of fine black powder or soot. If we raise the chimney up from the card, as shown in fig. 467, so as to leave enough

* "The New Chemistry," by J. P. Cooke, Jr.

space between them at the bottom of the chimney to permit air to enter, as indicated by the darts, *c c*, and supply the flame with oxygen, the smoke will instantly cease, as the particles of carbon are then consumed. The same principle is illustrated in an ordinary kerosene lamp. It is well known that without a chimney the flames of nearly all such lamps smoke intolerably, whereas with a glass chimney and the peculiarly formed deflector which surrounds the wick, the light burns without smoke unless the wick is turned up high. The effect of the chimney is to produce a draft which is thrown against the flame by the deflector, and thus a sufficient supply of oxygen is furnished to consume all the particles of carbon, whereas, without the draft produced by the chimney, the supply of oxygen is insufficient to ignite all the carbon, which then escapes in the form of smoke or soot.

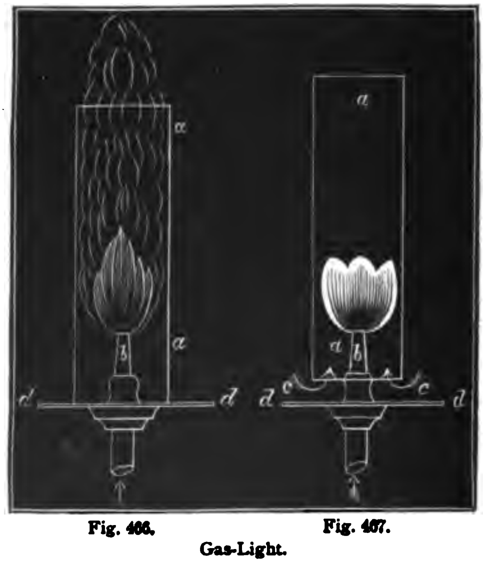


Fig. 466. Fig. 467.

Gas-Light.

It must not, however, be hastily assumed that if the flame does not give out a bright light, therefore the combustion is not complete. As has already been stated, the light of the gas flame is due to the presence of burning particles of solid carbon, which is set free by the combustion of the hydrogen with which it is combined. After it is separated from the hydrogen it immediately assumes a solid form. If the coal gas is mixed with a sufficient quantity of air before it is burned, the oxygen in the latter will be in such intimate contact with the former that the difference of affinity of oxygen for the carbon and hydrogen does not come into play, and as there is enough oxygen for all, the carbon is burned before it is set free, and as there are then no solid particles in the flame, there is no light. This is illustrated by what is called a "Bunsen burner," fig. 468,

Fig. 468. Bunsen Burner. Fig. 469. Candle.

which is much used in chemical laboratories. It consists of a small tube or burner, *a*, which is placed inside of another larger tube, *b*. The latter has holes, *c c*, a little below the top of the small tube. The current of gas escaping from the small tube draws the air in through the holes, *c c*, and produces what is called an *induced current* of air in the large tube. This air enters through the holes, *c c*, and is mixed with the gas in the tube, *b*, and the mixture is burned at *d*. The flame from such a burner gives hardly any light, but the heat is intense, as is shown if a metal wire is held in it for a few seconds, which will very soon glow with heat.

QUESTION 731. *What important difference is there in the structure of the flame of a Bunsen burner and that of an ordinary gas-burner or candle?*

Answer. The gas which escapes from the mouth, *d*, of the pipe, *b*, fig. 468, is mixed with air, and therefore contains within itself the elements which only need to combine to produce combustion; whereas, with an ordinary gas-burner or candle, the air comes in contact with the flame only from the outside, or on its surface. This is shown better, perhaps, in the flame of an ordinary candle. The heat of such a flame distills a gas from the melted tallow, which is similar in nature to that which escapes from coal at a high temperature. Now, by observing the candle very closely, it will be seen that at the bottom, close to the wick, there is very little combustion, as the gas there first escapes from the wick and is not heated to a sufficiently high temperature to burn freely. A little above the lowermost part the flame is of a pale blueish color, which is due to the combustion of the hydrogen. Above that, where the carbon is set free, its particles glow with heat imparted by the burning hydrogen, and are then consumed by uniting with the oxygen of the air. The combustion occurs only at the surface of the flame, the inside being a mass of combustible gas which cannot burn until it in turn comes in contact with the oxygen of the air. This can be proved by inserting one end of a small tube, *a*, fig. 469 (a pipe stem will do), which is open at both ends, into the flame. The combustible gas will then escape at the other end, *b*, and can easily be lighted with a match.

It will be found that the flame from the Bunsen burner is much more intense than that of an ordinary candle or gas-burner. The reason of this is that combustion, as already stated, takes place through the whole mass of its flame, whereas an ordinary flame burns only at its surface. Common gas-jets are therefore arranged so that the flames will be flat, thus exposing as much surface to the air as possible, and, as explained in answer to Question 545, in describing the lamps for head-lights, their burners are usually made with a circular wick, through the centre of which a current of air circulates. This arrangement exposes a larger surface of the flame to the air, and also with the aid of a chimney furnishes an abundant supply for combustion. In stationary boilers, with long flues of a large sectional area, the flame will often extend for thirty feet, showing that while combustion is going on only at the surface of the flame, it takes a long time to complete the process. The same thing is shown if a gas-burner is made with a single round hole. The flame will then be very long and liable to smoke at the top.

QUESTION 732. *From the preceding considerations what may we infer to be necessary in order to consume coal gas perfectly?*

Answer. In the first place there must exist a certain degree of what chemists call "molecular activity," which is produced by heat, or what we have called the *igniting temperature*. The necessity of this is sufficiently obvious with ordinary gas-burners, as they must always be *lighted* before they will burn. Now imagine that it was required to burn gas which was issuing from a hundred jets, of every variety of size, in a violent wind storm, or gusts of wind. Obviously it would be necessary to keep a lighted torch all the time to relight those which would be blown out. The gas in a locomotive fire-box is in reality burned in a storm of wind more violent than any natural one. It is therefore necessary to be constantly ready to relight the streams of gas which the faintest breath would extinguish, or those of larger volume which have absorbed a great deal of heat and thus reduced the temperature at the time and place of their birth, when they assumed the gaseous form, as was explained in answer to Question 727. To relight them with certainty it is necessary to keep a constant temperature in the fire-box high enough to ignite the gas which escapes or is distilled from the coal.

Second. That the chemical change in combustion consists simply in the union of the elements burned with the oxygen of the air; and, therefore, to burn the gas perfectly, without smoke or waste, *enough* air must be furnished to supply all the oxygen which will combine with the fuel.

Third. That the air must be mixed with the gas, otherwise combustion will occur only at the surface of the flame, and will therefore be so slow that much of the gas will escape unconsumed.

It must be clearly kept in mind that no one or two of these requirements alone, without the third, will burn coal perfectly. What is needed is all three in combination. A very common error is to suppose that passing smoke over a hot fire, or, in other words, maintaining an igniting temperature, will alone effect perfect combustion; or that if a sufficient supply of air is admitted, without an igniting temperature in the fire-box, the fuel will be burned completely. Neither of them will accomplish the object alone, and the gas and air must at the same time be thoroughly mixed with the burning gas in the fire-box.

QUESTION 733. *What substances are produced by the combustion of coal gas?*

Answer. The hydrogen of coal gas unites during combustion with oxygen in the proportion, as indicated by their chemical equivalents, of 1 part by weight of hydrogen with 8 parts of oxygen, the product of which is water. Of course at the high temperature at which the gases combine or burn, the water is produced in the form of steam. That water or steam is one of the products of combustion is shown every cold evening, when the insides of shop show-windows are covered with moisture, which is due to the steam that is given off by the burning gas-lights or lamps inside, and is then condensed against the cold glass.

Carbon combines with oxygen in two proportions: first, 6 parts of the former will unite with 8 of the latter, forming what is called *carbonic oxide;* or, 6 parts of carbon will combine with 16 parts of oxygen, forming *carbonic acid gas* or *carbonic dioxide* or *carbonic anhydride*, as it is called in some of the new books on chemistry. It is probable that the former compound, that is, carbonic oxide, is never or very rarely formed in the flame of coal gas; but, as will be seen hereafter, is a very common and wasteful product of the combustion of the solid portion of the coal which is left after the gas is expelled from it. When there is not enough oxygen for the perfect combustion of the carbon in the flame, it smokes, and the carbon escapes in the form of soot. This, as will be shown, may in a locomotive fire-box help to form carbonic oxide after it leaves the flame.

QUESTION 734. *What remains in the coal after all the gas is expelled by heat?*

Answer. What remains is ordinarily called coke, which, with the exception of some incombustible substances, such as sand, ashes, and cinders, which the coal contains, is nearly pure carbon.

QUESTION 735. *What is the chemical process of the combustion of coke?*

Answer. The solid carbon of the coke when raised to an igniting temperature, or, in other words, on being lighted, unites with the oxygen in one of the two proportions already given; that is, if the supply of oxygen is sufficient, 6 parts of the carbon of the coke unite with 16 parts of oxygen, forming carbonic acid gas, or carbonic dioxide. If, however, the layer of fuel on the grates is thick, or the supply of air is comparatively small, there will not be enough oxygen to supply 16 parts of the latter to each 6 parts of the carbon, so that when that occurs, instead of combining in that proportion, and thus forming carbonic dioxide, 8 parts of oxygen will unite with 6 parts of carbon and form carbonic oxide. Now it should be carefully kept in mind that the heat of combustion is due to the union, or, as it is sometimes expressed, it is the clashing together of the molecules of the two elements which unite. If, therefore, only half the quantity of oxygen unites with 6 parts of carbon, evidently there will be less heat evolved than there would be if twice that amount of oxygen combined with the carbon. From carefully made experiments, it was found that the total heat of the combustion of 1 lb. of carbon, when converted into *carbonic oxide*, was 4,400 units, whereas when it was converted into *carbonic dioxide*

14,500 units were given out. It will thus be seen that it is extremely wasteful to burn coal without a sufficient supply of air to produce carbonic dioxide. The danger of waste from this cause is also increased by the fact that carbonic oxide is colorless and odorless, and therefore its production is not apparent, especially as most persons have the impression that when there is no smoke from a fire combustion is then complete. It burns with a blue or yellowish flame when air is admitted into the fire-box, and its presence can often be detected by these phenomena when the furnace door is opened.

QUESTION 736. *How can the requisite quantity of air be supplied to the fire in a locomotive fire-box?*

Answer. It is done in two ways: one way is to keep but little coal on the grates, or, in the phraseology of firemen, to "carry a light fire." The other method is to admit fresh air above the fire. If the latter plan is adopted when the supply of air through the grates is insufficient for perfect combustion, the carbonic oxide will unite with the oxygen of the air above the fire, and thus a second combustion will take place, the product of which will be carbonic dioxide. It must be kept in mind, however, that not only must there be enough air supplied to the fire to consume the coke, but the gases which are distilled from the coal must also be supplied with oxygen in order to effect their perfect combustion. Even if enough air is admitted to consume the coke perfectly, if the carbonic dioxide thus formed is mixed with large quantities of smoke above the fire, the solid carbon or soot of the smoke may then combine with the dioxide and thus form carbonic oxide, if there is not enough fresh air present to furnish the requisite oxygen for the carbon in the smoke. A very common error is to suppose that smoke can be burned by passing it over or through a very hot fire. The smoke may thus be made invisible, it is true, but it does not therefore follow that it is perfectly consumed.

QUESTION 737. *Is it possible to admit too much air into the fire-box of a locomotive?*

Answer. Yes; probably all the air that is admitted which is not necessary for combustion, or, in other words, the oxygen of which does not combine with the fuel, instead of increasing, diminishes the amount of steam which is generated. It does this in two ways: first, by reducing the temperature of the gases in contact with the heating surfaces, and second, by increasing the volume or quantity of the gases which must pass through the tubes. Heat is transmitted through the heating surface of a boiler in proportion to the *difference* of the temperature of the products of combustion on one side, and the water on the other.* Thus, if the temperature of the water on one side is 250 degrees, and the hot gases on the other is 500, there will be only half as much heat transmitted to the water in a given time as there would be if the gases had a temperature of 750 degrees. If the volume of gases is doubled by the admission of too much air, then obviously in order to pass through the tubes they must move at double the velocity, so that not only is their temperature reduced, but the time they are in contact with the heating surface is diminished in like proportion. This is shown by the effect of opening the furnace-door, or of allowing the fire to burn away so that portions of the grate are left uncovered. The volume of cold air which will in either of these cases enter the fire-box will be so great that the pressure of the steam in the boiler will begin to fall at once.

QUESTION 738. *What determines the amount of air which must be admitted to the fire-box of a locomotive to effect perfect combustion?*

Answer. This depends chiefly upon the *rate of combustion*—that is, the number of pounds of coal consumed per hour on each square foot of grate surface. Of course if 100 lbs. is burned it will require twice the supply of air that would be needed if only 50 lbs were burned.

QUESTION 739. *How should the air be admitted so as to burn the coal perfectly?*

Answer. In burning bituminous coal it has been shown that there are two distinct bodies to be dealt with, the one coke, a *solid*, the other coal gas, which is, of course, a *gaseous body*. The combustion of each of these is necessarily a distinct process. If the requisite quantity of air is supplied to the burning coke, or solid portions of the coal, it will, as has been shown, be converted into carbonic dioxide, and thus be perfectly consumed. If the supply of air is insufficient, the product of the combustion will be carbonic oxide, which is very wasteful. If, for example, there is a thick layer of coke on the grate, the air will enter and unite with the lower layer of coal and form carbonic dioxide, but as it rises there will not be enough air to supply oxygen to the carbon, and another equivalent of the latter will therefore combine with the carbonic dioxide and form carbonic oxide. It is evident, though, that the thinner the fire, the easier it is for air to pass through it, and consequently the greater will be the quantity which will enter the fire-box. Nothing would seem easier, then, than to regulate the thickness of the fire on the grates, so that just the needed amount of air would pass through it. If coke alone was to be

* This law is perhaps not absolutely correct, but is near enough for our present illustration.

burned, undoubtedly very perfect combustion would be (and has been) effected in this way; but if a charge of fresh coal, say 100 lbs., is thrown on the fire, coal gas is very soon generated and escapes into the fire-box. This gas needs an additional amount of air for its combustion. It would seem that this could be supplied by reducing the thickness of the fire still further, so that more air would pass through it than was needed for the combustion of the coke alone. If this was done, then too much air would pass through the coke after the gases had all escaped from the fresh coal and were burned. Besides, the passage of the air would be the most restricted after the fresh charge had been put on the fire, just at the time when the most is needed. This difficulty might be overcome if a constant supply of fresh coal just equal to that consumed were kept on the fire all the time, and the thickness of fuel on the grates was then regulated so as to admit just air enough for the combustion of the coke and also that of the gases, the production of which would then be uniform. An approximation to this method of feeding the fire is, in fact, what is aimed at on most locomotives, and probably the best practical results are produced by that method.

Two difficulties are, however, encountered in this method. In the first place, it is impossible to feed a fire continuously with a shovel. There will be intervals between the charges which are thrown in, so that the supply is not uniform, even if the charges do not consist of more than a portion of a shovelful at a time; and, if the fire was fed in this way as uniformly as possible, it would then be necessary to open the furnace door every time fresh coal was put on the fire, and so much cold air would thus be admitted that more would be lost by lowering the temperature of the boiler than would be gained by the improved combustion.

Another difficulty, also, is encountered in this method of burning coal in locomotives. In order to admit enough air through the fire it is necessary to keep the latter so thin on the grates that the violent draft produced by the blast lifts the coal from the grate-bars and carries the lighter particles through the flues unconsumed. It is thus extremely difficult to keep the grate uniformly covered with coal, and if it is not, the air will enter in irregular and rapid streams or masses through the uncovered parts, and at the very time when it should be *there* most restricted. Such a state of things at once bids defiance to all regulation or control, so that it is found almost uniformly that firemen of locomotives keep enough coal on the grates to avoid the danger of "losing their fire," as they express it—that is, having all the burning coal drawn through the tubes by the blast. *Now on the control of the supply of air depends all that human skill can do in effecting perfect combustion and economy;* and unless the supply of fuel and the quantity on the bars can be regulated, it will be impossible to control the admission of the air.*

Another method of feeding locomotive boilers is to pile up the coal in the back part in a thick layer as shown in fig. 476, and slope it downward toward the front, so that there is a comparatively thin fire in front. The mass piled up at the door becomes converted into coke, and the production of gas from the coal is more gradual and uniform than it is when only a small quantity is thrown in at a time, and therefore a more uniform supply of air is needed for its combustion. But it is apparent that very little air can pass through the thick heap of coal at the back part of the fire-box, and that therefore all, or nearly all the air which enters it must come in through a comparatively small portion of the grate. It will of course be difficult to admit the requisite quantity, for the reasons already stated.

It is, therefore, plain that it is practically impossible to admit enough air through the grates to effect a constantly perfect combustion of bituminous coal. It is, then, necessary to admit a portion of the air above the fire. When this is done the air thus admitted must be thoroughly mixed with the gases, to effect perfect combustion and in order to be able to enter into chemical combination, or, in other words, to burn, the gases must combine with the air at an igniting temperature. If too much air is admitted, it will reduce the temperature in the fire-box so much that the gases will not ignite; or, if it is admitted in strong currents, the air and the gases will flow side by side like the currents of two streams of water, the one muddy and the other clear, which, as is well known, mingle very slowly. Besides, if a hot stream of gas encounters a strong stream of cold air and comes in contact with it only at its surface, the latter will be cooled down below the igniting temperature; whereas, if the two had been intimately mixed in the right proportion, the whole mixture would have been hot enough to burn. It is therefore important that the air which is admitted above the fire should enter the fire-box in many small jets. None of the openings for its admission should exceed half an inch in diameter. With the violent draft in a locomotive fire-box there is an extremely brief period of time for chemical combination to take place after the gases are expelled from the coal and before they are hurried into the tubes. As the chemical action between the gases and the oxygen can

* "The Combustion of Coal," by Wye Williams.

only take place when the two are in intimate contact, too much pains cannot be taken to distribute the currents of admitted air and thus mix them with the combustible gases. In many cases means are adopted to delay the air and the gases in the fire-box so as to give them time for chemical combination or combustion before entering the tubes.

QUESTION 740. *Does any combustion take place after the gases enter the tubes?*

Answer. Very little; as the flames are extinguished soon after they enter:

QUESTION 741. *Why are the flames extinguished in the tubes?*

Answer. They are then in contact with large quantities of incombustible gas and beyond the reach of a supply of air; besides, the temperature of the tubes which are surrounded with water is so low that the flame is soon cooled down below an igniting temperature.

QUESTION 742. *What temperature is necessary to ignite coal gas or produce flame?*

Answer. A temperature about equal to that of red-hot iron is needed, as can easily be shown by the fact that a gas-light can be ignited with a bright red-hot poker, but will not light after the poker is cooled down to a dark color.

QUESTION 743. *Are there any parts of the fire-box where the temperature is probably below the igniting point?*

Answer. Yes; along the sides and ends near the plates, which are covered with water on the opposite side. At these points the coal is usually "dead," as it remains at too low a temperature to burn. For this reason, in some cases a space of from 8 to 12 inches on each side and still more at the ends of the grates is made of solid plates, without any openings, and therefore called "*dead-grates,*" so that no cold air can enter at those points. These plates are made sloping downward from the sides toward the centre of the fire-box, so that the coal which falls on them and is thus coked can easily be raked toward the middle of the fire. This arrangement of dead plates often improves the combustion, and results in greater economy of fuel. When dead plates are used the reduction of the area of the openings between the grate-bars for the admission of air can usually be compensated by making the bars narrower or the spaces between them wider.

QUESTION 744. *What should be the condition of the coal when it is put on the fire?*

Answer. It is true of the coal as well as of the gases that the chemical action between it and the oxygen can only take place when the two are in intimate contact, and therefore the rapidity and completeness of combustion and intensity of heat will be increased by increasing the number of points of contact, or by reducing the size of the fuel. The coal should therefore be broken up, but not so small as to fall between the grate-bars or be carried out of the fire-box by the blast.

QUESTION 745. *What amount of air must be admitted to the fire to effect perfect combustion?*

Answer. It was stated that average bituminous coal contains about 80 per cent. carbon, 5 per cent. of hydrogen, and 15 per cent. of other substances. As a large proportion of the latter are incombustible, we will confine ourselves for the present to the consideration of the combustion of the hydrogen and carbon alone.

The hydrogen, as has been explained, unites with oxygen in the proportion by weight of 1 part of the former to 8 parts of the latter, and the product of this union is water or steam. As 36 parts of air contain only 8 of oxygen, IN ORDER TO BURN THE HYDROGEN IT MUST BE SUPPLIED WITH 36 TIMES ITS WEIGHT OF AIR.

In order to burn the carbon perfectly it must, as has been explained, be converted into carbonic dioxide, which consists of 6 parts of carbon and 16 of oxygen; and as air consists of 28 parts of nitrogen to every 8 of oxygen, we must furnish 72 parts of air to every 6 of carbon, or, in other words, CARBON NEEDS 12 TIMES ITS WEIGHT OF AIR FOR ITS PERFECT COMBUSTION.

Every pound of average bituminous coal, therefore, requires 1.8 lbs. of air to burn its hydrogen, and 9.6 lbs. for the carbon, or 11.4 for both. As a portion of the other substances of which coal is composed, besides the oxygen and hydrogen, which others have been classed as impurities, are combustible, there will be no material error if we estimate the amount of air required for the combustion of bituminous coal at 12 LBS. PER LB. OF FUEL. As each cubic foot of air weighs 0.08072 lb., 12 lbs. will be equal to

$$\frac{12}{0.08072} = 148.6 \text{ cubic feet of air,}$$

or, for the sake of even figures and a quantity which can easily be remembered, we will say 150 CUBIC FEET OF AIR ARE NEEDED FOR THE COMBUSTION OF EACH POUND OF COAL. This is the theoretical quantity of air which is needed for combustion. Now, unfortunately, the process of combustion in the fire-boxes of locomotives is one in which any very exact combination of the substances which unite is not possible with the appliances which are now employed. If, therefore, we admitted the exact amount of air given above, while some portions of the fire where combustion was not very active might have more air than is needed, other portions would have too little; and if the air is not very thoroughly mixed, the flame and burning coal may be surrounded with the products of combustion, which would exclude the air and thus reduce its effect upon the fire. For this reason, besides the air required to furnish the oxygen necessary for the complete combustion of the fuel, it is also necessary to furnish an additional quantity of air for the *dilution* of the gaseous products of combustion, which would otherwise prevent the free access of air to the fuel. The more minute the division and the greater the velocity with which the air rushes among the fuel, the smaller is the additional quantity of air required for dilution. In locomotive boilers, although this quantity has not been exactly ascertained, there is reason to believe that it may on an average be estimated at about *one-half* of the air required for combustion.* We would, therefore, have as the quantity of air needed for combustion

$$150 + \frac{150}{2} = 225 \text{ cubic feet.}$$

This estimate, it will be seen, is roughly made, and doubtless with very careful firing and perfect appliances a smaller quantity of air would give better results. It is probable that the supply of air required for dilution varies considerably in different arrangements of the fire-box and for different kinds of fuel, and it is possible that by admitting the air for combustion in small enough jets, and deflecting the currents of smoke and gases so as to cause them to mingle with the air, the quantity required for dilution might be reduced below that indicated by the above calculation. Undoubtedly all the air which is admitted into the fire-box which does not combine with the chemical elements of the fuel lessens the amount of steam generated in the boiler, both with reference to time—that is to say, per minute—and to fuel—that is, per pound of coal consumed. But with the present locomotive boiler it is simply a choice of two evils. If no more air is admitted than theory indicates to be needed for combustion,

* Rankine. In a paper read before the Chemical Society of Paris by M. Scheurer-Kestner, he reported that in some experiments made to determine the quantity of air most favorable to combustion that of the furnace was fed with a volume of air about 5 per cent. more than the theoretical quantity required for combustion.

then, owing to the imperfect means which are usually employed to cause the air and fuel to combine, a portion of the latter will escape unconsumed; and if *more* air is admitted, the temperature of the products of combustion is lowered and their volume increased, the evils of which have already been pointed out. It therefore becomes a matter in which we are obliged to consult experience and determine by experiment what amount of air it is necessary to admit to the fuel to produce the most economical results.

QUESTION 746. *What proportion of the air should be admitted through the grate, and how much above the fire?*

Answer. This, too, is a question which can probably be answered best by consulting experience. The relative quantity of air required above and below the fire depends very much on the nature of the fuel. Coal which "runs together" or cakes very much or has a great deal of clinker in it, doubtless, will need more air above the fire than other coal which is said to be "drier," for the reason that it will be found impossible to admit so much air through the caking coal in the grate as through the other kind. An idea of the relative quantity which should be admitted above and below the fire may be found if we know how much air is needed to burn the solid carbon or coke which is left after the gas is expelled from it, and how much for the gas itself. The gas which is expelled from a pound of coal consists of about 0.05 lb. of hydrogen and 0.15 lb. of carbon. Now, it has been show that hydrogen requires 36 times its weight of air to burn it perfectly, so that 0.05 lb. would need $0.05 \times 36 = 1.8$ lbs.; and carbon requires 12 times its weight of air, so that for 0.15 lb. of carbon $0.15 \times 12 = 1.8$ lbs. is needed, so that for both 3.6 lbs. of air is required for perfect combustion. As has been shown, 12 lbs. is needed to consume the whole of the fuel, so that 30 per cent. of the whole supply is required for the combustion of the gas alone. If this is diluted in the same proportion as that required for the combustion of the carbon, and it probably should be even more so, we would have 30 per cent. of $225 = 67.5$ cubic feet of air required for the combustion of the gas. It is certain, however, that the solid coke on the grates is not perfectly consumed, or, in other words, converted into carbonic dioxdide, especially when the layer of it on the grates is very thick. When this is the case the air coming in contact with the lower layer of coke forms carbonic dioxide, but as it rises through the burning coke another equivalent of carbon unites with the carbonic dioxide, and thus forms carbonic oxide. If, now, enough air is admitted above the fire, this carbonic oxide will combine with it, and, as has been explained before, a second conbustion will take place if there is time and opportunity for combination before the gases enter the flues. It is therefore probable that more than 30 per cent. of the whole supply of air should be admitted above the fire. It is at any rate best to provide the means for admitting more, and also appliances for regulating the supply, so that it can be governed as experience may indicate to be best.

QUESTION 747. *Is it not possible by enlarging the grate to admit enough air to the fire to produce perfect combustion?*

Answer. Yes; when no air is admitted above the fire, large grates are found to produce the best combustion. But while it is true that the same amount of heat will be produced by the union of each equivalent of oxygen and fuel, yet if we can force *more* air and fuel to unite in the *same place*, a higher temperature is produced in that place, just as a fire in a blacksmith's forge is hotter because of the forced blast than that in an ordinary stove, or a smelting furnace than a parlor grate. If, then, we can concentrate the draft in the fire of a locomotive, we secure a greater *intensity* of combustion; and when the air is urged against the solid carbon with considerable force it comes in contact with every point of its surface, and therefore less dilution of the air is needed, and consequently the products of combustion have a higher temperature, and, as has been explained, a larger proportion of the heat is then transferred to the water than if the temperature is lower and the volume greater.

Intensity of combustion also has the effect of maintaining an igniting temperature; whereas, if the same amount of fuel is burned slowly, its heat may not be high enough to ignite the gases as they are produced.

It is desirable, however, to have all the space that is possible in the fire-box, so as to give room for the mixing of the gases; but with a large fire-box and large grate a decided improvement and economy will often result by diminishing the effective area of the grate by covering a part of it with dead-plates, but at the same time making provision for the admission of air above the fire.

QUESTION 748. *What is meant by the "Total Heat of Combustion?"*

Answer. It is the number of units of heat given out by the combustion of a given quantity (usually a pound) of fuel.

QUESTION 749. *How is this determined?*

Answer. The heat given out by the combustion of 1 lb. of the chemical elements of which coal is composed has been determined by experiment, and from such data, knowing the substances of which fuel is composed, we can determine the amount of heat which would be developed if they were each perfectly consumed. Thus the total heat of combustion of 1 lb. of hydrogen is 62,032 units, and of the same quantity of carbon 14,500 units.* Therefore, if a pound of coal contains 5 per cent. of hydrogen, the heat given out by the combustion of that element will be $62,032 \times 0.05 = 3,101.60$ units, and if it has 80 per cent. of carbon, the combustion of the latter would develop $14,500 \times 0.80 = 11,600$ units, so that the total heat of the combustion of these two elements would be $3,101.6 + 11,600 = 14,701.6$ units. It was shown in answer to Question 84 that it required 1,213.4 units of heat to convert water at zero to steam of 100 lbs. pressure. As steam is usually generated from water at a temperature of about 60°, the total heat required to convert it into steam of 100 lbs. pressure would be $1,213.4 - 60 = 1,153.4$ units. A pound of average bituminous coal, therefore, contains heat enough to convert 12¾ lbs. of water of 60° temperature into steam of 100 lbs. absolute pressure. Ordinarily only about half that amount of water is evaporated in locomotive boilers per pound of fuel.

QUESTION 750. *What are the chief causes of this waste of heat?*

Answer. It is due, first, to the waste of unburned fuel in the solid state. This occurs when fuel which is very fine falls through the grates, or is carried through the tubes and out of the chimney in the form of cinders.†

Second, to the waste of unburned fuel in the gaseous or smoky state. The method of preventing this waste by a sufficient supply and proper distribution of air has been explained in the answer to preceding questions. The quantity of heat wasted by smoke is, however, much smaller than is ordinarily supposed. Experiments have shown that however black and thick it may be, it does not exceed 1½ per cent. of the carbon in the coal and if air enters the fire freely the loss falls to ½ per cent.‡

Third, to the waste or loss of heat in the hot gases which escape up the chimney or smoke-stack. The temperature of the fire in a locomotive fire-box in a state of active combustion is probably from 3,000 to 4,000°. This heat is in part radiated and conducted to the heating surface of the fire-box, and it is found that more water is evaporated by this portion of the heating surface in proportion to its area than by any other in the boiler. The gases when they enter the tubes transmit a portion of their heat to the surfaces with which they are first in contact. The amount of

* The experiments which have been made to determine these amounts do not agree exactly, but those given are thought to be the most trustworthy.

† It should be remarked here that some, and perhaps many, of the cinders which are carried out of the chimney are not combustible, but are composed of the same materials that form clinkers on the grate.

‡ See paper read by M. Scheurer-Kestner before the Chemical Society of Paris.

heat thus transmitted, as has been stated, is in proportion to the *difference* in temperature of the gases inside the tubes and that of the water outside. After passing over the part of the tube with which the gases are first in contact, they then arrive at another portion of the tube surface with a diminished temperature, and the rate of conduction is therefore diminished, so that each successive equal portion of the heating surface transmits a less and less quantity of heat, until the hot air at last leaves the heating surface and escapes up the chimney with a certain remaining excess of temperature above that of the water in the boiler, the heat corresponding to which excess is wasted.* It is, therefore, desirable to extract as much heat as possible from the gases before they escape from the tubes. Now it will be impossible to heat the water outside of the tubes hotter than the gases inside. When the temperature of the water is equal to that of the gases, no more heat will be transmitted from one to the other. If the temperature of the water is 350°, that of the gases in the tubes will never be any lower, but will escape into the smoke-box with not less, but usually considerably more, than that amount of heat. If, however, the cold water is introduced at the front end of the tubes, so that the surface with which the gases are last in contact has a temperature considerably lower than 350, then an additional amount of heat will be transmitted before they escape. It is, therefore, important that the cold feed-water should be admitted near the front end of the boiler, so that the products of combustion will be in contact with the coldest part of the heating surface last, and thus give out as much of their heat as possible before they escape. As a matter of fact, the gases escape at a much higher temperature. Experiments made by the writer showed that the temperature in the smoke-box of a locomotive when first starting was 270°, and when working at its maximum capacity on a steep grade and with a heavy train it was as high as 675°. The average temperature while running was, in three trials on different parts of the road, as follows:

Average steam pressure, 98.8 lbs.; average temperature, 499.8 lbs.
Average steam pressure, 106 lbs.; average temperature, 535.1 lbs.
Average steam pressure, 112.2 lbs.; average temperature, 554 lbs.

In making these experiments a record was made of the indications of a pyrometer and of the steam gauge once every minute while the engine was running. The distance run was 19 miles for the first experiment, 13 for the second, and 6 for the third, with 30 loaded freight cars in the train.

* Rankine.

The last experiment was made while the engine was working on a heavy grade and very nearly up to its maximum capacity.

It will thus be seen that a great deal of heat is wasted by escaping up the chimney.

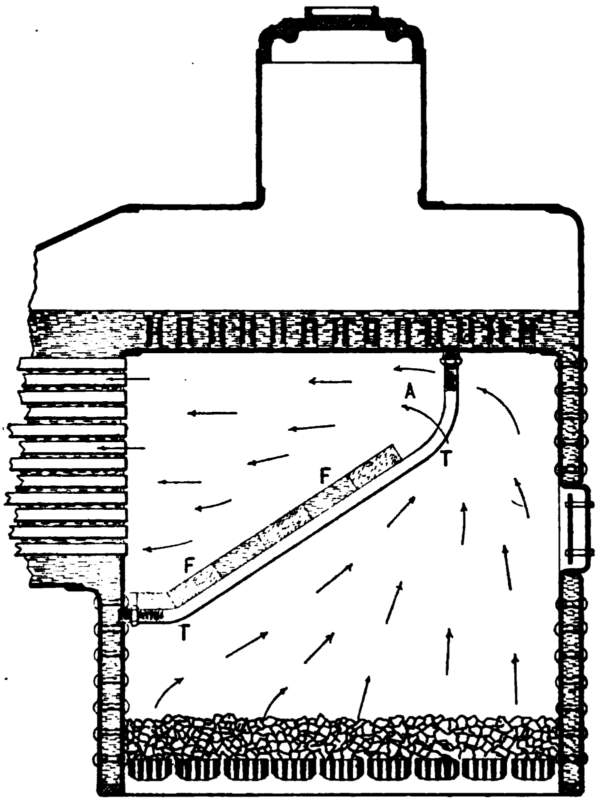


Fig. 470. Longitudinal Section of Fire-Box with Brick Arch. Scale ⅜ in.=1 ft.

Fourth, by external radiation from the boiler. This occurs chiefly from the fact that it is not sufficiently well protected or covered with non-conducting material. The practice, or rather the neglect, of not covering the outside of the fire-box with lagging doubtless causes a very considerable loss of heat by radiation and convection from the hot boiler plates.

QUESTION 751. *What is the ordinary form of fire-box employed for burning bituminous coal?*

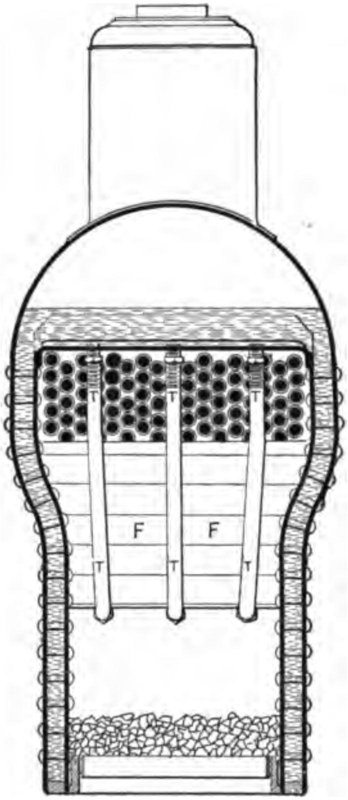


Fig. 471. Transverse Section of Fire-Box with Brick Arch. Scale ⅜ in.—1 ft.

Answer. It is that represented in Plate IV and figs. 121–123, and is simply a rectangular box, and for that reason it is often called a *plain* fire-box. Sometimes provision is made for admitting air into such fire-boxes through hollow or rather tubular stay-bolts, which are put into the sides and front. In most cases, too, the fire-box door has openings for admitting air.

QUESTION 752. *What other appliances are used for burning bituminous coal?*

Answer. The most common appliances which are added to the plain fire-box are what are called *fire-brick arches* or *deflectors*. These are sometimes made of an arched form, and rest on supports on the sides of the fire-box. In other cases the fire-brick, *F F*, figs. 470 and 471, is supported on tubes, *T T*, which are fastened to the front and back ends of the fire-box or into the crown-sheet. These tubes permit the water in the boiler to circulate through them, which prevents them from being burned by the intense heat in the fire-box. The fire-brick deflector extends backward and upward from a point on the tube sheet a short distance below the tubes. A space, *A*, between the top of the deflector and the crown-sheet is left open, so that the smoke and gases from the fire must pass under the deflector and around and over its back end, as indicated by the arrows in fig. 470. In this way the products of combustion are delayed in the fire-box before they enter the tubes, which gives time for the gases and air to combine and combustion to take place. The fire-brick becomes heated, and thus to some extent prevents the gases from being cooled down below an igniting temperature by contact with the cold surface of the fire-box before combustion is complete. The fire-brick, however, soon burns out, and must often be replaced, but owing to its cheapness and the ease with which it can be removed, this is not a very serious objection to its use. Air is nearly always admitted above the fire when the brick arch is used, either by tubular stay-bolts or perforations in the door, or both. The tubes, *T T*, are fastened in the front and top or back plates of the fire-box by caulking.

When air is admitted at the furnace door of an ordinary fire-box, it is very apt to rush directly into the tubes without mingling with the gases. It was found by some of the firemen on English railroads that by placing an inverted shovel in the top of the furnace door opening, the current of air which entered could thus be deflected downward, and in this way smoke could be almost entirely prevented. This led to the adoption of a hood or deflector, *A*, fig. 472, which is made of sheet iron and is placed over the fire-box door and is arranged with a lever, *B*, so that it can be raised in order to be out of the way when coal is thrown on the fire. It is suspended from a hook, *C*, from which it can easily be detached and taken out for repairs. This is frequently necessary, as the intense heat of the fire-box burns away the sheet iron, of which it is made, very rapidly. It can be made of old boiler plate, so that the expense of renewal is very

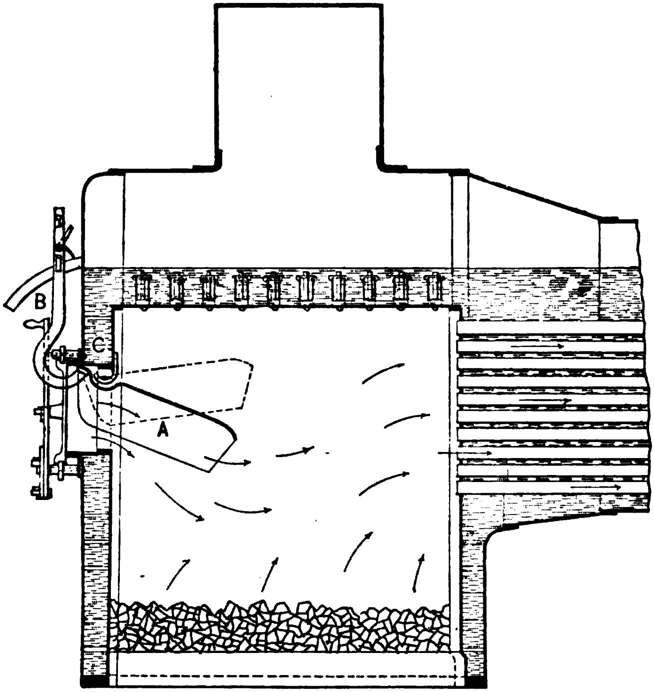


Fig. 472. Section of Fire-Box with Deflecting Plate over Door. Scale ⅜ in.—1 ft.

slight. When this plan is used, a double sliding door, shown in fig. 473, is commonly used with it. These doors are opened by the levers, *f d g* and *e h*, which are connected together by the rod, *r*. With these sliding doors the area of the opening for the admission of air can easily be regulated.

Figs. 474 and 475 represent a furnace door used on an English railroad. The door, *A*, is hinged so as to open inward. It is opened and closed, and its position can be adjusted by the lever, *C*. *B* is a door hinged at the bottom to protect the fireman from the heat of the fire. By leaving the door, *A*, partly open air is admitted and deflected downward on the fire for the reason already described.

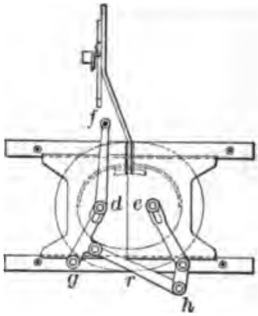
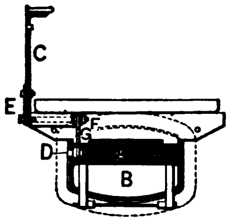


Fig. 473. Double Furnace Door. Scale ⅜ in.—1 ft.

On the New York Central & Hudson River Railroad the form of fire-box, shown in figs. 476–478, which was designed by Mr. William Buchanan, Superintendent of Machinery of that line, is used quite extensively, and avoids the inconvenience and expense of frequently replacing the fire-brick and gives very perfect combustion. This consists of what is called



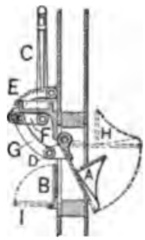


Fig. 474. Fig. 475.
English Furnace Door. Scale ⅜ in.—1 ft.

a water-table, *A A*, fig. 476—that is, two plates with water between them similar to the sides of the fire-box. This extends completely across the fire-box from the tube-sheet to the back-plate, thus dividing the fire-box into two compartments, *M* and *N*. In order to afford communication from the lower one to the upper one a round hole, *D*, about 18 inches in

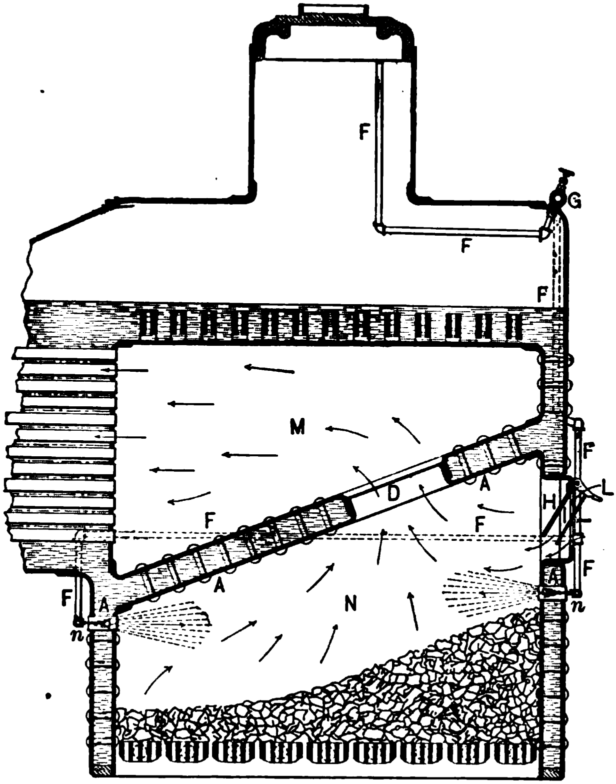


Fig. 476.

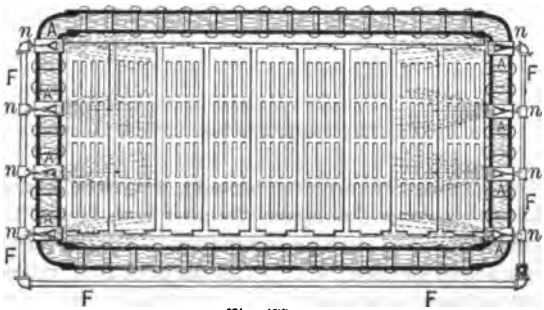


Fig. 477.
Buchanan's Fire-Box. Scale ⅜ in.—1 ft.

diameter, is put in the water-table in the position shown. It will thus be seen that all the currents of gas, smoke, and air must unite in passing

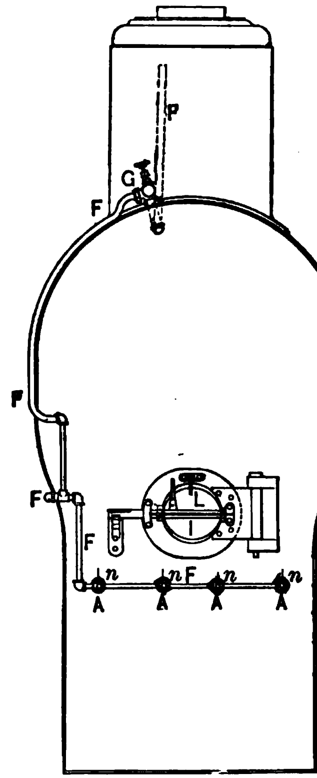


Fig. 478. Buchanan's Fire-Box. Scale ⅝ in.—1 ft.

through this opening, and are thus brought into close contact with each other. After they enter the upper chamber and before they enter the tubes, there is room and time for combustion. For the purpose of supplying fresh air above the fire, Mr. Buchanan puts four tubes, *A A A A*—shown in an enlarged scale in figs. 479 and 480—in the front end and an equal number in the back end of the fire-box just above the fire. These tubes each have a cone, *C*, fig. 479, inside of it, which has an annular opening or space, *D D*, around it. The cone is held in position by the ribs, *E E*, fig. 480, which are attached to it. Each of these tubes has a steam nozzle, *n n*, opposite to it. Steam is conducted to these nozzles by the pipe, *F F—F*, the supply being regulated by the cock, *G*, fig. 478. A jet of steam can thus be discharged into each one of the tubes, the effect of which is to create an *induced* current of air into the tubes, or, in other words, the steam carries a large amount of air into the tubes with it. When the steam and air strike the cone, *C*, fig. 479, it deflects or spreads them as indicated by the dotted lines which diverge from the nozzles in the different figures. The effect is to distribute and mix the air with the gases in the fire-box, and thus promote combustion. The furnace doors of these fire-boxes also have deflectors, *H*, and movable dampers, *I*, which are

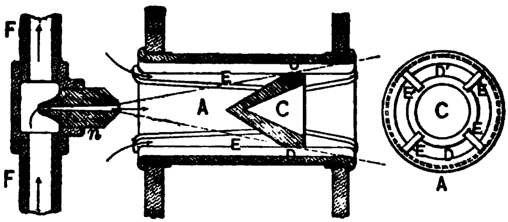


Fig. 479. Fig. 480.
Steam Jet for Buchanan's Fire-Box. Scale ¼ in.—1 in.

swung on trunnions so that their position can be adjusted by a latch, *L*. The air can thus enter the fire-box through the door, and is deflected downward as indicated by the arrows in fig. 476. The direction of the smoke and gases is indicated by the arrows which show how they come into contact in passing through the opening, *D*, in the water-table. The steam jets and the furnace door furnish the means of supplying an abundance of air to the fire, which is intimately mixed below the water-table and in passing through the opening, *D*, with the gases from the coal, so that very complete combustion results in the chamber, *M*.

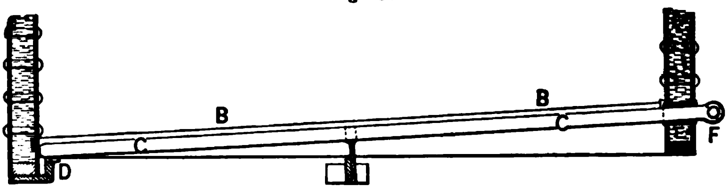
QUESTION 758. *How do the plans for burning coal which have been described operate?*

Answer. They will all burn coal more perfectly, and therefore more economically, if they are carefully and skilfully managed, than is possible in ordinary plain fire-boxes; but it is probable that as much economy in the consumption of coal would result from the improvement of the practice and knowledge of firemen as can be expected from the use of any of the appliances described, if they are used without care or knowledge of the principles of combustion.

QUESTION 754. *In what respect does anthracite coal differ from bituminous?*

Answer. It differs chiefly in the fact that it contains a much larger proportion of carbon and less of hydrogen, and in the fact that it conse-

Fig. 481.



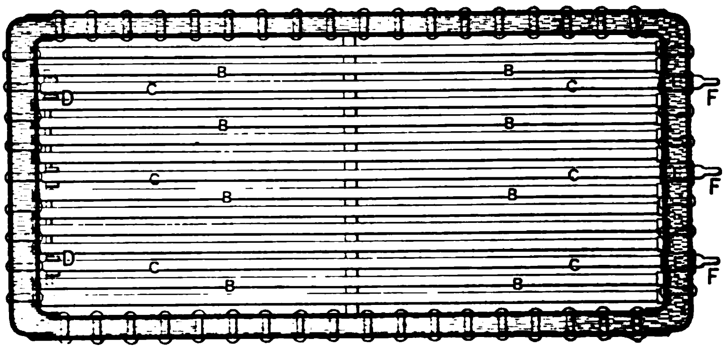


Fig. 482.
Water Grate for Anthracite Coal. Scale ⅜ in.—1 ft.

quently gives off very little or no coal gas. Its combustion is therefore more simple than that of bituminous coal, as there is very little else than solid carbon to burn.

QUESTION 755. *In what kind of a fire-box is anthracite usually burned?*

Answer. It is usually burned in very a long grate, figs. 481–483, and as the heat is very intense, the grate-bars, *B B*, are usually made of iron tubes, through which a current of water circulates, so as to prevent them from melting. These tubes are screwed into the front-plate of the fire-box, and are fastened with tapered thimbles in the back ends, which are driven into holes in the back-plate so as to make a tight joint around the tube. As these tubes are fastened in the plates and are immovable, it is essential that some means be provided for drawing the fire from the fire-box. This is done by using solid bars, *C C*, instead of tubes at intervals in the grate, as shown in figs. 481–483. These solid bars rest on a support

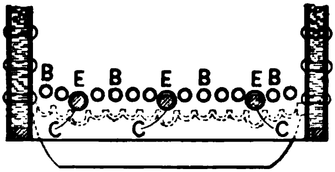


Fig. 483. Water-Grate for Anthracite Coal. Scale ⅜ in.—1 ft.

or bearing-bar, *D D*, as it is called, at the front end, and pass through tubes, *E E*, in the back end of the fire-box. These tubes are caulked in each plate so as to make them tight. The bars have eyes, *F F*, on the ends for drawing them out when the fire must be removed.

QUESTION 756. *Is it important to admit air above an anthracite coal fire to facilitate combustion?*

Answer. It is not so important as it is in bituminous coal, but if the layer of anthracite in the grates is very thick, it will be impossible to get enough air through the coal to convert all the carbon into carbonic dioxide, and the carbon and oxygen will therefore unite so as to form carbonic oxide. If air is admitted above the fire, as has already been explained, another equivalent of oxygen will unite with the carbonic oxide, and a second combustion will then take place above the fire, and the carbonic oxide will thus be converted into carbonic dioxide. If, under these circumstances, no air was admitted above the fire, the second combustion would not occur, and all the heat produced thereby would be lost.

QUESTION 757. *In what way is combustion influenced by the arrangements in the smoke-box of the locomotive?*

Answer. The draft is dependent on the proportions, location, and adjustment of the blast orifices and the other appliances used in the smoke-box. The smaller the blast orifices are the more violent will be the escape of steam and the draft of air through the fire. But the draft is also dependent on the arrangement and proportions of the wire netting, deflectors, chimney, and other appliances used in the smoke-box. No exact rules can be given for the arrangement of these parts, as the principles of their operation are still very imperfectly understood. The best arrangement for them must, to a very great extent, be determined by experiment.

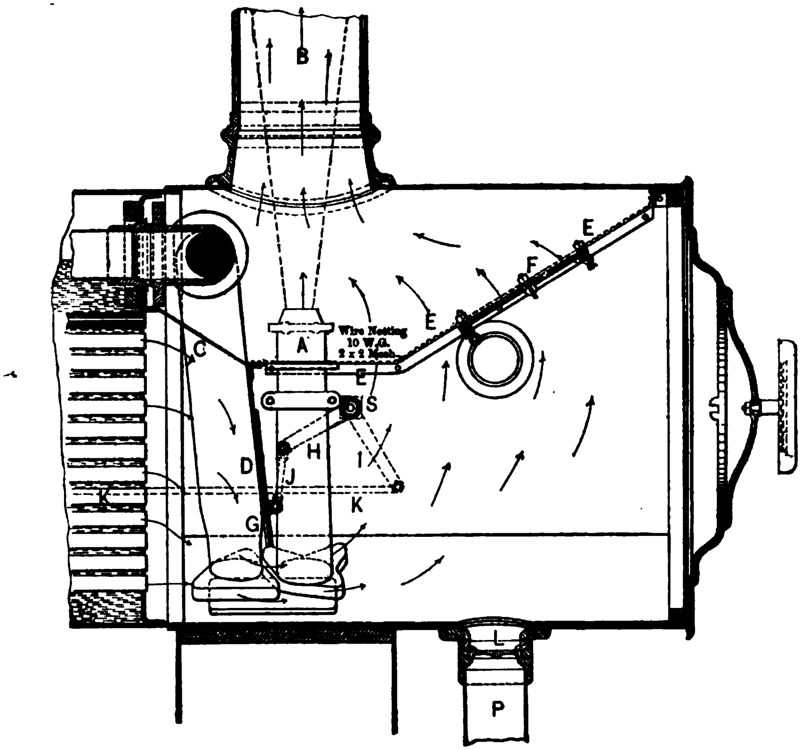


Fig. 484. Longitudinal Section of Extended Smoke-Box Front. Used on the New York Central and Hudson River Railroad. Scale ⅜ in.=1 ft.

QUESTION 758. *What is an extended smoke-box or extended front-end, and what is it for?*

Answer. As it name implies, it is an extension of the smoke-box in front of the chimney, and its object is to give room for wire netting and for collecting sparks and cinders. Such a smoke-box is shown in Plates

III and IV, and also in figs. 484 and 485. In the latter figures, *A A* are the exhaust orifices or nozzles, *B* is the chimney, *C* and *D* are deflectors or plates in front of the tubes. The deflector, *D*, has a sliding door, *G*, which is moved up and down by the shaft, *S*, which has arms, *H* and *I*, the former connected to the door by rods, *J J*, and the latter by another rod, *K K*,

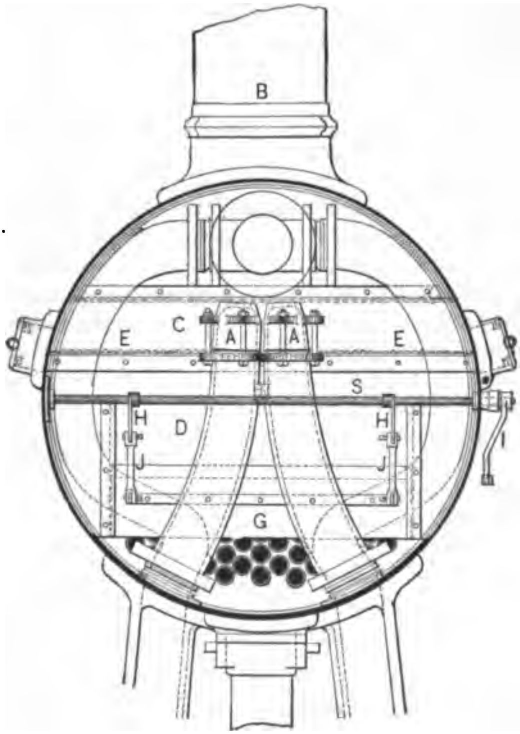


Fig. 485. Transverse Section of Extended Smoke-Box Front. Scale ⅜ in.—1 ft.

with the cab. *E E* is wire netting which has an opening or man-hole, *F*, also covered with netting, which can be removed to give access to the exhaust nozzles.

The purpose of the movable door or deflector, *G*, is to regulate the draft, the direction of which is indicated by the arrows.

QUESTION 759. *How does an extended smoke-box help to arrest sparks and cinders?*

Answer. By means of the deflectors the sparks are thrown forward into the extension of the smoke-box where the current of air and gases is not violent. As the wire netting at the same time offers some obstruction to the movement of the sparks, they are deposited in the extension of the smoke-box, from which they can be removed by means of the pipe, *P*, which is closed by a sliding door, *L*.

QUESTION 760. *How can we determine the relative value of different kinds of fuel for use in locomotives?*

Answer. This can only be determined satisfactorily by actual experiment. The chemical composition, excepting so far as it indicates the presence of deleterious substances, such as sulphur, ashes, clinkers, etc., affords but little assistance in determining the value of fuel. Nearly the same quantities of elements in different fuels may arrange themselves, before and during combustion, so as to produce very different series of compounds. It is true that the composition of coal gives us some indication of its heat-producing *capacity*, but the extent to which that capacity can be converted into actual steam in locomotive boilers depends to a very great extent upon the conditions under which the fuel is burned. It should also be remembered that the rapidity with which steam can be generated is a very important matter in locomotive practice. Whether a heavy freight train can be taken up a given grade, or a fast express make time, often depends upon the amount of steam which can be generated by the fuel in each second of time that the boiler is worked to its maximum capacity. Therefore any appliance for improving combustion, which reduces the quantity of steam which can be generated by the boiler in a given time, is quite sure to fall into disuse or be abandoned. It is of course often necessary to adapt the appliances for burning fuel to the fuel itself; and when a poor quality of the latter must be used, more boiler capacity must be given than is needed to do the same work with better fuel.

CHAPTER XXXI.

THE RESISTANCE OF TRAINS.*

QUESTION 761. *What is meant by the resistance of trains or cars?*

Answer. It is the power required to move them on the track. Thus, if a rope, fig. 486, was attached to a car at one end, and the other passed over

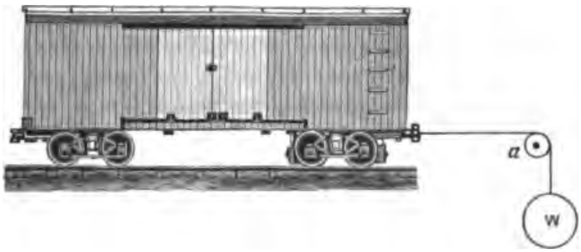


Fig. 486. Diagram Showing Resistance of Car.

a pulley, *a*, and a sufficiently heavy weight, *W*, was hung on the end of the rope, it would move the car. The weight, *W*, would then be equal to the resistance of the car.

QUESTION 762. *How can the resistance of cars under different circumstances be determined?*

Answer. It has been found that it takes a force of from 4 to 6 lbs. per ton (of 2,000 lbs.) to move a car slowly on a level and straight track after it is started. That is, if a car weighs 20 tons, and a rope, fig. 486, is attached to it at one end and the other passed over a pulley, *a*, with a weight, *W*, suspended to it, it will require a weight equal to $20 \times 6 = 120$ lbs. to keep the car moving slowly. If two cars of the above weight were coupled together, it would require twice 120, or 240 lbs., and if three were

* Since 1878, when the above chapter was written, a considerable number of experiments have been made on the resistance of cars and trains, and much has been written on the subject, but not much additional light has been thrown on it. The original data relating to this subject are therefore retained, although the resistances of cars given are probably too high rather than too low.

attached to each other, three times 120, or 360 lbs., and so on. In other words, MULTIPLYING THE TOTAL WEIGHT OF THE CARS IN TONS (OF 2,000 LBS.) BY 6 WILL GIVE US THEIR RESISTANCE, OR THE FORCE REQUIRED TO KEEP THEM MOVING ON A LEVEL AND STRAIGHT TRACK AT A SLOW SPEED AFTER THEY ARE STARTED. The resistance is represented by the weight, *W*, above, and the locomotive must exert a force eqûal to that weight to keep the train moving. As the speed increases the resistance increases, as is shown by the following table. It should be stated here, however, that our knowledge regarding this whole subject of the resistance of American cars and trains is exceedingly inaccurate and imperfect, and the data given in the books are largely based on experiments made in Eurôpe, with cars of a different construction from those used here. There is reason for believing, however, that the resistance of American cars is less than that of European cars, and we have assumed it to be 6 lbs. per ton on a level at very slow speed, which is less than the resistance which is usually given; but the following figures should be regarded merely as an approximation to the actual facts, of which we are still in ignorance:

Velocity of trains in miles per hour....	5	10	15	20	25	30	35	40	45	50	60	70
Resistance on straight line in lbs. per ton (of 2,000 lbs.).................	6.1	6.6	7.3	8.3	9.6	11.2	13.1	15.3	17.8	20.6	27	34.6

Now, if we want to get the resistance at 30 miles an hour of a train of 10 cars weighing each 20 tons, the calculation would be $10 \times 20 \times 11\frac{1}{4} = 2,250$ lbs. This will give the resistance on a level and straight track. On an ascending grade the resistance is greater than that given above, because, besides pulling the car horizontally, it is necessary to raise it vertically a distance equal to the ascent of the grade. Thus if we have a grade with a rise of 40 feet in a mile, the amount of energy required to simply raise the weight of a car would be equal to its weight in pounds multiplied with the vertical height of the ascent. Thus, supposing a car which weighs 40,000 lbs. to be run 1 mile on a grade of 40 feet ascent in that distance, then the energy expended in simply raising the car will be equal to $40,000 \times 40 =$ 1,600,000 foot-pounds. If it was necessary to raise that weight by a direct vertical lift or pull, it would require a force equal to or a little greater than the load to do it. But in pulling a car or train up a grade, which is an inclined plane, the force, which is the locomotive, instead of being exerted through the vertical distance is exerted through the horizontal distance, which in this case is 1 mile, or 5,280 feet. Therefore, if we divide the number of foot-pounds of energy required by the distance through which the power is exerted, it will give us the force exerted through one foot. That is,

$$\frac{1,600,000}{5,280} = 303.03 \text{ lbs.}$$

The resistance due to the ascent alone of a train on a grade or incline can therefore be calculated by MULTIPLYING THE WEIGHT OF THE TRAIN IN POUNDS BY THE ASCENT IN ANY GIVEN DISTANCE IN FEET AND DIVIDING THE PRODUCT BY THE HORIZONTAL DISTANCE IN FEET. Thus in the above example the rate of the ascent is given in so many feet per mile; we therefore multiply by 40 and divide by 5,280, which is the number of feet in a mile. If the rate of the gradient had been given, as it sometimes is, as 1 in 132, we would simply have divided the weight of the train by the latter number. If we want to get the resistance per ton of train we substitute for its weight that of 1 ton in pounds; thus:

$$\frac{2,000 \times 40}{5,280} = 15.1 \text{ lbs.}$$

If, now, we have the resistance which is due to the *ascent or gravity alone*, we must add to this the resistance on a straight and level track, at the speed at which the train runs, in order to determine the total resistance on the grade. On a level road, at a speed of 5 miles per hour, it would be 6.1 lbs. per ton, so that on a grade of 40 feet to a mile at that speed the resistance would be $6.1+15.1=21.2$ lbs. per ton, and at 10 miles it would be $6.6+15.1=21.7$ lbs., and at 30 miles per hour on the grade the resistance would be $11.2+15.1=26.3$ lbs. per ton. To get the total resistance on a grade for any speed, we ADD THE RESISTANCE FOR THAT SPEED ON A STRAIGHT AND LEVEL LINE TO THE RESISTANCE DUE TO THE ASCENT ALONE. The resistances for various rates of speed and grades has been calculated, and is given in the following table:

TABLE OF RESISTANCES OF RAILROAD TRAINS WITH DIFFERENT GRADES AND SPEEDS.

Rise of gradient, feet per mile.	Resistance due to ascent alone in lbs. per ton (2,000 lbs.) of train.	Total resistance, lbs. per ton, at rate of 5 miles per hour.	10 miles per hour.	15 miles per hour.	20 miles per hour.	25 miles per hour.	30 miles per hour	35 miles per hour.	40 miles per hour.	45 miles per hour.	50 miles per hour.	60 miles per hour.	70 miles per hour.
0..........	....	6.1	6.6	7 8	8.3	9.6	11.2	13.1	15.3	17.8	20.6	27.0	34.6
5..........	1.8	7.9	8.4	9.1	10.1	11.4	13.0	14.9	17.1	19.6	22.4	28.8	36.4
10..........	3.7	9.8	10.3	11.0	12.0	13.4	14.9	16.8	19.0	21.5	24.3	30.7	38.3
15..........	5.6	11.7	12.2	12.9	13.9	15.2	16.8	18.7	20.9	24.4	27 2	33.6	41.2
20..........	7.5	13.6	14.1	14.8	15.8	17.1	18.7	20.6	22.8	25.3	28.1	34.5	42.1
25..........	9.4	15.5	16.0	16.7	17.7	19.0	20.6	22.5	24.7	27.2	31.0	37.4	45.0
30..........	11.3	17.4	17.9	18.6	19.6	21.9	22.5	24.4	26.6	29.1	31.9	38.3	45.9
35..........	13.2	19.3	19.8	20.5	21.5	22.8	24.4	26.3	28.5	31.0	33.8	40.2	47.8
40..........	15.1	21.2	21.7	22.4	23.4	24.7	26.3	28.2	30.4	32.9	35.7	42.1	49.7
45..........	17.0	23.1	23.6	24.3	25.3	26.6	28.2	30.1	32.3	34.8	37.6	44.0	51.6
50..........	18.9	25.0	25.5	26.2	27.2	28.5	30.1	32.0	34.2	36.7	39.5	45.9	53.5
60..........	22.7	28.8	29.3	30.0	31.0	32.3	33.9	35.8	38.0	40.5	43.5	49.9	57.5
70..........	26.5	32.6	33.1	33.8	34.8	36.1	37.7	39.6	41.8	44.3	47.1	53.5	61.1
80..........	30.3	36.4	36.9	37.6	38.6	39.9	40 5	42.4	44.6	47.1	49.9	56.8	63.9
90..........	34.0	41.0	40.6	41.3	42.3	43.6	45.2	47.1	49.3	51.8	54.6	61.0	68.6
100..........	37.8	43.9	44.4	45.1	46.1	47.4	49.0	51.9	54.1	56.6	59.4	65.8	73.4
110..........	41.6	47.7	48.2	48.9	49.9	51.2	52.8	54.7	56.9	59.4	62.2	68.6	76.2
120..........	45.4	51.5	52.0	52.7	53.7	55.0	56.6	58.5	60.7	63.2	66.0	72.4	80.0

TABLE OF RESISTANCES OF RAILROAD TRAINS WITH DIFFERENT GRADES AND SPEEDS.

Rise of gradient, feet per mile.	Resistance due to ascent alone in lbs. per ton (2,000 lbs.) of train.	Total resistance lbs. per ton, at rate of 5 miles per hour.	10 miles per hour.	15 miles per hour.	20 miles per hour.	25 miles per hour.	30 miles per hour.	35 miles per hour.	40 miles per hour.	45 miles per hour.	50 miles per hour.	60 miles per hour.	70 miles per hour.
130...........	49.2	55.3	55.8	56.5	57.5	58.8	60.4	62.3	64.5	67.0	69.8	76.2	83.8
140...........	53.0	59.1	59.6	60.3	61.3	62.6	64.2	66.1	68.3	70.8	73.6	80.0	87.6
150...........	56.8	62.9	63.4	64.1	65.1	66.4	68.0	69.9	72.1	74.6	77.4	83.8	91.4
160...........	60.6	66.7	67.2	67.9	68.9	70.2	71.8	73.7	75.9	78.4	81.2	87.6	95.2
170...........	64.3	70.4	70.9	71.6	72.6	73.9	75.5	77.4	79.6	82.1	84.9	91.3	98.9
180...........	68.1	74.2	74.7	75.4	76.4	77.7	79.3	81.2	83.4	85.9	88.7	95.1	102.7
190...........	71.9	78.0	78.5	79.2	80.2	81.5	83.1	85.0	87.2	89.7	92.5	98.9	106.5
200...........	75.7	81.8	82.3	83.0	84.0	85.3	86.9	88.8	91.0	93.5	96.3	102.7	110.3
210...........	79.5	85.6	86.1	86.8	87.8	89.1	90.7	92.6	94.8	97.3	100.1	106.5	114.1
220...........	83.3	89.4	89.9	90.6	91.6	92.9	94.5	96.4	98.6	101.1	103.9	110.3	117.6
230...........	87.1	93.2	93.7	94.4	95.4	96.7	98.3	100.2	102.4	104.9	107.7	114.1	121.7
240...........	90.8	96.9	97.4	98.1	99.1	100.4	102.0	103.9	106.1	108.6	111.4	117.8	125.4
250...........	94.6	100.7	101.2	101.9	102.9	103.2	105.8	107.7	109.9	112.4	115.2	121.6	129.2
260...........	98.4	104.5	105.0	105.7	106.7	107.0	108.6	110.5	112.7	115.2	118.0	124.4	132.0
270...........	102.2	108.3	108.8	109.5	110.5	111.8	113.4	115.3	117.5	120.0	122.8	129.2	136.8
280...........	106.0	112.1	112.6	113.3	114.3	115.6	117.2	119.1	121.3	123.8	126.6	133.0	140.6
290...........	109.8	115.9	116.4	117.1	118.1	119.4	121.0	122.9	125.1	127.6	130.4	136.8	144.4
300...........	113.6	119.7	120.2	120.9	121.9	123.2	124.8	126.7	128.9	131.4	134.2	140.6	148.2

The top horizontal row of figures of the table gives the rates of speed. The left hand vertical row gives the rise of grade in feet per mile. The resistance for any given grade and speed is given where the vertical row of figures under the rate of speed and the horizontal row opposite the rise of the grade intersect each other. Thus, for a grade of 30 feet per mile and a speed of 45 miles per hour, we follow the vertical column under the 45 downward, and the horizontal column opposite 30 to the right, and where the two intersect the resistance, 29.1 lbs., is given.

QUESTION 763. *What effect do curves have on the resistance of trains?*

Answer. They increase the resistance, but in what proportion or to what extent is not known accurately. European authorities say that the resistance is increased, over what it would be in a straight and level line, about 1 per cent. for every degree* of the curve occupied by a train. It is probable, however, that the resistance of American cars, which nearly all have double trucks, is not so great on curves as that of European cars, which nearly all have long and rigid wheel-bases, and whose wheels therefore cannot adjust themselves so easily to the curvature of the track as they can when the American system of double trucks is used.

QUESTION 764. *What is meant here by a degree of a curve?*

Answer. In order to measure circles, they are all supposed to be divided into 360 equal parts, which are called degrees. One degree of a curve is therefore $\frac{1}{360}$ of a complete circle. If a curve has a long radius, one degree of such a curved track will be longer than one degree of a curve with a short radius, but each will have the same amount of "bend" or curvature. It is this latter which increases the resistance of trains, and the greater the number of degrees of a curve occupied by a train of cars, the greater will be the "bend" of the track, and therefore the greater the resistance.

QUESTION 765. *In what other sense is the term "degree" used in describing railroad curves?*

Answer. The term is used by civil engineers to designate the "*deflection angle*" of a curve, the meaning of which may be most clearly defined by explaining the usual method of laying out railroad curves, which is as follows: To lay off a curve, beginning from *B* on the straight line, *A D*, fig. 487, an engineer would place his instrument at *B* and lay off an angle, *D B s*, called the "*tangential angle*," and then measure 100 feet on the

* The "degree" of a curve here means $\frac{1}{360}$ part of a complete circle. The term is not used here in the sense in which it is employed by civil engineers, which is explained in answer to Question 765.

line, *B s*, and *s* would then be the second point or "station" in the curve. From *s* he would then lay off an angle, *m s t*, called the "*deflection angle*," which is equal to twice the tangential angle, and then measure 100 feet on the line, *s t*; *t* will then be the third point or station in the curve. From *t* another deflection angle, *n t u*, is again laid off, and 100 feet is measured from *t* to *u*, which gives the fourth station, *u*. This process is continued

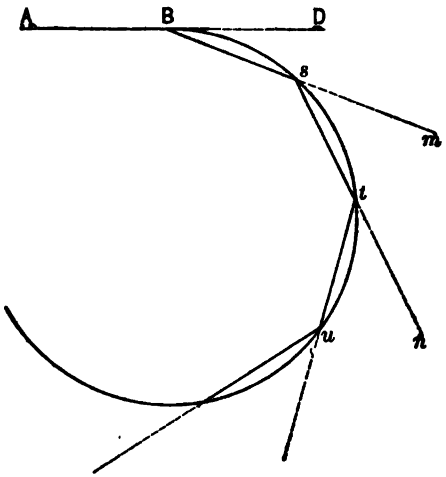


Fig. 487.

for any length of curve. The amount of curvature depends, of course, upon the deflection angle, and consequently curves as designated as of so many degrees, meaning a curve laid down with deflection angles of that many degrees, and chords of 100 feet in length. The deflection angles are expressed in degrees and minutes, which are written as follows: 3°, 15′, which means 3 degrees and 15 minutes. The following table gives the radii in feet of curves corresponding to different deflector angles:

DEFLECTION ANGLE AND RADII OF CURVES.

Angle of Deflection.	Radius in Feet.	Angle of Deflection.	Radius in Feet.	Angle of Deflection.	Radius in Feet.	Angle of Deflection.	Radius in Feet.	Angle of Deflection.	Radius in Feet.	Angle of Deflection.	Radius in Feet.
° ′		° ′		° ′		° ′		° ′		° ′	
1	343761	23	14947	45	7639	1 14	4646	1 58	2913.5	2 42	2122.3
2	171880	24	14324	46	7473	16	4523	2	2864.9	44	2096.4
3	114587	25	13751	47	7314	18	4407	2	2818.0	46	2071.1
4	85940	26	13222	48	7162	20	4297	4	2772 5	48	2046.5
5	68752	27	12732	49	7016	22	4192	6	2728.5	50	2022.4
6	57293	28	12278	50	6876	24	4093	8	2685.9	52	1998.9
7	49109	29	11854	51	6741	26	3997	10	2644.6	54	1975.9
8	42970	30	11459	52	6611	28	3907	12	2604.5	56	1953.5
9	38197	31	11090	53	6486	30	3820	14	2565.6	58	1931.5
10	34378	32	10743	54	6366	32	3737	16	2527.9	3	1910 1
11	31252	33	10417	55	6251	34	3657	18	2491.3	2	1889.1
12	28648	34	10111	56	6139	36	3581	20	2455.7	4	1868.6
13	26444	35	9822	57	6031	38	3508	22	2421.1	6	1848 5
14	24555	36	9549	58	5927	40	3438	24	2387.5	8	1828.8
15	22918	37	9291	59	5827	42	3370	26	2354.8	10	1809.6
16	21486	38	9047	1	5730	44	3306	28	2323.0	12	1790 7
17	20223	39	8815	2	5545	46	3243	30	2292.0	14	1772.3
18	19098	40	8594	4	5372	48	3183	32	2261 9	16	1754.2
19	18094	41	8385	6	5209	50	3125	34	2232.5	18	1736.5
20	17189	42	8185	8	5056	52	3070	36	2203.9	20	1719.1
21	16370	43	7995	10	4911	54	3015.7	38	2176.0	22	1702.1
22	15626	44	7813	12	4775	56	2963.7	40	2148.8	24	1685.4

DEFLECTION ANGLE AND RADII OF CURVES.

Angle of Deflection.	Radius in Feet.	Angle of Deflection.	Radius in Feet.	Angle of Deflection.	Radius in Feet.	Angle of Deflection.	Radius in Feet.	Angle of Deflection.	Radius in Feet.	Angle of Deflection.	Radius in Feet.
° ′		° ′		° ′		° ′		° ′		° ′	
3 26	1669.1	4 20	1322.5	6 5	942.3	7 50	732.0	12 45	450.3	20	287.9
28	1653.0	25	1297.6	10	929.6	55	724.3	13	441.7	21	274.4
30	1637.3	30	1273.6	15	917.2	8	716.8	15	433.4	22	262.0
32	1621.8	35	1250.4	20	905.1	15	695.1	30	425.4	23	250.8
34	1606.7	40	1228.1	25	893.4	30	674.7	45	417.7	24	240.5
36	1591.8	45	1206.6	30	881.9	45	655.4	14	410.3	25	231.0
38	1577.2	50	1185.8	35	870.8	9	637.3	15	403.1	26	222.3
40	1562.9	55	1165.7	40	859.9	15	620.1	30	396.2	27	214.2
42	1548.8	5	1146.3	45	849.3	30	603.8	45	389.5	28	206.7
44	1535.0	5	1127.5	50	839.0	45	588.4	15	383.1	29	199.7
46	1521.4	10	1109.3	55	828.9	10	573.7	15	376.8	30	193.2
48	1508.1	15	1091.7	7	819.0	15	559.7	30	370.8	31	187.1
50	1495.0	20	1074.7	5	809.4	30	546.4	45	364.9	32	181.4
52	1482.1	25	1058.2	10	800.0	45	533.8	16	359.3	33	176.0
54	1469.4	30	1042.1	15	790.8	11	521.7	30	348.5	34	171.0
56	1457.0	35	1026.6	20	781.8	15	510.1	17	338.3	35	166.3
58	1444.7	40	1011.5	25	773.1	30	499.1	30	328.7	36	161.8
4	1432.7	45	996.9	30	764.5	45	488.5	18	319.6	37	157.6
5	1403.4	50	982.6	35	756.1	12	478.3	30	311.1	38	153.6
10	1375.4	55	968.8	40	747.9	15	468.6	19	302.9	39	149.8
15	1348.4	6	955.4	45	739.9	30	459.3	30	295.3	40	146.2

QUESTION 766. *What other causes affect the resistance of trains?*

Answer. The condition of the track and the force and direction of the wind. On a rough track the resistance is very much greater than on a smooth one, and in a strong head wind it is much more difficult to pull a train than in calm weather.

CHAPTER XXXII.

PERFORMANCE AND COST OF OPERATING LOCOMOTIVES.

QUESTION 767. *What are the elements of cost of operating locomotives?*

Answer. They are (1) the cost of fuel: (2) of the service or wages of the engineer and fireman; (3) of lubricating and illuminating oil, waste, and miscellaneous supplies; (4) of repairs to the engine and tender, and (5) cleaning and watchmen.

QUESTION 768. *In what way may the cost of operating locomotives be counted and compared?*

Answer. The cost is usually counted at so much per train mile or per car mile.

QUESTION 769. *What is the usual cost of these items of expense?*

Answer. The cost per train mile, of course, varies very much with the loads hauled, the speeds, grades, condition of the road, weather, price of coal, etc. The following table, taken from one of the monthly performance sheets of the Lake Shore & Michigan Southern Railroad, gives the cost per train mile for the different classes of trains:

COST OF LOCOMOTIVE SERVICE.

Kind of Train.	Cost per Train Mile.					
	Fuel, Cents.	Wages, Cents	Oil, Waste, etc., Cents.	Repairs, Cents.	Cleaning and Watchman, Cents.	Total, Cents.
Passenger........	4.27	6.61	.05	3.77	.21	14.91
Freight............	6.43	6.61	.05	3.33	.21	16.63
Working..........	2.86	6.61	.05	2.03	.21	11.76
Switching........	2.57	6.61	.05	2.19	.21	11.63
Average..........	4.94	6.61	.05	3.15	.21	14 96

The Lake Shore line has no very steep grades, and consequently its engines are not so heavy as those on some other roads. On the Pennsylvania road, for example, which has steep grades and heavy engines, the average cost of repairs in 1887 was 6.43 cents per train mile or more than double that on the Lake Shore line, for the month quoted.

QUESTION 770. *What proportion do the locomotive expenses bear to the total cost of operating a railroad?*

Answer. In 1888, on the Lake Shore Railroad, the expenses named in the table were nearly 15 per cent. of the total operating expenses.

QUESTION 771. *How much coal is consumed per mile by a locomotive and tender without a train?*

Answer. No very reliable experiments have been made with large engines to determine this, but in some experiments which were reported to the Master Mechanics' Association in 1876,* it was shown that the coal consumed in running an engine and tender, the total weight of which was about 50 tons, over a road without a train at an average speed of between 20 and 25 miles per hour, was from 18½ to 25½ lbs. of coal per mile, or an average of 21 lbs. Experiments with an English engine showed a consumption of 12 lbs. per mile. The tests reported to the Master Mechanics' Association were, however, made with western coal, which is not of so good a quality as English coal.

QUESTION 772. *How much coal do locomotives usually consume per train mile in ordinary service?*

Answer. This, too, varies within very wide limits. On the Lake Shore line, for example, the consumption for the year 1888 per train mile was 70 lbs. On the Pennsylvania road, in 1887, it was 91.2 lbs., whereas on the Philadelphia & Erie line, for the same period, it was 105.4 lbs.

QUESTION 773. *How much coal is consumed per car per mile?*

Answer. On the Pennsylvania Railroad, in 1887, the consumption of coal was 12.37 lbs. per passenger car per mile, and the average number of cars per train was 4.89. This was the total consumption of fuel by the locomotive which was apportioned to the cars alone, no coal being allowed for moving the engine and tender.

In the same year the consumption of coal per freight car per mile was 5.03 lbs. per car per mile, and the average train consisted of 24.16 cars. On the Philadelphia & Erie Division, which is a nearly level line, the coal consumed was only 3.18 lbs. per car per mile, and the average train consisted of 38.78 cars. The consumption of coal was divided among the cars

* See report of that year, page 145.

alone, no allowance being made for the engine and tender. The monthly premium sheets of the Pennsylvania Railroad show that the consumption of coal, if apportioned to the cars alone, varies from 3.8 to 17 lbs. per freight car per mile, and from 9 to 24 lbs. for passenger cars. These figures give the *average* results on the roads named.

The following report of experiments, which were carefully made by the writer, will give the performance of a locomotive when great care is taken to produce good results. It should be stated, however, that the engine with which these experiments were made had been in service 18 months without receiving thorough repairs, and that the boiler at times primed badly, so that the rate of evaporation of water per pound of coal is not a fair indication of the performance of the engine in that respect. The coal used was known as Brazil coal, from Indiana, and in order to compare the performance of two engines only lumps of coal were used, so as to leave no room for question regarding the relative amount of fine coal used by each engine. The maximum grades on the road on which the experiments were made were 30 feet per mile, and the total ascent from the lowest to the highest point on the road was 374 feet.

LOCOMOTIVE EXPERIMENTS.

	1873.	1873.	1873.
Date of experiment	July 21.	July 28.	August 2.
Number of miles run	145	145	145
Number of cars hauled	41	31	41
Total weight of cars, lbs	1,497,240	1,119,650	1,508,860
Total amount of coal burned, lbs.	8,676	5,102	7,221
Total amount of water consumed, lbs.	63,531	45,719	52,609
Water evaporated per lb. of coal, lbs.	7.32	8.02	7.04
Miles run per ton (of 2,000 lbs.) of coal.	33.4	50.8	38.8
Coal consumed per car per mile, lbs.	1.45	1.13	1.21
Average speed, including stops, miles.	11.1	13	13.8

QUESTION 774. *How can we determine the speed at which an engine is running?*

Answer. In the absence of any special instruments for the purpose, BY COUNTING THE NUMBER OF REVOLUTIONS OF THE DRIVING-WHEELS PER MINUTE, THEN MULTIPLYING THE LENGTH OF THEIR CIRCUMFERENCE IN INCHES BY THE NUMBER OF THEIR REVOLUTIONS PER MINUTE AND THE PRODUCT BY 60, AND DIVIDING THE LAST PRODUCT BY 63,360. THE QUOTIENT WILL BE THE SPEED IN MILES PER HOUR. Thus, supposing driving-wheels which are 61½ inches in diameter, and whose circumference is therefore 193.2 inches, should make 164 revolutions per minute, then $193.2 \times 164 \times 60 \div 63.360 = 30$ miles (nearly) per hour.

CHAPTER XXXIII.

THE CARE AND INSPECTION OF LOCOMOTIVES WHILE IN THE ENGINE HOUSE.

QUESTION 775. *What are the principal divisions of the work of operating or running a locomotive?*

Answer. They are:

1. Inspection and lubrication—that is, an examination of the parts to see that they are in good working order, and the application of oil to the journals and other parts subjected to wear.
2. Getting up steam and firing.
3. Setting the engine in motion and starting the locomotive and train.
4. Management while running.
5. Management in case of accident.
6. Stopping the engine and train.
7. Laying up.
8. Cleaning the engine.

QUESTION 776. *When should a locomotive be inspected?*

Answer. It should be inspected after it has finished its run, and when there is no fire in the fire-box and when the engine is cold, so that the grates, smoke-box, chimney, and other parts can be examined. The object of this inspection is to see whether any repairs are needed before the next run. The engine should again be inspected before making another run, to see whether every part is in good condition, and that the repairs, if any were needed, have been properly made.

QUESTION 777. *When the locomotive is first inspected, what should be especially observed about the boiler?*

Answer. In the first place, all new boilers should be tested by pressure before being used, and ALL boilers, whether new or old, SHOULD BE TESTED PERIODICALLY. The oftener the better. The ways of applying the pressure test are:

1. The cold water test—that is, by filling the boiler with cold water and then forcing in an additional quantity with a force-pump so as to raise the pressure to that at which it is intended to test the boiler.

2. The warm water test, by filling the boiler entirely full of cold water and then kindling a fire in the grate, so as to warm this water. As water expands about $\frac{1}{24}$ in rising from 60 to 212°, the rise in temperature will cause a corresponding increase in pressure; boilers are also tested with warm water by forcing it into them with an injector, which receives a supply of steam from another boiler.

3. By steam pressure.

If the latter method were not so commonly used, it would seem the height of madness to test a boiler—which is neither more nor less than an attempt to explode it—in the shop where it is built or repaired, and where the results of an explosion would be more disastrous and fatal than anywhere else, in order to see whether it will explode when put into service on the line of the road. The danger of explosion is also increased at such times by hammering and caulking at leaky rivets and joints.* It would seem, therefore, very much more rational to test boilers first by hydraulic pressure. For a first test this is preferable, because cold water will leak through crevices which would be tight when the boiler is heated, so that leaks can be more surely detected with cold than with warm or hot water. It is, however, doubtless true that boilers are often strained much more by the unequal expansion of the different parts than by the actual pressure. It is, therefore, thought that after the hydraulic test has been applied the second or warm water test should be used. This can be easily done, as the boiler must be filled full of water for the first test. When the boiler is subjected to the test pressure, it should be carefully examined to see whether any indications of weakness are revealed. Any material change of form or any very irregular change of pressure is indicative of weakness. The flat stayed surfaces should be carefully examined by applying a straight edge to them before and after they are subjected to pressure, to see whether they change their form materially. One of the greatest dangers and most common accidents to locomotive boilers, as has been pointed out in a previous chapter, is the breaking of stay-bolts, to detect which, a locomotive engineer and master mechanic should exercise constant vigilance. While the pressure is on, the outside surface of the boiler should be thoroughly examined with slight blows of a hammer, which will often reveal a flaw in the metal or a defect in workmanship. After the hydraulic and warm water tests have been applied, the boiler should be emptied, and the inside examined carefully, to see whether any of the stays and braces have been broken or displaced by the test. After this

* Wilson on Boiler Construction.

has been done, and not until then, should steam be generated in the boiler. In making the latter test it would doubtless be more safe to employ a pressure somewhat lower than that employed with the cold and warm water.

There is great diversity of opinion regarding the maximum pressure which should be employed in testing boilers. It is doubtless true that a weak boiler might be injured and thus made dangerous by subjecting it to a very severe pressure, while without such a test it would have been safe. Recent experiments have indicated, however, that in most cases the ultimate strength of material is actually increased by subjecting it to a strain which even *exceeds* the elastic limit, provided such a strain is imposed only a few times. Although no absolute rule can be given to govern all such cases, it is thought that for the hydraulic and warm-water tests, a pressure about 50 per cent. greater and for the steam test 25 per cent. greater than the maximum working pressure should be employed.

Before old boilers are tested, they should be very carefully examined, both inside and outside, to see whether they are injuriously corroded. It is to be regretted that the insides of locomotive boilers are usually made so difficult of access that it is impossible to discover the extent and the effects of corrosion without the most careful examination. This is not possible without getting inside of the boiler. Whenever this can be done, a prudent locomotive engineer should use the opportunity of inspecting the boiler of his engine himself, and not depend upon the boiler-makers who are employed for that purpose. He should remember that it is his life and not theirs which is exposed to danger by any weakness or defect in the construction of the boiler of the locomotive which he runs.

Before starting the fire in a locomotive, the fire-box should be carefully examined to see if there are any indications of leaks, which will often reveal cracked plates, defective stay-bolts or flues. If the latter simply leak at the joints, they can generally be made tight by caulking or by the use of a tube expander. This is easily done when the engine is cold, but if not attended to may be very troublesome on the road. Bran or other substances containing starch, mixed with the feed water, may stop leaks, but this is only a temporary expedient. Leaks of the boiler should always be causes for suspicion, and a leaky seam or stay-bolt may be caused by dangerous internal corrosion. A leak about the boiler head should lead to an examination, to ascertain whether any of the inside stays or braces are broken. If this occurs it may be indicated by the bulging of the plate which forms the boiler head. Leaks at other parts of the boiler should be examined, as they may reveal dangerous fractures.

It is of the utmost importance, both for safety and for economy of working, that boilers should be kept clean—that is, free from mud and incrustation. In some sections of the country, especially in the Western States, this is the greatest evil against which locomotive engineers and those having the care of locomotives must contend. The cures which have been proposed are numberless, but that which is now chiefly relied upon is, first, the use of the best water that can be procured, and second, frequent and thorough washing out of the boiler.

QUESTION 778. *How can defects, such as cracked plates or dangerous corrosion, be discovered in a locomotive boiler?*

Answer. Such defects are usually indicated by leakage while the engine is in service. They are shown by a little water or steam oozing at the point where the defect exists. When the engine is cold a slight collection of incrustation or rust on the outside of the boiler will show that there has been a leak. A defect in the fire-box will often be shown by a leak at the mud-ring. When a fire-box plate is cracked it usually opens suddenly, so that the leak shows at once. Tubes are liable to leak when there is no other defect excepting that they need caulking, but when this is done the tube-plate should always be examined to see whether it is cracked.

QUESTION 779. *How can internal corrosion or grooving be discovered?*

Answer. Unless it has become so serious as to cause an external leak, this cannot be discovered excepting by an internal inspection of the boiler. To do this the dome-cover must be taken off and a person must go inside of the boiler and examine carefully every part that is accessible. To make an internal inspection thorough the tubes must be taken out. When water is of a corrosive character, or contains much solid matter which is deposited inside of the boiler, such an inspection should be made frequently, but when the water is pure it is not essential to do it often.

QUESTION 780. *How can defects in braces or stays or broken stay-bolts be discovered?*

Answer. Broken braces and stay-bolts are indicated sometimes by the bulging of the plates of the flat parts of the boiler. Broken stay-bolts may often be discovered by an expert by sounding them with a hammer, and if their ends are drilled, as explained in answer to Question 228, their fracture is shown by the leakage. An internal inspection is the only way of being sure that the braces are in good condition.

QUESTION 781. *What must be done to prevent the inside of the boiler and the tubes from becoming covered with incrustation?*

Answer. The first and most effective preventative is to get the purest water that is obtainable for use in the boilers. Having done this, if it contains much solid matter, the boiler must be blown out and washed out often. If the water forms a solid deposit it will be necessary to take out the tubes and crown-bars at intervals, and clean them and the inside of the boiler thoroughly.

QUESTION 782. *How often should the tubes be cleaned?*

Answer. That depends very much upon the kind of fuel used, as some coal fills up the tubes much more than other kinds do. Every time the engine is washed out the tubes should be thoroughly cleaned. If the fuel used leaves considerable deposit in the flues, it is well to brush them out as thoroughly as is possible from the furnace door.

QUESTION 783. *What should be observed with reference to the smoke-box?*

Answer. It should be noticed whether the front and door are securely fastened so as to be air-tight. If air leaks into the smoke-box the sparks or cinders are liable to take fire on the inside of it, which heats all the parts about it, blisters the paint outside, may cause the steam and exhaust-pipes to leak, and destroy the wire netting. The smoke-box door should be opened occasionally to see whether the petticoat-pipe, deflecting-plates, and wire netting are in good condition and properly secured, as a failure of any of these parts when the engine is on the road is very annoying and is liable to cause much delay. The smoke-box should be kept clear of ashes and cinders.

QUESTION 784. *What may happen to the convey or exhaust-pipes?*

Answer. They may get loose or may require adjusting. Moving them up or down has an important influence on the draft, but experience is the best teacher with reference to their adjustment.

QUESTION 785. *What may happen to the wire netting in the smoke-box or in the top of the chimney?*

Answer. As the wire netting on the smoke-stack often has holes worn into it by the action of the sparks, it should be frequently examined to see whether it is in good condition. As soon as holes are cut into the netting there is danger that the sparks which escape will set fire to the combustible material near the track. When the engine "throws fire" from this cause the netting should be renewed. If the engine "works water" the netting is liable to get clogged. It is also liable to be "gummed up," especially if too much oil is used in lubricating the cylinders and valves. If the netting is obstructed the engine will not make steam freely and is liable to "kick-back," that is, the fire is liable to be blown out of the furnace door and burn the men in the cab. Unless oil from the cylinder gets into the netting the obstruction can usually be beaten out, but if the obstruction is due to an accumulation of gummy matter, it can often be removed by building a fire on top of the netting. In this way the oil in the gummy matter is burned up, which leaves a dry material which can then, at least to some extent, be beaten out of the netting.

QUESTION 786. *What should be noticed in connection with the steam and exhaust-pipes?*

Answer. The steam pipes should be kept tight. If there is any suspicion that the steam pipes leak, the throttle-valve should be opened slightly, so as to give the engine steam while the smoke-box door is open. The leak will then be indicated by the escaping steam. If they leak the joints must be reground. Exhaust nozzles sometimes get obstructed by a collection of oil and dirt, which should be cleaned out. It should also be noticed whether the nozzles are located so that the blast from the exhaust-pipes is discharged in the centre of the chimney.

QUESTION 787. *In what way do the grates get out of order?*

Answer. They are liable to be burnt out, bent or broken. It should be observed whether the grate-bars or drop-doors of the grate are properly fastened, whether any of them are broken, and whether the ashes have been cleaned out of the ash-pan, and also whether the fire is clean—that is, whether the grates are free from cinders or clinkers.

QUESTION 788. *What should be noticed in connection with the throttle-valve?*

Answer. As a failure of the throttle-valve to work may be the cause of a most serious accident, it should be certain that it is in good working condition, that all the bolts, pins, and screws, and other accessories are in good working order. It should also be known whether the throttle-valve is steam-tight. This can be learned by observing whether steam escapes from the exhaust-pipes or cylinder-cocks when the latter are open, the reverse-lever in full gear, and the throttle-valve closed. If the throttle-valve leaks, enough steam may accumulate in the cylinder, when there is no one on the engine, to start it, and in this way cause a serious accident. The throttle-lever should always be fastened with a set-screw or latch of some kind when the engine is standing still. If a throttle-valve leaks it should be reground. A disconnected throttle is now a rare occurrence, but it should be certain that the connections are all right.

QUESTION 789. *What kind of attention must be given to the safety-valves?*

Answer. They should be adjusted so as to blow off at the required pressure, and it should be known whether the springs retain their elasticity, as it is affected by the heat of the steam, which makes it essential to renew them occasionally. One of the safety-valves should have a lever or other appliance for opening it in case it is necessary to relieve the boiler of pressure, and it should be raised occasionally to know that it is in good working order.

QUESTION 790. *What is essential with reference to steam gauges?*

Answer. Their most important function is to indicate the steam pressure correctly, and as there is no part of a locomotive more liable to disorder than the steam gauge, they should be frequently tested, and whenever there is any indication of irregularity in their action it should be investigated. When this is done the date should always be marked on the back of the gauge, or some other record of it should be kept of the inspection,

QUESTION 791. *What kind of attention should be given to the other boiler attachments?*

Answer. The height of water in the boiler should be observed by testing it with the gauge-cocks and by noticing it in the glass gauge, if one of these is used. It is also well to blow out the sediment and mud from the glass gauge before starting, and to see that the valves which admit steam and water to the glass are open. They should, however, be opened only a very short distance, so that only a small quantity of steam or hot water will escape in case the glass tube should be broken. The whistle-valve should be kept tight, the gauge-cocks should be kept clear by running a wire through them. A careful engineer will always know whether the injectors work satisfactorily, and if either of them is out of order it should be taken off and a spare one substituted in its plaee. Check-valves should be taken down occasionally and cleaned, and it should be observed whether the blower-valves and pipes are in good condition.

QUESTION 792. *In inspecting the cylinders, pistons and guides, to what points should the attention be directed?*

Answer. It should be known whether the piston packing is properly set out—that is, whether it is so tight that it will not "*blow through*," or leak steam from one end of the cylinder to the other, which, of course, will waste a great deal of steam. Of the two evils, it is, however, better to have piston-packing too loose than too tight, because if it is too tight it is liable to cut or scratch the cylinders so as to make it necessary to rebore them, and at the same time if the packing-rings are lined with Babbitt metal, the heat created by the intense pressure and friction will melt the metal. In some cases the cylinders become heated to so high a temperature from this cause that the wood-lagging with which they are covered on the outside is burned. Examination should be made to see that neither the piston-rods, pump-plungers nor guides are bent or sprung.

QUESTION 793. *What must be done to keep the insides of the cylinders in good condition—that is, to prevent the packing from cutting them?*

Answer. They must be well lubricated when not using steam, and the packing must be properly set up, not so tight as to bind nor so loose as to blow, or allow the piston-heads or followers to rub on the bottoms of the cylinders, as the two cast iron surfaces will then scratch each other. It is also important that the piston be central in the cylinder; if anything, have it a little higher than central. It should be set by callipering on the projection on the front side which holds the follower-plate in place.

QUESTION 794. *How can it be known whether the piston-packing is too loose or "blows through"?*

Answer. It can usually be noticed in the sound of the exhaust, which can be heard very distinctly on the foot-board when the furnace door is opened. If the packing is not tight, it produces a peculiar wheezing sound between and after each discharge of steam. If the packing leaks, it will also be indicated by the escape of steam from *both* the cylinders-cocks, if they are open, just after the crank passes the dead point. This will usually show in which of the cylinders the packing is too loose. The same thing will occur, however, if either or both of the main valves leak, so that it is often hard to determine whether the "blow" is due to a leak from the valve or from the piston. Of course it may sometimes happen that both leak, or that the piston on one side of the engine and the valve on the other leak, so that often the diagnosis of the disease, as the doctors say, is extremely difficult. Careful observation and experience will, however aid a locomotive runner in detecting such defects much more than any directions which can be given here.

QUESTION 795. *What is meant by piston-packing being "follower-bound"?*

Answer. It means that when the follower-plate is bolted up hard against the piston-head that it clamps or binds the packing-rings between the plate and the piston-head so that the rings cannot move.

QUESTION 796. *How can it be known whether the packing is follower-bound?*

Answer, When the packing can move as it should between the piston-head and follower-plate its movement is usually shown by marks on the follower-plate when it is taken off. If such marks are not apparent, and there is reason to think that the packing is too tight, the piston should be taken out, the packing put in place, and the follower-plate bolted on. The packing should then be loose enough, so that it can be moved by tapping it with a piece of wood. If it is too tight a piece of paper should be inserted between the follower-plate and piston-head where they are in contact with each other.

QUESTION 797. *What is meant by "setting out packing," and how should it be done?*

Answer. "Setting out packing" is simply expanding the rings when they get too loose. With ordinary spring packing, figs. 225 and 226, which is now generally used, this is done by screwing up the nuts, *b b b*, which, as was explained in answer to Question 338, compresses the springs, *a a a*, and thus expands the rings, *A A*. In doing this, as already stated, great care must be exercised not to screw the nuts up too hard, and it is always better to have the packing too loose than too tight. Care must also be taken to keep the piston-rods in the centres of the cylinders, otherwise there will be undue pressure and wear on the stuffing-box. After the nuts are screwed up, the position of the piston-head should be tested with a pair of calipers. This is done by placing one leg of the calipers against the side of the cylinder, and setting them so that the other leg will just touch the edge of the projection, *C*, fig. 226, or the end of the piston-rod. Then by placing the calipers above and below, and on each side of the piston, it will appear whether it is too high or too low or too near either side. If the piston is not in the middle of the cylinder, by loosening the nuts on one side and tightening them on the other it can be moved to a central position. Ordinarily this work is intrusted to persons who are employed for the purpose. A young locomotive runner, fireman, or mechanic will, however, always do well to familiarize himself with such duties, and, if possible, do it himself, under the direction of those who are skilled in that kind of work.

QUESTION 798. *If the stuffing-box of the piston-rod leaks, what should be done?*

Answer. If it is packed with fibrous packing and it is in good condition, it can usually be made tight by simply screwing up the nuts on the gland. In doing this, they should not be screwed up more than is necessary to make the packing steam-tight. Any greater pressure only increases the friction on the piston-rod unnecessarily. The two bolts should be screwed up equally, otherwise the gland will be "canted—" that is, inclined so as to "bind" or bear unequally and very hard against the piston-rod, and thus be liable to cut or scratch it. After packing has been in the stuffing-box a long time, it becomes very hard and compact, and sometimes partly charred. It must then either be removed and new packing should put be in, or, if it is in tolerably good condition, it can often be made to work well by simply reversing it—that is, by putting that which was at the bottom of the stuffing-box on top and *vice versa*. Before packing is put into a stuffing-box, the former should always be thoroughly oiled.

QUESTION 799. *What kind of attention should be given to piston-rods?*

Answer. They should be oiled occasionally and kept keyed up tight in the cross-head and piston.

QUESTION 800. *What must be done to keep the cross-head slides and the guide-bars in good condition?*

Answer. They must be "in line" or parallel with the centre line of the cylinder and they must be kept well lubricated. There are no parts of a locomotive which require more careful attention in order to keep them lubricated, and thus prevent them from heating and being "cut," than the bearings on the crank-pins and the slides of the cross-head. A little lost motion in the guides is not a serious evil unless it becomes excessive.

QUESTION 801. *When the slides of the cross-heads are considerably worn, how is the lost motion taken up?*

Answer. When there are gibs on the cross-head, the lost motion can be taken up by putting "*liners*" or "*shims*"—that is, thin pieces of metal, between them and the cross-head, so that they will fill up the space between the guide-bars. When there are no gibs, the guide-bars must be taken down, and the blocks between them at each end should be reduced in thickness so as to bring the bars nearer together. In doing this, great care must be taken that the guides are accurately "in line" with the centre line or axis of the cylinder when they are put up again. This work should never be intrusted to any excepting skilled workmen, from whom those who are inexperienced should seek instruction.

QUESTION 802. *What kind of attention should be given to the crank-pins and connecting-rods?*

Answer. They are all liable to break, and they should be examined often to see whether there are any cracks or flaws in them, or whether any of them are bent or sprung. Whenever the rods are taken down the straps should be looked over carefully, especially in the inside corners, to see whether any flaws exist. Main-rods are less liable to break than coupling-rods. Attention should be given to the brass bearings of the connecting-rods to see that they are not so loose as to thump, nor keyed so tight on the crank as to be liable to heat. The latter can be easily known by moving the stub-end lengthwise of the journal. They should never be so tight that they cannot be thus moved with the hand. Especial attention should be given to seeing that all the bolts and nuts on the connecting-rods are tight.

QUESTION 803. *When the brass bearings of the connecting-rods become too loose on their journals, what should be done?*

Answer. They must be taken down, and the two surfaces in contact must be filed away so as to bring them closer together. In doing this they must be filed square with the other surfaces, otherwise they will not bear equally on the journals when they are keyed up. Before attaching them permanently to the rods, they should be keyed on the journal in the strap alone, so that it can be known by trial whether they move freely and yet are tight enough to prevent thumping on the journal. When they are attached to the rod, it is very important, especially with coupling or parallel-rods, that the correct length from centre to centre of the bearings be maintained. It is much better to leave coupling-rods loose on their journals, because, if the bearings are keyed up tight, the rods are sure to throw an enormous strain on the crank-pins, as the distance between the centres of the axles is not always absolutely the same, owing to the rise and fall of the axle-boxes in the jaws. It is therefore always best to have a little play in the coupling-rods, and it is safe to say that much more mischief is done by meddling with the coupling-rod brasses than by neglecting them.

Lost motion in a main connecting-rod will cause a thump, but a little play in coupling-rods will do no harm. It is better to have the bearings of coupling-rods too loose than too tight. If the coupling-rods have solid ends and bushings they require no attention excepting oiling, and when the bushings are worn too much they should be taken out and replaced with new ones.

QUESTION 804. *How should the valve-gear be taken care of?*

Answer. The principal defects of valve gear are due to want of proper lubrication. The oil-holes should all be kept clear, otherwise it will be impossible to keep the journals well oiled. The eccentric straps and the link blocks are very liable to be imperfectly oiled, and when the former become dry and cut, they throw a great strain on the eccentric-rods, which is liable to break them. When this occurs, the strap and the portion of the rod which is attached to it revolve with the eccentric, and frequently a hole is thus knocked in the front of the fire-box, which disables the engine. The valve gear is, with the exception, perhaps, of the pumps and injector, the most delicate part of the locomotive, and more liable to get out of order than any other, and should therefore be examined carefully, and if there are any indications that the eccentric straps or any of the pins are cutting, they should be taken apart, examined, and thoroughly oiled.

It is usual now to key eccentrics fast to the axle so that it is impossible for them to slip. If they are fastened with set screws alone they should be examined occasionally to see whether they have moved from their original position.

All the bolts, nuts, and keys should be carefully examined to see that they are properly fastened. The bolts and nuts in the eccentric straps are especially liable to become loose, and as they are between the wheels, and therefore not easy of access, are often neglected.

QUESTION 805. *How can it be known whether the main valves of a locomotive are tight?*

Answer. As already indicated, the symptoms which manifest themselves when a valve leaks are very similar to those which appear when the piston packing leaks. If the valve is moved to its middle position and steam is admitted into the steam-chest, and it then escapes from both cylinder-cocks, it is apparent that the valve is not tight. But the valve faces of locomotives usually wear concave, because the valves are worked most about half-stroke, so that they will often be tight when in the centre of the face, but will leak at the ends of the full stroke. This will become apparent by the peculiar wheezing sound, already referred to, when the engine is at work. As has been explained, it is often very difficult to determine whether this sound is due to a leak at the pistons or the valves. If the packing of the valve-stem leaks, it can be remedied in the manner described for making that of the piston-rod tight.

QUESTION 806. *What is meant by an engine "going lame"?*

Answer. It means that one or two of the four blasts of steam from the cylinder are not equal to the others, so that the exhaust has an irregular or limping sound.

QUESTION 807. *To what cause is "going lame" generally due?*

Answer. It may be because one or more eccentrics are not set right, or a valve-stem or eccentric-rod is too long or too short. Sometimes it is due to lost motion in the valve-gear, or the links may be suspended in such a way, that when the reverse-lever is in a given position one of them hangs lower than the other. To guard against the latter evil it should be observed, in setting the valves, whether they cut-off at the same points of the stroke on each side of the engine.

QUESTION 808. *How should the running-gear be taken care of while the engine is in the shop?*

Answer. First the journals of the axles must be kept well oiled. The oil-cellars should be taken down occasionally and cleaned. They should be packed with woolen waste, which has more elasticity than cotton and bears against the axle, while cotton waste packs down solid. With the heavy loads now carried on the driving-axles of some locomotives, there is often much trouble from the journals heating. This is often due to the want of end play between the boxes and hubs, and collars on the axles. This play should be about $\frac{3}{16}$ of an inch. The driving-boxes, tires, wheels, and axles should be examined often to discover flaws, as they are liable to break. Engine axles usually break just inside of the hub. When the oil-cellars are taken down, the portions of the axles which are inside of the box should be examined carefully for cracks or flaws. The axles should be examined too to see that the wheels have not worked loose on the wheel-seat. When this occurs it often becomes apparent by the oil from the axle-boxes working through between the hubs of the wheel and the axle. This can be observed on the outside of the wheels when the bearings are inside, and inside the wheels when the bearing is outside.

All the wheels of the engine and tender should be carefully examined, to see that they are sound. A fracture in a driving-wheel is usually apparent if the wheel is carefully examined. The condition of ordinary cast iron tender and truck-wheels is often revealed on striking them with a hammer, when if they are sound they will give out a peculiar clear ring; whereas if they are fractured, the sound produced by the blow of the hammer may be dead, like that of a cracked bell.

An inspector should not rely entirely on this test, as broken wheels will sometimes give a clear ring. He should examine them carefully for cracks or other fractures, and should see that the flanges are not broken, as this may occur and not be revealed by the sound produced by a blow from a hammer. If any of the flanges of the wheels are unduly worn the fact should be reported to the proper person. The wearing of flanges is due to a variety of causes which are sometimes difficult to discover, such as the difference in the diameters of the wheels or the hardness of the tires in the same axle; axles not parallel or the truck "out of square," centre-plate or pin not in the centre of truck, bent axles or malformation of rails are some of the causes which produce sharp flanges. The steel tires of both the driving and the truck-wheels should be examined for flaws and broken flanges, and to see whether they have worked loose on the wheel-centres. Moisture and dirt issuing from between the tire and wheel indicates that the former is becoming loose, which is more liable to occur when the tires are worn thin than before. Tires are most liable to split circumferentially, or "bulge" sideways. An engineer should always be vigilant to detect circumferential flaws or any bulging which usually indicates the beginning of a fracture.

QUESTION 809. *What are the principal causes which make an engine "pound" or "thump"?*

Answer. It is generally due to lost motion somewhere. If an engineer hears a "knock," he should examine to see whether there is lost motion in either of the ends of the main connecting-rods. Lost motion in coupling-rods is not liable to cause a thump, although they may be so loose that their side motion may make them rattle. A loose piston-rod in the cross-head or piston may cause a "pound." The most difficult cause to discover is when the piston-rod gets loose in the piston, because it cannot be examined when the engine is working. If a piston strikes the cylinder-head it will also cause a "knock."

The working of the driving-boxes up and down between the jaws will in time wear them so that there will be some lost motion. This or a loose journal bearing in one of the driving-boxes will be indicated by a thump when the cranks pass the dead-point. A similar thump will, however, be produced by lost motion in the boxes of the main connecting-rod, so that it is difficult to determine, without special examination, the cause which produces the concussion. By reversing the engine with a little steam on when it is standing still, it can be known whether there is lost motion in the driving-boxes, and by watching them carefully it can be seen whether they are loose between the wedges or on the journal of the axle.

It is therefore best when an engine works with a thump at each revolution for the runner to stand by the side of it where he can touch the connecting-rods and driving-wheels, and then have the fireman open the throttle-valve, so as to move the engine slowly. If the lost motion is in the connecting-rods it can be felt by the jar as it passes the dead-points. The same is true of lost motion in the jaws, which can be felt by touching the driving-wheels. When the jaws become worn the lost motion can be taken up by moving up one or both of the wedges. When this is done, great care must be taken to keep the centres of the driving-axles the same distance apart on both sides of the engine, and also to keep their centre lines square with the frames. In the best designed locomotives the driving-boxes now have only one wedge, which is usually on the back side of the box, as shown in fig. 349. The frame in front of the box is protected by a straight shoe or by a wedge the full length of the jaw so that it cannot be moved up or down. This is done so that the position of the box cannot be changed by carelessly or ignorantly moving one wedge up and the other down. There should always be centre-punch marks placed on the frames or guide-yokes on each side of the engine in front of the main axle, and at equal distances from its centres, so that when the boxes or jaws become worn the position of the axle can be adjusted with a tram from these marks. Of course, if the main axle is square, it is easy to adjust the trailing axle from it with a tram. If the axles are not square with the frames and parallel with each other, the engine will run toward one side or the other of the track, according to the inclination of the axles. It sometimes happens that the bolts which hold up the wedges in the jaws are broken. When this occurs the wedge drops down, and of course the box has so much lost motion that it soon manifests itself in the working of the engine. These bolts, and also those which hold up the clamps on the frames at the bottom of the jaws, should be examined when the engine is inspected, so as to be sure they are in good condition.

QUESTION 810. *What precaution must be taken with reference to springs, hangers, and equalizers?*

Answer. Like all other parts, they should be examined often to see that they are in good condition, and it should be observed whether the springs come in contact with the boiler—if they do they may rub against it and wear a hole in it.

QUESTION 811. *In the examination, care of, and repairs to injectors, what precaution should be observed?*

Answer. 1. The pipe connections should be kept perfectly tight to prevent air leaks.

2. The steam-valves should be kept tight to prevent escaping steam from heating the suction-pipe, which interferes with the formation of a vacuum and prevents the instrument from lifting the water.

3. The packing of the different spindles and valve-stems should be kept in good condition, so that they will be steam or air-tight.

4. The nozzles of the injector must be taken out and thoroughly cleaned more or less often—according to the character of the water used

—so as to keep them as far as possible free from incrustation. Mineral oil drawn with the water, when the injector is at work, will have an excellent effect in keeping it free from scale. Some injectors are arranged to receive an oil-cup for this purpose.

5. The boiler check-valves must be kept tight and free from dirt and incrustation, to prevent the back-flow of hot water and the sticking of the valves.

QUESTION 812. *If a lifting injector is tested and does not lift the water properly, to what causes may it be due?*

Answer. It may be due:

1. To a leak in the steam-valve, and the consequent heating of the suction-pipe to such a degree as to prevent the formation of sufficient vacuum in that pipe. This defect can be remedied only by grinding the steam-valves, so as to make them tight. Such a leak will be indicated by an escape of steam from the overflow when the steam-valves are closed.

2. To a leak in the suction-pipe or its connection, in which case the air drawn in by applying the lifting jet will prevent the formation of the vacuum. Such a leak can be detected by closing the heater-cock and opening the main steam-valve only—if there is a separate lifting jet—or, with a single lever instrument, by opening both steam-valves at once. The steam blowing back to the tank will then escape through the leak, if there is one. The trouble will usually be remedied by tightening up the suction-pipe connections.

3. To a leak in the boiler check-valves and the consequent heating of the suction-pipe by the hot water from the boiler flowing back through the injector. Grinding the check-valve will remedy this.

QUESTION 813. *If the injector lifts the water, but does not take it up and throw it out through the overflow, or the stream flowing into the boiler breaks, to what causes may it be due?*

Answer. 1. To a slight leak in the suction-pipe, not sufficient to prevent a short lift, but enough so that the air drawn in disturbs the current in the nozzles. Such a leak can be detected and remedied as explained in answer to the previous question.

2. To obstructions in the suction-pipe, floating matter, bits of wood, hemp, leaves, obstructions in the strainer, or not sufficiently large strainer to admit the proper supply of water. If the strainer is obstructed it must be taken out and cleaned. The present strainers in general use, consisting of a perforated cone inside of the suction-pipe, are a frequent cause of trouble in the working of injectors. They are usually not large enough,

and difficult of access for cleaning. The suction-pipe itself can be cleaned by blowing steam through it with the heater-cock closed.

3. To boiler check-valves sticking fast, on account of corrosive incrustation, or dirt in the valve-chamber, which prevents the free action of the valves. The remedy is to open the valve-chamber, and thoroughly clean the valve, its seat, and guides.

4. To leaky heater-cock check, which will be indicated by a sputtering sound, which is again caused by the air taken in through the overflow. Grinding the check will remedy it.

QUESTION 814. *What must be done to keep oil-cups in good condition?*

Answer. The principal thing to do is to keep them clean, free from dirt and gum, and adjust the spindles—if they have any—so that the oil will flow freely, and yet not too rapidly, on the surfaces exposed to friction.

In inspecting a locomotive, it should be observed whether the oil-cups are screwed down tight to the part to which they are attached. They are liable to work loose and be lost, or by getting between some of the working parts, to cause a breakdown.

QUESTION 815. *What else should a locomotive runner observe in making an inspection of his locomotive?*

Answer. A good locomotive runner will always give ample time for the inspection of his engine before starting out. It is assumed that the inspection which has been described has been made after the engine has completed a trip, and when there is no fire in the fire-box. Before starting, a careful locomotive runner should begin at the front of his engine and see that the pilot and all its fastenings are in good condition. He should be especially alert in inspecting this, as well as all other parts of the locomotive, to see that none of the bolts and nuts have been lost, and that they are screwed up tight, and the keys are all right.

The engine and tender should occasionally be lifted up from the centre plates of the trucks, and the plates should be lubricated with tallow. It often happens that these become dry, so that they are difficult to turn when the weight rests on them, and therefore they will not adjust themselves easily to the curves of the track.

It should be certain that the brakes on the tender are in good working condition—that is, that the bolts, nuts, and keys are all secure, the levers, rods, and chains properly connected, and the shoes fastened and not too much worn. If either an atmospheric or vacuum brake is used, it should be tested before starting, as was fully explained in Chapter XXVII.

The inside of the water-tank should also be examined occasionally, to see whether it is clean, and if not it should be thoroughly washed out. If the tank is new or has had any repairs done to it, the inside should be carefully examined to see whether any waste rags or other objects have been left in it, as these might obstruct the strainers over the water-supply pipes. The strainers should be examined occasionally to see whether they are clear. The man-hole of the tank should always be covered, excepting while taking water, so as to exclude cinders and coal, which are liable to obstruct the pump valves. It is hardly necessary to say that it must always be certain before starting that there is enough water in the tank to feed the boiler until the next point is reached at which a supply can be obtained. The sand-box must also be filled, the bell-rope be in good condition, and if running at night the reflector of the head-light must be polished and the lamp supplied with oil and the wick trimmed so as to burn brilliantly. The locomotive runner must also see that the proper signals are displayed in front of his engine.

QUESTION 816. *What precaution should be taken if any repairs have been done to the engine?*

Answer. The parts which have been repaired should be examined carefully to see that they have been properly done, and if they require lubrication, it should receive especial attention, as new parts are always liable to heat or cut.

QUESTION 817. *What tools, etc., should every locomotive runner on the road carry?*

Answer. A coal shovel, coal pick, long-handled hoe* and poker, a pair of jacks—either screw or hydraulic, chains, rope and twine to be used in case of accident, a heavy pinch-bar for moving the engine, a small crow-bar, oil-cans with short and long spouts and another smaller one with spring bottom, a steel and a copper hammer, a cold and a cape chisel, a hand-saw, axe and hatchet, one large and one small monkey-wrench and a full assortment of solid wrenches for the bolts and nuts of the engine, cast-iron plugs for plugging tubes, with a bar for inserting them, two sheet-iron pails or buckets, different colored lanterns and flags, according to the colors used for signals on the line, and a box with a half dozen torpedoes.

QUESTION 818. *What duplicate parts should be carried with the engine?*

Answer. Keys, bolts, and nuts for connecting-rods, split-keys, wedge-bolts, bolts for oil-cellars of driving and truck-boxes, driving and truck spring-hangers, wooden blocks for fastening guides in case of accident.

* These are of course not needed on wood-burning engines.

blocks for driving-boxes and links, a half dozen $\frac{3}{4}$-inch bolts, from 6 inches to 2 feet long, to be used in case of accident, two extra water-gauge glasses, two glass head-light chimneys.

QUESTION 819. *What should be observed in lubricating a locomotive or any other machinery?*

Answer. The most important thing to observe is that the oil reaches the surface to be lubricated. It is of much greater importance that the lubricant should reach the right place than that a large quantity should be used. A few drops carefully introduced on a journal will do much more good than a large quantity poured on the part carelessly. For this reason all oil-cups and oil-holes should be kept clean so as to form a free passage for the oil. It should also be remembered that no automatic oil-cup will work satisfactorily a great while unless it receives the attention which all of them require.

CHAPTER XXXIV.

RUNNING LOCOMOTIVES.

QUESTION 820. *Before starting the fire in a locomotive what should be observed?*

Answer. It should always be noticed before kindling the fire whether the boiler has the requisite quantity of water in it; that all cinders, clinkers, and ashes are removed from the grates and ash-pan, and from the brick-arch or water-table, if the boiler has either of these appliances; that the grates and drop-door are in their proper position and securely fastened; that the throttle-valve is closed and the lever secured; and, if the boiler was filled through the feed-pipe by means of the engine-house hose, it should be observed whether the check-valves are closed. If they are not closed it will be shown by the escape of water when the engine-house hose is detached, or by the water and steam blowing back into the tank when the tender-hose are coupled up, and after steam is generated in the boiler. Locomotive boilers are sometimes seriously injured by building a fire in them when they have not been filled with water. This can only occur from the grossest carelessness on the part of the person who starts the fire, and is or should be a cause for suspension or discharge of the person who is guilty of such neglect. In filling a boiler it must be remembered, however, that when the water is heated it will expand, and that when bubbles of steam are formed they will mix with the water and thus increase its volume, so that after the water is heated its surface, as shown by the water-gauge and gauge-cocks, will be considerably higher than when it is cold.

QUESTION 821. *How should the fire in a locomotive be started?*

Answer. It should be started slowly, so as not to heat any one part suddenly. Probably the greatest strains which a locomotive boiler has to bear are those due to the unequal expansion and contraction of its different parts. When the fire is started, of course the parts exposed to it are heated first, and consequently expand before the others do. If the fire is kindled rapidly, the heating surfaces will become very hot before the heat is communicated to the parts not exposed to the fire. Thus, the tubes, for example, will be expanded so as to be somewhat longer than the outside shell of the boiler, and therefore there will be a severe strain on the tube-plates, which will be communicated to the fire-box, stay-bolts, braces, etc. The inside plates of the fire-box will also become much hotter than those on the outside, and as they are rigidly fastened to the bar to which both the inside and the outside shells are attached at the bottom, the expansion of the inside plates will all be upward, which thus strains the stay-bolts in that direction. As the motion due to this expansion is greatest near the top of the fire-box, the top stay-bolts are of course strained the most, and it is those in that position, as has already been pointed out, which are the most liable to break. When steel plates are used, the expansion or contraction sometimes cracks them, and occasionally hours after the fire is withdrawn from the fire-box, the inside plates will crack with a report like that of a pistol. It is, therefore, very important both to heat and cool a locomotive boiler slowly, and it is best to kindle the fire several hours before the engine starts on its run.

QUESTION 822. *If the fire in the fire-box has been banked, what should be done before leaving the engine-house?*

Answer. The fire should be broken up with a bar and the ashes shaken out of it, and fresh coal should be thrown on the fire if it is needed.

QUESTION 823. *What should be done when the locomotive leaves the engine-house and before the train is started?*

Answer. Before leaving the engine-house the cylinder-cocks should be open, so that any water or steam which is condensed in warming the cylinders can escape. The engineer should know that the tank is filled with water, the sand-box with sand, and that there is a proper supply of oil, waste, packing, tools, and lamps on the engine. Before the engine is started from the engine-house the bell should be rung and time enough allowed for any workmen employed about the engine to get out of the way. This rule must be scrupulously obeyed under *all circumstances*, and a locomotive should *never* be started without first giving such a signal. Without it there is always danger that some one about the engine will be hurt or killed. While running from the engine-house to the train the engineer should observe very carefully the working of all the parts of his engine, and as far as possible see that they are in good working condition. If the engine is without a steam or air-brake, the fireman should operate the hand-brake on the tender when it is needed. The junction with the train, especially when it is a passenger train, should be made very gently, as otherwise passengers may be injured by the shock. Before starting, the engineer should see *himself* that the engine and tender are securely coupled together, that the frictional parts are properly lubricated, as explained heretofore, that the fire is in good condition, and that the requisite quantity of steam has been generated. If the steam is too low, the blower should be started, which stimulates the fire. He should also test the air-brakes, as explained in another chapter.

QUESTION 824. *When the train is ready, how should the engine be started?*

Answer. After the signal to start is given by the conductor, the engineer also gives a signal by either ringing the bell or blowing the whistle. The latter should, however, be used, especially at stations, as little as possible, on account of the risk of frightening horses and the shock which it produces on persons who are unaccustomed to hearing it, or are suffering from any nervous disorder. After giving the requisite signal, the engineer places the reverse lever so that the valve will work either in full gear or very near it. He then opens the throttle *slowly* and *cautiously* so as to start the train gradually. If the train is a very heavy one, it is best to back the engine so as just to "take up the slack of the train"—that is, to push the cars together so that there will be no space between them, and thus compress the car draw-springs. When the cars stand in this way, those at the front end of the train are started one after another, which makes the start easier than it would be if it were necessary to start them all at once. If the throttle is opened too rapidly, the driving-wheels are apt to slip, but with a heavy train, even with the greatest care, this is liable to occur. If the train cannot be started otherwise, the rails must be sanded by opening the valves in the sand-box. As little sand should be used as possible, because the resistance of cars running on sanded rails is somewhat greater than on clean rails, and thus the train is more difficult to draw after it reaches the rails to which sand has been applied. The difficulty to be overcome may thus be increased by the means employed to overcome it.

While the train is slowly set in motion the fireman and engineer should ascertain by watching whether the whole train moves together, and that none of the couplings are broken in starting, and also whether any signal is given to stop, as is sometimes necessary after the train has started. On leaving the station he should observe whether all the signals indicate that the track is clear and that the switches are set right, and also look out for obstructions on the track. The train should always be run slowly and cautiously until it has passed all the frogs, switches, and crossings of the station yard, and not until then, and when the engineer has seen that everything is in order, should he run at full speed. As the engine gains in speed the reverse lever should be thrown back and nearer the centre of the quadrant or sector, so as to cut off "shorter."

QUESTION 825. *After the engine is started, how can it be run most economically?*

Answer. The advantage of using steam expansively has already been explained in Chapter VII; it is more economical to use steam of a high pressure, which is done by keeping the throttle-valve wide open, and then regulating the speed by cutting off shorter—that is, expanding it more—than it is to throttle the steam. If the speed is reduced by partly closing the throttle-valve, the steam is wire-drawn, and it then produces less useful effect than it would if it was admitted into the cylinder at full boiler pressure.

There is also another practical difficulty in using steam of a pressure and running with the throttle wide open and regulating the speed with the reverse lever alone. The link-motion, as has already been explained, will not be effective in cutting off at a point below about one-quarter of the stroke. Now it often happens, even when cutting off at that short point, with light trains on a level or slightly descending grade, that the speed will be too great if the throttle is wide open and with full steam pressure in the boiler. When this is the case, it is absolutely necessary to reduce the speed by partly closing the throttle. Undoubtedly if valve gear for locomotives was so constructed that steam could be cut off effectively at a shorter point of the stroke, it would result in some increased economy in the use of steam.

The engineer should aim to run at as nearly uniform speed as possible, and in order to do so should divide the distance between stopping points and the time given for running it into as small divisions as he conveniently can, so as to be able to tell as often as possible whether he is running too fast or too slow, and thus travel over the shorter spaces in corresponding periods of time.

QUESTION 826. *How should the boiler be fed?*

Answer. The feeding of the boiler should, if possible, be continuous, and the quantity of water pumped into should be adjusted to the amount of work which the engine is doing. Ordinarily one pump or injector is more than sufficient for feeding the boiler, so that usually only the one on the right side of the engine, where the engineer stands, is used. The flow of the water with a pump is regulated by partly opening or closing the feed-cock. In feeding the boiler it must be seen that the water is neither too high nor too low. If it is too low there will be danger of overheating the crown-plates or even of an explosion; if it is too high, the steam space in the boiler is diminished unnecessarily, and will cause the water to rise in the form of a spray, and thus be carried into the cylinders with the steam, or the boiler will *prime* or *foam*, as it is called. This water, if it collects in the cylinder, as already explained, may by the concussion produced by the motion of the piston break the cylinder.

QUESTION 827. *What is the cause of priming in a boiler?*

Answer. One of the chief causes of priming is impure water. If grease, oil, or soap gets into the boiler, it is almost sure to cause priming. Mud or other dirt is also liable to cause it. It is often due to the difference in the temperature and pressure in the water below and the steam above. Thus, if we have a boiler in which the water is heated to a temperature due to 150 lbs. effective pressure, or 366°, and we then open the throttle-valve suddenly, so as to relieve the pressure on top of the water, there will at once be a rapid generation of steam in the water which will rush to fill the space from which the steam has been drawn, just as the gas in soda water will rush toward the mouth of a bottle when the cork is drawn. This newly generated steam will be formed at the hottest part of the boiler first—that is, next to the heating surface. It will, therefore, happen that as soon as the pressure is relieved, bubbles of steam from all parts of the heating surface of the boiler will flow to the point at which the steam escapes. The motion of these bubbles will be so rapid that large quantities of water will be carried with them. The same thing will also occur if the heat of the water is increased very rapidly. The water will then become hotter than the temperature, due to the pressure of the steam above it, and consequently there will be a rapid formation and escape of bubbles of steam from the water, which will thus have the same effect as they would have if the steam pressure was reduced.

The amount of water carried up with the steam is increased if the escape of the latter is obstructed in any way, owing to imperfect circulation of water in the boiler, or by floating impurities, such as oil, on the surface. When this condition of things exists, the ebullition is, as it were, convulsive, and the water is thus carried up with the steam when it escapes. Priming is also probably due in some measure to the flow of steam over the surface of the water to the point of outflow,* carrying particles of water with it just as a high wind will, when blowing over the crests of the waves of the sea.

* Wilson on Steam Boilers.

When steam is drawn, as it usually is in locomotives, from the top of the dome to which the safety-valves are attached, the tendency to prime is very much increased when they are blowing off, so that some engineers advocate the use of two domes, from both of which the supply of steam is sometimes drawn, and in other cases the safety-valves are mounted on one, and the steam-pipe is placed in another dome. Whenever the safety-valves begin blowing off steam, the pressure in the boiler should be reduced as soon as possible, not only because when they are blowing off it tends to produce priming, but because the steam which escapes from them is wasted. The pressure can be most economically reduced either by increasing the amount of water which is fed into the boiler, or by opening the heater cocks and allowing the steam to escape into the tank and thus warm the water in the tank. If the boiler is too full, the former method cannot be employed, and in heating the water in the tank the engineer must be careful not to get it too hot, because in that case neither the pumps nor the injectors will work satisfactorily, and the paint on the tenders is also liable to be blistered and destroyed by the heat. By feeling the tank with the hand it can soon be discovered whether the water is too hot. If the steam pressure cannot be reduced in any other way, the furnace door must be partly opened.

The use of muddy water will also sometimes cause a boiler to prime. It is probable that priming is sometimes due to the formation of foam on the surface of the water, and therefore all priming is often called foaming; whereas it is thought that often a boiler will prime when the water does not foam. More accurate information regarding the priming of boilers is, however, much needed, as many of the phenomena have thus far not been satisfactorily explained. The principal causes of priming in ordinary practice are, however, undoubtedly owing to defective circulation, too little steam room, impure water, or too much water in the boiler.

QUESTION 828. *How can it be known whether an engine is priming, and what should be done to prevent it?*

Answer. The priming of a boiler can be known by the white appearance of the steam which escapes from the chimney and the cylinder cocks. Dry steam always has a bluish color. When an engine primes or works water into the cylinders, it is usually indicated by a peculiar muffled or dead sound of the exhaust, which from this cause loses its distinctly defined and sharp sound. This can be observed best when the furnace door is opened. It is also indicated by the discharge from the gauge-cocks as the steam from the upper cocks is not clear, but is mixed with water.

To use a phrase employed by practical men, the priming or foaming of the boiler may be known by the "flutter" of the gauge-cocks. The water will also rise in the glass water-gauge, and it will not indicate correctly the quantity of water in the boiler. As soon as there are any indications of priming, foaming, or that water is working into the cylinders, the cylinder cocks should be opened at once, otherwise the cylinders, cylinder-heads, or pistons may be broken. The throttle-valve should be either partly or entirely closed. When the latter is done the foaming will in most cases cease for the time, so that the engineer can tell then how much "solid" water there is in the boiler. When the flow of steam from the boiler is stopped the priming usually stops, and the true level of the water will be shown by the gauge-cocks and glass water-gauge. If it is found that there is too much water in the boiler, it is best to shut off the feed, and in some cases the blow-off cock should be opened. The latter is, however, attended with some danger, because if any obstruction should get into the blow-off cock, or it should stick fast, so that it could not be closed, all the water would escape from the boiler, and with a heavy fire in the fire-box there would be great danger of overheating, and thus injuring the boiler or of "burning" it, as it is ordinarily termed. In that event it will be imperative to put out the fire at once. Another method of affording relief, if a boiler foams, is to place what is called a *surface-cock* in the back end of the fire-box, about half way between the upper and lower gauge-cocks. With such a cock, the water can be blown off from the surface instead of from the bottom. As foaming or priming is often caused by oil or other floating impurities on the surface, they can be blown out of the boiler with this arrangement, whereas, if the water escapes from the bottom of the boiler, the floating impurities will always remain after it is blown off. A perforated pipe, which extends for some distance along the surface of the water inside the boiler, is sometimes attached to the surface-cock, so that the water which is blown off will be drawn from a number of points along the surface. If it is essential to keep the train in motion when the boiler foams, it is a good plan to place the reverse lever in full gear and open the throttle-valve very little, so as to diminish and equalize the flow of steam into the cylinders.

If the steam is rising rapidly when foaming begins, it will be well to cool the boiler off by opening the furnace door part way. This means of relief, as mentioned before, should, however, be used as little as possible, because there is always danger of causing the tubes or other parts of the boiler to leak, by either heating or cooling suddenly or rapidly. If the engine primes when there is but little water in the boiler, and at a time when the steam is rising rapidly, it may sometimes be remedied by increasing the amount of feed-water, and thus partly cooling the water inside. The use of pure water, careful firing so as to keep the steam pressure regular, feeding the boiler so that the level of the water will be nearly uniform, and then starting the engine carefully—that is, opening the throttle-valve gradually, are the most effective means in practice of preventing a locomotive boiler from priming.

QUESTION 829. *What is the economical effect of priming on the consumption of fuel in locomotives?*

Answer. It causes a great waste of heat, first by the escape of that contained in the hot water which passes through the cylinders and which does no work, and second, when steam is mixed with a great deal of water, it will not flow either to or from the cylinders as quickly or easily as dry steam will. Consequently the initial pressure on the piston, if the engine is running even moderately fast, and is cutting off short, will not be so great as it would be if dry steam was used. Wet steam is also more difficult to exhaust from the cylinders than that which is dry, and therefore the back pressure on the piston is greater when the boiler primes than when dry steam alone is used.

QUESTION 830. *When running on the open road, what should the locomotive engineer observe?*

Answer. Either he or the fireman should *constantly* watch the track in front of them, and also observe, from time to time, whether the train of cars, especially if it is a long one which he is handling, is in good condition. HE MUST OBSERVE EVERY SIGNAL SCRUPULOUSLY, AND SHOULD NEVER PASS ONE UNTIL HE IS SURE THAT HE IS AUTHORIZED TO DO SO. The well-known maxim, "Be sure you are right; then go ahead," should be changed for locomotive engineers to, DON'T GO AHEAD UNTIL YOU ARE SURE YOU ARE RIGHT. Another excellent railroad maxim is, "WHEN IN DOUBT ALWAYS CHOOSE THE SIDE OF SAFETY."

In running through a curve, the speed of the train should always be moderated in proportion to the sharpness of the curve, and before reaching it, as the train has a tendency to continue in a straight line, and there is thus danger of running off the track. The higher the speed, of course, the greater is the resistance which is required to prevent the train from running in a straight line, and consequently the greater is the strain which is thrown on the flanges of the wheels and on the rails and axles. On a curve it is also impossible, usually, to see further than a short distance ahead, and therefore, if the train is running very fast, it cannot be stopped in time, should there be any obstruction or danger on the track.

QUESTION 831. *What precautions should be observed in running over steep grades?*

Answer. On approaching an ascending grade the fireman should see that the fire is in good condition, and as much coal should be put on it as can be burned to advantage. The engineer should also fill the boiler as full of water as he safely can, without danger of priming, and should heat this water as hot as possible without blowing off steam at the safety-valves. The object of this is to have a supply of water already heated before reaching the grade. If, as often happens with a heavy train, the boiler will not make as much steam as the engine consumes, if there is a large supply of hot water in the boiler it can be used as a reserve, should it be necessary to do so, without danger of injury to the boiler If there was so little water in the boiler that it would be dangerous to allow it to get lower, then it would be necessary to feed cold water as rapidly as the hot water escaped in the form of steam. When the engine is working hard, it is often impossible to heat all this cold water as fast as it is pumped into the boiler, without reducing the steam pressure until there is not sufficient power to pull the train. If, however, there is a supply of hot water in the boiler, at the critical point on the grade, where the engine is most liable to fail, the pump or injector can be partly shut off, and thus less water will be fed into the boiler, and the steam pressure will be maintained without danger. Undoubtedly it is better to feed locomotive boilers uniformly, if that is possible, but it often happens that a reserve supply of hot water in the boiler enables an engine to pull a train up the most difficult place, whereas, without such a supply, the locomotive would stick fast. As the capacity of locomotives is rated on nearly all roads by the number of cars they can "pull up the hill," of course whatever aids them at the critical point increases their capacity. This fact gives engines with large boilers much advantage over those with small ones.

In running up steep grades, allowance should always be made for the effect of the inclination of the track upon the position of the water surface in the boiler, and also the fact that as soon as the throttle valve is closed, and steam shut off, the surface of the water will be considerably lower than when the engine was working hard. On a grade of 50 feet to a mile the front end of the tubes of an ordinary locomotive would be about 2 inches higher than the back end of the crown-sheet. If, then, on working hard up such a grade, it is succeeded by another of equal descent, the front end of the tubes would be 2 inches *lower* than the back end of the fire-box, so that if the crown-sheet was covered with 2 inches of water just before reaching the top, it would be exposed to the fire as soon as the engine reached the descent. This exposure would be dangerous, because not only would the water be 2 inches lower over the crown-sheet, but it would fall considerably more when the throttle-valve was closed. These considerations will show the danger of running the water too low while ascending steep grades.

In pulling trains up steep grades, especial caution should be exercised to prevent any of the cars from breaking loose from the train, because such an accident may cause great disaster.

If the engine is not equipped with an automatic cylinder oiler, as soon as the top of the grade is reached the fireman should oil the main valves, because it can only be done when steam is shut off, as the oil will not run into the steam-chest when there is a pressure of steam in it; and as the valves are always subjected to the severest wear while pulling up a steep grade, the valves and valve-faces are apt to become dry. As saturated steam, to some extent, prevents valves from cutting, it is not so important that they be lubricated while the engine is working with steam, but as soon as steam is shut off they should be oiled, otherwise there is danger of their being injured by their friction on the valve-seats.

In running down grades, the engineer has the greatest possible cause for using every precaution, because not only is the train much more difficult to control, but usually frequent sharp curves prevent a view of the track for any considerable distance ahead. He should, therefore, watch the track in front of him with the greatest vigilance, so as to be ready to give the requisite signals to the brakemen to apply the brakes, or, if the engine and train are provided with continuous brakes, to apply the latter, or even reverse his engine, in case of danger.

QUESTION 832. *What must be done on approaching a drawbridge or a crossing of another railroad at the same level?*

Answer. In many of the States it is provided by law that all trains must come to a *dead stop* before crossing a drawbridge or another railroad at the same level. When interlocking signals are provided at such places it is not considered essential to stop, but the engineer should then be absolutely certain that the signals indicate that the line is clear, and he should approach such places with his train under sufficient control, so that he can stop it in case of danger. The train should under no circumstances run up to such points until a signal has been given that the line is clear. An engineer should *never assume* that the signal has been given, nor take another person's word for it, but should see and know it himself. In some conditions of the weather, and with the light falling on a signal in certain directions, it is sometimes difficult to determine its color or form. If there is any doubt about it, the testimony of another person should always be sought. There is good reason for believing that color-blindness—that is, an incapacity for distinguishing one color from another, is, if not a common infirmity, at least one that is not unknown. It is certain, too, that people who ordinarily distinguish colors very accurately are subject to color-blindness in certain conditions of health, and that it is sometimes the result of overwork or great weariness; and a case is recorded of a person who was always color-blind after a debauch. There are, therefore, good reasons why a locomotive engineer should not always place too implicit confidence in what he "sees with his own eyes," but if he has any doubt, he should take the "benefit of the doubt," which should always lead him to take the side of safety.

QUESTION 833. *How should the engine and train be managed in running into a station?*

Answer. First of all, when running into a station, if the train must stop the speed should be checked so that the train will not enter with very great momentum. Therefore, at a distance varying, according to the nature of the grades and track, the steam should be shut off, so that the speed will be reduced so much that the train under any circumstances will be under full control. It is always better to enter a station at too low a speed than to run in too fast, because if it is necessary, more steam can always be admitted to the cylinders to increase the speed before coming to a stop; whereas it is not so easy to stop the train if it is running too fast, and it becomes necessary to check it before entering the station. This will sometimes be necessary, because it may readily happen through negligence or accident at stations that in switching cars one or more may be left standing wholly or partly on the track, which the arriving train must run over, in which case a collision, with its terrible consequences, may be unavoidable. When steam is shut off the reverse lever should be thrown into full gear, because in that position there is less compression of steam in the cylinders, and therefore not so much liability of raising the valve from its seat.

When a train is equipped with continuous brakes, the control which they usually give to a locomotive engineer over the train is so great that he is apt to approach stations, crossings or drawbridges at a high rate of speed, and rely on such brakes to stop the train. This practice is always attended with danger, because if it was found, on getting near to the station, crossing or drawbridge, that the track was not clear, and that it was obstructed by a car or train, or the draw was open, if the engineer should attempt to apply the brakes and from some cause they should fail to work, as sometimes occurs, then a collision or other disaster would be inevitable, because it would be impossible to stop the train with the ordinary hand-brakes. For this reason a locomotive engineer should always approach such places cautiously and with his train under sufficient control, so that if he finds there is danger ahead he can stop the train with the ordinary means, or at the worst by reversing the engine. Continuous brakes should always, excepting in cases of imminent danger, be applied gradually, so as not to check the cars with a jerk or too suddenly. The practice of opening the engineer's valve, which was formerly used with the Westinghouse brake, suddenly, and then turning it back again as quickly, is almost sure to produce disagreeable and dangerous shocks to the cars. This cock should be opened gradually, so as to check the cars slowly at first. The new engineer's valve, illustrated and described in answer to Question 631, is arranged so that air can be turned on and shut off quickly without producing disagreeable shocks.

QUESTION 834. *What must be attended to when running a locomotive at night?*

Answer. As soon as it begins to grow dark, the head-light must be lighted and properly trimmed, and the proper lamp signals placed in front of the engine, if the rules of the road require the display of such signals. A lamp should always be placed in the cab, so as to throw its light on the steam-gauge, but not into the engineer's face, because he is unable to see distant signals so well if his eyes are exposed to the glare of a light near him.

At night, as objects which are passed cannot be seen distinctly, it is more difficult to tell the speed at which an engine is running than it is in the daytime. An engineer should, therefore, consult his watch frequently.

QUESTION 835. *What must be attended to in very cold weather?*

Answer. Great care must be exercised to prevent the water in the pumps, pipes, and in the tender, from freezing. If it does it will be almost certain to break the pump or burst the pipes. To avoid this the heater cocks must be opened, so as to keep the water in the tender warm. In excessively cold weather the engine should be run with greater caution than at other times, as iron is then more brittle, and also more liable to break, owing to the frozen condition and consequent solidity of the track.

QUESTION 836. *In running a locomotive in severe snow or rain storms, what should be observed?*

Answer. Whenever it snows the pilot or cow-catcher should be covered with boards, or, better still, with sheet iron, so as to act like a snow plow. Brooms made of steel wire or scrapers should be placed in front of the front wheels of the engine, so as to clean the snow from the rails. The front damper on the ash-pan should be kept closed so as to exclude the snow from the ash-pan, which would soon fill it up, and in this way obstruct the draft. If the fall of snow is very heavy or it blows into drifts, the train must of necessity run very slowly, and even if a part of the track is clear of snow, it is unsafe to run fast on it, as there would be danger of throwing the engine off the rails, if it should run into a heavy drift at a high speed.

In severe rain storms bridges, culverts, and such portions of the track as are liable to be washed away should be approached cautiously, especially at night. In both snow and rain storms, and also in fogs, great caution is required, owing to the difficulty of seeing signals.

QUESTION 837. *What is meant by a reserve engine or "helper?"*

Answer. A *reserve engine* is a locomotive which is not employed in hauling a regular train, but is kept as a "reserve" to go to the help of an engine which may be compelled to stop on account of an accident of any kind, or to assist engines in moving trains up heavy grades, or is used in clearing away a wrecked train, rebuilding bridges, or other structures.

QUESTION 838. *What must be observed in running a reserve engine?*

Answer. As no special arrangements are usually made in preparing time-tables* for the running of reserve or, as they are usually called by railroad men "*wild*" engines, it may very probably happen that it will be called upon to assist other engines when the road is not clear, and therefore its engineer must consequently be on the lookout for signals to stop, which are often given suddenly. He must switch off with special caution in order to be sure to keep out of the way of regular trains running in the opposite direction on the same track. When he reaches the train or place where the assistance of the reserve engine is needed, he must approach it *slowly* and *carefully*, in order to avoid a violent shock. On

* A *time-table* is a table which gives the time when each train shall arrive at the stations it passes, the stations at which it shall stop, and all the regulations by which it shall be run.

the return from the assisted train, he incurs the same danger, and must pay close attention to any signal to stop made to him by any opposite train on the same track, and also on his part warn such trains by the proper signals.

When a train is run with two engines, both in front of it, the forward engineer always takes the management of the train. The engineer of the hind engine must be guided by the signals of the one on the forward engine. In starting, the forward engine must be set in motion first and then the one behind it. In stopping, the steam must be shut off first in the hind engine. Likewise in decreasing the speed during the trip, the hind engine must first regulate the flow of steam. If these precautions are not observed the forward engine may easily be thrown from the track by the faster motion of the hind one. When there are two engines the air-brakes should always be operated from the front engine, but the air-pump on the rear one should be kept running to assist in charging the brake reservoirs with compressed air. When a train is assisted by a "helper," placed *behind* the train, and therefore pushing it, the forward engine must likewise be set in motion first, and steam should be let on in the hind engine only after a signal has been given by the engineer of the head engine.*

QUESTION 839. *How should switching engines be managed?*

Answer. In pushing and switching freight cars in a station-yard, they should be moved carefully and severe shocks must be avoided, as the cars, the goods with which they are loaded, and the persons employed about them may be injured by violent concussions. The engineer must also follow the instructions of his superior *strictly* and *cheerfully*, and should examine patiently and observe with discretion the suggestions of employees who are not his superiors.

In this service it is also of special importance that the engineer give a *distinct* signal with the whistle or bell before every movement of his engine, in order to warn in time those who at such times often stand on the track in the way of the engine or cars, or the persons engaged in loading, cleaning or repairing the cars, and thus give them time to get out of the way.*

QUESTION 840. *In firing a locomotive, what are the most important ends to be attained?*

Answer. That which is of first and chief importance is to make steam

* "Katechismus der Einrichtung und Betriebes der Locomotive," by Georg Kosak.

enough, so that the locomotive can pull its train and "*make time;*" * second, it should make the requisite quantity of steam with the least consumption of coal, and third, with the least production of smoke, although the latter, independent of the economy of combustion, is considered of importance only with passenger trains. What is frequently lost sight of in considering this subject is the fact that with all locomotives it often happens that it is a matter of extreme difficulty to make enough steam to do the work required of the engines. When a freight train is struggling up a grade with a heavy train, or an express engine is obliged to make time under similar conditions, it often depends entirely upon the quantity of steam which can be generated in the boiler in a given time whether the engine will fail or not. In firing, therefore, the most important end to be aimed at is often simply to produce the largest amount of steam possible in a given time, even at the sacrifice of economy or by producing any quantity of smoke. Any means of economizing fuel or of smoke prevention, which reduces the steam-producing capacity of boilers, is therefore quite sure to be abandoned in time.

QUESTION 841. *How can a boiler be made to produce the largest quantity of steam in a given time?*

Answer. By burning the greatest quantity of fuel possible on the grate in that time. This can be done by keeping the grates free from clinkers and the ash-pan from ashes, and then distributing the coal evenly over the grates in a layer 6 to 12 inches thick. The thickness of the layer which will give the best results will, however, vary with the quality of the fuel, and must be determined by experience. If the layer is too thick, not enough air will pass through it to burn the coal. If it is too thin, then so much air will pass through that the temperature in the fire will be reduced. The rapidity of combustion will also be promoted by breaking up the coal into lumps the size of a man's fist or smaller. If fine coal is used it should be wet, otherwise it will be carried into the flues by the blast before it is burned, or caked, or even before it reaches the grate. Experience will indicate the amount of air which can advantageously be admitted above the fire in order to secure the maximum production of steam. The best size of the exhaust nozzles and the position of the petticoat-pipe must also be determined by experience. It will usually be found, however, that if enough air is admitted above the fire to prevent smoke, it will reduce the maximum amount of steam which can be generated in a given time. The fire should also be fed regularly and with comparatively small quan-

* The term *make time* means to run at the speed indicated on the time-tabl

tities of fuel at a time, although if the feeding is too frequent there is more loss from the cooling effect which results from the frequent opening of the furnace door than is gained from the regularity of the firing. In this, too, a fireman must consult experience to guide him.

QUESTION 842. *How can a locomotive be fired with the least consumption of coal?*

Answer. Two systems of firing are practised in this country, one known as the "banking system" and the other the "spreading system." When the banking system is employed, the coal is piled up at the back part of the fire-box, as shown in fig. 476, and slopes down towards the front of the grate, where the layer of coal is comparatively thin and in an active state of incandescence. The heap of coal behind is gradually coked by the heat in the fire-box, and the gases are thus expelled. Openings in the furnace door admit air, which mingles with the escaping gases which then pass over the bright fire in front, and are thus supposed to be consumed. When the "bank" of coal behind becomes thoroughly coked, it is pushed forward on the bright fire and fresh coal is again put on behind to be coked. This system of firing is practised on some roads with good results, but it is doubtful whether it could be used successfully with coal which cakes and clinkers badly.

The spreading system is most commonly employed in the Western States, where the coal contains a great deal of clinker. When this is practised, the coal is spread evenly over the whole of the grate in a thin layer, and its success and economy depend upon the regularity and evenness with which this layer of coal is maintained and the fire fed. The thickness of the coal must be adapted to the working of the engine. When it is working lightly, the layer of coal should be thin, but when the engine is pulling hard the layer of coal must be thicker, otherwise the violent blast may lift the coal off the grates. The success of this system, as was explained in answer to Question 739, depends upon the manner in which the thickness of the fire is regulated, on the admission of the proper amount of air above the fire, and on the frequency with which the fire is supplied with coal. When this system of firing is employed not more than two shovelsful of coal should be put into the fire-box at once, and if the engine is not working hard, one or even less will be sufficient. The fireman must, however, determine by experience the thickness of fire, amount of air which should be admitted and the frequency of firing which will give the best results in practise. Doubtless these will vary with different kinds of fuel and the construction of engines. Usually the greatest obstacle in the way of producing good results is the fact that firemen would rather "take things easy" than exercise that diligence and observation which will alone insure success in any occupation.

QUESTION 843. *How can smoke be most effectually prevented?*

Answer. The means of preventing smoke were very fully explained in answer to Questions 752 and 753. It may be said briefly that this can be done only by properly regulating the supply of air which is admitted to the fire. The means of doing this have already been explained.

QUESTION 844. *What method of firing is employed when anthracite coal is used?*

Answer. The spreading system alone is then used.

QUESTION 845. *How may the rules which firemen should observe when bituminous coal is used be briefly stated?*

Answer. (1) Keep the grate, ash-pan and tubes clean. (2) Break the coal into small lumps. (3) Fire often and in small quantities. (4) Keep the furnace door open as little as possible. (5) Consult the steam-gauge frequently, and maintain a uniform steam pressure, and if necessary to reduce the pressure do it by closing the ash-pan dampers rather than by opening the furnace door.

QUESTION 846. *On arriving at a station where a train stops longer than a few minutes, what should the locomotive engineer and fireman attend to?*

Answer. The engineer should examine thoroughly all the parts of his engine, as has been heretofore explained. He should especially examine all the journals and wearing surfaces to see whether they are hot. This he can discover by feeling them. If any of them have become very much heated, they must be cooled by throwing cold water on them, and then thoroughly oiled. The working parts should be thoroughly lubricated, as already explained.

The fireman should examine the tank and see whether it is necessary to take in a fresh supply of water. He should then examine the grates and ash-pan, and clean the cinders and clinkers from the former, and the ashes from the latter. Neglecting to clean the ash-pan may result in melting and destroying the grate-bars, and by obstructing the admission of air to the grates, the ashes prevent the combustion from being as complete as it would otherwise be. With some kinds of fuel it is necessary to clean the tubes frequently, which must often be done at stations where the train stops.

During the stop, as thorough an inspection of the engine should be made by the engineer and fireman as the time will permit; but any unnecessary waste of time must be avoided, and the firing should be so managed that nothing need be done about it during the halt at the station. On starting again the same precautions should be exercised as on making the first start.

QUESTION 847. *After reaching the end of its run, how should an engine be cleaned and repaired?*

Answer. Before reaching the last station the firing should be so managed that there will be as little fire as possible remaining in the fire-box at the end of the run. After the arrival the engine should be run over a pit which is usually provided for the purpose, and the fire should be raked out of the fire-box by dropping the drop-door, if there is one to the grate, or turning the grate-bars edgewise, or withdrawing one or more of them, if it is necessary to do so. In this way the fire will fall into the ash-pan, from which it can easily be raked. After all the fire is withdrawn, the dampers and furnace door should be closed so as not to allow the cold air to cool the fire-box and tubes too rapidly.

In order to keep the boiler clean—that is, as free as possible from sand, sediment or incrustation, it is necessary to blow it out frequently, if the water which is used contains much solid or incrustating matter. With "bad water" the boiler should be blown out as often as possible. On some roads this is done after each trip. In blowing a boiler out, the blow-off cocks must be left open, and after all the water has escaped the engine should be left to stand until it is cooled off. If there is any considerable accumulation of mud or sediment the hand-holes at the bottom of the fire-box and the cover to the mud-drum should be taken off, and as much of the mud removed as can be scraped out through those apertures. A hose-pipe attached to the hose of a force pump should then be inserted through these same openings, and a strong stream of water forced into the boiler. By this means much of the loose mud and scale will be washed out. The oftener this is repeated, of course, the cleaner can a boiler be kept. If a large amount of incrustation or mud has accumulated about the tubes, some or all of them must be taken out, so as to be able to remove the dirt.

After an engine is blown out, under no circumstances, excepting absolute necessity, should it be filled with cold water until it is cooled off. It should be remembered that any sudden change of temperature in a boiler subjects it to very great strains and incurs the danger of cracking the fire-box plates, or causing the tubes to leak.

The tender should also be cleaned of the mud which settles in it from time to time, but it is not necessary to do this as often as it is to clean the boiler. The strainers in the tank over the water-supply pipes should be examined and cleaned frequently. All the plates and flues should have the soot which sticks to them thoroughly cleaned off.

Although the cleaning of the boiler and the grates is usually committed to a special set of men, yet the locomotive engineer should examine them personally to see that it is properly done. He should pay attention to the condition of the grate, and see whether it is level and smooth. As soon as one or more of the bars are bent crooked, they usually burn out. If one of the bars is burned out the fire falls through the hole that it leaves into the ash-pan, and then the fire under the grate will heat it red hot, and finally may melt or "burn" every bar. Every grate-bar which is only a little damaged or bent must, therefore, be removed as quickly as possible and replaced with a new one. An opening in the grate larger than the spaces between the bars allows a superfluous amount of cold air to enter the fire-box, and diminishes the steam-generating capacity of the boiler.

As soon as the engine is run into the engine-house, the cylinder-cocks should be opened and left open while it is standing still, so that the condensed water can escape. All superfluous grease which has escaped from the wearing surfaces and the dust or mud which adheres to the engine should be wiped off with cotton waste or rags. This is usually done by men employed for the purpose. While they are doing this, they should examine every part thoroughly and observe whether it is in good condition, and if any defects are found they should be reported to the proper person whose business it is to have them repaired. As the faithfulness and skill of a fireman are often estimated by the good or bad condition of his engine, he should, if for no other reason, take pains to keep it clean and everything in as good condition as possible.

If the engine is taken to pieces in order to be thoroughly repaired, the engineer, if he does not help to do this, should watch carefully the taking it apart, and the putting it together again, as in this way he can become thoroughly familiar with the construction of the machine or machines he runs.

QUESTION 848. *What precaution must be taken to prevent the water in a locomotive from freezing, if it is laid up?*

Answer. In very cold weather, if engines are laid up for any considerable time, no water must be left in the tender, boiler, or any of the pipes. If, however, the engine must be soon used, and it is impracticable to let the water out of the boiler and tender, then, if exposed to the cold, a light fire must be kept in the boiler sufficient to make steam enough to warm the water in the tender. The water should, however, be drawn out of the pumps, injectors, and the feed and supply pipes. This can be done by opening the pet-cocks, and closing the tender-valves and uncoupling the hose, which will allow the water in the supply pipes to run out. By running the engine a few revolutions the pumps will then be emptied. The pipes and the pumps can also be prevented from freezing without uncoupling the hose, if the tender-valves are closed and the pet-cocks opened, and steam is then admitted into the supply pipes by the heater-cocks. This forces part of the water which is in the pumps out of the pet-cocks and warms the rest. This, however, requires constant watchfulness to prevent freezing, and in excessively cold weather, if the engine must lay up for any considerable time, it is always best to empty the pumps and pipes.

CHAPTER XXXV.

RESPONSIBILITY AND QUALIFICATIONS OF LOCOMOTIVE ENGINEERS.*

QUESTION 849. *What are the dangers to which the engineer and the fireman are exposed by their work on the engine?*

Answer. Engineers and firemen are not only exposed to great bodily injury or even death by every accident which may happen to their engine, but unless they are very careful to preserve their health it is quickly destroyed by the constant changes of the weather to which their position exposes them, and also by the effect of the heat of the fire and by the smoke by which they are often surrounded.

In order to protect themselves in a measure from the injurious effects of change of weather, smoke, cold, etc., frequent bathing and cleansing of the skin are very beneficial, and also the wearing of a woolen undershirt next the skin at all seasons.

The gases of coal which pour out of the furnace door, if it is opened when the throttle is closed, have an especially injurious effect on the throat, lungs, etc. They should see to it, therefore, that the blower is always started before the fire-door is opened, in order that these injurious gases, which have collected during a halt, may be drawn forward and up the chimney by the draft.

The steady, loud clatter, which the engine makes while running, has an injurious influence on the nervous system. The engineer should therefore endeavor to lessen these shocks of the engine as far as possible by keeping watch over it and keeping its parts accurately adjusted. In order to keep himself fresh and strong in his service, which is extremely exhaustive to body and mind, the engineer should try to strengthen himself by regular, temperate living, and eating abundant nourishing food. The common use of strong drinks, which undermines the mental and physical strength of men, should be avoided by a person occupying the exhaustive and responsible position of a locomotive engineer. If in ordinary life a drunken man is unfit for any simple work, how shall a drunken engineer

* A portion of this chapter is a translation from Professor Georg Kosak's "Katechismus der Einrichtung und Betriebes der Locomotive."

or fireman undertake the difficult management of so great, so delicate, and so costly a machine as a locomotive? How can hundreds of men quietly trust their lives and limbs to such a man, whom no one can help despising? Rightfully, therefore, conscientious railroad managers place the greatest stress on the *sobriety* of the engineers and firemen, and instantly discharge from their service those who give themselves up to a passion for drink.

Owing to the demands which their daily labor makes upon their strength and endurance, locomotive engineers should be careful not to increase the drain by dissipation, irregular hours, or overwork. There seems to be something about the power of endurance of the human frame analogous to the capacity of a bar of iron or steel to resist strains. So long as the strains do not exceed the elastic limit—that is, if the bar recovers its original length when the strain is removed, it will bear millions of such strains without becoming weaker; but if it is strained so hard that it is permanently stretched, then comparatively few applications of the force will rupture the bar. In a similar way, if the strain or fatigue which a man endures is no more than he will recover from after the ordinary rest, he can endure an almost unlimited number of such strains, but if the fatigue exceeds his "elastic limit," then he soon becomes permanently injured thereby. It often happens that an excessive amount of work is unavoidable, but when it can be avoided it should be by those who wish to preserve their health and strength.

In order to save themselves from great injuries, engineers and firemen should always act with the greatest caution, and never rush carelessly into danger. They should never adopt the principle of foolhardy and thoughtless people, who by the consciousness of continual danger fall into the habit of carelessly "trusting to their luck," etc. On the contrary, they should always face the danger with their eyes open and with the greatest conscientiousness. Many try to show great courage by scorning the danger, and some such even wish to meet a little in order to be able to show that they are not afraid. These should bear in mind that they have a great responsibility laid upon them, and that it is not alone their own well-being or life which is at stake in case of any mishap, but that by their careless behavior they may wound or kill the helpless people who are committed to their care, cause incalculable misery by robbing families of their sole support and of their children, and bring great sorrow and mourning to their fellow men. The thought of the curse and the despair of the survivors may give sleepless hours even to a locomotive engineer who knows himself to have been without any fault regarding an accident; how much more must it be with him who cannot give himself this assurance? There are not wanting instances in which the engineer who caused such an accident by his thoughtlessness, driven to despair by his own heavily-burdened conscience, went miserably to ruin.

QUESTION 850. *What should a locomotive engineer and fireman do to preserve their health?*

Answer. The following excellent suggestions* to workingmen for the *prevention* of sickness may be followed by all locomotive engineers and firemen, to their own great advantage and that of their families.

They include, first, attention to home surroundings, and second to personal habits.

In regard to the first, one of the earliest physicians, Hippocrates, said that the essentials of health were pure air, pure water, and a pure soil. Your home should, above all things, be free from damp. It should not be built upon made land or where it can be flooded by rains or by a rise of tide. Dampness is a source of consumption, rheumatism, croup, diphtheria, and other diseases. The nearer your living rooms are to the ground, the more danger there is of damp. It is better to occupy an attic, where you can get the sun and the air than a basement.

Again, new houses are liable to be damp from the evaporation from the plaster and mortar, which contain a large amount of water. A Spanish proverb says of new houses, "The first year for your enemies, the second year for your friends, and the third you may live there yourself." Again, cellar air is unwholesome; and this is another reason why basement rooms are bad. It is very unwise to store vegetables in cellars, or anything that will cause impurity of the air.

Pure air is the most vital thing of all. One may live without proper food and drink, and on a damp soil with impunity, but foul air slays like a sword. Every person needs pure air to breathe. Each time we empty our lungs a certain amount of impure air is thrown off. Thousands die yearly for lack of pure air. It is free to all; it costs nothing. Open the window, and it flows in abundance to the beggar as to the millionaire, bringing health and life to all—if only people would not shut and bar it out in their blind, stupid ignorance.

What is it that makes most people sick? Eating too much and too fast; drinking too much; want of fresh air; want of sunlight; want of exercise; want of cleanliness. Few persons die of starvation—many do of gluttony.

* Published by the Citizens' Sanitary Association of Brooklyn, N. Y.

Bathe as often as you can.* Remember "cleanliness is next to godliness," and a foul body usually means a foul mind. Keeping the pores of the skin open is a prime element of health. How carefully we groom our horses! and is not a man's health as precious as that of a horse?

Let your wife and children have as much out-door exercise as they can get. It will be a change, and won't do the least harm.

Don't sit in damp clothes if you come home wet. If you feel chilled and cold, soak your feet in a pail of hot water, then go to bed and pile on the clothes till you sweat, and you will escape catching cold. In such cases, hot tea, or coffee, or soup is better than whiskey to warm you. In cold countries tea is preferred to any drink. Liquor should never be taken by a sick person, unless by a doctor's orders.

Clothes should fit loosely, should be light, warm, and porous, should be adapted to the season as to color, should be frequently changed, and should be scrupulously clean.

In cooking, use the frying pan as little as possible; greasy food is very unwholesome. Avoid too much pork and liquors.

Eat slowly, chewing the food well, and drink very little liquid of any kind while eating. Tea is not food, and too much of it is drunk by many persons, especially women and children. Eat hominy in preference, and give children plenty of milk. Beans are very nutritious.

Don't shut every cranny and crack to keep out the air from the rooms, but let the windows stay open for a time.

Don't forbid the blessed sun from entering your windows. Don't stay in a house that has a bad smell in it.

Don't live in dark, gloomy, close rooms if you can get sunny, cheery ones.

Remove all garbage and refuse as soon as possible from your houses.

Have the walls and ceiling whitewashed or kalsomined once or twice every year.

In looking for apartments, always strive to secure a well-ventilated bedroom. Air the room and bed-clothing every morning. Keep as few clothes, not in use, as possible in the bedroom, and do not sleep in any garment which is worn by day.

QUESTION 851. *What requirements and duties should every locomotive engineer fulfil?*

Answer. Every locomotive engineer should fulfil the following requirements and duties:

* If a bath tub is not available, a damp or wet towel—the coarser the better—rubbed briskly all over the body every morning is an excellent substitute for a bath.

1. He should have an exact knowledge of the engine entrusted to him, and a general knowledge of the nature and construction of steam-engines generally. Likewise, he should be perfectly familiar with the management of the boiler, the running of the engine, and the way of keeping the working parts in good condition; also with the forms and peculiarities of the line of road on which he runs, the rules which govern the running of trains and with the signal system adopted.

2. *Health* and *bodily strength* he must have in abundant measure in his position, which is exhausting and in which he is exposed to all sorts of weather.

3. He should have at least a good, plain common-school education, and be ready at reading, writing and arithmetic.

4. He should always carry out *exactly* and *cheerfully* the regulations of the service, or the instructions given him by special orders from the officers over him.

5. *Faithfulness, frankness and honesty*, which characterize an upright man in ordinary life, and also the strictest *temperance* in the use of strong drink, he should possess in a high degree in his very responsible position.

6. He should have acquired a certain degree of skill in putting together and taking apart locomotives, and also in repairing separate parts of them. It is desirable that he should always be present when his own engine is taken apart, put together, or repaired, in order that he may acquire a thorough knowledge of its condition and learn to understand properly the importance of its various parts.

7. In caring for his engine, he must preserve perfect cleanliness and order, and in using fuel he should manifest the greatest care and rigid economy.

8. Whenever there is danger, coolness and self-possession are indispensably necessary, and any thoughtlessness or recklessness is to be strictly avoided.

9. Toward his superior officers his behavior should be respectful and obliging; towards those under him, patient and kindly, and at all times he should avoid profanity and all intemperate language, and obey the Ten Commandments. He should endeavor, as far as possible, to instruct the fireman who accompanies him and make him familiar with the construction and management of the engine, and should see that he does his work strictly in accordance with his instructions.

It is the *fireman's* duty to follow the engineer's instructions strictly, and in case of any sudden disability of the engineer he must stop the engine in accordance with the instructions given him, and then give the proper signals for help, until another engineer arrives. In the meanwhile the engine is to be kept at a halt with all the usual precautions.

10. The engineer should try to keep himself informed of the progress and improvement of locomotives by reading suitable books and technical periodicals, and when possible acquire some skill in geometrical and mechanical drawing, in order to accustom himself to accurate work and sound and systematic thinking.

QUESTION 852. *What studies should mechanics, locomotive engineers and firemen take up, and what technical books should they read?*

Answer. As already stated, they should know how to read and write their own language, and understand arithmetic and have some knowledge of geography. Every locomotive runner and fireman has a good deal of spare time, a part of which he can devote to study, and all of them, even if they have not had the advantage of early education, could by industry and perseverance acquire a knowledge of "reading writing, and ciphering." The assistance of a good teacher should always be procured, if possible. With so much knowledge, some book on natural philosophy can be read to advantage, and then some book on mechanics. It should always be remembered, however, that the mere buying of books contributes very little knowledge to the owner. It is the reading and *understanding* them which "increases knowledge." Before buying books it will be well to ascertain from persons capable of judging of their character, whether they are worth buying, as there is more difference in the quality and character of books than there is in almost any other commodity which is sold. Many which are written and published are not worth buying or are unsuited to the wants of the purchaser, while a really good book —and there are many such—is a treasure.

CHAPTER XXXVI.

ACCIDENTS TO LOCOMOTIVES.

QUESTION 853. *What are the most serious accidents which may happen in running a locomotive?*

Answer. The most serious accidents are:

1. Collision of two trains approaching each other.
2. Collision of a moving with a standing train.
3. Collision of trains at the crossing of two railroads.
4. Running a train into the opening left by an open draw-bridge.
5. Escape of an engine without any one on it.
6. Running off the track.
7. Explosion of the boiler.
8. Bursting or rather collapse of a flue.
9. Overheating and burning of the crown-sheet.
10. Blowing out of a bolt, stud, rivet, cock, or any accident which makes or leaves a hole in the boiler for the escape of steam or water.
11. Failure of the feed-pumps, injector, or check-valve.
12. Breaking or bursting of a cylinder, cylinder-head, steam-chest, or steam-pipe.
13. Breaking or getting loose of the piston or cross-head, or bending of the piston-rod.
14. Breaking or bending of a connecting-rod or crank-pin.
15. Breaking of a tire, wheel, or axle.
16. Breaking of a spring, spring-hanger or equalizer.
17. Breaking of a frame.
18. Breaking or getting loose of a part of the valve-gear.
19. Failure of the throttle-valve.
20. Breaking of the smoke-box front or door.
21. Breaking of a coupling between the engine and tender, or between the tender and front part of train, or between two cars.
22. Failure of the air-pump or other part of the brake.

QUESTION 854. *What should be done to prevent a collision when two trains are approaching each other?*

Answer. The obvious thing to do is to stop the trains as soon as possible. This is done by applying the brakes at once with all their power, and then reversing the engine, although it is best not to do the latter until the train is somewhat checked, as there is always danger of bursting the cylinder or breaking the cylinder-heads, piston, or connections if an engine is reversed suddenly at a high speed. Of course the higher the speed, the greater is the danger of injury from this cause, and therefore it is best if there is time, first to check the speed of the train before reversing the engine. When the engine is reversed, the sand-valves should be opened so as to increase the adhesion of the wheels, so that when their motion is reversed they may check the speed of the train as soon as possible. On perceiving danger ahead the order of procedure should be as follows :

1. Shut the throttle-valve.
2. If the train is equipped with hand-brakes alone, blow the danger signal for their application, or if the train has a continuous brake, apply it with its full force.
3. Reverse the engine and open the throttle and the sand-valves.
4. If a collision is inevitable, shut the throttle-valve before the engines meet, because if it is left open after the collision, and when the speed of the train is checked, the engine, if not disabled will by its own power crush through the wreck, and thus do additional damage.

To the credit of locomotive engineers, it can be said that they rarely leave their engines, no matter how imminent the danger is, until after they have applied all the means of checking the speed of the train. If a violent and dangerous collision is inevitable, then the engineer may protect himself by jumping from his engine, or remain on it as may seem best; but he is in duty bound to do all in his power to prevent dangerous collisions, especially if he is running a passenger train.

QUESTION 855. *What kind of collisions occur oftenest?*

Answer. What are called "tail-end collisions"—that is, collisions of trains which run in the same direction, although there are unfortunately many collisions of trains running in opposite directions, or "butting collisions," as they are called.

QUESTION 856. *What should be done if another train is approaching a standing train, and there is danger of a collision?*

Answer. The locomotive runner of the standing train should start his engine in the same direction as the approaching train is running as quickly as possible, because the shock of the collision will be very much lessened if both trains are moving in the same direction compared with what it would be if one was standing still.

QUESTION 857. *What should be done to avoid a collision at a railroad crossing?*

Answer. If there are no interlocking and distant signals at the crossing, trains should always come to a dead stop before crossing another railroad on the same level.

If there are interlocking and distant signals, the engineer should be absolutely sure that they indicate to him that the crossing is clear. If by reason of fog or inadvertance in looking for the signals or *any other reason* he has the slightest doubt about the position of the distant signal, he should slack up when he passes it so as to be able to stop before he reaches the home signal at the crossing. If, however, through any cause danger of a collision should be incurred at a crossing, then evidently the one train should be stopped and the other moved out of the way as soon as possible. The following is a safe rule for all persons, as well as locomotive engineers to adopt: NEVER CROSS A RAILROAD WITHOUT FIRST STOPPING TO SEE WHETHER THE ROAD IS CLEAR. If those who drive horses as well as those who drive locomotives, and also foot travelers, would scrupulously observe this rule, many lives and much suffering would be saved each year.

QUESTION 858. *How can an accident by running into the opening at a drawbridge be avoided?*

Answer. The precautions to be taken are very much the same as those which should be observed at crossings. It is a safe rule ALWAYS to come to a dead stop before reaching a drawbridge, and second, never start again until it is absolutely certain that the draw is closed. Of course if a locomotive runner of an approaching train finds a draw open, the only thing he can do is to stop as soon as possible.

QUESTION 859. *What measures should be taken to prevent locomotives from escaping and running away without a responsible person on them?*

Answer. In the first place, when a locomotive is left standing, the throttle-valve should always be *closed* and *fastened;* the cylinder-cocks should also be opened, so that if any steam leaks into the cylinders it will not accumulate there, but will escape, and the reverse lever should be placed in the centre of the sector, so that if by any accident the throttle should be opened the engine will not start.

QUESTION 860. *If a locomotive should escape, what should be done, and how may it be captured?*

Answer. The first thing to be done is to telegraph to the stations toward which the escaping engine is running, either to keep the track clear, or if there is a train approaching, to open a switch, and thus let the engine run off the track. An escaped engine may be captured by a swifter engine following it, but this is always attended with great danger, as the first engine may leave the track or become wrecked. A safer plan is to telegraph ahead of the escaping engine, and have an engine placed in a position where the track can be seen for a long distance in the direction in which the runaway is expected. As soon as the latter comes in sight, the waiting engine should start in the same direction, so that when they get near to each other they will both be running the same way and at nearly the same speed. By regulating the speed of the front engine, the following one may be allowed to come up to it quite gently, and then a man can easily climb from the one engine to the other, and thus both be stopped.

QUESTION 861. *What should be done in case an engine gets off the track?*

Answer. The first thing to do is to close the throttle-valve and "signal for brakes,"* or apply the continuous brakes if the train is equipped with them, and then reverse the engine. As soon as the engine has stopped it should be seen that the proper signals are given to protect it from approaching or following trains. If the boiler is in such a position that the heating surfaces are liable to be uncovered with water, they may get red hot and be burned. If there is danger of this the fire should be either drawn, quenched with water, or extinguished by covering it with sand, gravel, earth, sod, or snow, and then wetting the covering.

QUESTION 862. *How is a locomotive replaced on the track in case it gets off?*

Answer. If the engine is still standing on its own wheels, and has not gone far from the rails, it can usually run itself back by the aid of hydraulic jacks, wrecking frogs, or blocking under the wheels. Generally it can be replaced on the track best by running it the reverse direction to that in which it ran off. Often a derailed engine can be put back with the aid of another engine when it could not run itself back. It is impossible to give any directions for replacing locomotives on the track which will meet the great variety of circumstances which occur in practice. If an engine has fallen on its side or has run down an embankment, it is usually necessary

* This expression means, among railroad men, to signal to brakemen by blowing the whistle to apply the brakes.

to send for the appliances which are now provided on nearly all roads for removing wrecks and replacing engines on the track. These appliances are generally stored in what is called a wrecking or tool car, which is placed at a convenient point on the road, from which it can be sent to any place where its services are likely to be needed. Such cars are provided with ropes, jack-screws, chains, crowbars, levers, etc., to be used in such cases, and generally a special set of men is sent with the wrecking car to direct and assist in replacing engines and cars on the track. It would lead us too far to describe all the methods of doing this employed under various circumstances; and as such work seldom forms part of the duties of a locomotive runner, a complete description would be out of place here.

QUESTION 863. *After an accident which disables the engine, what is the first thing to do?*

Answer. The first thing to do is always to PROTECT THE TRAIN, that is, to send out signal men in each direction to stop approaching trains, otherwise they might run into the wrecked train, and thus cause a double accident.

QUESTION 864. *What is the chief cause of boiler explosions?*

Answer. The cause of all boiler explosions, as happily expressed by a prominent American engineer,* is THAT THE PRESSURE INSIDE THE BOILER IS GREATER THAN THE STRENGTH OF THE MATERIAL OUTSIDE TO RESIST THAT PRESSURE." This may occur in two ways: first, and most frequently with locomotives, from insufficient strength of the boiler to bear the ordinary working pressure; and second, from the gradual increase of heat and pressure until the latter is greater than the boiler was calculated to bear.

Insufficient strength may be due: 1, to defects of the original design, owing to the ignorance of the strains to which the material of the boiler will be exposed, and its power of resistance; 2, to defective workmanship and material, which can usually be discovered by careful inspection; 3, to the reduction of the original strength of the boiler by corrosion or other ordinary wear and tear or neglect, which can also usually be discovered by careful inspection.

The first two causes have been fully discussed in the part relating to Boiler Construction, and the last under the head of Inspection of Locomotives.

* Coleman Sellers. See Fifth Annual Report of the American Master Mechanics' Association, page 196.

Over-pressure is nearly always due to some defect of the safety-valve, or to the fact that it is overloaded. This latter often occurs when safety-valves are set by an incorrect steam-gauge, which indicates too little pressure. Over-pressure may also occur by letting an engine stand alone with a large fire in its fire-box and possibly with the blower turned on.

A boiler may, by suddenly opening the throttle-valve, undoubtedly be subjected to very severe strain that may possibly be sufficient to cause its destruction, even though it had sufficient strength to bear the ordinary pressure at which the safety-valve blows off. Suddenly opening or closing the throttle-valve may produce a violent rush of steam and water against the part of the boiler whence the steam is drawn. The percussion of the water and steam in such cases has been known to shake the whole boiler, and to lift the safety-valve momentarily right off its seat.* The weakest parts of a locomotive are the two sides where the barrel joins the outside fire-box. Many boilers, especially those with a high wagon-top, have flat spaces at this point, which it is impossible to stay properly. It is at this point, too, that the expansion and contraction of the tubes and the outside shell exert their greatest strains, and it will therefore be found, generally, that the seams at this point begin to leak before any others, and for these reasons it is believed that all the seams which join the outside shell of the fire-box to the barrel should be double-riveted.

The practice of ascribing steam-boiler explosions to obscure causes has been productive of much mischief, as it engenders a carelessness on the part of those having charge of them, who have been led to believe that no amount of care will avail against the mysterious agents at work within the boiler. Explosions are also, in the absence of other convenient reasons, very generally attributed to shortness of water. This is often nothing more than a convenient method of shifting the responsibility from the builder or owner of the locomotive to the engineer or fireman, who, if not killed by the explosion, in many cases might almost as well be, so far as his ability to defend himself is concerned.†

QUESTION 865. *What should a locomotive engineer and fireman do to avoid and prevent explosions?*

Answer. 1. The height of the water in the boiler should always be maintained so as to cover the heating surfaces. 2. The boiler should be kept as clean—that is, as free from scale, mud, and other impurities, as possible. 3. It should never be subjected to strains from sudden heating

* Wilson on Boiler Construction.

† Ibid.

or cooling. 4. The steam-gauge and safety-valves should be examined and tested frequently, to be sure they are in order; and, 5, they should examine every part of the boiler which is accessible, but especially the stay-bolts, to see that there is no fracture of any part or any injurious corrosion or other dangerous defect.

QUESTION 866. *If from any defect of the safety-valve or other cause the steam should rise beyond the limit of pressure that should be carried, what should an engineer do?*

Answer. He should open the furnace-door and heater-cocks, and let the steam blow into the tank, start the injector, and if the case is critical blow the whistle, which will allow some of the steam to escape.

QUESTION 867. *What should be done in case of the bursting or collapse of a tube?*

Answer. As soon as possible after it occurs, the engineer must stop the train and reduce the steam pressure. The water escaping from the flue will usually quench the fire. When the steam pressure is reduced the engineer should close, first, the end of the flue in the fire-box, and then that in the smoke-box, by driving in *iron plugs*, which are usually provided for the purpose. These plugs are attached to the end of a bar, with which they are inserted into the tubes. If the escape of water and steam from the tube is so great as to make it difficult to see the end of the tube, the steam may sometimes be drawn up the chimney by starting the blower. If, however, the escape is so great as to make it impossible to insert the plug, then the steam pressure must be reduced by running with both pumps on, or by starting the injector; or it may be necessary to smother or draw the fire and cool off the engine. When a flue collapses, the front end of which is behind the steam or petticoat pipes, it is usually necessary to cool off the engine before a plug can be inserted, especially if any considerable amount of water and steam escape from it. While driving in the plug, the engineer and fireman should always keep themselves in such positions that the plug cannot hit them in case it is blown out by the steam. If the engine is not supplied with iron flue-plugs, a wooden plug can be cut of the proper size and driven in. This can be attached to the bar referred to and inserted; but if no such bar is carried with the engine, the wooden plug can be made on the end of a long pole and then cut nearly off. It is then inserted into the flue and driven in and broken off. It will be found that such plugs will burn off even with the end of the flue, but will not burn entirely out.

QUESTION 868. *What should be done in case a bolt, stud, rivet,* *or cock blows out of the boiler and thus allows the steam or hot water to escape?*

Answer. If the opening is accessible, cut a plug on the end of a long pole and drive it into the hole in the same way as described above. This will avoid the necessity of cooling off the engine; but in some cases it will be found that a plug cannot be inserted or driven in without drawing the fire and cooling off the boiler.

QUESTION 869. *In case it is found necessary to draw the fire and cool off the boiler, and if so much water has escaped as to uncover the crown-plate, what must be done?*

Answer. If the leak has been stopped or the fault remedied, one of the safety-valves should be taken off and water poured into the boiler with pails or buckets through the opening left by the removal of the safety-valve until the crown-sheet is covered. The fire may then be kindled again and the engine complete its journey. When bituminous coal is used for fuel, the necessity for drawing the fire in case of accident may often be avoided by completely covering or "banking" the fire with fine coal which has been wet, and closing the dampers and opening the furnace door. In this way the fire may be smothered and the boiler cooled without putting the fire out, so that after the defect is remedied it will not be necessary to rekindle it.

QUESTION 870. *What must be done in the case of the failure of one or both the injectors, feed-pumps, or check-valves?*

Answer. If one of the injectors or pumps fails the other one may be used, but the defect or obstruction to the first should be remedied as soon as possible, because the second may also fail. A description of the most common defects of injectors will be found in answer to Questions 811, 812 and 813.

QUESTION 871. *In case a pump fails, how should it be examined in order to discover the defect?*

Answer. It should first be seen whether there is plenty of water in the tank, and whether the strainer is obstructed or not. The working of a pump is usually indicated by the stream which escapes from the pet-cock. If, when this is opened, steam and water escape, it is an indication that the check-valve is not working properly. If it is not working well hot water will escape if the pet-cock is opened when the engine is standing still, but the pump may still feed the boiler if the upper or pressure-valve works properly. When the check-valve does not work as it should, it is also indicated by the heating of the feed-pipe, owing to the escape of hot water from the boiler through the check-valve when the pet-cock is opened. If, when the plunger is drawn out of the pump, air is sucked in through the open pet-cock, then the upper or pressure-valve of the pump does not work, but the working of the pump may still be secured by the working of the check-valve; but if the pump, air-chamber, and feed-pipe then get filled with air, the plunger may compress this air at each stroke, and as it can then follow the plunger during its outward stroke, the latter will not suck water, but will simply compress the air during the inward stroke, which will then expand during the outward stroke. This will be indicated by the escape of air from the pet-cock when the plunger is moving inward, and the suction of air when the plunger is moving outward. This can be known by holding the hand in front of the pet-cock. Usually, however, the air is mixed with water, so that the stream which escapes from the pet-cock is broken or irregular. If air escapes from the pet-cock during the inward stroke of the plunger, but none is sucked in during the outward stroke, it shows that there is a leak somewhere in the pump or pipes, and that it is pumping air instead of water. The leak may be in the stuffing-box of the plunger, the joints of the pump or pipes, in the hose or their connections with the supply-pipe or tender. If neither air nor water escapes from the pet-cock during the inward stroke of the pump-plunger, or if the stream of water at that time is weak, then it indicates that the suction or lower valve of the pump is not working properly. The same thing will occur if the pipe, pump, or tender-valve is obstructed. If there is a cock, as there always should be, just above the suction-valve, it will aid very much in discovering the fault when the pump will not work. If, when this cock is opened, cold water escapes from it, the fault is in the suction-valve; if hot water, then it is the pressure and check-valves which are leaky, obstructed, or broken, and consequently the hot water from the boiler leaks back into the pump. In the absence of such a cock, the fault can often be discovered by feeling the pump barrel with the hand. If the pump cannot be made to work, and the fault is found to be in the lower valve, it must be taken out and examined; or if the fault is in the pipes, it can usually be easily remedied. If the pipes are burst with only a small fracture, it can usually be repaired temporarily by covering the aperature with canvas or india rubber and wrapping twine around it tightly. The upper valve of a pump must, however, never be taken down without first being sure that the check-valve is tight, because if it is not, the person will be likely to be scalded in taking the pump apart.

Only after all the appliances for feeding the boiler have failed and the water is so low as to be in danger of exposing the crown-sheet, should the fire be drawn or banked, and the engineer should then at once give the proper signals for warning and the protection of his train, and if he is unable to repair the pumps or injector, he must send for aid to the nearest accessible point.

Directions for taking care of pumps in cold weather have already been given in the answers to Question 292.

QUESTION 872. *What are the principal causes of broken cylinders and cylinder-heads?*

Answer. Such accidents are usually caused by collisions, water in the cylinders, broken cross-heads, piston-rods, main connecting-rods, crank-pins, or pistons.

QUESTION 873. *What is often the origin of such accidents?*

Answer. They are often due to neglect in opening the cylinder-cocks, taking up lost motion in boxes, keys, or bolts. Lost motion of the brass bearings of the main connecting-rod, or a loose key in the piston-rod, or loose bolt in the follower-plate cause an undue strain on the connected parts which eventually results in a breakage. The same thing occurs when such parts as the piston-rods, guides, or pump-plungers are out of line.

QUESTION 874. *What should be done in case of the breaking or bursting of a cylinder or cylinder-head?*

Answer. If the guides, cross-head, main connecting-rod and crank-pin are uninjured they need not be removed, but the piston-rod may be disconnected from the cross-head, and the piston should be taken out of the cylinder. If any of the above parts are injured so that they will not work, then the main connecting-rod must be taken down on that side of the engine. In doing this care should be taken to put back, in their proper places, all liners—if there are any—in the straps. This will save some trouble in replacing the rods. The piston should then be moved to the front or back end of the cylinder and wooden blocks be placed between the guides so as to fill up the space between the cross-head and the end of the guide-bars, and thus prevent the cross-head and piston from moving. If a single guide is used, blocks can be put above and below the cross-head, and bolted or tied with rope in their places. It is usually best to block the piston at the extreme back end of the cylinder, because in that position, if it should get loose and be driven to the front end, less damage would be done than would follow if the piston was at the front end and was driven backward so as to injure the back-head.

guides, etc. On some engines, such as moguls and consolidations, the piston must be placed in the front end of the cylinder when the cross-head is blocked, because the crank-pin of the front driving-wheel may not clear the cross-head if the latter is at the back end of the guides. When the cross-head is blocked the valve stem should be disconnected from the rocker, and the valve moved to the middle of the valve face, so as to cover up both steam-ports and prevent steam from entering the cylinders and moving the piston. It can be known whether the valve is in the middle of the valve face by admitting a little steam to the steam-chest and opening the cylinder-cocks. If it is not in the middle of the face so as to cover both ports, steam will escape at the end of the cylinder whose port is uncovered. When the valve is in the middle of the face no steam —excepting that due to the leakage of the valve—will escape at either end. It must then be fastened in that position by screwing up *one* of the bolts of the stuffing-box of the valve stem, so as to make the gland bind against the valve stem. When metallic packing is used the valve stem must be wedged or tied in its place.

If both front cylinder-heads are broken and the working parts of the engine are uninjured the steam-chest cover should be taken off, and the front steam-ports filled with wood. The engine can then be run with a light train, by admitting steam into the front ends only of the cylinders.

If one or both of the cylinders are disabled the train should be run cautiously to the next station. If the engine is not able to haul the train, then it should be uncoupled and run to the first telegraph station or other point where the aid of a helping engine can be obtained or telegraphed for. In the mean while, the train must be protected by the proper signals. Should the engine continue its journey, it must be started, if it should happen to be standing at the dead-point, by *pushing* or by means of *crow-bars*. In so doing, however, the bars should not be put between the spokes of the wheels, as they may easily be caught in the wheels when the engine starts, and in this way the spokes be broken or the persons using the crow-bars be badly hurt. If it is necessary to disconnect the engine, in freezing weather, then all pipes, pumps, and injectors liable to freeze must be drained. If there are no cocks or plugs for this purpose, then the connections should be slacked up so as to allow the water to run out, and when it is possible to do so blow steam through the pipes to clear them of water.

QUESTION 875. *In case an engine must be towed, what must always be done?*

Answer. The main rods and the valve stems must always be disconnected, for the reason that it is impossible, or very difficult to keep the pistons and valves properly lubricated without steam on the engine, and, therefore, if they were in motion when the engine was running without steam, they are liable to cut the cylinder and valve-seats. If there is danger of the water in the boiler and in the tank freezing, they should both be emptied.

QUESTION 876. *What must be done in case a steam-chest or steam-pipe is broken?*

Answer. The main rod and valve-stem on that side must be disconnected, as already explained. If a steam-chest is broken a block of wood should be bolted over the mouth of the steam passage, so as to prevent the escape of the steam from the steam-pipe on that side. It will sometimes require considerable ingenuity to devise means of fastening such a block or blocks of wood so as to cover the mouth of the steam passage. As cylinders are now usually made, the blocks can be fastened by cutting them to the proper form and size, and then placing a thick block on top, and bolting the steam-chest cover down on top of it. If the cover is broken, a part of it may be used or a piece of plank with a few holes bored into it, or fish-plates may be employed instead. In some cases a piece of board can be bolted over the end of the steam-pipe. When the latter is broken, it should be taken down and a piece of board or plank bolted over the opening of the T-pipe to which the steam-pipe was attached. Usually it is difficult to take down a steam-pipe in the smoke-box, for the reason that the bolts and nuts are rusted fast and cannot be unscrewed.

QUESTION 877. *What must be done if a piston, cross-head, connecting-rod, or crank-pin is broken or bent?*

Answer. If the piston, cross-head, or main connecting-rod, or main crank-pin is broken, the same course must be pursued as when a cylinder is broken. If a coupling-rod or a crank-pin of a trailing-wheel of an engine with four coupled wheels is broken, then it is necessary to take down both the coupling-rods but not to disconnect the main connecting-rods or their attachments, unless they are injured. On engines with six or eight wheels coupled, if any excepting the main crank-pins are broken, then the only coupling-rods which must be taken down are those connected to the pair of wheels on which the crank-pin is broken.

QUESTION 878. *If one of the coupling-rods connected to a pair of wheels on one side is taken down, why must the one on the other side be taken down also?*

Answer. Because if only one rod is used on a pair of wheels there is then nothing to help the cranks of those wheels past the dead-points, so that in starting, or if they are moving slowly when they reach these points, they are quite as likely to revolve in one direction as the other. If they happen to turn in the reverse direction to that in which the wheels to which they are coupled are moving, then the crank-pins of one or the other pair of wheels are very liable to be broken or bent.

QUESTION 879. *What must be done if a driving-wheel or tire breaks?*

Answer. If a tire on a main driving-wheel or the wheel itself breaks, the broken wheel or tire should be held up clear of the rails by putting a wooden block under the driving-box. If the crank-pin, connecting-rods, etc., have not been injured it is not essential to take the coupling-rods down. If, however, it is necessary to disconnect the main rods on both sides, then, of course, all the coupling-rods must be taken down. If both of the main driving-wheels have been disabled, then both of them must be blocked up. It is possible but not probable, that both tires and even part of both wheels might be broken, leaving the crank-pins and connecting-rods intact. In that event by blocking up the boxes it would not be essential to disconnect any of the rods. Usually, however, when both of the main driving-wheels are broken both sides must be disconnected and the engine be towed in.

If a trailing or leading driving-wheel or tire is broken the wheel should be blocked up and the coupling-rods connected to the pair of disabled wheels must be taken down. When both trailing wheels or axles are broken the engine can sometimes be run to a side track by supporting part of the back end of the engine on the tender. This can be done sometimes by chains and pieces of rails or timber, attached either to the engine or tender frame. An ordinary American engine can then be run on three driving-wheels, but it must be run with the utmost caution. If the engine has more than four driving-wheels there is usually less difficulty in running it, if one of the main wheels is injured, than if there are only four.

QUESTION 880. *What should be done in case the flange of a tire or wheel is broken?*

Answer. All that can be done is to run very cautiously and slowly, especially over frogs and switches.

QUESTION 881. *What should be done in case a driving-axle breaks?*

Answer. If a main driving-axle breaks outside of one of the boxes, the wheel next to the break should be removed, the box blocked up, and the engine be disconnected on that side and all the coupling-rods on the other side be taken down. The engine can then be run without the train to the nearest telegraph station. If the main axle is broken between the boxes, all that can be done is to disconnect both sides, block up the wheels of the broken axle, and send for assistance.

If a leading or trailing axle breaks the coupling-rods connected thereto must be taken down. If the break is outside the boxes, the loose wheel must be removed, and its box blocked up. If the break is between the boxes, both wheels must be blocked up and the engine run without the train, as described for broken wheels or tires.

It is almost impossible to give directions which will be applicable to all the accidents of this kind that may occur to different kinds of engines. In such cases, if assistance or a telegraph office is near where the accident occurs, it is usually best to send for help at once, rather than take the risks which attend the attempt to run an engine so seriously injured.

QUESTION 882. *What must be done if an engine truck-wheel or axle breaks?*

Answer. It is usually best to chain up the end of the truck-frame over the broken axle or wheel to the engine-frame and place a cross-tie across the other end of the truck-frame, between it and the engine-frame, so that the weight of the engine may rest on the cross-tie. If a part of the flange or a piece of the wheel is broken out, the wheels should be turned around so that the unbroken part will rest on the rail, and they should then be chained or otherwise fastened so that they cannot revolve, and thus be made to slide on the rails and carry the weight of the engine in that way. The same plan is employed if a tender wheel breaks, but one end of a tender-truck frame must be chained up. It is usually necessary to place a cross-tie across the top of the tender, and fasten the chains to it.

QUESTION 883. *What must be done in case a driving-spring, spring-hanger or equalizing-lever breaks?*

Answer. As the breaking of a spring or spring-hanger may cause a more serious accident, the engine and train should be stopped as soon as possible after it occurs. If the hanger is broken and there is a duplicate on hand, it should be substituted in place of the broken one. If there is no duplicate, then the spring should be taken down, and a wooden block be placed between the top of the driving-box and the frame, to support the weight which before rested on the spring. In order to insert this block, if it is a front spring which is broken, it is usually best to raise the engine with jack-screws, or run the back wheels on inclined blocks of wood placed under each of the back wheels. This raises the weight off from the front wheels, and the block can then be inserted between the box and frame. If it is one of the springs over the back wheels which is broken, the front wheels should be run on the wooden wedges. Such wedges can soon be cut out of a cross-tie with an axe, or by sawing a square stick of wood diagonally it will make two such wedges. The end of the equalizing-lever next to the broken spring must be supported by inserting a piece of wood under it. This will usually be held securely by the weight which is suspended from the opposite end, bearing the blocked end down on the block.

In case a hanger breaks a chain may be used as a temporary substitute.

QUESTION 884. *What should be done if an engine-truck or tender-spring breaks?*

Answer. Very much the same course must be pursued that is employed when a driving-spring breaks, excepting that usually the weight can be lifted off from a truck-box easier by placing a jack under the end of the truck-frame than by the method described. Usually, too, each of the truck-springs supports the weight on two of the wheels, so that the two boxes must be blocked up.

QUESTION 885. *If a truck wheel or axle breaks or an axle is bent, what should be done?*

Answer. If a back wheel of a truck is broken, it can be chained up, clear of the track, to a cross-tie on top of the engine-frame or on top of the tank, or it can be fastened so that it cannot revolve and be allowed to slide on the rails. If a front wheel or axle of a four-wheeled truck is broken or bent, the engine may be jacked up and the truck turned around so as to bring the sound pair in front.

QUESTION 886. *What must be done in case the engine-frame is broken?*

Answer. Usually very little need be done excepting to exercise more than usual caution in running, and to reduce the speed. Of course the breakage of a frame may disable the engine, but ordinarily in such accidents that is not the case.

QUESTION 887. *How can it be known if an eccentric has slipped on the axle?*

Answer. It is indicated at once by the irregular sound of the exhaust, or, as locomotive runners say, the engine will be "*lame*."

QUESTION 888. *When it is known that an eccentric has slipped, how can it be learned which is the one that is misplaced?*

Answer. This can usually be learned by examining the marks which should always be made on the eccentrics and on the axles. If no such marks have been made by the builder of the engine, the engineer himself should make them, after the valves have been set correctly. The effect upon the valve when an eccentric slips is either to increase or diminish the lead. Therefore, by running the engine slowly with the link first in full forward and then in full back gear, and observing whether steam is admitted at each end of the cylinder just before the crank reaches the dead points, it can be known which eccentric has moved. If it has slipped in one direction the lead will be increased and steam will be admitted to the cylinder some time before the piston reaches the end of the stroke. If it has moved the opposite way, the lead will be diminished and steam will not be admitted until after the piston has reached the end of its stroke. The admission of steam will be indicated by its escape from the cylinder-cocks.

QUESTION 889. *If by any means the valve-stem or either of the eccentric-rods should be lengthened or shortened, how can it be known?*

Answer. The crank on one side should be placed at one of the dead-points and the cylinder-cocks opened; then admit a little steam to the cylinder, by opening the throttle-valve slightly, and throw the reverse lever from full gear forward to full gear backward, and observe whether steam escapes all the time from the end of the cylinder at which the piston stands. Then repeat the operation with the crank at the other dead-point. If either of the eccentric-rods or the valve-stem have been lengthened or shortened, it will cause the valve to cover the steam-port either at the front or back end of the cylinder, so that no steam will escape from the cock at that end. If the length of one of the eccentric-rods has been changed, then when the altered rod is in gear the valve will have too little or no lead at one end of the cylinder and too much at the other. If, therefore, this occurs when the forward rod is in gear and *not* in back gear, it indicates that the length of the forward rod has been altered. If the reverse occurs it shows that it is the back-motion rod whose length has been changed. It must be observed that if the length of an eccentric-rod is altered the lead will be changed only at that part of the link which is operated by the altered rod. That is, if the forward eccentric-rod is too long or too short, the lead at the front and back ends of the cylinder in forward gear only will be affected. If the back eccentric-rod is changed the valve will be affected only in back gear. If, however, the length of the valve-stem is changed, the lead will be changed in both forward and back gear. The valves on each side of the engine can, of course, be tested in the same way.

QUESTION 890. *When it is discovered which eccentric has slipped, how should it be reset?*

Answer. If it has been marked, it is simply turned back so that the marks correspond with each other again. This is done by first loosening the set-screws, and, after the eccentric is turned to the proper place, tightening them up again. When an eccentric slips it is often caused by the cutting of the eccentric-straps, valve or other part of the valve-gear, so that these should always be examined to see whether they are properly oiled. If the eccentrics have not been marked, the valve may be set by placing the crank at the forward dead-point, and the reverse lever in the front notch of the sector and the full part of the forward-motion eccentric *above* the axle. Then admit a little steam into the steam-chest, open the cylinder-cocks, and move the forward-motion eccentric slowly forward until steam escapes from the front cylinder-cock, which will show that the steam-port is opened and the valve has some lead. To set the backward-motion eccentric the crank is placed in the same position, but the reverse lever is thrown into the back notch and the full part of the eccentric is placed *below* the axle. Then move this eccentric forward until steam escapes from the *front* cylinder-cock as before. In order to verify the position of the eccentrics the crank may be placed at the back dead-point and the reverse lever moved backward and forward, at the same time observing whether steam escapes from the back cylinder-cock when the link is in both back and forward gear.

QUESTION 891. *What should be done in case an eccentric-strap or rod, or rocker arm, rocker shaft, or the valve-stem breaks?*

Answer. If an eccentric-strap or rod breaks, the broken rod and strap should be taken down, and the valve-stem disconnected from the rocker and the valve fastened in the middle position of the valve-face, and the engine should be disconnected on one side and be run with one cylinder only. The same course must usually be pursued if a rocker breaks. If the valve-stem breaks, it is not necessary to disconnect the link and eccentric-rods, but simply to fasten the valve in the centre of the valve face.

QUESTION 892. *If a link-hanger or saddle, or a lifting-arm should break, what should be done?*

Answer. The valve-gear may be used on that side of the engine by putting a wooden block in the link slot above the link block, so as to support the link near the position at which it works the valve full stroke forward. Of course the engine can then be run in only one direction, and should therefore be run with the utmost caution. If, however, it should be necessary to back the train on a side track, it can be done by taking out the wooden block and substituting a longer one, so that the link will be supported in a position near that at which it works the valve full stroke backward. These blocks must be fastened in some way, either with rope or twine, so that they will be held in their position when the engine is at work.

QUESTION 893. *If the lifting-shaft itself or its vertical arm, the reverse lever or rod, should break, what can be done?*

Answer. If it is impossible to devise any temporary substitute or method of mending them, but both links can be blocked up as described above. The engineer should determine as near as he can the point of cut-off at which the engine must work to reach its destination. For forward motion long pieces of wood would be placed below the link-block and short ones above. To back the engine these pieces must be reversed. The same plan can be used if one or both of the lifting shaft-arms, the reversing-rod, the link-hanger, or the hanger-pin breaks.

QUESTION 894. *If a valve, valve-yoke, or valve-stem is broken inside of the steam-chest how can it be known and located?*

Answer. It will make itself known by the irregular exhaust of the steam. To ascertain on which side the defect is, one of the crank-pins should be placed at a dead-point, and the throttle-valve and cylinder-cocks opened. Then move the reverse-lever from full stroke forward to full stroke back. In doing this, if the valve gear is in good condition, the valve will have good lead alternately at the front and the back end, and steam will escape from the front and back cylinder-cocks as the reverse-lever is moved. If the valve-stem or yoke is broken the valve will not be moved as it should be by the reverse-lever, and if the valve is broken, probably it will be indicated by the irregular or constant escape of steam. By trying both sides of the engine the defect can thus be located.

QUESTION 895. *If the valve, valve-stem, or yoke is broken, what must be done?*

Answer. If the valve-stem is broken outside of the steam-chest the valve must be moved to cover both ports and then fastened in that position and the engine disconnected on that side, as already described. If the break is inside, the steam-chest cover must be taken off and the valve secured, with blocking or otherwise, so as to cover the ports, and the opening for the valve-stem must be closed with a wooden plug inserted from the inside of the chest, so that the steam pressure will not blow it out.

If the valve is broken a wooden board, 1 inch thick should be placed over the valve-face and blocks placed on top of it, so that when the steam-chest cover is screwed down it will hold the board on to the valve-face.

QUESTION 896. *If the valve-face is broken, what should be done?*

Answer. If the metal of the face is broken, so that the front port cannot be closed, then the piston should be fastened at the back end of the cylinder and the valve should be secured, so as to cover the exhaust and the back steam-ports, that side of the engine being disconnected. If the back steam-port is the one injured, then the piston and valve should be placed in the reverse position. If either of the bridges between the ports are broken, then the valve should cover all of them.

QUESTION 897. *In case the throttle-valve should fail, what should be done?*

Answer. If such an accident occurs, especially if it happens about a station, it is attended with great danger. If it is found that steam cannot be shut off from the cylinders with the throttle-valve, all the brakes should be applied and the reversing lever should be placed in the middle of the sector. If this does not prevent the engine from moving, the reversing lever should be alternately thrown into forward and then into back gear, and at the same time every aperture, such as the safety-valve and heater-cocks, should be opened, and every means be taken to cool the boiler as quickly as possible. The fireman should open the furnace door, close the ash-pan dampers, and start the blower so as to draw a strong current of cold air into the furnace and through the tubes. At the same time the injector should be started and the fire drawn as quickly as possible. After the boiler is cooled, the cover of the steam-dome may be removed and the valve examined if the defect cannot be discovered in any other way. Of course if the accident occurs on the open road, the train must be at once protected by sending out signals in each direction.

QUESTION 898. *What must be done in case a coupling breaks?*

Answer. When a coupling between the cars or tender breaks, if the front end of the train is immediately stopped, there will be danger that the back end of it, which is broken loose, will run into the front end, and thus do great damage. As it always occurs, when a coupling of a passenger train breaks, that the signal bell in the cab is rung, the first impulse of the runner under such circumstances is to stop the engine. He should, however, be careful not to do so if on shutting off steam he finds that the train has broken in two, but should at once open the throttle in order to get the front end of the train out of the way of the rear end. The case with which the speed of a train is arrested with continuous brakes may increase the danger of accident from this cause. Usually an engineer learns by the sudden start of the engine that the train has separated, and when that occurs he should never apply the brakes.

QUESTION 899. *If from any cause the supply of water in the tender becomes exhausted, what must be done?*

Answer. It is best, if it can be done without risk of injury to the engine, to run the train on a side track and then draw the fire. If no water can be obtained near enough to supply the tender with buckets, help must be sent for; but if there is a well, stream, or pond of water near, the tender can be partly filled by carrying water.

QUESTION 900. *In case an engine becomes blockaded in a snow-storm with plenty of fuel, but runs out of water, what can be done?*

Answer. Snow should be shoveled into the tender and steam admitted through the heater cocks so as to melt the snow.

QUESTION 901. *If a locomotive without an injector should be obstructed in a snow-storm or in any other way so that it could not move, and therefore could not work the pumps, what should be done in case the water in the boiler should get low?*

Answer. The weight of the engine should be lifted off from the main driving-wheels and the coupling-rods disconnected from the main crank-pin, so that the main wheels can turn without moving the engine. These can then be run and the pumps thus be worked. The weight can usually be most conveniently taken off from the main wheels by running the trailing wheels on wooden blocks, and thus raising up the back end of the engine.

QUESTION 902. *If it is impossible, in a snow-storm or in very cold weather, to keep steam in the boiler without danger, what should be done?*

Answer. Draw the fire, blow all the water out of the boiler, empty the tanks, disconnect the hose, and slacken up the joints in the pumps and injector so that all the water in them can escape, and thus prevent them from freezing up.

CHAPTER XXXVII.

ACCIDENTS AND INJURIES TO PERSONS.

QUESTION 903. *In case an accident occurs and one or more persons are seriously injured, what can be done by those present?*

Answer. In such cases it very often happens that with knowledge, and sufficient coolness to apply that knowledge, one or more non-medical persons who are present when an accident occurs can do as much or more toward saving life and allaying pain *before* a doctor comes than he can *afterward.* The following cases cited by Dr. Howe in his book on "Emergencies, and How to Treat Them," will illustrate this:

"*Case* 1.—A machinist was admitted to a New York hospital suffering from wounds of the wrist and palm of the hand. On arriving at the hospital the entire clothing on one side of his body was saturated with blood, from the loss of which he was partly insensible. On making an examination, it was found by the surgeon that a folded handkerchief was bandaged over the centre of the wrist, and that the wound in the palm of the hand was untouched. The pad was placed on the wrist, as if the greatest care had been exercised to avoid pressing on either of the two arteries. The bleeding in this case could easily have been controlled if the bandage and pad had been properly applied. The patient, however, developed erysipelas, and not having sufficient vitality to carry him through, died the fifth day."

"*Case* 2.—A laborer fell from the front platform of a car at Harlem and had his right foot crushed by one of the wheels. An ordinary bandage was placed on the limb, without any compress over the vessels. In bringing the man to the hospital, the rough jolting of the carriage set the wound bleeding, and by the time he reached his destination he was apparently lifeless. The vessels were tied and stimulants administered, but he never rallied. Death occurred six hours after his admission. His injuries, independent of the bleeding, might indeed have terminated his life; still the chances would have been in his favor if a compress had been applied to the limb to prevent bleeding. The fact that such a thing was not done shows either culpable negligence or deplorable ignorance."

Many similar cases constantly occur where a little intelligent, timely action of those present would save the life of an injured person who, without such help, must die before professional surgical aid can be obtained.

QUESTION 904. *When it is found that one or more persons are seriously injured, what is the first thing to be done?*

Answer. The first thing to do is to extricate the person or persons from the danger, and at the same time send a messenger for a doctor. If it is doubtful if one can be obtained by sending in one direction, send two or more messengers in different directions.

QUESTION 905. *To what kind of injuries are locomotive runners and other persons employed or travelling on railroads exposed?*

Answer. They are liable to be bruised or crushed in case of collision or running off the track, or of injury from falling off the train, or of being run over by a moving train. Brakemen and others whose duty it is to couple cars are liable to have their hands, arms, or bodies crushed between the cars, and locomotive engineers are sometimes burned or scalded if an accident happens to their engines. Train-men are also frequently exposed to very great cold in winter and heat in summer, and are thus liable to be frost-bitten or sun-struck. Passengers are seldom injured excepting through their own carelessness, unless in cases of collision or running off the track and the destruction of the cars. Strangers and railroad employees are frequently run over by trains while walking or being on railroad tracks. It is estimated that from five to six thousand people are killed and wounded every year from "being on" railroad tracks. Frequent accidents occur to deaf people in this way, and it is not very unusual to hear of train-men who sit on the main track at night while their trains are waiting on the side-track for another train to pass, go to sleep while in that position, and then are run over by the passing train.

QUESTION 906. *How can accidents from being on the track be avoided?*

Answer. The obvious way is to stay off of railroad tracks, unless called there by duty, then to stay there as short a time as possible, and while there exercise the utmost vigilance to keep out of the way of moving engines and cars. It should be remembered that there is comparatively little danger to persons on engines or cars, but A RAILROAD TRACK IS ALMOST AS DANGEROUS AS A BATTLEFIELD TO THOSE ON FOOT OR WHO ARE TRAVELLING IN WAGONS OR CARRIAGES. It should be a universal rule with every person, whether a railroad employee or not, ALWAYS

TO COME TO A FULL STOP BEFORE CROSSING OR GOING ON A RAILROAD TRACK. It will be repeated here that if this rule was universally adopted many lives would be saved and much suffering avoided.

QUESTION 907. *When persons are crushed or dangerously wounded, what are the chief immediate sources of danger and death when their wounds are not necessarily fatal?*

Answer. First, excessive bleeding in case an artery is ruptured; second, the shock to the whole system, from which the sufferer may not have the strength to recover.

QUESTION 908. *When does bleeding from a wound become dangerous?*

Answer. Profuse bleeding is always dangerous, but it should be remembered that bleeding occurs from two sources; first, from the arteries, which are the vessels which convey the blood *from* the heart, and second, from the veins, through which the blood flows back to the heart. The first is called *arterial* bleeding and the second *venous* bleeding. Now it must be remembered that the heart is the great force-pump of the body, and that it supplies all parts of the body with blood, somewhat as the feed-pump of a locomotive supplies the boiler with water. The arteries referred to fulfil the same purpose that the feed-pipe does to a locomotive pump—they convey the fluid from the pump to the place where it is needed. Now the blood is forced into these arteries with a certain amount of pressure, so that if any of them are cut or injured the blood will flow out in a jet or spurt just as the water will escape from a feed-pipe if that is ruptured. The blood which flows through the veins back to the heart may, on the other hand, be compared to the water in the supply-pipes of a locomotive pump—that is, there is very little pressure on it, and therefore if they are injured the flow of blood from them is less rapid than from the arteries. It will therefore be seen that arterial bleeding is much more dangerous, because the blood flows from them under a pressure.

QUESTION 909. *How can arterial bleeding be distinguished from venous bleeding?*

Answer. The blood is of a bright scarlet color, and is forced out in successive jets; each jet corresponds with the movements of the heart. This characteristic spurting is caused by the intermittent force-pump action of the heart, driving out the blood. Venous bleeding is distinguished from arterial by the dark blue or purple color of the blood when flowing from the wound. It never flows in repeated jets, but oozes slowly from the wounded surfaces. Venous blood is travelling toward the heart, and there is consequently little force behind to cause a more rapid flow. This form of bleeding is comparatively harmless, unless occurring from very large veins.*

QUESTION 910. *How can the bleeding be stopped in case an artery is but or ruptured?*

Answer. The most efficient and available method is the application of PRESSURE on the artery BETWEEN THE WOUND AND THE HEART. Under ordinary circumstances this can be most effectually done by simply passing a handkerchief around the limb above the wound, or between it and the heart; the ends of the handkerchief are then tied together. A pad is then made, either of cloth rolled up, cotton waste, a piece of wood, or a round stone about the size of a horse-chestnut well wrapped, or any substance from which a firm pad can be quickly made, which is placed over the artery. The handkerchief, folded in the form of a bandage, is placed over the pad and passed around the limb and tied on the opposite side to the pad, and then a rounded stick about six inches long and three-fourths of an inch in thickness is passed under the knot, so that the handkerchief may be twisted sufficiently tight to stop the bleeding by pressing the pad upon the artery; the twisting of the stick and the pressure upon the artery should only be sufficient to stop the bleeding from the artery; too much pressure or twisting would be painful, and might produce other serious consequences. While the bandage is being prepared, some one should compress the artery with his fingers or thumb so as to prevent as much loss of blood as possible.

QUESTION 911. *What is the position of the arteries in the body and how can their location be known?*

Answer. The position of the principal arteries is shown in fig. 488. They proceed from the heart, *h*, with branches, *a a* and *b b*, which extend along each limb. These branches subdivide again below the knees and elbows, and again in the hands and feet. The position of the arteries can be felt by their pulsation at almost any part of them, but at some places they are covered so thickly by the muscles, that it is more difficult to feel their throb than it is where they are near the surface. At *a* and *a* they are near the surface of the body, and also at the thighs at *b b*, and again at *c c*, immediataly back of the knees, and in the wrists at *d d*. At these places the pulsations of the blood can be distinctly felt.

QUESTION 912. *In case of a wound and rupture of the arteries in the arm, what should be done?*

* "Emergencies and How to Treat Them," by Joseph W. Howe, M. D.

Answer. The artery should be firmly compressed at *a* with the thumb until a bandage and pad can be prepared. The pad should then be applied over the artery and compressed as explained in answer to Question 910. The bleeding can also be stopped by placing a round piece of wood or other form of pad between the arm at *a* and the body and then tying

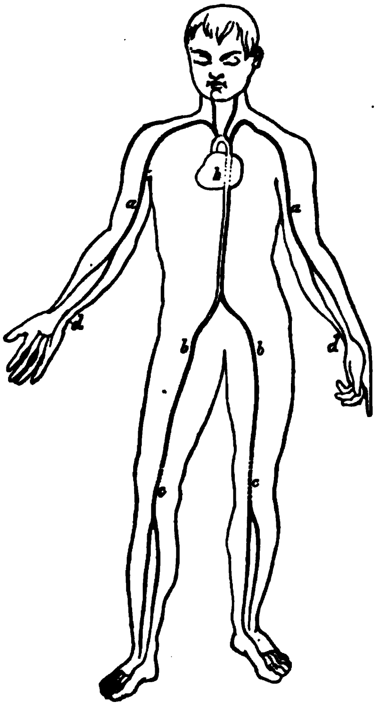


Fig. 488. Figure Showing Position of Arteries.

the arm tightly against the body, so that the pad will be pressed against the arm.

QUESTION 913. *In case of rupture to an artery below the knee, where should the pressure be applied?*

Answer. The artery approaches near the surface at *c c*, immediately back of the knee, where it is represented in dotted lines, in fig. 488. Pressure should therefore be applied at that point first with the thumb until a bandage can be applied. The bleeding can also be stopped by elevating the leg and allowing it to rest on the back of a chair or other similar support. The weight of the leg will then bring sufficient pressure on the artery to stop the bleeding. A towel or other soft material should be placed over the back of the chair, so that the pressure will not be too painful to the sufferer.

QUESTION 914. *If an artery is ruptured in the thigh above the knee, where should the pressure be applied?*

Answer. In the thigh, at *b*, where the beating or pulsations in the artery can be distinctly felt. The reader should familiarize himself with the position of the arteries by feeling their location in his own body. By doing so he may be able to save his own life, the life of a companion or other person in case of accident, whereas without such knowledge the injured person might die.

QUESTION 915. *After the arterial bleeding has been stopped, if blood should continue to ooze out of the wound, what should be done?*

Answer. The wound should be filled with lint or clean cotton waste; and the limb then be bandaged by beginning at its extremity and wrapping the bandage closely and evenly around it, so as to bring, as nearly as possible, an equal pressure on the whole of it. Bandaging the limb in this way up to the point where the pressure is applied to the artery, will prevent swelling, and the veins will be compressed so that the blood will not flow from their torn extremities.

QUESTION 916. *When the bleeding has been stopped, what should be done?*

Answer. The injured person should be laid in as comfortable a place as can be procured for him, and should be given a moderate drink of water. If much exhausted, two or three tablespoonsful of brandy or whiskey, mixed with an equal quantity of water, should be given first, and smaller quantities, *of not* MORE THAN A TABLESPOONFUL at a time, should then be given every half hour. Usually wounded persons are given too much stimulants, so that frequently they are injured more than they are benefited thereby.

After a person has lost much blood, he feels an intolerable thirst, but if too much water is given him, he is apt to become sick and vomit, which weakens him still more. It is therefore best to give him very little water, say a spoonful at a time, after the first drink, or if ice can be obtained, give the sufferer pieces of ice frequently which can be allowed to melt in his mouth.

QUESTION 917. *In case any bones are broken, what should be done?*

Answer. The limb should be supported as comfortably as possible until a doctor's services can be obtained. There is danger with a broken limb that the bones will protrude through the flesh and skin, to avoid which the limb should be placed in a natural position and laid on a pillow, car cushion, or other soft object. This should then be wrapped around the limb and tied in this position, so as to prevent any movement of the broken bones. A temporary splint may be made by tying an umbrella or light strips of wood to the broken limb, or by tying an injured leg to the other which is uninjured.

QUESTION 918. *When a person is insensible, what should be done for him?*

Answer. Lay him down in as comfortable a place as the circumstances will permit, and protect him from cold, rain, or hot sun, as may be needed. A common error is to place injured and insensible persons in an erect position or in a chair. If he is insensible he should *always* be laid down with his head slightly lower than his body. Then water should be dashed two or three times on his face, and warm bricks, stones, or pieces of iron, such as coupling links or pins applied to his feet, and in the arm-pits and between the thighs, being careful that the warm objects applied are not hot enough to burn. Then cover the person with blankets, heavy coats, or anything else which will keep him warm. Wounded persons soon become cold and chilled, the effects of which are very injurious, and therefore especial pains should be taken to keep them warm. In very cold weather there is great danger that injured persons will be frost-bitten, which must be carefully guarded against.

QUESTION 919. *What is meant by "shock" or "collapse"?*

Answer. "Shock" is a condition in which there is more or less diminished energy of the heart and circulation, and is the result of a severe impression made upon the nervous system, produced by either a physical injury or a mental emotion. The majority of cases met with are the result of extensive burns or other grave injuries, particularly those produced by gunshot wounds and railway accidents, which are generally associated with great laceration and crushing of the tissues, and mental excitement. Severe cases of "shock" may be produced by fright alone. "Shock" may be of a very mild character, as the result of a trifling injury or fright, the symptoms being hardly noticeable, of short duration, and demanding no treatment; or, it may assume a form which is rapidly fatal.*

* From a Manual of Instruction in the Principles of "Prompt Aid to the Injured," by Alvah H Doty, M.D., published by D. Appleton & Co., New York.

QUESTION 920. *What are the symptoms of "shock"?*

Answer. In some cases, when the injury is slight, the symptoms may be hardly apparent, or, only a pale face and a weak and rapid pulse, a slight nausea, and a general sense of prostration may be produced. In cases of severe injury, such as might be caused by a serious railroad accident, the person injured is conscious, but dazed and flighty, cannot realize his condition, and apparently only appreciates loud and repeated questions; articulation is difficult although there is no paralysis present. The sensibility to pain may be so blunted that an operation can be performed without the patient knowing it. The extreme pallor and coldness of the skin are startling; the surface of the body is covered with moisture; large beads of sweat cover the forehead; the pulse at the wrist may be lost, or, if perceptible, is weak, rapid, and irregular; the features are shrivelled, particularly about the nose, which appears pinched; the eyes are lustreless, sunken deeply in the sockets, and turned upward, the pupils being generally dilated. There is no other condition which so closely resembles death. The symptoms may continue for a few minutes or a number of hours, and often end in death.

QUESTION 921. *What should be done for a person in the condition described?*

Answer. Those in attendance should at once loosen the clothing, or cut it open rather than have too much delay, and make a rapid examination to ascertain whether severe bleeding exists, or if one or more of the bones in the legs or arms are broken. If there is bleeding it should be stopped as already directed, or if any of the bones are broken a temporary splint should be applied as quickly as possible. The patient should then be carried to the most convenient and sheltered place within reach. While being removed the head should be as low as, or somewhat lower, than the body, or the extremities may be slightly elevated, so as to favor the flow of blood toward the brain. If possible, four persons should assist to carry the patient, one for each extremity and the contiguous portions of the body. His clothing should be removed, and he should be made as comfortable as possible, and, as has been explained, kept warm by proper covering and applying bottles of hot water, warm coupling-pins, links, or other pieces of iron, or bricks, or stones. These should be placed about the arms and legs, inside the thighs, and under the arm-pits and about the body, but not about the head, as this might favor congestion when reaction occurs. If heat cannot be applied as described, the injured person should be rubbed in order to excite circulation. If able to swallow, he should be given about two teaspoonsful of whisky or brandy, with a small amount of hot water, or, still better, hot milk; this may be repeated every ten or fifteen minutes, until four or five doses have been taken, or reaction becomes apparent. When the latter occurs, the stimulant should be diminished or discontinued. When reaction occurs, the color and warmth gradually return to the skin, the eyes are brighter, and the symptoms indicate an approach to the normal condition. Vomiting is regarded as a favorable symptom and generally denotes reaction. This does not always insure safety, and the sufferer should be carefully watched. When reaction has taken place warm beef-tea, broth, or milk should be given in small quantities.*

All assistance and attention should be given to a wounded person with the least noise and excitement, and all crowds and idle spectators should be driven away and every effort made to keep the sufferer comfortable and quiet.

QUESTION 922. *If a person is crushed or severely burned, what should be done?*

Answer. The immediate danger from such injuries arises from the "shock" to the system. It is usually best to bandage the part which is crushed until surgical aid can be obtained, and the sufferer treated as explained in answer to Question 921.

QUESTION 923. *What should be done for a person who has been burned or scalded?*

Answer. The wound should be dusted with bicarbonate of soda (common baking soda, *not washing soda*), wheat flour, starch, chalk, or charcoal, and then dressed with lint or clean cotton waste and loosely bandaged. Vaseline, cosmoline, olive or linseed oil, or molasses, may be employed for dressing burns or scalds. If blisters are produced the clothing should never be forcibly removed from them, but carefully cut off with scissors as close to the burn as possible. The small pieces adhering to the skin may be afterwards washed away with warm water, or softened with oil and detached later. If the blisters are large, they should be pricked at their lowest part and the contents allowed to escape. The oily substances already recommended should then be applied as described.*

If the injury should be severe, a shivering, followed by depression, is very likely to come on. To check this, warmth in the form of hot applications and stimulants should be used, as already explained.

QUESTION 924. *What should be done for a frost-bite?*

* From "Prompt Aid to the Injured," by Alvah H. Doty, M. D.

Answer. Warmth should be applied to the frozen part very gradually by rubbing with snow or pouring cold water on it. The occurrence of stinging pain, with a change in color, is a signal to stop all rubbing or other measure which might excite inflammation. If the frozen part turns black the next day, a poultice should be applied.

If persons exposed to the cold become very much exhausted or sleepy, stimulants should be given, as explained in answer to Question 921, and the body briskly rubbed with the hands and warm flannel or other woolen material.

QUESTION 925. *How should a person be treated who has been sun-struck?*

Answer. Apply cold water or ice to the head, place the sufferer in a cool place, and make him comfortable. After being sun-struck the person should not work for some days or weeks thereafter, until his health and strength are fully recovered.

QUESTION 926. *How should persons who have been under water for a short time, and unconscious when taken out, be treated?*

Answer. Persons who have been under water for four or five minutes or more are not usually restored to life, although numerous cases are recorded where resuscitation was effected after an interval of twenty minutes. If they have been under water but a few moments, the water, mud, and mucus should be removed from the mouth and nose, and the tongue should be pulled forward, and the person should be turned on his side, face downward, to allow the water to escape. He should then again be turned on his back, while the hands of the attendant are placed on the belly and pressure directed upward and inward toward the diaphragm. This movement tends to stimulate respiration, and should be repeated two or three times at intervals of two or three seconds. The mouth in the meantime should be kept open by a cork or piece of wood, or a knot tied in a handkerchief, etc., in order that the passage of air to the lungs should not be interfered with. Tickling the nose with a feather or straw also stimulates breathing. When breathing commences and consciousness returns, the patient should be carefully divested of all wet clothing as soon as possible, be well rubbed, and wrapped in warm covering, and stimulants be given in the manner already described for cases of "shock."

If these simple measures are productive of no good result after a short trial, artificial respiration should be at once resorted to.

Before artificial respiration is begun, the patient should be stripped to the waist, and the clothing around the latter part should be loosened so that the necessary manipulations of the chest may not be interfered with.

The water and mucous having been removed from the mouth and throat as described, the patient is to be placed on his back, with a roll made of a coat or shawl under the shoulders; the tongue should then be drawn forward and retained by a handkerchief, which is placed across the extended organ and carried under the chin, then crossed and tied at the back of the neck. An elastic band or small rubber tube or suspender may be substituted for the same purpose. If no other means can be made available, a hat or scarf-pin may be thrust vertically through the end of the tongue without permanent injury to this organ. The attendant should kneel at the head and grasp the elbows of the patient and draw them upward until the hands are carried above the head, and kept in this position until one, two, three can be slowly counted. This movement elevates the ribs, expands the chest, and creates a vacuum in the lungs into which the air rushes, or, in other words, the movement produces *inspiration*. The elbows are then slowly carried downward, placed by the side, and pressed inward against the chest, thereby diminishing the size of the latter and producing *expiration*. These movements should be repeated about fifteen times during each minute for at least two hours, provided no signs of animation present themselves.

If after using the above method evidence of recovery appears, such as an occasional gasp or muscular movement, the efforts to produce artificial respiration must not be discontinued, but kept up until respiration is fully established. All wet clothing should be removed, the patient rubbed dry, and if possible placed in bed, where warmth and stimulants can be properly administered.*

* From "Prompt Aid to the Injured," by Alvah H. Doty, M. D.

THE END.

PROPERTIES OF SATURATED STEAM.

Total pressure per sq. inch, measured from a vacuum.....	Pressure above the atmosphere	Sensible temperature in Fahrenheit degrees.	Total heat in degrees from zero of Fahrenheit.........	Weight of one cubic foot of Steam........	Relative volume of the steam compared with the water from which it was raised........
Lb.	Lb.	Deg.	Deg.	Lb.	
1	....	102.1	1144.5	.0030	20582
2	....	126.3	1151.7	.0058	10721
3	....	141.6	1156.6	.0085	7322
4	....	153.1	1160.1	.0112	5583
5	....	162.3	1162.9	.0138	4527
6	....	170.2	1165.3	.0163	3813
7	....	176.9	1167.3	.0189	3298
8	...	182.9	1169.2	.0214	2909
9	....	188.3	1170.8	.0239	2604
10	....	193.3	1172.3	.0264	2358
11	....	197.8	1173.7	.0289	2157
12	....	202.0	1175.0	.0314	1986
13	....	205.9	1176.2	.0338	1842
14	....	209.6	1177.3	.0362	1720
14.7	0.	212.0	1178.1	.0380	1642
15	.3	213.1	1178.4	.0387	1610
16	1.3	216.3	1179.4	.0411	1515
17	2.3	219.6	1180.3	.0435	1431
18	3.3	222.4	1181.2	.0459	1357
19	4.3	225.3	1182.1	.0483	1290
20	5.3	228.0	1182.9	.0507	1229
21	6.3	230.6	1183.7	.0531	1174
22	7.3	233.1	1184.5	.0555	1123
23	8.3	235.5	1185.2	.0580	1075
24	9.3	237.8	1185.9	.0601	1036
25	10.3	240.1	1186.6	.0625	996
26	11.3	242.3	1187.3	.0650	958
27	12.3	244.4	1187.8	.0673	926
28	13.3	246.4	1188.4	.0696	895
29	14.3	248.4	1189.1	.0719	866
30	15.3	250.4	1189.8	.0743	838
31	16.3	252.2	1190.4	.0766	813
32	17.3	254.1	1190.9	.0789	789
33	18.3	255.9	1191.5	.0812	767
34	19.3	257.6	1192.0	.0835	746
35	20.3	259.3	1192.5	.0858	726
36	21.3	260.9	1193.0	.0881	707
37	22.3	262.6	1193.5	.0905	688
38	23.3	264.2	1194.0	.0929	671
39	24.3	265.8	1194.5	.0952	655
40	25.3	267.3	1194.9	.0974	640
41	26.3	268.7	1195.4	.0996	625
42	27.3	270.2	1195.8	.1020	611

PROPERTIES OF SATURATED STEAM.

Total pressure per sq. inch, measured from a vacuum....	Pressure above the atmosphere	Sensible temperature in Fahrenheit degrees.	Total heat in degrees from zero of Fahrenheit........	Weight of one cubic foot of steam......	Relative volume of the steam compared with the water from which it was raised........
Lb.	Lb.	Deg.	Deg.	Lb.	
43	28.3	271.6	1196.2	.1042	598
44	29.3	273.0	1196.6	.1065	585
45	30.3	274.4	1197.1	.1089	572
46	31.3	275.8	1197.5	.1111	561
47	32.3	277.1	1197.9	.1133	550
48	33.3	278.4	1198.3	.1156	539
49	34.3	279.7	1198.7	.1179	529
50	35.3	281.0	1199.1	.1202	518
51	36.3	282.3	1199.5	.1224	509
52	37.3	283.5	1199.9	.1246	500
53	38.3	284.7	1200.3	.1269	491
54	39.3	285.9	1200.6	.1291	482
55	40.3	287.1	1201.0	.1314	474
56	41.3	288.2	1201.3	.1336	466
57	42.3	289.3	1201.7	.1364	458
58	43.3	290.4	1202.0	.1380	451
59	44.3	291.6	1202.4	.1403	444
60	45.3	292.7	1202.7	.1425	437
61	46.3	293.8	1203.1	.1447	430
62	47.3	294.8	1203.4	.1469	424
63	48.3	295.9	1203.7	.1493	417
64	49.3	296.9	1204.0	.1516	411
65	50.3	298.0	1204.3	.1538	405
66	51.3	299.0	1204.6	.1560	399
67	52.3	300.0	1204.9	.1583	393
68	53.3	300.9	1205.2	.1605	388
69	54.3	301.9	1205.5	.1627	383
70	55.3	302.9	1205.8	.1648	378
71	56.3	303.9	1206.1	.1670	373
72	57.3	304.8	1206.3	.1692	368
73	58.3	305.7	1206.6	.1714	363
74	59.3	306.6	1206.9	.1736	359
75	60.3	307.5	1207.2	.1759	353
76	61.3	308.4	1207.4	.1782	349
77	62.3	309 3	1207.7	.1804	345
78	63.3	310.2	1208.0	.1826	341
79	64 3	311.1	1208.3	.1848	337
80	65.3	312.0	1208.5	.1869	333
81	66.3	312.8	1208.8	.1891	329
82	67.3	313.6	1209.1	.1913	325
83	68.3	314 5	1209.4	.1935	321
84	69.3	315.3	1209.6	.1957	318
85	70.3	316.1	1209.9	.1980	314

PROPERTIES OF SATURATED STEAM.

Total pressure per sq. inch, measured from a vacuum.....	Pressure above the atmosphere	Sensible temperature in Fahrenheit degrees.	Total heat in degrees from zero of Fahrenheit	Weight of one cubic foot of steam	Relative volume of the steam compared with the water from which it was raised. ....
Lb.	Lb.	Deg.	Deg.	Lb.	
86	71.3	316.9	1210.1	.2002	311
87	72.3	317.8	1210.4	.2024	308
88	73.3	318.6	1210.6	.2044	305
89	74.3	319.4	1210.9	.2067	301
90	75.3	320.2	1211.1	.2089	298
91	76.3	321.0	1211.3	.2111	295
92	77.3	321.7	1211.5	.2133	292
93	78.3	322.5	1211.8	.2155	289
94	79.3	323.3	1212.0	.2176	286
95	80.3	324.1	1212.3	.2198	283
96	81.3	324.8	1212.5	.2219	281
97	82.3	325.6	1212.8	.2241	278
98	83.3	326.3	1213.0	.2263	275
99	84.3	327.1	1213.2	.2285	272
100	85.3	327.9	1213.4	.2307	270
101	86.3	328.5	1213.6	.2329	267
102	87.3	329.1	1213.8	.2351	265
103	88.3	329.9	1214.0	.2373	262
104	89.3	330.6	1214.2	.2393	260
105	90.3	331.3	1214.4	.2414	257
106	91.3	331.9	1214.6	.2435	255
107	92.3	332.6	1214.8	.2456	253
108	93.3	333.3	1215.0	.2477	251
109	94.3	334.0	1215.3	.2499	249
110	95.3	334.6	1215.5	.2521	247
111	96.3	335.3	1215.7	.2543	245
112	97.3	336.0	1215.9	.2564	243
113	98.3	336.7	1216.1	.2586	241
114	99.3	337.4	1216.3	.2607	239
115	100.3	338.0	1216.5	.2628	237
116	101.3	338.6	1216.7	.2649	235
117	102.3	339.3	1216.9	.2674	233
118	103.3	339.9	1217.1	.2696	231
119	104.3	340.5	1217.3	.2738	229
120	105.3	341.1	1217.4	.2759	227
121	106.3	341.8	1217.6	.2780	225
122	107.3	342.4	1217.8	.2801	224
123	108.3	343.0	1218.0	.2822	222
124	109.3	343.6	1218.2	.2845	221
125	110.3	344.2	1218.4	.2867	219
126	111.3	344.8	1218.6	.2889	217
127	112.3	345.4	1218.8	.2911	215
128	113.3	346.0	1218.9	.2933	214

PROPERTIES OF SATURATED STEAM.

Total pressure per sq. inch, measured from a vacuum.....	Pressure above the atmosphere	Sensible temperature in Fahrenheit degrees.	Total heat in degrees from zero of Fahrenheit........	Weight of one cubic foot of steam........	Relative volume of the steam compared with the water from which it was raised........
Lb.	Lb.	Deg.	Deg.	Lb.	
129	114.3	346.6	1219.1	.2955	212
130	115.3	347.2	1219.3	.2977	211
131	116.3	347.8	1219.5	.2999	209
132	117.3	348.3	1219.6	.3020	208
133	118.3	348.9	1219.8	.3040	206
134	119.3	349.5	1220.0	.3060	205
135	120.3	350.1	1220.2	.3080	203
136	121.3	350.6	1220.3	.3101	202
137	122.3	351.2	1220.5	.3121	200
138	123.3	351.8	1220.7	.3142	199
139	124.3	352.4	1220.9	.3162	198
140	125.3	352.9	1221.0	.3184	197
141	126.3	353.5	1221.2	.3206	195
142	127.3	354.0	1221.4	.3228	194
143	128.3	354.5	1221.6	.3250	193
144	129.3	355.0	1221.7	.3273	192
145	130.3	355.6	1221.9	.3294	190
146	131.3	356.1	1222.0	.3315	189
147	132.3	356.7	1222.2	.3336	188
148	133.3	357.2	1222.3	.3357	187
149	134.3	357.8	1222.5	.3377	186
150	135.3	358.3	1222.7	.3397	184
155	140.3	361.0	1223.5	.3500	179
160	145.3	363.4	1224.2	.3607	174
165	150.3	366.0	1224.9	.3714	169
170	155.3	368.2	1225.7	.3821	164
175	160.3	370.8	1226.4	.3928	159
180	165.3	372.9	1227.1	.4035	155
185	170.3	375.3	1227.8	.4142	151
190	175.3	377.5	1228.5	.4250	148
195	180.3	379.7	1229.2	.4357	144
200	185.3	381.7	1229.8	.4464	141
210	195.3	386.0	1231.1	.4668	135
220	205.3	389.9	1232.3	.4872	129
230	215.3	393.8	1233.5	.5072	123
240	225.3	397.5	1234.6	.5270	119
250	235.3	401.1	1235.7	.5471	114
260	245.3	404.5	1236.8	.5670	110
270	255.3	407.9	1237.8	.5871	106
280	265.3	411.2	1238.8	.6070	102
290	275.3	414.4	1239.8	.6268	99
300	285.3	417.5	1240.7	.6469	96

TABLE OF HYPERBOLIC LOGARITHMS.

Num.	Logarithms.	Num.	Logarithms.	Num.	Logarithms.	Num.	Logarithms.
1.01	.0099	1.46	.3784	1.91	.6471	2.36	.8586
1.02	.0198	1.47	.3852	1.92	.6523	2.37	.8628
1.03	.0295	1.48	.3920	1.93	.6575	2.38	.8671
1.04	.0392	1.49	.3987	1.94	.6626	2.39	.8712
1.05	.0487	1.50	.4054	1.95	.6678	2.40	.8754
1.06	.0582	1.51	.4121	1.96	.6729	2.41	.8796
1.07	.0676	1.52	.4187	1.97	.6780	2.42	.8837
1.08	.0769	1.53	.4252	1.98	.6830	2.43	.8878
1.09	.0861	1.54	.4317	1.99	.6881	2.44	.8919
1.10	.0953	1.55	.4382	2.00	.6931	2.45	.8960
1.11	.1043	1.56	.4446	2.01	.6981	2.46	.9001
1.12	.1133	1.57	.4510	2.02	.7030	2.47	.9042
1.13	.1222	1.58	.4574	2.03	.7080	2.48	.9082
1.14	.1310	1.59	.4637	2.04	.7129	2.49	.9122
1.15	.1397	1.60	.4700	2.05	.7178	2.50	.9162
1.16	.1484	1.61	.4762	2.06	.7227	2.51	.9202
1.17	.1570	1.62	.4824	2.07	.7275	2.52	.9242
1.18	.1655	1.63	.4885	2.08	.7323	2.53	.9282
1.19	.1739	1.64	.4946	2.09	.7371	2.54	.9321
1.20	.1823	1.65	.5007	2.10	.7419	2.55	.9360
1.21	.1962	1.66	.5068	2.11	.7466	2.56	.9400
1.22	.1988	1.67	.5128	2.12	.7514	2.57	.9439
1.23	.2070	1.68	.5187	2.13	.7561	2.58	.9477
1.24	.2151	1.69	.5247	2.14	.7608	2.59	.9516
1.25	.2231	1.70	.5306	2.15	.7654	2.60	.9555
1.26	.2341	1.71	.5364	2.16	.7701	2.61	.9593
1.27	.2390	1.72	.5423	2.17	.7747	2.62	.9631
1.28	.2468	1.73	.5481	2.18	.7793	2.63	.9669
1.29	.2546	1.74	.5538	2.19	.7839	2.64	.9707
1.30	.2623	1.75	.5596	2.20	.7884	2.65	.9745
1.31	.2700	1.76	.5653	2.21	.7929	2.66	.9783
1.32	.2776	1.77	.5709	2.22	.7975	2.67	.9820
1.33	.2851	1.78	.5766	2.23	.8021	2.68	.9858
1.34	.2926	1.79	.5822	2.24	.8064	2.69	.9895
1.35	.3001	1.80	.5877	2.25	.8109	2.70	.9932
1.36	.3074	1.81	.5933	2.26	.8153	2.71	.9969
1.37	.3148	1.82	.5988	2.27	.8197	2.72	1.0006
1.38	.3220	1.83	.6043	2.28	.8241	2.73	1.0043
1.39	.3293	1.84	.6097	2.29	.8285	2.74	1.0079
1.40	.3364	1.85	.6151	2.30	.8329	2.75	1.0116
1.41	.3435	1.86	.6205	2.31	.8372	2.76	1.0152
1.42	.3506	1.87	.6259	2.32	.8415	2.77	1.0188
1.43	.3576	1.88	.6312	2.33	.8458	2.78	1.0224
1.44	.3646	1.89	.6365	2.34	.8501	2.79	1.0260
1.45	.3715	1.90	.6418	2.35	.8544	2.80	1.0296

TABLE OF HYPERBOLIC LOGARITHMS.

Num.	Logarithms.	Num.	Logarithms.	Num.	Logarithms.	Num.	Logarithms.
2.81	1.0331	3.26	1.1817	3.71	1.3110	4.16	1.4255
2.82	1.0367	3.27	1.1847	3.72	1.3137	4.17	1.4279
2.83	1.0402	3.28	1.1878	3.73	1.3164	4.18	1.4303
2.84	1.0438	3.29	1.1908	3.74	1.3190	4.19	1.4327
2.85	1.0473	3.30	1.1939	3.75	1.3217	4.20	1.4350
2.86	1.0508	3.31	1.1969	3.76	1.3244	4.21	1.4374
2.87	1.0543	3.32	1.1999	3.77	1.3271	4.22	1.4398
2.88	1.0577	3.33	1.2029	3.78	1.3297	4.23	1.4422
2.89	1.0612	3.34	1.2059	3.79	1.3323	4.24	1.4445
2.90	1.0647	3.35	1.2089	3.80	1.3350	4.25	1.4469
2.91	1.0681	3.36	1.2119	3.81	1.3376	4.26	1.4492
2.92	1.0715	3.37	1.2149	3.82	1.3402	4.27	1.4516
2.93	1.0750	3.38	1.2178	3.83	1.3428	4.28	1.4539
2.94	1.0784	3.39	1.2208	3.84	1.3454	4.29	1.4562
2.95	1.0818	3.40	1.2237	3.85	1.3480	4.30	1.4586
2.96	1.0851	3.41	1.2267	3.86	1.3506	4.31	1.4609
2.97	1.0885	3.42	1.2296	3.87	1.3532	4.32	1.4632
2.98	1.0919	3.43	1.2325	3.88	1.3558	4.33	1.4655
2.99	1.0952	3.44	1.2354	3.89	1.3584	4.34	1.4678
3.00	1.0986	3.45	1.2383	3.90	1.3609	4.35	1.4701
3.01	1.1019	3.46	1.2412	3.91	1.3635	4.36	1.4724
3.02	1.1052	3.47	1.2441	3.92	1.3660	4.37	1.4747
3.03	1.1085	3.48	1.2470	3.93	1.3686	4.38	1.4778
3.04	1.1118	3.49	1.2499	3.94	1.3711	4.39	1.4793
3.05	1.1151	3.50	1.2527	3.95	1.3737	4.40	1.4816
3.06	1.1184	3.51	1.2556	3.96	1.3726	4.41	1.4838
3.07	1.1216	3.52	1.2584	3.97	1.3787	4.42	1.4888
3.08	1.1249	3.53	1.2612	3.98	1.3812	4.43	1.4883
3.09	1.1281	3.54	1.2641	3.99	1.3837	4.44	1.4906
3.10	1.1314	3.55	1.2669	4.00	1.3862	4.45	1.4929
3.11	1.1346	3.56	1.2697	4.01	1.3887	4.46	1.4914
3.12	1.1378	3.57	1.2725	4.02	1.3912	4.47	1.4973
3.13	1.1410	3.58	1.2753	4.03	1.3937	4.48	1.4996
3.14	1.1442	3.59	1.2781	4.04	1.3962	4.49	1.5018
3.15	1.1474	3.60	1.2809	4.05	1.3987	4.50	1.5040
3.16	1.1505	3.61	1.2837	4.06	1.4011	4.51	1.5062
3.17	1.1537	3.62	1.2864	4.07	1.4036	4.52	1.5085
3.18	1.1568	3.63	1.2892	4.08	1.4060	4.53	1.5107
3.19	1.1600	3.64	1.2919	4.09	1.4085	4.54	1.5129
3.20	1.1631	3.65	1.2947	4.10	1.4109	4.55	1.5151
3.21	1.1662	3.66	1.2974	4.11	1.4134	4.56	1.5173
3.22	1.1693	3.67	1.3001	4.12	1.4158	4.57	1.5195
3.23	1.1724	3.68	1.3029	4.13	1.4182	4.58	1.5216
3.24	1.1755	3.69	1.3056	4.14	1.4206	4.59	1.5238
3.25	1.1786	3.70	1.3083	4.15	1.4231	4.60	1.5260

TABLE OF HYPERBOLIC LOGARITHMS.

Num.	Logarithms.	Num.	Logarithms.	Num.	Logarithms.	Num.	Logarithms.
4.61	1.5282	5.06	1.6213	5.51	1.7065	5.96	1.7850
4.62	1.5303	5.07	1.6233	5.52	1.7083	5.97	1.7867
4.63	1.5325	5.08	1.6253	5.53	1.7101	5.98	1.7884
4.64	1.5347	5.09	1.6272	5.54	1.7119	5.99	1.7900
4.65	1.5368	5.10	1.6292	5.55	1.7137	6.00	1.7917
4.66	1.5390	5.11	1.6311	5.56	1.7155	6.01	1.7934
4.67	1.5411	5.12	1.6331	5.57	1.7173	6.02	1.7950
4.68	1.5432	5.13	1.6351	5.58	1.7191	6.03	1.7967
4.69	1.5454	5.14	1.6370	5.59	1.7209	6.04	1.7984
4.70	1.5475	5.15	1.6389	5.60	1.7227	6.05	1.8000
4.71	1.5496	5.16	1.6409	5.61	1.7245	6.06	1.8017
4.72	1.5518	5.17	1.6428	5.62	1.7263	6.07	1.8033
4.73	1.5539	5.18	1.6448	5.63	1.7281	6.08	1.8050
4.74	1.5560	5.19	1.6463	5.64	1.7298	6.09	1.8066
4.75	1.5581	5.20	1.6486	5.65	1.7316	6.10	1.8082
4.76	1.5602	5.21	1.6505	5.66	1.7334	6.11	1.8099
4.77	1.5623	5.22	1.6524	5.67	1.7351	6.12	1.8115
4.78	1.5644	5.23	1.6544	5.68	1.7369	6.13	1.8131
4.79	1.5665	5.24	1.6563	5.69	1.7387	6.14	1.8148
4.80	1.5686	5.25	1.6582	5.70	1.7404	6.15	1.8164
4.81	1.5706	5.26	1.6601	5.71	1.7422	6.16	1.8180
4.82	1.5727	5.27	1.6620	5.72	1.7439	6.17	1.8196
4.83	1.5748	5.28	1.6639	5.73	1.7457	6.18	1.8213
4.84	1.5769	5.29	1.6658	5.74	1.7474	6.19	1.8229
4.85	1.5789	5.30	1.6677	5.75	1.7491	6.20	1.8245
4.86	1.5810	5.31	1.6695	5.76	1.7509	6.21	1.8261
4.87	1.5830	5.32	1.6714	5.77	1.7526	6.22	1.8277
4.88	1.5851	5.33	1.6733	5.78	1.7544	6.23	1.8293
4.89	1.5870	5.34	1.6752	5.79	1.7561	6.24	1.8309
4.90	1.5892	5.35	1.6770	5.80	1.7578	6.25	1.8325
4.91	1.5912	5.36	1.6789	5.81	1.7595	6.26	1.8341
4.92	1.5933	5.37	1.6808	5.82	1.7613	6.27	1.8357
4.93	1.5953	5.38	1.6826	5.83	1.7630	6.28	1.8373
4.94	1.5973	5.39	1.6845	5.84	1.7647	6.29	1.8389
4.95	1.5993	5.40	1.6863	5.85	1.7664	6.30	1.8405
4.96	1.6014	5.41	1.6882	5.86	1.7681	6.31	1.8421
4.97	1.6034	5.42	1.6900	5.87	1.7698	6.32	1.8437
4.98	1.6054	5.43	1.6919	5.88	1.7715	6.33	1.8453
4.99	1.6074	5.44	1.6937	5.89	1.7732	6.34	1.8468
5.00	1.6094	5.45	1.6956	5.90	1.7749	6.35	1.8484
5.01	1.6114	5.46	1.6974	5.91	1.7766	6.36	1.8500
5.02	1.6134	5.47	1.6992	5.92	1.7783	6.37	1.8515
5.03	1.6154	5.48	1.7011	5.93	1.7800	6.38	1.8531
5.04	1.6174	5.49	1.7029	5.94	1.7817	6.39	1.8547
5.05	1.6193	5.50	1.7047	5.95	1.7833	6.40	1.8562

INDEX.

Bis—Boi

Boi—Bra

Bra—Bra

Bra—Cap

Cap—Che

Che—Coa

Coa—Com

Com—Con

Cur—Cyl

Dam—Dia

Dia—Dri

Dri—Ecc

Ecc—Equ

Equ—Exp

Exp—Fir

Fir—For

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Gid—Gui

Gui—Hig

Hig—Ind

Ind—Jou

Jou—Lea

Lea—Loa

Loc—Loc

Loc—Mac

Mag—Mot

Mot—Off

Oil—Pas

Pas—Pis

Pul—Rai

Rai—Res

Res—Rod

Rod—Run

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