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ELECTRIC RAILWAYS

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ELECTRIC RAILWAYS

AND

THE ELECTRIC TRANSMISSION OF POWER

DESCRIBED IN PLAIN TERMS

BY

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ELECTRIC RAILWAYS.

CHAPTER I.

THE ELECTRIC TRANSMISSION OF POWER.

THE key-stone of modern science is the truth that matter and energy, the components of the universe, are never destroyed. To put the converse of half this truth into scientific parlance, energy is always conserved. It may change its form or its place, but it never increases or diminishes, never grows, never shrinks. Energy may be active, or it may be dormant, — in scientific phrase, potential. The great problem which confronts mankind to-day, which always has confronted, always will confront the human race, — the problem of problems in the physical world, — is, how to utilize to the best advantage the energy dormant in matter. How shall we get the most work out of coal, wood, water, and every other form in which matter presents itself to us? Energy is seldom in the place we want it, — almost never in the form we want it. We must carry it to the desired place in its original bonds, as, for example, in coal, or we must transform it and carry it in some new prison, as, for example, in coal gas. The question is, In what form can we transport energy so as to lose the least of it while performing the least labor? Students of dynamical electricity maintain to-day that they have solved the problem. They maintain that energy can be transmitted by electricity more cheaply, with less net loss, than in any other way known to modern science. The claim is surely worth investigating.

To discuss intelligently the methods by which energy, *alias* power, is usually transformed into electricity, it will be necessary to go back to the beginnings of electrical science; and yet it is not so very far back, for it was but little over a century ago that the science was in so rude a state that the Electoral Academy of Bavaria actually proposed the following subject for a prize dissertation: "Is there a real and physical analogy between electric and magnetic forces; and if such analogy exists, in what manner do these forces act on the human body?" At that time physicists were divided as to the correct answer to the question at issue, and for forty-five years they quarrelled over it, until at last Oersted settled it forever by demonstrating the magnetic properties of electric currents. In 1829 this Danish physicist noticed that a magnetized needle was deflected from its direction when it was placed near a closed electric circuit. The same phenomenon occurring when the current was replaced by a magnet, it became evident to him, as to all contemporary physicists, that a complete analogy existed between electricity and magnetism. From this first observation really dates one of the most beautiful achievements of the human mind in the domain of natural philosophy. Before 1820 the intimate relation between the electric current and a magnet had often been spoken of, and had even served as a basis for several electric theories; but no one had rendered it palpably evident until Oersted's experiment opened to science the luminous path which scientific men have since trodden with so much success. It was in 1820 that Ampère made known to the world the mutual action of two currents; and in the same year Arago discovered that an electric current imparts magnetic properties to iron and steel. Ten years later Faraday supplemented the labors of Oersted, Ampère, and Arago, by demonstrating that a magnet can create an electric current.

From the discoveries of these four men has been developed the science of dynamical electricity. Just as geometry was constructed from axioms, self-evident truths, so this science has been built up from certain truths which may be termed electrical axioms; and it cannot be too forcibly impressed on the reader that these electrical axioms must be thoroughly understood, with all their significance, and in all their bearings, before proceeding further. They are known from the name of their formulator as Ampère's laws, and are : —

I. Two currents which are parallel and in the same direction attract one another.

II. Two currents parallel, but in contrary directions, repel one another.

From these we deduce two more laws, which can easily be verified by experiment : —

III. Two rectilinear currents, the directions of which form an angle with each other, attract one another when both approach or both recede from the apex of the angle.

IV. They repel one another if one approaches and the other recedes from the apex of the angle.

To continue our mathematical simile : In geometry, every proposition has its converse ; likewise, the laws of parallel and angular currents have their converse in what is known as Lenz's law, which is : —

"If the relative position of two conductors A and B be changed, of which A is traversed by a current, a current is induced in B, in such a direction that, by its electrodynamic action on the current in A, it would have imparted to the conductors a motion of the contrary kind to that by which the inducing action was produced."

From these laws, it is easy to see how motion will produce currents of electricity, and *vice versa*, how currents of electricity will produce motion. The elaborate dynamo-electric machines of to-day are worked on these very principles, according as they are used respectively as generators or motors. Strange to say, nearly half a century passed before any one thought of what they had in common ; so we must consider them separately, and the two sets of machinery which slowly developed from their application.

Evolution of the Dynamo.

In 1820 the great Faraday succeeded in rotating a system of wires through which ran currents, by means of a permanent magnet placed near it ; but he did not grasp the practical importance of his discovery, and it was reserved for Pixii, a French manufacturer of physical instruments, to make, in the year 1832, the first magneto-electric machine, *i. e.*, a machine for inducing currents of electricity in a wire or coil of wire by means of a magnet. Pixii revolved the poles of a horseshoe magnet before the poles of a double electro-magnet. Thus, two conductors changed their relative positions, and since one (the permanent magnet) was traversed by a current, in accordance with Lenz's law, a current was induced in the other. As this machine had the mechanical disadvantage of having the heavier part (the permanent magnet) put in motion, a change was soon made, so that, instead, the magnets were fixed and the coils rotated. For many years after this step, no material advance was made in the construction of magneto-electric machines. They were unsatisfactory in use, because their effect did not increase proportionally to their dimensions; and therefore machines for the production of powerful currents were cumbersome and costly.

In October, 1854, Soren Hjörth, of Copenhagen, applied for a patent in England, which was granted in the following April, for a machine embodying the principle which puts the electric generators of to-day so far ahead of those of half a century ago, viz., the principle of the accumulation of currents by their mutual action on one another. But Hjörth retained the permanent magnet for part of his machine, and the full force of his discovery was not appreciated by the scientific world. A dozen years later it was found that the permanent magnet could be dispensed with.

Hjörth's discovery was re-discovered, so to speak, the announcement being made in the winter of 1866–7, quite independently and almost simultaneously by S. Alfred Varley, Dr. Werner Siemens, and Sir Charles Wheatstone. The honor is also claimed by Prof. Moses G. Farmer, of Massachusetts, who advances evidence that he conceived the idea of mutual accumulation before the fall of 1866.

In the machine thus brought into being, the permanent magnet is replaced by an electro-magnet, which is put in the same circuit with the coils of the other electro-magnet revolving before it. There is always enough magnetism in the coils of the other when the machine is started. This induced current in the second induces a still stronger current in the coils of number one, and this new one, added to the little one already there, induces yet a stronger one in number two, and so it goes back and forth, the strength of the current produced being limited only by the capacity for saturation which the coils possess. In this way a trace of magnetism suffices to originate torrents of electricity. Such a generator is commonly called a dynamo-electric machine.

Electric Terms Defined.

For the sake of those readers not thoroughly conversant with electrical science, let us pause here to define the terms commonly used in discussing the electric transmission of power.

In the popular acceptation of the word, a *magnet* is a piece of steel which has the peculiar property of attracting iron to its ends. Certain kinds of iron ore called loadstone have the same property.

If a piece of soft iron be placed within a coil of insulated wire through which a current of electricity passes, the iron assumes this power of attraction, keeping it only so long as the current continues in the wire. This is called an *electro-magnet*. As magnetized steel long retains its magnetic power, it is often spoken of as a *permanent magnet*.

The greatest manifestation of force in a long, thin magnet is near its ends, and the ends of any one such magnet possess opposite qualities; this peculiarity has caused the name of *poles* to be given to these ends.

The earth is a magnet, and by its influence turns any other straight magnet free to turn, so that it is nearly parallel to the earth's axis. This property of a magnet has done the world inestimable good in the mariner's compass. The end of the magnet that turns toward the north is called its *north pole;* the other end, its *south pole*.

For the sake of convenience, magnets are very often bent so as to bring the poles near together. In this form they are usually called *horseshoe magnets*.

The terminals of the wires connected with the two metals in a galvanic battery are also called poles. Connect these and a current begins to flow. The path of this current is called the *circuit*. We make or break the circuit according as we join or separate the poles. The current that comes from the battery to the point of connection is called the *positive* current; the current that goes from the point of connection back to the battery is called the *negative* current. The wires or other conductors are called *positive* or *negative* conductors, according as they bear positive or negative currents. The substitution of a magneto-electro or dynamo-electric machine for a battery does not affect the use of these terms.

A machine using the principle of Pixii's, described above, *i. e.*, having permanent magnets revolving before the coils of an electro-magnet, is called a *magneto-electric* machine, because *by a magnet electricity* is produced. The same name is used when the coils are revolved and the permanent magnet is stationary. On the other hand, where the principle of mutual accumulation by electromagnets is employed, the term *dynamo-electric — by power electricity* — is applied. For the sake of brevity, a dynamo-electric machine is generally spoken of as a *dynamo*.

Later we shall come to a class of machines in which a current of electricity generated by chemical means is transformed into power. These are known as *electro-magnetic* machines, without any real reason for the name, save that it is the reverse of "magneto-electric"; perhaps the man that invented it wanted to signify that *by electricity magnets* are revolved. No distinctive name has been applied where a current generated by power is employed, but since we call the generator a "dynamo-electric" machine, we may, with as much accuracy, call the motor an *electro-dynamic* machine, for here we have *by electricity*, *power*. It would be well to shorten this into *electro*, just as the other is shortened into *dynamo*, but the electricians are content to call such a machine simply a *motor*, sometimes making the term more specific by speaking of the machine as an *electric motor*. The dynamo is often referred to as the *generator*.

The *armature* is the soft iron core with coils of insulated copper wire about it, making an electro-magnet, which revolves between or before the poles of the stationary electro-magnet or electro-magnets.

A *commutator* is a device for taking the currents off the armature and uniting them into one current which shall flow continuously in one direction. There are many different arrangements for this purpose, but an explanation of the simplest will suffice for all. In this the shaft of the armature will be made of two pieces of copper, A and B, with a strip, M, of ivory or some other non-conducting substance between. A is connected with one end of the wire in the coils of the armature, B with the other. Two stationary springs (called *commutator brushes*) press against opposite sides of the revolving shaft. These are connected with the wires of the stationary magnet. As the armature revolves between the poles of this stationary magnet, half its coils are always leaving the south pole and going toward the north pole, or *vice versa*. As the north pole induces the same sort of a current in the wire coming toward it as the south pole induces in the wire going from it, the currents in that half of the armature will have the same direction; *vice versa*, the currents in the other half of the armature will have the opposite direction. When these halves pass the poles, the direction of the currents in them is respectively reversed. But at the same time the connections between the strips A and B and the commutator brushes are reversed, so that a positive current will always flow from one wire and a negative from the other. The sparks seen when the dynamo is in motion are caused by the imperfect connections made by these commutator brushes with the strips of the revolving shaft. They are the only parts of a dynamo liable to wear and tear, and as they can be easily replaced, the item of repairs is, or ought to be, very small in the cost of running the machine.

The stationary electro-magnets in a dynamo are called the *field*.

Currents.

Nobody knows why electricity goes through a wire for a very long distance. In fact, nobody knows what electricity is. We call it a form of force, and we know how it manifests itself; but of the nature of the thing itself, if it be a thing, we can only conjecture. It is sufficient for us, however, to know that the power which we call electricity exerts itself over great distances. From the first, this phenomenon has been referred to as a current, and for the sake of convenience an electric current has been compared to a current of water. Each flows from point to point compelled by some unseen power. That power in the case of water we call "gravity"; in the case of electricity we call it "electro-motive force"; in other words, the cause that sets the electricity of a circuit in motion is called the *electro-motive force.*

The difference in height between where a current of water starts and where it ends we call its "head," saying, for instance, "That sluiceway gives sixteen feet head of water"; in electricity we speak of this difference as the *difference of potential*, and we measure it not in feet but in *volts*, one of the arbitrary standards adopted by the Electrical Congress, at Paris, in 1881.

The sides of a sluiceway or pipe offer resistance to a current of water. In the same way, the conductor of any electric currents offers *resistance* to it. That resistance is measured by the standard known as an *ohm.*

As the strength of a current of water varies according to its head, so the strength of an electric current varies according to its difference of potential. Experiment has proved that current strength is directly proportional to electro-motive force. As the more resistance a current of water meets the less strength it has, so the greater the resistance to electricity the less its strength. It has been found that electric current strength is inversely proportional to the resistance. These facts about electric currents are expressed in the form of an equation by what is known as Ohm's law: —

$$\text{E (electro-motive force)} = \text{C (current strength)} \times \text{R (resistance)},$$

$$\text{or, } (C\ (1 = \frac{E}{R}.$$

Electricians often speak of the current strength as the *intensity* of the current. It is measured by the standard known as an *ampere.* When an electro-motive force of one volt drives a current through a circuit with a resistance of one ohm, that current has an intensity of one ampère. We cannot tell from the intensity, the ampère's, alone, the rate of a current's work, its electrical horse-power, any more than we could tell from the strength of a laborer's arm the rate of the work he does with it. Knowing how many pounds his arm can raise, and how often he uses that strength, we can quickly find his rate of work. So knowing the strength of an electric current, and how fast the electro-motive force puts it in action, we can find the electrical rate of work. This we do by multiplying the electro-motive force (the volts) and the current strength (the ampères). To get the mechanical horse-power, the following equation is used: —

$$(2)\ \text{Horse-power} = \frac{\text{Volts} \times \text{ampères}}{745.9}$$

With the help of these equations (1) and (2), we can solve many important questions that present themselves in connection with the electric transmission of power. Suppose we are getting a certain number of horse-power, but wish more; by equation (2) it is clear we must increase either the volts or the ampères. As the volts are but measures of the electro-motive force, and as the electro-motive force increases when the armature revolves faster, it is clear that the desired result can be attained by increasing the speed of the steam engine attached; or the electro-motive force can be increased by increasing the resistance according to equation (1). This is effected by the use of *shunts*, which may be resistance coils that can be put in the circuit, or extra coils in the field of the dynamo, to be put in or taken out of the interior circuit at will by means of a simple switch. As the electro-motive force, besides being proportional to the velocity of the armature, is also proportional to the number of convolutions of the wire in the armature coil, it is easy to see that by employing different methods of winding the wire, we can get whatever electro-motive force we desire. By altering the size of wire, we alter the internal resistance, and thus we have still another method of varying electromotive force.

In the last twenty years hundreds of ways have been devised for winding the armatures and the field magnets, for connecting the wires and for arranging coils, cores, and armatures. It would be an herculean task to describe them all, and it would be a needless task to describe even one, for the same general principles underlie each, and these principles have already been enunciated. It is sufficient for us to know that the theories have been proved thousands of times in practice.

Electro-Motors.

The most elementary arrangement for producing motion by electricity would be, of course, a simple mechanism operated in accordance with Ampère's laws, that two parallel currents in the same direction attract, and in opposite directions repel, one another. If we place a magnet so that it may move freely before the poles of an electro-magnet, and if by clockwork or some other device we send a current in alternate directions through the coils of the electro-magnet, then, since in accordance with the Ampèrian theory, a current is continually flowing around the permanent magnet, the latter will be alternately attracted and repelled. In other words, the current of the electro-magnet will have produced motion.

The simplest electro-motor is Froment's rotating engine. This consists of an electro-magnet radially outside the periphery of a drum capable of rotation. On this periphery are a series of soft iron coils. As the drum revolves it completes a circuit by suitable make and break pieces, sending a powerful current from a battery through the electro-magnet as each coil approaches the pole within 15° or 20°; the electro-magnet then attracts the armature, and the drum is forced to continue its revolution. The circuit is interrupted as the coil passes the electro-magnet, and the magnet, therefore, unmade. The drum continues its rotation by inertia, or by the action of another electro-magnet, until a second coil approaches the poles of the first electro-magnet, when the circuit is made as before.

Another form of electro-motor resembles the ordinary beam steam engine. In it a magnet takes the place of the piston, being sucked into a hollow coil, and then repelled as the current in the coil is reversed.

Electro-motors have never been of any considerable practical value because they are not economical. They are, necessarily, at least fifty times more expensive to run than the ordinary steam engine, because they depend for their source of energy upon the galvanic battery. In the galvanic battery some metal is acted upon by an acid, the chemical action developing the electric current. Zinc is the cheapest metal by the consumption of which electricity is produced, and zinc costs forty times as much as coal, and at the same time is a far worse fuel; for while an ounce of zinc will give heat equivalent to 113,000 foot-pounds of work, an ounce of coal will give the equivalent of 695,000 foot-pounds. Thus, you see that zinc as a power generator costs about forty times as much as coal, provided the power can be secured from the two metals with equal ease. This proviso, however, cannot be assumed, for a large fraction of the energy in the case of the zinc can be converted into an electric current, whereas we have not yet discovered any means of obtaining the energy of coal except as heat, and we necessarily waste a great part of the heat in the process of transforming it into mechanical energy. The whole of the energy either of heat or electricity can never be transmuted into mechanical effect. In the best steam engines not one quarter of the heat is so utilized, and more frequently it is only about one tenth. It is probable that larger fractions of the total energy than these could be transformed by an electro-motor into mechanical effect; but this advantage, even if realized, cannot nearly counterbalance the disadvantage entailed by the cost of zinc.

The electrician, Joule, has estimated that in an electro-magnetic engine, constructed most favorably to prevent loss of power, the consumption of zinc every twenty-four hours to produce one horse-power is in Grove's battery forty-five pounds, and in Daniell's battery seventy-five pounds.

The First Transmission.

For many years the sciences of magneto-electricity and electro-magnetism were growing up, developing, side by side. We of to-day cannot comprehend why it was so long before any one saw what they had in common. To whom the idea of uniting them first occurred is a mooted question. As far as record goes, the honor belongs to Pacinotti, an Italian, who printed a suggestion of the principle of reversibility in 1864. It did not attract the attention of other scientific men, and his invention remained for a long time forgotten.

There is even more uncertainty as to the identity of the man who first put the idea in practice, and used the electricity generated by power to produce power in turn. According to M. Figuier, accident, pure and simple, was the cause of the discovery. He relates that at the International Exhibition in Vienna, in 1873, the Gramme Company had two machines on view, intended for lighting purposes. One of these machines was in motion, and a workman who noticed that some cables were trailing on the ground, thinking they belonged to the second machine, placed them in its terminals. To the surprise of everybody, this second machine, which had been standing, began to turn of its own accord. Then it was discovered that the first machine was working the second.

This story is romantic, but, as the *Electrical World* well puts it, disappointing to a true lover of science, who would prefer to believe that a great discovery was the logical outcome of the working of a powerful intellect, and not the result of accidental meddling on the part of an ignorant workman. But there is another version of the story, told by M. Hippolyte Fontaine to the Société des Ancients Elèves des Ecoles Nationales d'Arts et Métiers a few months ago. M. Fontaine claims to have actually invented or discovered the electric transmission of power, as will be seen from the following short abstract of his paper read before the above-mentioned society : —

"On the 1st of May, 1873, — that is, on the date fixed four years previously by imperial decree, — the Exhibition in Vienna was formally opened. At that time the machinery hall was yet incomplete, and remained closed to the public until the 3d of June, when it was also thrown open. I was then engaged with the arrangement of a series of exhibits, shown for the first time in public, which were intended to work together or separately, as desired. There was a dynamo-machine by Gramme for electroplating, giving a current of four hundred ampères at twenty-five volts, a magneto-machine, which I intended to work as a motor for a primary battery, or from a Planté accumulator, to demonstrate the reversibility of the Gramme dynamo. There was also a steam engine of my invention heated by coke, a domestic motor of the same type heated by gas, a centrifugal pump placed on a large reservoir and arranged to feed an artificial cascade, and numerous other exhibits. To vary the experiments I proposed to show, I had arranged the pump in such a way that it could be worked either by the Gramme magneto-machine or by the steam engines.

"On the 1st of June it was announced that the machinery hall would be formally opened by the Emperor at 10 A. M. on the day after the morrow. Nothing was then in readiness, but those who have been in similar situations know how much can be got into order in the space of forty-eight hours just before the opening of a great exhibition. In every department members of the staff with an army of workmen under their orders were busy clearing away packing cases and decorating the spaces allotted to the different nations. These gentlemen visited all the exhibits in order to determine which of them should be selected for the special notice of the Emperor, so as to detain him as long as possible among the exhibitors of their respective countries.

"M. Roullex-Duggage, who superintended the work in the French section, asked me to set in motion all the machinery on my stand, and especially the two Gramme machines. I set about at once, and on the 2d of June I had the satisfaction of getting the large Gramme dynamo, the two engines (Fontaine), and the centrifugal pump to work; but I failed to get the motor into action from the primary or secondary battery. This was a great disappointment, especially as it prevented my showing the reversibility of the Gramme machine. I was puzzled the whole of the evening and the whole of the night to find a means to accomplish my object, and it was only in the morning of the 3d of June, a few hours before the visit of the Emperor, that the idea struck me to work the small machine by means of a derived circuit of the large machine. Since I had no leads for that purpose, I applied to the representative of Messrs. Manhis, of Lyons, who was kind enough to lend me two hundred and fifty meters of cable, and when I saw that the magneto-machine was not only set in motion, but developed so much power as to throw the water from the pump beyond the reservoir, I added more cable until the flow of water became normal. The total length of cable in circuit was then over two kilometers. This great length gave me the idea that by the employment of two Gramme machines, it would be possible to transmit mechanical energy to great distances. I spoke of this idea to various people, and I published it in the *Revue Industrielle*, in 1873, and subsequently in my book on the Vienna Exhibition. The publicity thus given to it was so great that I had neither time nor desire to protect my invention by a patent. I must also mention that M. Gramme has told me that he had already worked one dynamo by the other, and I have always held that the honor of my experiment belongs to the Gramme Company."

Theoretical Considerations.

The underlying principle in transmission is the coupling of two or more dynamos. Let the current generated by one flow over a short circuit, and let another machine be placed in the circuit; then the electro-magnet of the second will become excited, and a current will also pass through the coils of the armature. By Ampère's law, two currents attract or repel one another according as they run in parallel or opposite directions. Suppose in this case the first motion is repulsion and the armature begins to rotate. As its coils respectively approach the pole opposite the one by which they were repelled, they will be attracted. As soon as they pass the pole the commutator will have changed the direction of the current, and they will be repelled. On approaching the original pole from which they started, they will be attracted, since the current still remains inverse. We have now followed the armature through an entire rotation. This rotation will evidently be kept up, and the stronger the current the faster the armature will turn. By connecting shafting with this revolving armature, the power may be utilized.

It has now been shown: first, that power can be made to generate an electric current; secondly, that an electric current can flow to a considerable distance; thirdly, that an electric current can generate considerable power; in other words, that electric transmission is possible. The question now comes up, Is it practicable? To answer this we must first ascertain three things: (1.) How much power can be advantageously employed on the dynamo? (2.) How much power in the shape of electricity can be economically carried over a wire? (3.) How much of that power can be reclaimed from the motor?

(1.) Suppose we apply power to a dynamo at rest. The armature begins its movement, gradually increases its speed, producing a gradually increasing electro-motive force and intensity of current up to that moment when the second machine is energized, begins to revolve in its turn and produces work. From that moment, if the speed of the generator is increased, the speed of the motor will follow suit and increase at the same time. It has been shown that by increasing the speed of a dynamo armature we increase the electro-motive force; and that when the electro-motive force is increased, the number of horse-power transmitted is increased. The electro-motive force can be increased till it is so powerful that the heat developed will burn out the insulation of the coils of the dynamo. Marcel Deprez, an eminent French electrician, who has been conducting extensive experiments on this point, had this accident happen recently when he was using an electro-motive force of about 6000 volts. As quarter that number of volts would be amply enough to run any one of the New York elevated railways, we need not trouble ourselves on this score. But if, perchance, an enormous electro-motive force should be required, electricians say it could be easily secured by using a number of dynamos. Thus, we see that practically there is no limit to the amount of power that can be advantageously employed.

(2.) But can a wire of economical size carry a current of enormous electro-motive force? This is a question electricians have been quarrelling over for the last ten years. To make the discussion concrete in its nature, many of them have argued *pro* and *con* the possibility of transmitting the immense power of Niagara Falls to New York City. The main objection is on the score of heat developed, those who advance it maintaining that the cable, unless extremely thick, would be melted. One asserted that such a cable would require more copper than exists in all the enormous deposits about Lake Superior. Another estimated the cost of the cable at sixty dollars a lineal foot. These objections were met in an able paper presented to the Franklin Institute some time ago by Profs. Thomson and Houston, in which they clearly proved that it is possible, if deemed desirable, to convey the total power of Niagara a distance of five hundred miles or more by a copper cable not more than half an inch thick, provided the cable could be completely insulated. They would do this by getting an enormous electro-motive force from the use of many dynamos; a comparatively small current must be used, for it is the current wasted that shows itself in the form of heat; the amount wasted is proportional to the square of the current. Owing to the equation,

$$E = C \times R,$$

the resistance (R) must be increased as is the electromotive force (E), if the current (C) is to be kept small; the great length of the cable would give the necessary resistance, they have mathematically proved.

Sir William Thomson ascribes the credit of originating the idea of utilizing Niagara to C. W. Siemens, in March, 1877. In May, 1879, Thomson stated before a committee of the House of Commons, that taking Niagara as an example, under practically realizable conditions of intensity, a copper wire of half an inch in diameter would suffice to take 26,250 horse-power from water wheels driven by the falls, and (losing only twenty per cent. on the way), to yield 21,000 horse-power at a distance of 300 British statute miles; the prime cost of the copper amounting to £60,000, or less than £3 per horse-power actually yielded at the distant station.

In his inaugural address to the British Association, in 1881, he gave a solution to the problem of what was to be done with the enormous electro-motive force at the New York end of the wires, which consisted in the use of large numbers of accumulators. All that is necessary to do, he thought, in order to subdivide this enormous force of 80,000 volts into what may be called small commercial electro-motive forces, is to keep a Faure battery of 40,000 cells always charged direct from the main current, and apply a methodical system of removing sets of fifty and placing them on town supply circuits, while other sets of fifty are being regularly introduced into the main circuit that is being charged. Of course, this removal does not mean bodily removal of the cells, but merely disconnecting the wires.

The most serious difficulty in the way of transmitting currents of vast electro-motive force will probably be that of insulation. In one of Deprez's recent experiments, his wire at a certain point happened to be near a telegraph wire; a discharge took place, something like a flash of lightning in a thunder-storm. The result was the burning out of the telegraph instruments and the stopping of his own machines. However, it is tolerably certain that with a cable of limited size, a great quantity of power can be transmitted to a considerable distance, and as far as electric railways are concerned, there is no question about the possibility of easily transmitting all the power required.

(3.) How much power can be reclaimed? This depends on the amount wasted in the transformation into electricity, in the current's passage over the conductor, and in the re-transformation into power; in other words, on the efficiency of the dynamo, the current waste, and the efficiency of the motor.

To determine the efficiency of dynamos, as at present constructed, careful and elaborate tests were recently made by a committee of the Franklin Institute. It was found that the *electrical* efficiencies of the machines under a full load ran from 94.67 to 96.65 per cent.; the *commercial* efficiencies ran from 87.66 to 91.96 per cent. The difference between electrical and commercial efficiency is that we take account in the latter, but not in the former, of friction and other mechanical losses. In machines built expressly for transmitting power, it is probable that the average commercial, practical efficiency will be 90 per cent.; in other words, in transforming mechanical into electrical energy, about one tenth of the power used will be lost, and we shall get nine tenths in electricity.

The current waste will, in the first place, be determined by the resistance of the circuit, and so it is desirable to reduce this as much as possible. Increase in length and decrease in size of the conductor both increase resistance and hence current waste. In practice, however, it has been repeatedly found that an ordinary telegraph wire does not offer resistance enough to make material difference in the transmission of much power to many miles. We must look further for the important cause of current waste, and we shall find it, not in the conductor, but in the motor. This brings us to the problem which perhaps of all the problems in dynamical electricity has been least understood and most debated. It is, moreover, the most important problem in connection with the electric transmission of power, for on its answer depends the practical value of the system. Let us see, then, if we can tell *how much current is wasted in its transformation into mechanical energy.*

In considering this question, we may for the time being assume that the machines are physically perfect, and that there is no loss by friction, imperfections in the coils, or anything of the sort. Then the answer can be reasoned out from Ohm's law that

$$E = C \times R,$$

and Joule's law that the power wasted is equal to the square of the current multiplied by the intensity, or $C^2 R$. Now, if an electric current does no work whatever, *i. e.*, flows from dynamo terminal to dynamo terminal without either mechanical or chemical action, all its energy will show itself in the form of heat. This by Joule's law would be C^2 R. Then, if we let some of the current do work, not so much will be wasted. But the resistance (R) of a given circuit is constant, whether part or all of it is in motion or at rest. How, then, can the formula C^2 R still hold good for the current wasted?

To answer this, consider for a moment the action of a motor. As has been shown, when a current is conducted into the coils of the motor, its armature will begin to revolve. Its rotation is exactly the same as it would be if the motive power came from a pulley belt attached to its wheel. The result is that a current is induced in the coils. But this current is directly the opposite of that which is produced by the dynamo, and which is giving the armature of the electro motion. Thus, the motor produces what is called a *counter electro-motive force*, which is referred to as e. According to its strength, it lessens the direct electro-motive force E. Then the total electro-motive force of the circuit will be $E - e$. The resistance (R) is constant. Then if one side of the equation

$$E = C \times R$$

is diminished by e, the other must be, so that we see the counter electro-motive force diminishes the intensity as well as the direct electro-motive force. Thus, as C^2 R is determined by e, it is important to find out the relative value of e. Now e may vary from zero, when the motor is loaded so heavily that it cannot move, up to E, when the motor is moving as fast as the generator, but is doing no work. When e is smallest, C will be biggest, and there will be the most current waste. When e is biggest, C will be smallest, and there will be the least current waste. Clearly, then, there will be the greatest efficiency, the most work done with the least waste, when e and C are just half-way between the extremes, *i. e.*, when the armature of the motor is moving at half the velocity of that of the generator. Theoretically, then, the maximum efficiency of a dynamo would be fifty per cent., if we left resistance out of the question. I have said that even an ordinary telegraph wire does not offer resistance enough to make

make material difference in transmission to considerable distances, and in a general treatise like this it may be left out of account.

Remembering that the current waste is due to two things, the resistance of the circuit and the counter electro-motive force, and that for the moment we take no account of the resistance, it is not hard to see that the ratio of e to E determines the waste, because of the counter electro-motive force. As E is proportional to the velocity of the generator armature V, so e is proportional to the velocity of the motor armature v. We have seen that if the work done by the motor remains constant, an increase of velocity of the dynamo armature is followed by an increase in that of the motor armature. If, then, we start with V at 200 and v at 100, and increase V by 500, v will increase by 500. Then as the ratio of $\frac{100 + 500}{200 + 500}$ or $\frac{600}{700}$ is far greater than that of $\frac{100}{200}$, it is clear that we shall have the least current waste, the greatest efficiency, when the dynamo armature revolves at a high rate of speed and the motor armature does the same.

This greatest efficiency must not be confounded with the greatest rate of working. Work is done by the motor most rapidly when the energy it absorbs is half that derived from the source of supply. The efficiency of the motor is accordingly only fifty per cent. when it is doing work at the most rapid rate, with a given source of supply. But to get the maximum of efficiency, we must have the minimum of current waste, the minimum of energy absorbed. It is evident, therefore, that the efficiency is at its maximum when the motor is running with a velocity the nearest possible to that of the generator. Perhaps this can be better understood by remembering that the work per second is the same, whether the load is great and the speed small, or the speed great and the work small. The greater the speed the less the current waste, and so the greater efficiency. In other words, the maximum of power employed will be turned into useful work when the motor is running under a very light load, *i. e.*, when little power is being transmitted. Then the motor will be doing only a small portion of the work of which it is capable, and much more than fifty per cent. of the power employed will be transmitted. It is desirable, then, to have machines of such size or in such numbers that they will never be called upon to do all the work of which they are capable. In this way there will be comparatively little power lost; of course, larger machines require more capital, and so the needs and resources of the consumer must always be consulted in the purchase of machines for transmission.

Another conclusion from the above considerations is that for the most economical transmission we must employ currents of high electro-motive force and low intensity; this, it will be seen, was also the conclusion reached when the question of transmitting Niagara's power was discussed.

In all this it has been assumed that the dynamo and motor are identical in size and construction. Then the mechanical efficiency is the same in each, *i. e.*, about ninety per cent. If the two are coupled so close together that the resistance of the circuit is inconsiderable, and the generator is worked to its full capacity, the power reclaimed will be ninety per cent. of fifty per cent. of ninety per cent., or 40.5 per cent. But if the relative size and construction of the machines are varied, the conditions are varied, and in this way, as well as by not running the machines to their full capacity, much better results can be obtained. Thus the power reclaimed has been run up to sixty or seventy per cent., and even higher.

Experiments by Marcel Deprez.

The question of the amount of power reclaimable was the subject of much discussion in connection with experiments made at the Electrical Exhibition in Munich, in the fall of 1882, by M. Marcel Deprez. He succeeded in transmitting power from the village of Miesbach, a distance of thirty-five miles, over an ordinary telegraph wire. The insulation was good, but differed in nothing from that usually employed on all telegraph lines. A heavy rain fell during almost the whole duration of the experiments, — a most unfavorable condition. In the first trial there was immediately obtained at Munich a speed of 1500 revolutions per second, the generating machine moving at the rate of 2200. "The two machines being identical," said Deprez, "the proportion of the work recovered at Munich to the work expended at Miesbach was, setting aside passive resistance of every kind, $= \frac{1500}{2200}$, or more than sixty per cent." These figures were subsequently sharply criticised in the *Electrical Review*, by the electricians Hospitalier and Cabanellas, and Deprez was finally forced to admit that while the electrical result, as he termed it, varied from fifty to beyond sixty per cent., the industrial result varied only from twenty-five to more than thirty-five, according as the generator turned at 1600 or 2000 revolutions. Nevertheless, the experiments were of great importance, when we consider that hitherto no great amount of power had been transmitted over anything but a copper conductor, and no considerable distance had been covered. Everybody knows that copper is a far better conductor than iron, of which telegraph wires are made. Had Deprez's conductor been of copper, he might have transmitted the power more than two hundred miles with no more resistance, and consequently no more loss. As Deprez overcame the great resistance of nine hundred and fifty ohms, it is easy to see, from the results he obtained, how small a factor is resistance, under ordinary conditions, in the electric transmission of power. This is also shown by the fact that after several hours of steady work the machines showed no appreciable heating. Considering their great internal resistance, it is clear that the intensity of the current and thus the quantity of energy lost was very slight.

In experiments made by M. Deprez in France, on the 1st of September, 1883, the generator was placed over eight and one half miles away from the motor, which was at

Grenoble. The power came from a turbine by means of gearing. The following table summarizes the principal results: —

Revolutions per Minute.			Horse-Power.		
	Generator. I.	Motor. II.	Supplied Generator. III.	Received at Motor. IV.	Per cent. transmitted. V.
(*a*)	720	484	6.97	3.30	47.3
	730	446	8.20	3.55	43.2
	732	406	8 96	3.69	41.1
(*b*)	865	614	8.33	4.19	50.3
	865	586	9.82	4.66	47.4
	875	558	11.05	5.08	45.9
(*c*)	946	712	8.42	4.86	57.7
	954	686	10.10	5.46	54.
	970	662	11.46	6.02	52.5
(*d*)	1040	830	9.69	5.66	58.3
	1040	778	11.08	6.19	55.8
	1050	734	12.33	6.68	54.1
(*e*)	1140	875	11.18	6.97	62.3

In this table no account is taken of the power lost in transmission from the turbine to the dynamo armature.

Study of these figures will throw additional light on one of the principles enunciated above. The figures are arranged in groups (*a*, *b*, etc.), because the three trials in each of these were made with practically the same speed of the generator armature, while by means of the Prony brake that measured the work done at the motor, the load was varied, being successively six, seven, and eight kilograms. This means that the work done by the motor was thus increased. You will notice that in each group as the work done was increased, the work supplied had to be increased, and in a greater ratio. The conclusion is that if the speed of the motor be not increased, any increase of work means a decrease in the ratio of power transmitted. On the other hand, you will notice that as the weight on the brake remained constant and the speed of the generator was increased, then the speed of the motor increased in a greater ratio, and a greater per cent was transmitted. This accords with the theory advanced above, that "the efficiency is at its maximum when the motor is running with a velocity the nearest possible to that of the generator." In other words, a great speed and a light load produce the greatest efficiency.

At Creil, France, M. Deprez has recently made extensive preparations for experiments in connection with the electric transmission of power. At preliminary tests in October, 1885, a circuit seventy miles in length was used. The generator was driven by a portable steam engine; five trials were made at different speeds; the results of the first and last of these follow: —

Generator.		
Electro-motive force in volts	3624.7	5469.75
Available work applied to driving shaft	43 h. p.	62 h. p.
Electric work of generator	37.38 h. p.	53.59 h. p.
Difference absorbed	5.62 h. p.	8.41 h. p.
Line.		
Energy lost in conductor	7.59 h. p.	7.21 h. p.
Motor.		
Electric work	24.10 h. p.	41.44 h. p.
Available work given out at shaft	22.10 h. p.	35.8 h. p.
Difference-absorbed	2 h. p.	5.64 h. p.

During the experiments the current varied from 7.59 to 7.21 ampères; no heating of any kind was observed. Notice that the electro-motive force reached over five thousand volts without endangering the line.

Electric Transmission in Practice.

In all these experiments M. Deprez has had in mind the transmission of great power to great distances. He has had no need to experiment in the transmission to small distances, for this question has already gone out of the realm of science into the realm of art. It is no longer a question of possibility or practicability, but of methods and means. Electric power in many places has for some years been sold just as steam power has been sold, and with profit to both seller and buyer.

Boston had the honor of furnishing the first recorded example of any considerable number of motors operated from a common centre, at least for commercial purposes. Here the dynamos of the Massachusetts Electric Power Company, using the Daft system, run by a steam engine, supply electric power to about twenty motors in various parts of the city. It is sold at so much a horse-power, the price at present being the same as that for steam. It is a curious circumstance that more power is sold than the engine can supply, — a paradoxical state of affairs explained by the fact that almost no set of machinery is kept running steadily, and the company supplying power gains by the stoppages.

The current never exceeds one hundred and twenty volts, and it has been demonstrated, in a course of very careful experiments conducted by the English Board of Trade, that any electric motive force under three hundred volts is safe for all ordinary conditions. So far, every motor in use has done the work required of it with complete success. One purchaser of power testifies that his motor has stopped only once since the system was introduced, and then only for a short time, because the wires were accidentally cut. The motor makes it possible for one firm of printers to be in a building where neither a gas nor a steam engine would be allowed in connection with a printing office. In another office the motor drives a long line of shafting with five printing presses attached; besides this, it drives a main shaft running through four buildings, to which are attached some lathes and sewing machines for heavy work connected with the trunk and valise business. Another user says: "It requires but little room, makes no dirt and no noise of any account." From experience it is said that the wear and tear in the motors is considerably less than that of any other motive machine of equal energy.

In New York and other American cities, as well as in many places abroad, the same and other results are being daily accomplished.

Sir William Siemens for several years demonstrated the variety of uses to which even on a single estate electric power can be put. He pumped water, cut wood and hay, lighted his house, and carried on experiments in electro-horticulture by electric energy derived from a common centre of steam power, with the most satisfactory results; the whole management was in the hands of a gardener and laborers who were without previous knowledge of electricity, and the only repairs found necessary were one removal of the commutators and an occasional change of the brushes. Sir William Armstrong, at his place near Newcastle, has utilized the power of a waterfall 1,500 feet from his house to light it by night and run a sawmill by day, using the same electric current for both purposes.

An interesting and suggestive use of electric transmission has recently been reported from New Zealand. It is said that there power is being transmitted from a waterfall in a valley straight over a mountain about two thousand feet high, and for a distance of about two miles, to run a stamping battery of twenty heads at a gold mine.

Possibilities.

The possible applications of the principle of the electric transmission of power are almost numberless. All the uses to which the energies of steam, water, or compressed air are now turned may be subserved as well by electricity, and this may be generated in places far more convenient than those now usually employed for the conversion into active energy of any of the forces latent in nature. We shall, I believe, at no distant date, have great central stations, possibly situated at the bottom of coal pits, where enormous steam engines will drive many electric machines. We shall have wires laid along every street, the electricity tapped into every house, and the quantity of electricity used in each house registered as gas is at present. The storage battery will fill a place corresponding to the gasometer in the gas system, making the current steady, rendering the consumer independent of the irregular action or stoppages of the dynamos of the central station, and enabling the use of dynamos of the highest electro-motive force. The electricity will be passed through little electric machines to drive machinery, to produce ventilation, to replace stoves, and to work all sorts of apparatus, as well as to give everybody an electric light.

By this strange and novel agency the power which is now daily wasted in a hundred ways is to do its share toward the support and advancement of the human race. The immense force of the tides will be called on to do work everywhere along the coast; the waterfalls and swift currents of rivers and streams, now uselessly spending millions and millions of horse-power every hour, will drive water wheels that shall send electric energy through every village and city. Will not the mechanical millennium arrive when the water power of a country is available at every door?

Then think of the power of the winds! It will not be a hard task to convert the energy of the zephyrs and the gales into electricity, which shall be stored away in accumulators till it is wanted to turn machinery.

Even if tides and winds and currents cannot be utilized, still there is an almost boundless field for the economical use of electric transmission. Go to any coal pit and see the tons upon tons of refuse coal, too poor to carry away, yet not too poor to burn on the spot. Go to the oil regions and see the gas burning night and day, — gas that might make steam if there was any use for the power.

There is no need to expatiate further upon the advantages to be gained from an economical method of transmitting power; the costly and persistent attempts of inventors and capitalists to get better methods are enough to prove their desirability.

Many systems have been tried and found wanting. Endless ropes and chains are too cumbrous and expensive. Water pipes are liable to all sorts of catastrophes, and water power from artificial reservoirs is both costly and inefficient. Gas motors are of limited power, and compressed air is hard to manage. But in electricity, thanks to living inventors, we have a force into which power can be transferred as by the wave of the magician's wand, a force which flows to any distance with the rapidity of lightning and the stillness of a ray of sunlight, and then at bidding resumes its original shape quicker than thought can follow it. No force appears in the conductor such as appears in shafting, in pipes with compressed air or water, in endless chains or belts; and, in case of powerful currents, insulation is easy. The conductor is inert and can be bent or shifted in any way whilst transmitting many horse-power, provided, of course, its continuity be not interrupted. It can be carried round the sharpest corners, through the most private rooms, into places where no other transmitter of power could possibly be taken. There is nothing to burst or to give way. In short, such a method of transmission would be the acme of dynamical science.

Steam, which in the last century has conferred so many benefits on the world, may yet give way before electricity. The dynamo may replace the steam engine. This prediction seems wild and visionary, yet when steam was first thought of as an available force, its advocates were considered, just as the advocates of dynamical electricity today are considered, mere enthusiasts. But public opinion never stops the march of intellect. After it had proved the powers of steam to be enormous, genius never halted, but straightway went on anticipating still more wonderful discoveries in the realms of electricity. The prophetic ken of science was happily exhibited by Dr. Lardner in his treatise on the steam engine. "Philosophy," said he, half a century ago, "already directs her fingers at sources of inexhaustible power in the phenomena of electricity and magnetism, and many causes combine to justify the expectation that we are on the eve of mechanical discoveries still greater than any which have yet appeared; and that the steam engine itself, with the gigantic powers conferred upon it by the immortal Watt, will dwindle into insignificance in comparison with the hidden powers of nature still to be revealed, and that the day will come when that machine which is now extending the blessings of civilization to the most remote skirts of the globe will cease to have existence, except in the page of history."

CHAPTER II.

THE HISTORY OF THE ELECTRIC RAILWAY.

Of all the uses to which the electric transmission of power can be put, its use for locomotion bids fair to be of the most benefit to the human race.

Very soon after electro-motors were invented, the idea of using them to facilitate locomotion was conceived. As to locomotion on sea, the honor of the conception must be given to Russia; but as to locomotion on land, the honor belongs to America. In other words, the electric railway was an American invention.

It had been found out that electric motors working on the oscillating or walking-beam principle, previously mentioned, were good for nothing but toys. A rotary motion was necessary, and whether this was first obtained in an electro-motor by M. Jacobi, a physicist of St. Petersburg, or Thomas Davenport, an inventor of Brandon, Vt., is a doubtful question. All the leading writers on electricity have given the great honor to Jacobi, without even mentioning Davenport. In fact, the man has been almost forgotten, and his claim entirely overlooked. It was in 1834 that Jacobi first produced rotary motion by means of an electro-magnet. There is clear proof given by an old pamphlet, discovered in the Boston Public Library by the writer, that in July of the same year Davenport also produced rotary motion by means of an electro-magnet.

Jacobi was a trained physicist, working in lines suggested by the labors of other physicists; Davenport was a country blacksmith of common education, and had never even heard of an electro-magnet till December of the year before. He saw one at the Penfield Iron Works, at Crown Point, on Lake Champlain, where it was being used for extracting iron from pulverized ore. It weighed only four pounds, but a weight of one hundred and fifty pounds could be suspended from it, and from this effect — wonderful to him it was — he immediately inferred, without any knowledge of the theory or the experiments of others, that he could propel machinery by "galvanic magnetism," as it was called. He immediately demanded the price of the apparatus, and bought it instead of the iron for which he had journeyed to the place. On returning home he showed it to his neighbors, and confidently told them that from this source he could get enough energy to move the largest boats. This declaration was received with general incredulity and ridicule, but, nevertheless, so positive was he of the great possibilities of his purchase, that he left his calling and devoted all his time to the object in view. When in the next year he had succeeded in producing rotary motion, he did not even know the names of the parts of his apparatus. The result of his arduous labor brought him many compliments, but, like most inventors, he found it far easier to get compliments than money. At last, after much difficulty, he got enough of the latter to enable him to go to Washington and deposit his specifications in the Patent Office, and to travel about the country somewhat, exhibiting his invention After his return from Washington, in the autumn of 1835, he went to Springfield, Mass., where, with the assistance of some mechanics, he built a small circular railway, on which he placed an electro-magnetic engine. So far as there is any record, this was the first electric railway in the world.

As Jacobi in Russia, and Davenport in Vermont, could not possibly have had any communication with each other in 1834, it is but fair to divide between them the honor of inventing the electro-magnetic motor, but the honor of inventing the electric railway most certainly belongs to Davenport alone. The originality of any plea whatever for him may be judged when we read among the writings of the celebrated physicist, Ganot, that "M. Jacobi, of St. Petersburg, was the first to construct an electro-magnetic engine, with which, in 1838, he moved on the Neva a small boat containing twelve persons." By reference to the Boston papers of the year 1835, it will be seen that in December of that year Davenport exhibited for two weeks at the Marlboro Hotel, in that city, an electro-magnetic engine, running on a small circular railway, the same that had previously been set up at Springfield. Thus, three years before Jacobi's boat swam the waters of the Neva, Davenport's engine, the result of American inventiveness, of American perseverance, of American intelligence, ran along the rails, giving America the proud honor of being the first to harness the giant force and compel it to do her bidding. Let Europe have the empty glory of the first electric steamboat; give America the glorious honor of the first electric locomotive!

We have seen that in the evolution of the dynamo-electric machine, the most important step was the substitution of electro-magnets for permanent magnets. The credit for this step has been given entirely to Europeans,— Hjörth, Varley, Siemens, and Wheatstone. No writer on the subject of electricity hitherto has seemed to doubt that all the honor in this connection belongs to Europe. Apparently not one of them has ever heard that seventeen years before Soren Hjörth applied for his first patent in England, a poor Yankee blacksmith had made practically the same improvement, though, to be sure, Hjörth was working with a magneto-electric machine, while the Yankee was working with an electro-magnetic machine. As one machine is just the other reversed, it is clear that the importance of substituting electro for permanent magnets is as great in one case as in the other. Moreover, Hjörth did not substitute electro-magnets, but merely combined them with the permanent magnets. It was Varley, Siemens, and Wheatstone who really substituted, and so this Yankee invention antedates theirs by thirty years. For the proofs, see an article by Prof. Benjamin Silliman, in *Silliman's Journal of Science and Arts*, for April, 1837. In it you will find this heading:—

"2. *Rotating Machine, composed entirely of Electro-Magnets, both in Fixed and Revolving Members.*"

And under it you will read:—

"A machine of this construction has been this day, March 29, 1837, exhibited to me by Mr. Thomas Davenport himself, who came from New York to New Haven for that purpose. It is the same machine that has already been described, except that the exterior fixed circle is now composed entirely of electro-magnets. The conducting wires were so arranged that the same current that charged the magnets of the motive wheel charged the stationary ones placed around it, only one battery being used. It lifted sixteen pounds very rapidly, and when the weight was removed, it performed more than six hundred revolutions per minute."

One of Prof. Silliman's conclusions at the end of his article is: —

"That it is not necessary to employ permanent magnets in any part of the construction, and that electro-magnets are far preferable, not only for the moving, but for the stationary parts of the machine."

Early Inventors.

The discoveries of Davenport and Jacobi excited great interest in electro-motors both in this country and abroad. In the next few years hundreds of them were manufactured to meet a demand that proved groundless. It was very natural that many inventors should try to develop Davenport's idea of using them on railways. One of these inventors, a Scotchman, named Davidson, was, so far as we know, the first European to build an electric locomotive. It was constructed in 1842, on a large scale, and was tried on the Edinburgh and Glasgow Railway; it weighed with its carriage, batteries, etc., five tons, but never travelled at a rate faster than four or five miles an hour.

In 1847, Prof. Moses G. Farmer constructed and exhibited in public an electro-magnetic locomotive, and with forty-eight pint-cup cells of Grove nitric acid battery drew a little car carrying two passengers, on a track a foot and a half wide. In the same year, Mr. Lilley and Dr. Colton, of Pittsburg, devised an electric locomotive which ran on insulated rails, each connected to a pole of the battery, the current being communicated to the engine through the wheels. The engine was provided with two magnets, which, by a process of alternate attraction and repulsion, drove the car over the track. Their invention is of especial interest because, so far as we know, this was the first conception of a source of power independent of the locomotive, *i. e.*, not carried along with it. In fact, this was the origin of the "central station" idea that is so conspicuous in all modern electric railway systems.

Prof. Page, one of the most eminent American scientists of the last generation, was led to the study of electro-magnetism by the discoveries of Prof. Henry and Mr. Davenport. He made many electrical inventions, among them perhaps the very important one of what is known as the Ruhmkorff coil; at any rate, his claims to that honor, though seldom now urged, are strong. Among the machines he constructed was a large and efficient electromotor which developed over ten horse-power. This motor proved so successful and attracted so much attention, that Congress was induced to appropriate and place at his disposal $30,000 for the construction and operation of an electric locomotive in accordance with his plans. Ben: Perley Poore has recently described the trial trip as follows: —

> "Professor Page made a trial trip with his electro-magnetic locomotive on Tuesday, April 29, 1851, starting from Washington. The progress of the locomotive was at first so slow that a boy was enabled to keep pace with it for several hundred feet. But the speed was soon increased, and Bladensburg, a distance of, I believe, about five miles and a quarter, was reached in thirty-nine minutes. When within two miles of that place, the power of the battery being fully up, the locomotive began to run on nearly a level plane, at the rate of nineteen miles an hour, or seven miles faster than the greatest speed heretofore attained. This velocity was continued for a mile, when one of the cells cracked entirely open, which caused the acids to intermix, and as a consequence, the propelling power was partially weakened. Two of the other cells subsequently met with a similar disaster. The professor proceeded cautiously, fearing obstructions on the way, such as the coming of cars in the opposite direction, and cattle on the road. Seven halts were made, occupying in all forty minutes. But, notwithstanding these hindrances and delays, the trip to and from Bladensburg was accomplished in one minute less than two hours. The cells were made of light earthenware, for the purpose of experiment merely, without reference to durability. This part of the apparatus could therefore easily be guarded against mishap. The great point established was, that a locomotive on the principle of Professor Page, could be made to travel nineteen miles an hour. But it was found on subsequent trials that the least jolt, such as that caused by the end of a rail a little above the level, threw the batteries out of working

order, and the result was a halt. This defect could not be overcome, and Professor Page reluctantly abandoned his discovery."

Although Dr. Page's hopes were not realized, he accomplished a great feat, and to the day of his death he contended that the time would surely come when electricity would be economically used as a motive-power on railroads.

In 1851, Thomas Hall, of Boston, constructed, and later exhibited at the Charitable Mechanics' Fair in Boston, a small electric locomotive which took its current from a stationary battery by means of the rails and wheels. The cut-off was in the engine, and worked automatically or by hand; so that when the engine reached the end of the track, the switch reversed it and it went back to the starting point.

Other inventors worked on the idea of electric locomotives, and the story goes that the inventor of one exhibited in Charlestown, Mass., refused $100,000 for his invention. He would have been wiser had he taken it. The trouble with his scheme, as with Page's and Davenport's and all the other electro-motors that have promised literally to electrify the world, was the comparatively high cost of getting electricity to run them. Jacobi's boat, though it had the current from three hundred and twenty Daniell cells, and later from one hundred and thirty-eight Grove cells, could n't get up a speed of three miles an hour at its very best. It cost the Emperor Nicholas $1,200 to find out that this method of employing electric energy was neither economical nor useful. How many thousands were spent elsewhere in the vain research, no man will ever know! The time for electric locomotion was not come. First the problem of cheap electricity had to be solved. When dynamos gave the solution, Davenport's idea of an electric railway gained practical importance.

CHAPTER III.

ELECTRIC RAILWAYS ABROAD.

Dr. Werner Siemens was the first to demonstrate practically that, with the new method of generating electricity, an electric railway could be operated on a useful scale. This he did in the year 1879 by building and operating an electric railway on the grounds of the Industrial Exhibition at Berlin. It was a narrow-gauge line, laid down in a circle nine hundred yards long. A train of three cars was placed upon it, and on the first car a medium-sized dynamo for a motor was fixed to the axle of one pair of wheels, in such a manner as to rotate the wheels when the armature of the machine was revolved by the passage of a current through its coils. A central rail supported upon insulating blocks of wood ran between the two working rails, and it was by this central conductor that the current was led from the generating machine placed at one terminus of the line. The current was drawn from this rail to the armature of the motor by means of a brush of copper wires; and after traversing the coils of the armature it was led to the axle of the driving wheels, which was insulated from the body of the car, and thence by the driving wheels to the outer rails, and by them back to the dynamo machine at the terminus.

Between twenty and thirty persons could be accommodated on the train at a time, including the conductor, who rode on the first carriage; and during the course of the summer no fewer than 100,000 people were conveyed over the line, at a maximum speed of from fifteen to twenty miles an hour. Crowded trains left the stations every five or ten minutes, and a considerable sum was earned in this way for the benefit of charitable institutions. The locomotive was capable of exerting five horse-power; to start or stop, it was simply provided with a switch for closing or opening the circuit of the current.

The success of Dr. Siemens' experimental railway soon led to the construction of the Lichterfelde line, in the suburbs of Berlin, for every-day work. It is a mile and a half in length and has a gauge of three feet three inches. There are no considerable grades. The rails are placed on insulated sleepers, one being used for the positive current and the other for the negative. The current was at first furnished by two dynamos, but these were afterward replaced by a single powerful machine connected direct to a rotary steam engine. Instead of a locomotive drawing the cars, each car carries its own motor. The cars are like those ordinarily used on horse railways, and will carry twenty-six persons each. The electro-motor is carried under the body of the car between the wheels, the armature being placed at right angles with the road. Its movement is transmitted to the wheels by means of a belt working on cylinders outside the wheels. The Lichterfelde road has been in constant operation since the 16th of May, 1881, and, it is said, has never failed to carry its daily traffic.

For the Electric Exhibition at Paris, in 1881, was built an electric railway one third of a mile in length and with a gauge of four feet eight and one half inches. Two suspended hollow tubes with a longitudinal slit were used for conductors, the contact being made by metallic bolts drawn through these slit tubes and connected with the motor on the car by copper ropes passing through the roof. Suspended tubes were used because the rails were necessarily laid even with the earth like those of an ordinary horse-car track, and the dirt sticking to the rails and the rims of the wheels made a kind of insulating crust, which prevented contact between rails and wheels good enough to permit of the rails serving as conductors. The maximum speed of the car on this road was at the rate of forty miles an hour; the average was at the rate of ten and one half. The line had one curve of sixty-one yards radius, and two others of thirty-three. At one point there was a grade of an inch a yard (one hundred and forty-seven feet to the mile). The car could carry fifty persons, and when filled weighed about ten tons. The armature of the dynamo revolved five hundred and fifty times a minute; of the motor, four hundred and sixty-five. Upon the straight part of the line the work expended at the average speed was three and a half horse-power; on the curve, seven and a half; on the ascending grade, more than eight and a half. The transmission of motion to the wheels was effected by means of a fall chain.

The Portrush Railway.

An electric railway has been in successful daily operation in the North of Ireland since Nov. 5, 1883. It starts from the railway terminus of the Northern Counties Railway at Portrush, in the County Antrim, and runs along the magnificent coast road to Bushmills, a distance of six miles, ending within a short distance of the Giant's Causeway. The total length of the way, including the branch way, to the harbor at Portrush, and the several sidings, is upward of seven miles. The road is one continuous series of long inclines; grades of one in forty-five and one in forty are frequent for upward of a mile in length, while steeper grades of one in thirty exist for shorter distances, the worst grade being one in twenty-five. The summit level occurs about midway, at an elevation of about one hundred and sixty feet above either terminus, the total rise from the depot at Portrush to the summit being two hundred and three feet. Some sharp curves exist along the line, the worst one having a radius of about forty feet. There was some doubt in the mind of Sir William Siemens, the constructor of the line, whether with the arrangements adopted these inclines could be worked satisfactorily; but experience has proved that they can be, and the car, when fully loaded, is drawn up the grades without difficulty. There are seven "passing places" along the line, where the "points" are set so that the cars travelling in opposite directions always take their own sides respectively.

At first the power was produced by a steam engine at Portrush, giving motion to a shunt-wound dynamo of twenty horse-power; but arrangements were subsequently made to utilize a waterfall of ample power on the river Bush, situated 1,600 yards from the nearest point of the tramway and six and a half miles from Portrush. A fall of twenty-six feet head of water is used to drive two turbines, each capable of working up to fifty-two horse-power; these turbines are provided with friction clutches, and drive a single shaft, which communicates by belting with a generating Siemens dynamo, working at a speed of about seven hundred revolutions per minute, and generating a maximum potential of two hundred and fifty volts with a current of one hundred ampères. This generator is connected with the conductor rail alongside the tramway by an underground insulated cable formed of thirty-seven strands of copper wire fully insulated, and covered with thirty-four strands of copper wire, which outer casing is used for the return current. The resistance in the cable connecting the generating dynamo with the conductor rail is .5 ohm, and in the conductor rail from Bushmills to Portrush is 1.4 ohms; the total resistance from the generating station to Portrush and back is therefore 1.9 ohms. The insulation resistance along the whole line varies from five hundred ohms in wet to one thousand ohms in dry weather, the total leakage along the line being 2.5 ampères, which is equal to a loss of three quarters of a horse-power. As the electricity in the conducting rail is never allowed to exceed two hundred and fifty volts as a maximum, only slight shocks are felt upon touching it with the hand.

The two carrying rails, three feet apart, are not insulated from the ground, but being joined electrically by means of copper staples, they form the return circuit, the current being conveyed to the car through a T-iron placed upon short standards and insulated. Where a gap necessarily occurs, such as at a cross-road, they simply stop the T-iron and begin it again at the other side of the gap, connecting the two ends by means of an insulated conductor below ground. In order to span the gap, two brushes are attached to the car, one in front and the other toward the back of the car, and the gap being a little less than the distance between the two brushes, the one brush catches the opposite side before the other one leaves. Thus, by a simple arrangement, they get over the difficulty of crossing by-roads.

The motor is contained in a small inclosed box underneath the floor of the car; the electricity is gradually turned on by a commutator starting handle, through several resistances to the motor; the speed is reduced by spur gearing and a pitch chain, driving on a toothed wheel upon the axle, whereby motion is communicated to the car, and a speed of ten miles an hour is readily obtained.

Mr. Traill, the engineer of this road, told the Inventors' Institute last year that, after repeated failures, they had at last hit on a thoroughly trustworthy plan for getting electricity from the conductor. This was by means of a steel spring in the form of a carriage spring; two concave steel springs were fastened at the top and rubbed along the bottom. Some had been running for nearly a year, and when new cost only a little over a dollar. His cars had then successfully travelled over thirty thousand miles with one hundred thousand passengers. The cost of electricity generated by water-power a mile distant was one quarter that of steam used on the same railway.

It is said that the construction of this road cost $225,000; that it is paying a twelve per cent. dividend; and that the working expenses are five cents per train mile. An extension of six miles is contemplated.

Other Practical Lines.

The electric railway on the beach at Brighton, England, has been running now for a year, and has carried a heavy traffic without hitch or delay. The motors in the cars have required no repairs beyond truing up the commutators occasionally; the generating dynamos have each had to be fitted with a new commutator. The cars on this road run incessantly twelve hours a day, and have a recorded mileage of 31,200 miles a year. The cost of traction (a gas engine being used) is a fraction over four cents a car mile, and the average earnings about thirty cents a mile.

The electric railway last opened in Great Britain runs between Newry and Bessbrook. It seems that the Bessbrook Spinning Company, owning very extensive mills and granite quarries at Bessbrook, has hitherto been obliged to cart all its coal, goods, and stores from the wharves and railway stations at Newry, three miles away. This traffic, including that furnished by the village of Bessbrook, amounts to about 28,000 tons a year, and much inconvenience has been felt from having no better method of conveying it than ordinary carts. A railroad has been contemplated for some time, but there were difficulties about carrying one end clear to the railway stations and the other to the various departments of the mills. Now they have built an electric railway, on which run cars with flangeless wheels, so that at the end of the rails horses can take the place of the electric motor. These wheels have tires wide enough (two and one half inches) to allow them to be run on the ordinary roads of the country. They run on light rails outside ordinary railway rails, the latter acting as a guard. The wagons carry a maximum load of two tons, and six of them make a train. Thirty-four passengers may be carried. There are inclines of as much as one in fifty. The trains move now at an average speed of about fifteen miles an hour, but it is expected that when the apparatús is perfected, this speed can be very much increased. The electric conductor consists of an inserted steel channel carried on insulators fixed midway between the rails. No steam whatever is used on the line. The dynamos are operated by means of the power collected from a waterfall, the water striking a turbine wheel with such force as to devolop sixty-five horse-power.

The electric railway at Blackpool, England, of which M. Holroyd Smith is the inventor and engineer, was formally opened on the 29th of September, 1885, amidst the most enthusiastic rejoicings. The Lord Mayor of York, the mayors of Manchester and Liverpool, and of about twenty-five other towns, accepted the invitation of the mayor of Blackpool to do honor to the occasion, and vast crowds poured in by ordinary and excursion trains from all the large towns in Lancashire and Cheshire. It is estimated that about 50,000 persons were present. The proceedings of the day comprised a big procession, speeches, a collation, and fire-works. One speaker eloquently compared the occasion with the opening of the Stockton and Darlington Railway in 1825.

The Blackpool line is about two miles in length, and consists of the ordinary rails, with the addition of a central channel sunk below the roadway, and presenting only a very narrow slit or opening to the surface. Within this channel are laid the two electric conductors, made of special drawn copper, and so placed against the sides of the channel as to be protected from the possibility of injury being occasioned to them through the slit at the top. Two twenty-five horse-power engines drive each a large dynamo, generating a current which it is calculated is enough to drive ten cars fully loaded with their four hundred passengers. (This will seem strange to one who does not know that in England the nominal horse-power of an engine is generally less than one quarter of its indicated power when under full load.) The starting gear consists merely of two handles or plugs, which fit into four holes arranged like the points of a diamond; if the car is to move forward he puts the handles in the top and bottom holes; if the car is required to move backwards he removes them into the two side holes. The first cost of the whole road was estimated at about $55,000.

The advantages of the use of electric railways in mines have already been practically demonstrated at Zankerode in Saxony. On the surface there is a dynamo, driven by belting from a small vertical engine placed with the cylinders inverted, the pulleys being about three to one. The engine is run at about two hundred revolutions a minute, and the dynamo at about six hundred. From this the electricity is conveyed by a half-inch copper wire down the pit shaft, which is one hundred and twenty fathoms deep. The road, which is a cross-cut mine, to get over a fault, has a double line of rails in it and is arched with brick throughout its length. As the rails could not be well insulated, and the road is used for rough work, the conductors were placed overhead, consisting of two inverted T-rails fixed to the roof of the tunnels by means of porcelain insulators fastened to the brick-work. On these T-rails run two traversers, connected by flexible conductors with the motor in the car beneath. This motor is placed with its armature lengthwise on the car, and works one pair of driving wheels by means of bevel gearing. The locomotive weighs about a ton and a half, and can draw a load of eight tons at the rate of seven or eight miles an hour. It makes twenty-five trips a day, and transports about two hundred tons of coal in that time a distance of between seven hundred and eight hundred yards. The journey is made in about four minutes. The following figures as to the power have been given: steam engine, ten horse-power; dynamo, five horse-power; motor, three horse-power. This would give thirty per cent. reclaimed; the whole plant cost about $4,500. The system has been in operation over two years, and has given satisfaction.

An electric railway on the Siemens system has been in successful operation since April, 1884, between Mœdling and Brühl, in the suburbs of Vienna, a distance of a little over two miles. The power has been generated by five dynamos, each giving thirty ampères, with a difference of potential at the terminals of five hundred volts.

It is annouced that the Swiss government has granted a firm of electrical engineers at Geneva the right to build an electric railway up Mt. Salève, near Geneva. The line will be laid with a central rack, like that of the Mt. Washington railway, but the toothed pinion of the engine that gears into it will be driven by electricity instead of steam.

The Use of Storage Batteries.

The idea of storing electricity has received its practical development within the last half-dozen years. Few inventions have ever been seized with such eagerness by capitalists. The news of Faure's discovery came just as the possibilities of the electric light were dazzling the eyes of the speculators and the telephone had made so many fortunes. Men were on the alert to get hold of some other profitable application of electricity, and they were only too ready to comprehend what benefits might be reaped from a device for storing it. Scientific men saw clearly what these benefits might be, but were foolish enough to think, or at least to let others think, that all these good things could be had at once. As usual, when the world once conceives the possibilities in an invention, no account was taken of the immense amount of work necessary to perfect it. So when the capitalists had sunk a great deal of money and the engineers had found what a task lay before them, sneers took the place of prophecies, and the storage battery fell in public esteem as fast as it had risen. Yet some men had confidence in the invention and kept on working at it. Though none of the vagaries of the theorists have yet been realized, much has been done in the line of improvement, and to-day it looks as if the storage battery is now almost ready to play a most important part in the electric world. Little of the work has been done in America, and the storage companies here have been content to hold to their rights without exercising them. In Europe, however, practical results have been attained to a degree warranting our consideration.

A storage battery, sometimes called a secondary battery or an accumulator, may be described in a very general way as a vessel containing acidulated water in which stand two lead plates. When an electric current from a dynamo or a primary battery is passed between these plates, a chemical action takes place which results in oxidizing one of them. When the two plates are joined by a wire a current will pass from one to the other just as in an ordinary battery. The effect of this current is to undo the work that charged the battery, so after a while the current will stop. Then the battery must be charged again by running a current through it. Thus, it is clear that, strictly speaking, electricity is not stored, but that electric energy is converted into chemical energy, which can be re-converted into electric energy at will.

The art of storing electricity is as yet so young that it would be impossible to say exactly how much energy is lost in this process of charging and discharging the cells. The most sanguine believers in the system assert that it has now been so nearly perfected that not ten per cent. is lost. It is safer to assume that in actual work the loss will be somewhere between twenty and forty per cent. The most serious objection to the use of storage batteries has been on the score of waste, but a moment's thought will show that they would be of great value even were the loss much greater. The convenience of storage would outweigh the evil of loss altogether when the power would otherwise be so completely wasted that every fraction of it stored is clear gain, as in the case of many waterfalls, or the refuse coal at the mouth of the pit. Waste would be a minor consideration, too, when regularity and continuity of supply are wanted, but the source is irregular and fitful, as in the case of the tides and the winds. On the other hand, if the source of supply is regular but weak, as in the case of a small current or engine, and the power is to be used but for a short time each day, the per cent. of loss is of little consequence.

In their application to railways, storage batteries merely take the place of the conductors previously described. The generating dynamo at a central station is still necessary, but if more power is at hand than is needed, the machine can do its work in a few hours each day; or if the trains run only a part of the day and the power is small, the dynamo can be kept at work all the time. In the working of the motor there will be no difference whatever. The storage battery must be carried about with the train, and its cells are both heavy and bulky. Whether this disadvantage, and the waste of power in charging and discharging the cells, will counterbalance the necessarily intricate arrangement of posts, wires, traversers, rails, or whatever may be used for conducting the current in the other systems, is a question that has hardly received discussion, much less solution. No thorough attempt to compare the cost of plant has been made. In the matter of safety alone it is clear that storage batteries have the advantage, and as it now seems likely that the conductors in the Daft system at least will be harmless, this point does not count very much one way or another.

One of the first assertions as to what storage batteries could do on railways was made in March, 1882, by Prof. W. E. Ayrton, a noted English electrician. He claimed that using only a single cell of Faure's accumulator, about three hundred pounds dead weight contains all the energy and all the machinery necessary for over ten miles' run of a street car with forty-six passengers. In spite of the temporary character of the arrangement at the time in use at Leytonstone, the total weight of the Faure cells, dynamos, and gearing combined was only a ton and a half, or one third the weight of the detached steam or compressed-air engine, commonly used for street cars.

In experiments made later at Kew Bridge, on the Acton tramway line, London, the car used was fitted with fifty cells, containing energy enough to run a street car with its full load for seven hours. The accumulators were stored under the seats of the car. The motor worked satisfactorily and showed an exertion of about eight horse-power. The speed was diminished or increased by throwing accumulator cells out of the circuit, or adding others. The car could carry nearly fifty persons, the total weight being about five tons. The speed attained was six miles an hour. The car was lighted with incandescent lamps, and supplied with electric bells, both worked by the accumulators. The cost of running cars in this way was estimated at $1.50 a day.

Since March, 1882, an electric railway using Faure accumulators has been in operation at Breuil-en-Auge, France, with great practical success. Ten baskets in the tender each contain six accumulators, the whole sixty weighing 1,100 pounds. The electric locomotive with the motor weighs 2,000 pounds; the tender with the accumulators, 1,500; each loaded car, 1,700. With the workmen and six passengers, the total weight of the train is seven tons. It takes three horse-power of an engine for from five to eight hours to charge the accumulators, and they furnish energy for three hours' running. This railway is the property of a large bleaching establishment, and runs through the bleaching fields to pick up the linen. When the train stops, the motor is thrown into gear with a set of windlass rollers employed to wind up the linen. With it a single workman can do in thirty minutes what it used to take eleven hours to accomplish. A steam engine would never do in a bleaching field, and the application of electricity in such a case is not only novel, but highly suggestive. The public may soon insist that its lungs, eyes, and ears have as much claim as the linen of the bleaching field to be protected from the smoke and cinders of a steam engine.

On the 6th of September, 1883, an ordinary three-horse street car driven by Faure accumulators ran without an accident for three hours over the most important Parisian thoroughfares, covering about thirty English miles.

Reckenzaun, the deviser of another railway system in which storage batteries are used, estimates that sixty of the cells used in his system will weigh a ton and a quarter, and propel a car with forty-six passengers for about two hours over a road with ordinary grades and curves, and sixty stops an hour. Assuming that the cells for several cars are being charged by one engine, and reckoning the cost of coal at $4.35 a ton, he estimates that the fuel per car-mile would cost less than two cents. He estimates the total cost of running, including depreciation, at seven cents a car-mile.

A rough estimate of the expenditure of capital necessary for the complete equipment for six cars puts the figure at about $25,000; a similar estimate of the total running cost per annum makes it about $12,000, not including wages of drivers and conductors.

Reckenzaun's system was recently put to the test in Berlin. The first trial took place in December, 1885, in the presence of many officials concerned in the public safety and convenience. No private trials had been allowed, because the car could only be run in the public thoroughfares. Moreover, the worst portion of the line was selected for the trial, there being to start with curves of thirty-three feet radius, a long incline, and the rails blocked with snow and ice. The car was filled with officials. Not the slightest hitch occurred during the whole trip, the car being stopped, started, and the speed varied at the command of the chief tramway inspector, the trial giving entire satisfaction to all present. The accumulators used in the car are charged from the central electric lighting station in the Ausstellungs Park, by a "Victoria" dynamo, at a distance of about a quarter of a mile from the starting shed. The same machine is used at night for illuminating some of the buildings in the park. Subsequent trials have had such favorable results that the adoption of the system on the greater part of the lines of the Berlin Tramway Company is considered probable, and as a result, the shares of that company have gone up more than one per cent.

According to reports from several papers, the boards of directors of the Berlin tramways, the Stettin and the Potsdam tramways, have resolved to equip a number of cars forthwith with the electric apparatus.

A novel and ingenious electric motor using accumulators is that recently devised by C. P. Elieson, a London inventor. Instead of being a fixture, the motor revolves bodily. To understand how this is done, imagine an ordinary dynamo used as a motor, placed on the floor of a car directly over the axle of one pair of wheels. To the centre of the base of this dynamo is fastened the top of a vertical shaft running through the bottom of the car and having on its lower end a bevel wheel which gears into other bevel wheels on the axle, so that if you turn the motor round bodily, the motion is transmitted through the vertical shaft and the bevel wheels to the axle, the car wheels revolve and the car moves. The motor is turned by means of its armature, which projects about two feet from the body of the dynamo, and has on its end a spur wheel. This gears into a circular rack fixed to the bottom of the car. As the current causes the armature to revolve, the spur wheel is started on its journey round the circular rack, and thus the whole motor is horizontally rotated. By means of friction clutches a backward or forward motion can be secured without reversing the direction in which the motor is revolving. Of this device one writer says:—

"He (Elieson) has applied a lever between the electro-motor and the axle of the locomotive in such a way that the motor, which must necessarily run at a high rate of speed in order to develop the greatest efficiency, acts through the lever by a method analogous to the case of a man using a crow-bar for the purpose of lifting a heavy weight. By this contrivance the inertia of the loaded car is easily overcome."

In the trials of this motor a secondary battery of fifty cells has been used, the electricity supplied having a total of about two hundred and eighty ampère hours. The average consumption is said to be forty-five ampères an hour, so that the car carries a six hours' supply of power. It is claimed that an engine consuming only two tons of coal a week will charge batteries sufficient to do the work of four cars requiring at present forty-four horses a week. The motor appears to be controlled with perfect ease, and though at present it is fitted up separately from the car itself, so as to take the place of horses and utilize existing cars, the inventor claims that it can in future easily be constructed as a part of the passenger cars. The speed obtained is eight miles an hour; but it is said the motor could do a great deal better if necessary.

CHAPTER IV.

ELECTRIC RAILWAYS IN AMERICA.

IT was natural that an idea developed like that of the modern electric railway should result in many claimants for the priority of invention. Three different inventors filed their claims in the Patent Office at Washington: Stephen D. Field, then of San Francisco, Cal., March 10, 1880; Ernst Werner Siemens, of Berlin, Germany, May 12, 1880; and Thomas A. Edison, of Menlo Park, New Jersey, June 5, 1880. They were independent inventors, and each had practically demonstrated the feasibility of the invention by building a track and running an electric locomotive over it. A protracted contest of four years followed, at the end of which time Examiner of Interferences McArthur rendered an elaborate opinion in which Field was adjudged to be the prior inventor and to be entitled to the patent therefor.

It had been argued that the modern electric railway system, as set forth in the application of these inventors for letters patent, merely consists in substituting the dynamo-electric machine for the galvanic battery employed by the early experimenters whose labors have been described, and that no invention whatever was required to make this substitution. The examiner, however, decided that a real invention was involved, and that this invention was a system, and should be considered apart from the particular mechanical construction in which it had been embodied. These constructions and devices, separately considered, presented no novelty whatever; they were all old and in common use. "The invention," said the examiner, "consists in combining them in the manner set forth for the purpose described. Such being the case, a conception of it must involve all the elements of the combination." He defined the invention as (putting it in plain English) the transfer, by means of an electric current, of try, labored under the legal disability imposed on him by Sect. 4,923 of the Revised Statutes, viz.: —

> "Whenever it appears that a patentee, at the time of making his application for the patent, believed himself to be the original and first inventor or discoverer of the thing patented, the same shall not be held to be null or void on account of the invention or discovery, or any part thereof, having been known or used in a foreign country before his invention or discovery thereof, *if it had not been patented or described in a printed publication.*"

No evidence was adduced to show that either Field or Edison had any reason to suppose that he was not the original and first inventor of the contested invention at the time of filing the respective applications. Hence, no proof of the prior completion of the invention, or of its introduction to practice, or even of its commercial use, in Germany, could avail, in a legal point of view, as against the dates of Field and Edison, whose inventions were made in the United States. It was in 1879 that Dr. Siemens' electric railway was shown at the Electrical Exposition, held in Berlin, and so the examiner held that on the 9th of June of that year, Dr. Siemens had completed the contested invention, and fully disclosed it to others, besides having reduced it to a practical working form.

From this the examiner concluded that Field, if not absolutely the first to conceive the invention, was certainly the first to do so in a manner entitling him to receive a patent under the statute. His application, however, was narrowed down by the commissioner to the simple claim for a combination of an electric motor operated by means of a current from a stationary source of electricity conducted through the rails. The work done by Hall and others in this line was overlooked, but since then the commissioner's attention has been drawn to this matter. This, however, by no means settled the question, and the litigation has since continued with unabated vigor. From the office of the Commissioner of Patents I learn that "the examiner reports that a new interference has been declared between Field and others, and it may be years before a conclusion will be reached."

It is improbable that the sole right to run electric railways will ever be allowed to any one inventor. Any one who reads the history of electric railways cannot doubt that their principle was first conceived half a century ago, and that to grant sweeping rights to any one recent inventor would be an act that justice would not sanction.

An historical sketch of electric railways in this country would be incomplete if no mention was made of the fact that in 1884 a determined effort was made to unite the interests of the American electric railway companies, and create a great monopoly in electric railroading. The American Electric Railway Company was to be the name of the resulting company. Each inventor and owner of patent rights was to transfer them to the new company, receiving in return stock therein in proportion to the rights transferred, their value to be determined by a board of arbitration. The arbitrators were appointed, but have never held a meeting, and it is doubtful if they ever will. In fact, it is not probable that the American Electric Railway Company will ever be anything more than a name.

Testing the Theory.

The first public experiment in the use of an electric motor driven by electricity from a dynamo on an ordinary railway in this country was made on the 24th of November, 1883, upon the line of the Saratoga, Mt. McGregor and Lake George Railroad at Saratoga Springs. The Daft motor "Ampère" was attached to an ordinary ten-ton passenger coach (it is a road of three feet gauge), into which sixty-eight passengers were crowded. The motor ran a mile without stopping at the rate of about eight miles an hour. On the return trip the motor jumped the track, but was afterward used with success. The car and passengers together weighed about sixteen tons, and it was pulled up a grade of ninety-three feet to the mile and round very sharp curves with no difficulty whatever. It was estimated that less than fifteen horse-power was consumed. The "Ampère" was the first machine of which there is any record wherein the regulation over a large range of speeds was performed entirely without the use of external resistances; as far as experiments were conducted, it proved its economical working at all speeds by maintaining an approximately uniform ratio of current to work. All the Daft electric motors have been regulated in the same way.

An electric railway operated by the Daft system was opened at Coney Island in the summer of 1884. It extended seven hundred and eighty feet along the west side of the West Brighton pier. The track was of two feet gauge; the rails were laid on strips of wood, firmly bolted to the pier planking. No attempt was made at insulation and none was needed, as on the wettest days the escape of current was hardly perceptible. The motor weighed about one thousand two hundred pounds. The running gear consisted of four twelve-inch wheels with four-inch centres. The rails were used as conductors, and to prevent short circuiting, the wheels on one side were insulated by the use of wooden centres. The maximum speed of the motor was from twelve to fifteen miles an hour, but this was limited by the shortness of the track.

The Bentley-Knight system of electric railways was put in use on the East Cleveland horse railroad, at Cleveland, Ohio, in August, 1884. The chief engineer of this system, W. H. Knight, has written to me about this road as follows: —

> "The Cleveland road was a temporary plant built to experiment with through all kinds of weather, and consequently after it had been run for a year (August, 1884, to August, 1885), it had served its purpose and had to give way to a more substantial road. It was found there that such a road could be run with perfect safety, control, economy, and cleanliness. The road was two miles long, had a wooden conduit between the rails, and operated two motors at a normal speed of eight miles an hour. It had a branch track, a turn-out, and a level railroad crossing at an angle of forty-five degrees; it had two curves of forty-five feet radius. Passengers were carried and fares collected in the regular operation of the road, and experiments conducted at the same time."

Mr. Knight does not explain why electricity was not adopted for the motive-power on the "more substantial road" spoken of. It is probable, however, that the failures, more or less numerous, incidental to the early experiments with any invention, led Cleveland capitalists to believe that electricity could not do the work. That the faith of the projectors was not shaken, but rather was strengthened by these experiments, is shown by the fact that they are going ahead and developing their ideas.

At Toronto, Canada, in 1884, the Van Depoele system was experimentally tried, and in the following year practical results were accomplished. The track was a mile long; the generator, a forty horse-power dynamo; and the motor, a thirty horse-power machine weighing about a ton. The current strength was small and the electro-motive force large. The inventor claimed that only twenty-five per cent. of the power was lost in transmission. It is said that the road worked regularly fourteen hours a day six days in the week, and carried during the busy portion of the day as many as two hundred and fifty passengers a trip.

Late in 1885 the Van Depoele system was put in operation at South Bend, Ind. As there applied, it has been described as follows: —

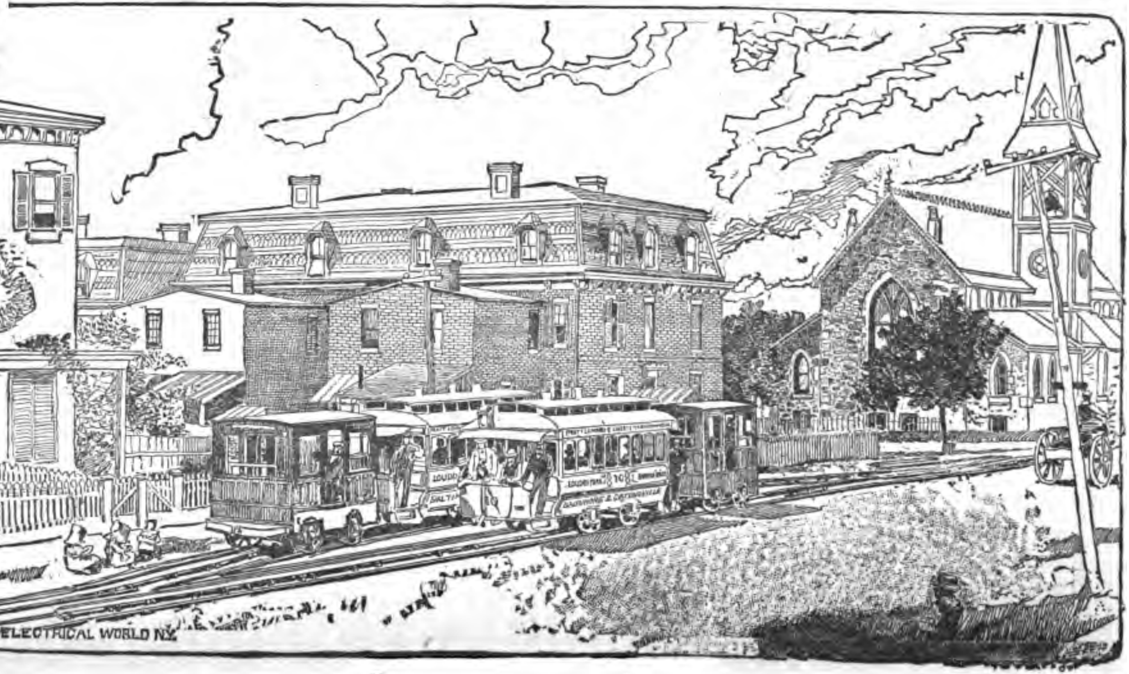
> "The railway at South Bend is operated by an electric current transmitted by overhead wires. The current is generated by three Van Depoele dynamos, which form the stationary motive-power plant, and is conducted to the motor of the street car by means of a wire extending from the overhead cable. From the motor the current passes through one of the wheels, and by means of the track the circuit is completed. In order to make the track a perfect conductor, strips of brass are laid under the joints of the rails. As but one track is used, the cars must pass each other on switches, and an ingenious device provides for this necessity. It consists of a brass and copper frog or switch, attached to the copper wire. This hangs directly over the frog in the track. It is so arranged that the motor-connecting wire passes through it on one side when going in one direction, and through on the other side when returning. The action is entirely automatic. A speed regulator is attached to each car, and operated by the driver. It consists of a small cylinder, through which the current passes. A crank handle on the top of this cylinder regulates the speed, and its position in numbered notches shows at a glance the rate at which the car is travelling. The highest speed allowed by the regulator is eight miles an hour."

The Daft Motor in Baltimore.

Meanwhile, Leo Daft has followed up the honor of making the first electric motor test on an ordinary railway, by equipping the first practical electric railway in America, that at Baltimore. His system and others had worked successfully at fairs in Boston, the New Orleans Exposition, and elsewhere. At the Chicago exposition of railway appliances the electric railway in a few days had carried in all over twenty-six thousand passengers. At Toronto, we have seen, electricity had done good work. But all these were in the nature of exhibitions; they were, in fact, toy roads. Even the Cleveland road was purely experimental. The Baltimore road, on the contrary, is a practical business affair, and so its details are of far more interest and value.

At a meeting of the American Society of Civil Engineers, held in the latter part of 1885, Robert L. Harris gave an account of this road which seems to be impartial and approximately accurate, so it may well be quoted here: —

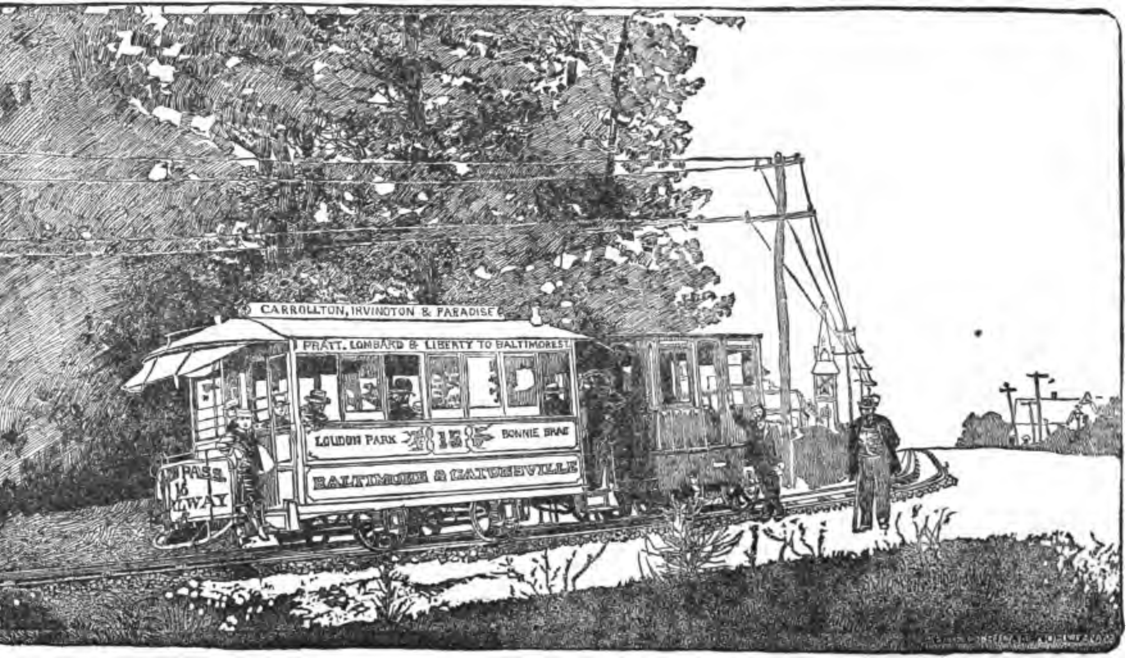
> "The Baltimore and Hampden Railroad is a suburban line of about two miles in length; gauge, five feet four and one half inches. It was heretofore an old horse railroad, and is a feeder to a main line of the Baltimore horse railroads. It is now operated by the Daft motors. This road has iron rails, twenty-five pounds per yard, laid on cross-ties in a cheap manner, and runs along the side of suburban streets or roads. The country is undulating and the route is crooked. Its curves are from forty feet to ninety feet radius, and the grades are from level to the rate of three hundred and thirty feet per mile. The superintendent, Mr. T. C. Robbins, says there are only about three hundred feet of continuous level on the route, and very little level on its entire distance. A twenty-five pound steel rail has been placed on insulators near the middle of the ties as conductor, and was roughly guarded by joists and planks laid on each side of it. The reason for using twenty-five pound rails as conductors was simply that in case of failure they would be useful for repairs. It was unnecessarily large for a conductor. Electricity has been used upon the road in place of horses since Sept. 1, 1885. The sections of conducting rail, as also of the track rails, are electrically connected by wires. In some places these wires are not insulated, and the rails were connected by a mere loop of one eighth inch copper wire. The connections at main dynamo are of three eighths inch copper wire insulated. At the engine-house there is a boiler, two doors to the fire-box, fourteen feet long, five feet diameter, with sixty-three and one half inch flues. The engine is sixteen by twenty-four inch cylinder, which, with thirty pounds of steam at one hundred and ten revolutions per minute, is said to develop about seventy-five horse-power. This engine drives two nominal fifty horse-power Daft dynamos, which supply the electric current to the rail. The engineer said that when



PASSING ON A TURN-OUT AT BALTIMORE.

both motors, each with a loaded car attached, were ascending the steepest hills, the full capacity of his engine was used, but when neither were on a hill not ten horse-power was used. This engine uses about one and one half tons of coal per day of eighteen hours, with fires banked at night. Two motors are in use, each weighing about four thousand five hundred pounds and rated at ten horse-power. A new motor, weighing about five thousand pounds and rated at twenty horse-power, has just arrived, and was connected with the current and moved about. The motion of the armatures was stated as about one thousand two hundred revolutions per minute; they were geared to the driving axle of the motor by ordinary tooth-geared wheels in the proportion of twelve to one, and the speed of the motor arranged for twelve miles an hour. But one strength of current has thus far been used, of low intensity; there has been no occasion for other powers of current. No electric brake is being used.

"We rode," said Mr. Harris, "on a regular trip to the end of the road and back with a street car attached, such as is ordinarily used with two horses. The average load was about eighteen passengers. We went around one curve of forty feet radius on a grade of two hundred and seventy-five feet per mile, and around a curve of seventy feet radius on a grade of three hundred and thirty feet per mile. While we were ascending a grade of about three hundred and twenty feet per mile, the other motor was said to be at the same time ascending a similar grade. We stopped near the middle of this grade and started from full stop without difficulty. The toothed gearing made some noise, but passing horses did not seem frightened. It is expected to avoid toothed gearing by friction gear. The motors are controlled by one man, and, with car attached, start from each terminus about once an hour, and pass each other by side track. Mr. Robbins told me that the 'Morse' has run one thousand and six miles with no repairs (except oiling). Its average duty is seventy-five miles per day. No especial skill is needed; he had at times run his motors with men taken right off the road. He is satisfied with this power, and hopes that his company will soon use it on the other six miles of suburban road which they own. His company own also fourteen miles of Baltimore city horse railroads. He considers that his present power would run on his road five motors, each carrying one car, and, were there but one hundred and fifty foot grades on his road, his present power would run five motors with three cars each. As now run the two motors take the place of thirty horses and are as cheap, and were he running eight cars there would be a saving of one half the cost of horses for the same duty. There has been no trouble in heavy rain and thunder storms; he thinks it works better in wet weather, and has even known the flange of the conducting rail to be in water for a short distance during a rain-storm. He says two of the men that have run the motors were locomotive engineers, and



GRADE AND CURVE ON THE BALTIMORE ROAD.

their expression was, 'It lays away over steam.' In fact, he thinks steam would not, with such light engines, carry such loads up such grades as has been done by the motors. Mr. Robbins states that he had had no troubles other than mechanical, which are now remedied. (The armatures and brushes were at first too light.)

As a test for himself, Mr. Robbins once sent to the city for one of their heaviest cars ....lbs.	5,100
And carried a load of 81 persons over the road (say 81 × 125 pounds).......................................lbs.	10,125
The weight of the motor used was.................lbs.	4,500
Total......................................lbs.	19,725
Thus he says that 19,725 pounds were carried over the road by one motor of...........................lbs.	4,500

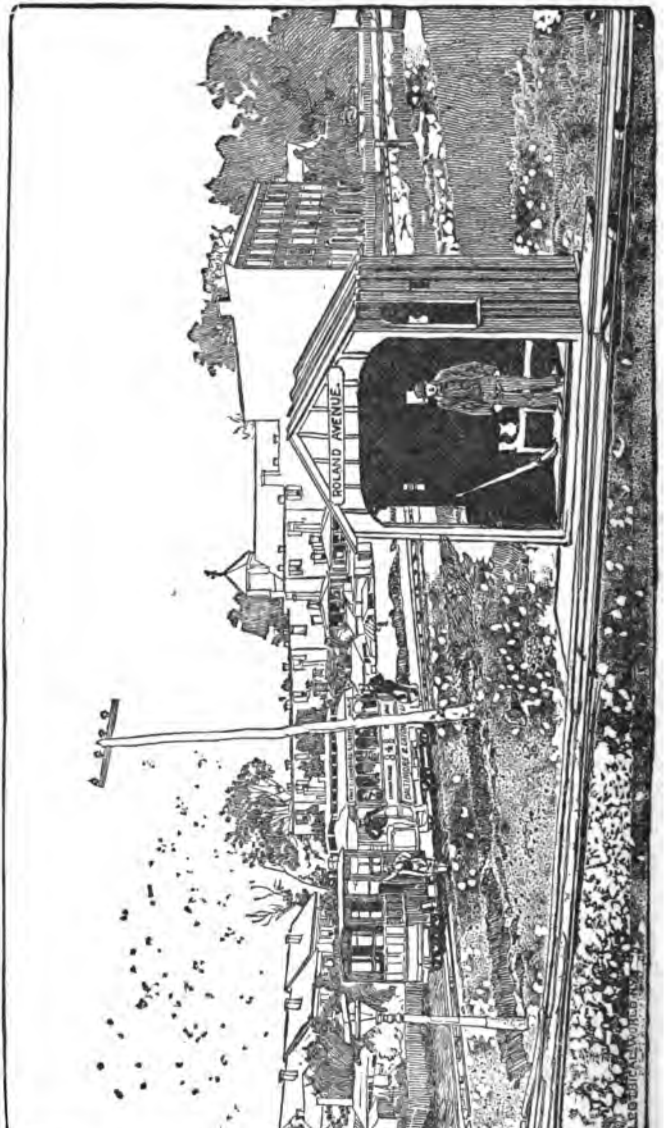
His engine and boiler cost, approximately............	$2,400 00
His two motors cost, approximately, $3,000 each....	6,000 00
Total..	$8,400 00

" There is also the expense of conducting rails and wires, insulation, protection, etc.

His expense of running per day is 1½ tons of soft coal	$4 75
Engineer and fireman at power station...............	4 50
Or, excepting oil, waste, wear and tear, per day,	$9 25

" The above represents the cost of his power, and equals the work of thirty horses per day. The average receipts from the cars carried by the two motors are $18 per day, and he has taken (on a Sunday) total receipts of $86 in one day."

From an article by John N. Bruns in the *Street Railway Journal*, it is learned that the average speed of the motors on the Baltimore road, with two cars filled with passengers, is ten miles an hour, although five miles is all that was contracted for. From the beginning, the traffic increased twofold, and the motors, instead of exerting ten horsepower, were and are actually doing the work of fourteen. The increased traffic is not due to the novelty alone, but also to the fact that business men and others who used carriages, rather than ride at the slow speed made by mules, now prefer the electric motor on account of rapidity and comfort. So satisfactory was the service that the residents at the extreme end of the road petitioned the



A Scene on the Baltimore Road.

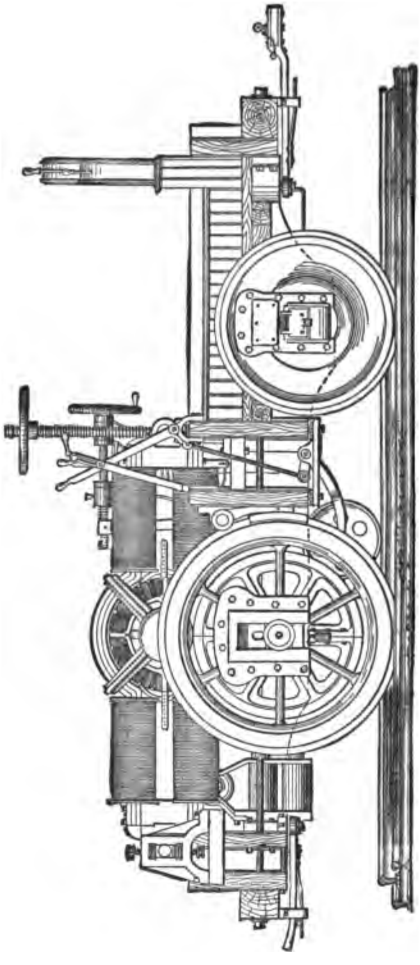
company to extend the track a mile, agreeing to pay all the charges for material, laying, etc., provided the company would equip the road with two more motors. This offer was accepted, the road extended, and two new motors of larger capacity ordered, one of which was shipped on the 10th of November, and is running very successfully. A grade of two hundred and seventy-five feet to the mile, on a curve of forty feet radius, was included in the extension.

In a letter dated Dec. 18, 1885, written to a Boston gentleman by General Manager Robbins of the Baltimore Union Passenger Railway Company, he said: —

"We are running one of our suburban lines from 5.40 A. M. until 11.30 P. M., by electricity. We use the Daft motor. We have four of them. Two of them weigh four thousand five hundred pounds each, and two of them five thousand pounds each. The four thousand five hundred pound motors would pull from two to three sixteen-foot body street cars loaded over grades of fifty feet to the mile at the rate of ten miles an hour; the five thousand pound motors, three to four cars loaded at the same rate. The weight of motors includes trucks, truck-frames, cab, and the dynamo machine. The machine weighs about one thousand two hundred pounds, and could be used in one end of passenger car. I had separate motors made, as I did not wish to put it on a passenger car until I knew what I could do with it. The cost of electric power per car per day over grades not exceeding fifty feet to the mile can be furnished at from $1.50 to $2.00 per car per day, where from eight to ten cars and upwards are to be operated. We are operating over grades from level to three hundred and fifty feet to the mile, at a cost of $3.00 per car per day for power. Our curves are from forty to ninty feet radius, and all of them on grades. The communities through which our cars run are much pleased with the change from horse and mule power to electric power, and speak of it as a bore to ride by horse power, and a pleasure to ride by electric power."

Trials on the Elevated Road.

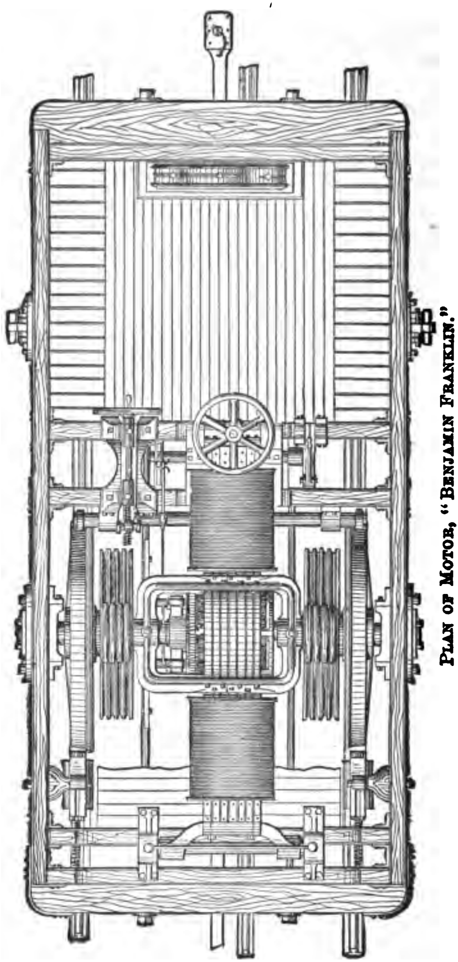
The desirability of substituting some such motive-power as electricity for steam on the elevated railroads in New York City has long been felt. Leo Daft was quick to grasp the possibilities of the case, and though other electricians went to work and are still working for the same end, Daft was the first to carry out his ideas to the extent



Elevation of Daft Electric Motor, "Benjamin Franklin."

of making an experimental test. The roads of the Manhattan Company having been offered for this purpose, the Ninth Avenue line was chosen. Work was immediately begun in laying a third rail between the two ordinary rails. As this was laid so as to insulate it completely, it took some time to lay it, and much time was consumed in setting the engine and dynamos at the central station. On the 21st of August, 1885, the motor "Benjamin Franklin" was placed on the track, but because of various delays it was Aug. 25 before it was started. Its first trip was from Fourteenth Street to Fifty-third Street, a distance of two miles, passing grades of ninety, one hundred and five, and one hundred and ten feet to the mile. The fastest speed was estimated to be at the rate of thirty miles an hour. No difficulty was found in starting or stopping.

The "Benjamin Franklin" is said to be the largest electric locomotive in the world. It is fourteen feet six inches long, six feet nine inches wide, and weighs nine tons. The motor was designed to exert seventy-five horse-power, the normal speed to be twelve miles an hour, with a possible speed of forty miles; its maximum capacity is three hundred ampères, with an electro-motive force of one hundred and eighty-five volts. The motion is transmitted to the wheels of the car by grooved friction gearing. A pair of friction gears, one keyed to either end of the armature, press against another pair of friction gears, geared to either end of the drive-wheel shaft. The amount of pressure can be regulated by a screw, and heavy rubber cushions insure perfect accommodation on the part of the motor to any irregularities in the road-bed. The device for controlling the motor consists of sliding contacts worked by a handle similar to the throttle in the locomotive cab, which raises or lowers the resistance in the field-magnet circuit, thus varying the strength of the field and so the speed of the motor; the motor can also be completely cut out of the circuit. By means of a reversing lever the commutator brushes can be set so as to give the motor a forward or backward motion. The motor is equipped with electric brakes, consisting of large electro-magnets, which, being energized, are attracted to the wheels and press against them like the ordinary brake.



PLAN OF MOTOR, "BENJAMIN FRANKLIN."

The connection with the middle rail is made by means of a heavy bronze wheel fourteen inches in diameter. This can be raised and lowered at will, so that stopping and starting can be effected by its means or by the cut-out mentioned.

The centre rail was covered with rust, and had to be thoroughly scoured. Since it was first cleaned, many trials of the motor have been made, some public and some private, with enough success to prove beyond a doubt the feasibility of operating elevated roads by electricity.

The Edison and Field companies have combined, and for some months have been preparing to test their system on the Second Avenue line. In this system the central rail has to be very carefully insulated on account of the high electro-motive force used, about six hundred volts. The contact with this rail is made by means of brushes sliding on it. The speed will be controlled by a friction brake, the motor running at a constant speed. Each car will be provided with a motor.

CHAPTER V.

THE COST OF ELECTRICITY.

WHETHER we run a railway train, lift an elevator, or make light by electricity, there is an electric transmission of power. The expansion of water into steam, the attraction of magnet for magnet, the incandescence of the carbon filament, are all forms in which energy manifests itself. We discussed in Chap. I. the question of the loss of energy in its transformation in the dynamo, in its journey over the conductor, and its retransformation in the motor. If the electric light were to be considered, that retransformation would be into light instead of into the power of shafting or gearing. In either case economy demands consideration, not only of the cost of transmitting, but of the cost of securing, power. In the matter of electric railways this consideration is of especial importance, for it will be economy, not convenience or comfort, that will have the most influence in supplanting the steam locomotive by the electric motor.

No matter what possibilities lie in tides and winds and waterfalls, it is sure that for many years the source of most of the power used in railway locomotion will be coal, and the steam engine will be the means of transforming into useful work the energy locked up by the carbon. It follows that the cost of coal is the first element in the cost of electricity, and the first thing to be considered in comparing the cost of steam and electric railways.

With the modern improved forms of stationary engines and boilers of large heating surface, the consumption of coal need not exceed three pounds an hour per horse-power. The largest estimate is four pounds an hour, and the makers of some of the large engines assert that tests have shown it to be nearer one and a half. Owing to the limited space and the unfavorable conditions under which the coal is burned in the ordinary locomotive, the average consumption an hour is very seldom less than six pounds per horse-power, and usually is much greater. Supposing the steam locomotive burns eight and the stationary engine three, we have at the outset a gain of about sixty per cent. in fuel by having the engine stationary instead of attaching it directly to the train. This leaves out of account the extra handling of the coal in lifting it to the tender, the cost of hauling it about with the train, and the cost of pumping and hauling the water for the steam locomotive. Thus, if the loss of energy by electric transmission were fifty per cent., instead of being only from thirty to forty, there would still be a saving of ten per cent. over steam locomotives, taking into account nothing but the cost of fuel.

Furthermore, no steam locomotive can burn anything but good fuel, because refuse fuel would be too bulky to carry, but under the boiler of a stationary engine set with the Jarvis furnace, now used in so many electric lighting stations, you can burn coal screenings, slack, cinders, sawdust, and anything that has the power of combustion, with practically the same return, pound for pound, as if good coal were used. On this point we have the authority of the Boston *Journal of Commerce*, in which recently it was said that " the evaporation of pounds of water to each pound of coal consumed to make steam in locomotive boilers does not average over three and one half pounds of water, using the best grades of bituminous coal, while with stationary boilers set with the Jarvis patent boiler setting, using coal screenings for fuel, an evaporation of nine pounds of water to one pound of fuel is made, and the reduction in cost of fuel is from one third to one half." Another writer says that the cost of coal when ready to be shovelled into the fires of the elevated-road locomotives in New York is about $4.00 a ton, and that a mixture of anthracite dust and bituminous or Cumberland coal could there be delivered to the furnace for $2.50 a ton. The manufacturer of the Harris-Corliss engine at Providence, R. I., uses a mixture costing but a few cents over $2.00 per two thousand pounds.

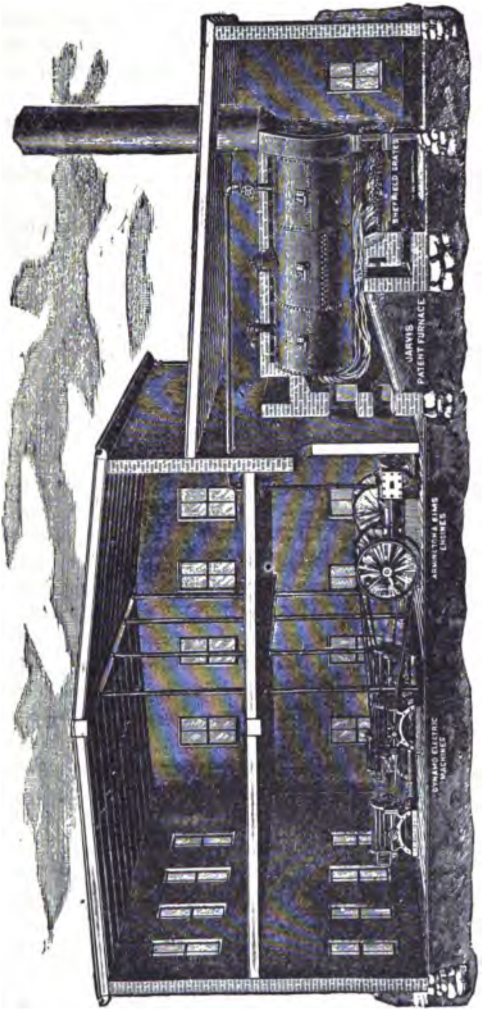
Thus the stationary engine has the advantage over the steam locomotive, not only in weight of fuel, but in cost of fuel. Not only is the weight about sixty per cent. less, power for power, but with the Jarvis furnace the cost, weight for weight, for the same evaporation of water, is anywhere from ten to thirty-five per cent. less.

In this connection, it may be suggested to electric light companies that they will find it very profitable to sell power from their dynamos in the daytime for charging storage batteries for railways, or for running machinery, just as they sell power at night for running lights. Wherever this has been tried the results have been most satisfactory.

The Cost of Transmission.

The theoretical loss of power in transmission by electricity has been already fully discussed, but other losses are met with in practical railway work that must be taken into account. The first of these occurs in the running of the dynamo. At present the energy of the steam is often utilized by means of shafting; but as through shafting we lose anywhere from five to twenty-five per cent. of our power, some more economical method is desirable. Very many of the electric light companies are reaching the end by belting the dynamos direct to the engine, using the Armington and Sims engine for this purpose. It is said that the cost of fitting up a station on this system is from twenty to fifty per cent. less than the old way, with long-stroke engines and long lines of shafting, and the saving in power is from fifteen to twenty-five per cent. on the cost of running. In this way the cost of transforming mechanical into electric energy is reduced to a minimum. Taking into account friction and all other mechanical imperfections, the total loss here may in practice easily be reduced much below the ten per cent. usually assumed.

As the electric efficiency of a dynamo has been considered, the next item in cost of transmission is the loss m the conductors. This is made up of two factors,



A MODEL POWER STATION.

the loss due to resistance and the loss due to imperfect insulation. In the discussion in Chap. I., of the efficiency of two machines coupled for transmitting power, it was said that the loss from resistance could be left out of the question. This of course can only be done where the conductor is large enough to make the resistance an unimportant item, the idea being that then increase in length to any degree desirable in practical work would not appreciably affect the results. The law in this case is: "Resistance in a conductor of constant section and material is directly proportional to the length and inversely proportional to the area of the cross-section." If, then, Deprez could transmit so much power to such a distance over an ordinary telegraph wire, it is easy to see of how much less importance is the loss due to the resistance of a conductor like a steel rail, of so much greater cross-section.

The loss due to imperfect insulation depends on the conductor used. If it be an overhead copper tube with a slot through which runs a wire connected to a traveller, there is practically no loss on this score. If it be placed in a conduit between and below the rails, the loss is insignificant. The ease of insulation on elevated roads is a strong point in their favor. For surface roads it now seems that in most cases the rails cannot be used for conductors. Where there is little crossing, as on the line at Brighton, England, insulation is comparatively easy; there it is said the loss of current on a wet day does not exceed ten per cent., and in dry weather is less than five per cent. In crowded city streets, where the rails cannot be raised above the level of the pavements, the leakage is so great from rails that the overhead or underground conductors are far more economical.

For long surface lines Profs. Ayrton and Perry, the noted English electricians, have proposed a simple method of overcoming this difficulty. They propose that a long line shall be divided into small sections, each moderately but not perfectly insulated. The current will be supplied to each section by well-insulated copper conductors running along the line, and as each train arrives at a new section it will automatically close the circuit by acting on speed, for electric motors are run most economically at a great speed, far more revolutions a minute than the driving wheels of the ordinary locomotive could ever safely attain. But on electric railways the driving wheels need never be as large as on steam railways, and so they can be driven at greater speed. Moreover, a comparatively slow-running motor can be built, as consideration of the principles explained in Chap. I. will show. For instance, if the energy from a small dynamo, having comparatively few turns of wire, be expended in a large motor having many more turns of wire, other things being equal, clearly the economical results may be reached with a comparatively slow speed of the motor. This principle was embodied in the electric locomotive with a relatively large armature, for which Leo Daft filed the specifications in the Patent Office, June 14, 1883. The same effect may be produced with machines of equal dimensions by giving the motor many more turns of smaller section than those of the dynamo. Precisely the same effect may be produced in another way by coupling a number of small machines in parallel to reduce the speed, as Leo Daft did on his track at Greenville, N. J., where he had been making tests for over a year previous to his Saratoga exhibition. There he showed the first example which had been seen in this country of a number of motors running on the same track at the same time. At that time prominent electricians declared the thing impossible, and refused to believe it had been accomplished till they had gone to Greenville, and seen it done.

For several months prior to the Saratoga test, Mr. Daft had a motor in operation with two driving wheels and an armature on the shaft of each, so arranged that the speed could be varied by using one or both, or both in series or parallel. This machine is still in existence just as it was then used. The idea involved in it will be applied in the Enos and Riley systems, to be described later on.

Thus it will be seen that here are various ways of regulating speed and getting slow-running motors. Another solution is suggested by Elieson's device, described above, of having the motor rotated by extending its armature into a long-motion shaft. The longer this shaft, the greater the circumference of the circular fixed rack, and the slower the rotation of the motor. No doubt, other devices of the same sort are possible. After light trains have once been put in successful running order on electric railways, he would be a rash man who asserted that then no way could be devised of hauling heavier trains economically.

Another objection that has been raised against electric railways is that either the cars must be mounted rigidly without springs upon at least one truck, or else the motor, which is mounted upon the car, and the axles with which the motor is geared, will move differently and will not always be in line; gearing between parts constantly moving in and out of line is impractical. This objection holds only in cases where the motor is applied to the car wheels, instead of being on a separate carriage, as a locomotive. Where each car will have a motor, the machine will in most cases be on the truck between the axles of the wheels, so that it will in no way interfere with the swing of the truck.

Still another objection is raised to the effect that no way of regulating speed has been devised save the insertion of resistance into the circuit, and that means waste. It has been pointed out that to a certain extent the motor regulates itself automatically, and therefore so much artificial regulation is not needed as in the steam locomotive. Furthermore, the motor, can be fixed so that it can be completely cut out of the circuit at will, but as this device is hurtful to the motor, it will be used merely as a supplementary means of regulation. More important is the device by which parts of the field can be thrown in or out of the circuit at will, thus allowing the strength of the machine to be gradually increased or diminished. At the same time automatic regulators at the central station act correspondingly to increase or diminish the supply of electricity.

Electricity *v.* Other Motive-Power.

All these objections are far more than counterbalanced by the many advantages in point of cost which electricity has over other forms of motive-power. In the comparison with steam, one of the most important of these is the saving in weight carried. In the first place, no fuel has to be carried, and the weight of the tender and coal hauled by a steam locomotive is a very considerable matter. Then the weight of the electric motor is far less than that of the steam locomotive which exerts the same amount of power. Of course, any locomotive, electric or steam, must have a certain amount of weight for tractive power, *i. e.*, it must be heavy enough so that the driving wheels will not slip on the rails; but most passenger steam locomotives have a good deal more than the necessary weight, while the electric motor need not have a pound more. If each car is equipped with a motor, the weight of the cars and their load are enough for the work of traction. As about a third of the power of the steam locomotive is used to move itself and the tender along, it is easy to see how much will be gained if the greater part of this weight can be dispensed with. It is said that in the present steam railway system nineteen tons of dead weight must be hauled for every ton of passengers carried. Furthermore, this dead weight is a fixed quantity and does not vary according to the load to be carried, for the locomotive and cars must be just as heavy in that part of the day when the traffic is small as in that when it is large. In a system having the tractive power distributed, as every passenger enters the car an additional weight is supplied for traction.

If there is less dead weight and still as much tractive power, steeper grades can be surmounted. Time and again the Daft motors have actually ascended a grade of 2,900 feet to the mile, or one in 1.82, without any other adhesive device than that due to the peculiar method of applying the current. By using electro-magnets acting on the rails, adhesion can be secured to any desired extent. Of course, this is practically the same as adding weight, but no steam locomotive has any such device, and where the rails are slippery it will be very useful.

Saving in weight is a very important thing in many ways. The lighter the train the less power it takes to overcome inertia in starting and stopping, and the quicker the train can acquire full speed or come to a rest. On the New York elevated roads fifty-nine per cent. of the power exerted by a locomotive in one round trip is expended in starting the train and bringing it to full speed. On the Third Avenue line the average distance between stations is 1,722 feet; the train has to travel one hundred and thirty feet in getting up to little more than half speed; thence to full speed, about four hundred and ninety-five feet; it travels at full speed eight hundred and eight feet; and in slowing to stop, two hundred and eighty-nine feet. These figures show the great desirability of having lighter teams that can be started quicker with less exertion and stopped quicker. With electric trains, you see, there will here be both a saving in power and a gain in speed.

Then, too, with less weight, greater curves can be passed with equal safety. With greater curves and heavier grades possible, railways can be built at less cost and with less length. On this point the experience of narrow-gauge roads is sufficient proof.

If the train can be stopped quicker, the danger of collision is reduced. Then, too, with less weight, there is less force of concussion to do damage in case of accident.

If the trains are lighter, both cars and road-bed can be constructed at less cost. It is the weight of the locomotive that does most in wearing out rails and road-bed. The pounding of a fifty-ton locomotive quickly disintegrates the best steel rails; and if there be the slighest flaw in the metal, it is the heavy locomotive that finds it out, breaking the rail and causing the disaster.

Bridges and all superstructures will be lighter and cheaper. If there are no locomotives, there will be no need of houses to keep them in or such extensive repair shops as must now be maintained. As the electric motor does not have to carry water and water tanks, there will be no need of pumps and cisterns along the line.

All this means less first cost, less fixed capital, and proportionally greater dividends.

In the cost of operating the electric railway there will be other considerable saving. For instance, a fireman will no longer be needed for each train. One fireman at the central station can do the work of five on the road. The engineers need not be trained mechanics; a mere boy, if he had caution and judgment enough, could run an electric train.

Calculations made by Dr. Wellington Adams, who has given much thought to the subject, lead him to believe that an electric railway may be operated at an average speed of sixty miles an hour, for one third the cost of operating by steam at the same speed.

The use of steam on city railways has very serious objections. In many cities steam motors are forbidden within certain limits. Where they are permitted on elevated roads, they are so noisy and dirty that complaints are many and loud. On surface roads in crowded streets they are more than a nuisance; they are exceedingly dangerous. Clearly, our cities must look to some motive-power other than steam to solve the vexatious street-car problem. Some have thought that the solution rests in cables, and cable roads have accordingly been built in several American cities, notably San Francisco and Chicago. If, then, electricity is to become a motive-power on surface street railways, it must show its superiority both to horse-flesh and to the cable.

Electricity *v.* Horse-Flesh.

It must be conceded that the utility of electricity as a motive-power on long railways that cross the country from city to city is yet an open question. Theoretically it can be proved that our largest roads can be run by electricity, but the theory has not yet been practically demonstrated. For short lines and small trains, however, there are many practical demonstrations to which one can point. It is no longer a question of whether street cars can be run by electricity. That has been answered in Berlin, at Baltimore, and elsewhere. The question now is, Can street cars be run cheaper and better with electricity than with horses as the motive-power? As far as suburban roads are concerned, this question, too, has been answered, unless all the reports about the Baltimore road are sheer fabrications; and if an electric railway can run successfully in suburbs, there is no reason why it cannot run in the heart of a city.

In this connection, the following estimate made by Leo Daft will be of interest. It refers to the relative cost of equipping a street railroad ten miles in length with an electric system and with horses: —

ELECTRICITY.

(The assumption is that fifty cars are to be run, that all may be loaded and moving at the same time, and that one hundred and fifty horse-power is to be ready for delivery on the track at all times.)

250 horse-power engine and boiler, set up	$10,000 00
Generators	12,000 00
50 motors, including the cost of attachment	40,000 00
	$62,000 00

Assuming a run of sixteen hours a day for each car, the daily running expense would be about as follows: —

Coal, 4 tons	$15 00
Engineers	6 00
Firemen	4 00
Machine men	6 00
Oil, waste, etc.	3 00
Depreciation	15 00
	$49 00

HORSES.

400 horses at $125 each	$50,000 00

Running Expenses per Day.

Maintenance of 400 horses, at 50 cents each	$200 00
24 stable-men, at $1.50 each	36 00
12 other stable employees, at $1.50 each	18 00
Depreciation	32 97
	$286 87

The cost of rolling stock, conductors, etc., being subject to local conditions, this comparison is simply one of electricity with horse-flesh as a motive-power. Many horse-cars have both conductor and driver: on a car driven by electricity, but one man is needed. Then, too, large stables are necessary for horses; small engine-houses will suffice for electric motors. Extra horses with drivers must be used to help pull horse-cars up steep grades; no such help is necessary for the electric motor. In this estimate no account is taken of the fact that at any given time a large proportion of the horses will always be found sick in the stables. But leaving out all these considerations, it appears from these figures that the expense of running a car sixteen hours by horse-power is nearly $6; by electricity, nearly $1.

The most considerable expense horse-railway owners are put to is in the maintenance of their full quota of horses. The average life of a car horse is said to be three years. If this be so, Mr. Daft has reckoned depreciation at altogether too low a figure. The work of pulling street cars is terribly wearing on animals, and, in many instances, is an absolute cruelty. Consider, for a moment, what these horses have to do. The power exerted in propelling a forty-six passenger street car, tractive force thirty pounds a ton, two horses pulling 4.5 tons, has been estimated at: —

	HORSE-POWER.
7 miles an hour on level road	2.52
6 " " " " " "	2.16
6 " " " " a grade of 1 in 75	4 32
5 " " " " " " " 1 " 37	5.40
4 " " " " " " " 1 " 37	4.32
3 " " " " " " " 1 " 25	4.32
4 " " " " " " " 1 " 25	5.76
3 " " " " " " " 1 " 18	5.40

This does not take into account at all the tremendous strain on the horses in starting a loaded car. It has been found by experiment that the momentary starting force is about four times the tractive force when once in motioin. James Watt ascertained experimentally that a strong adry horse is capable of producing a continuous effect equal to raising 33,000 pounds one foot a minute, and this we call one "horse-power"; but we see that one car horse very frequently is called upon to do the work of three or four dray horses. It is this that keeps so many of them sick in the stables, and shortens the lives of all.

Remembering that a street-railway motor, whether steam or electric, must weigh a number of tons, it is easy to see why its power must be so many more horse-power than the number of horses it replaces. For instance, a steam locomotive pulling a car full of passengers, the whole weighing thirteen or fourteen tons, must exert something like thirty-four indicated horse-power when travelling up an incline of one in thirty-seven. Therefore, it is of the utmost importance to reduce to a minimum the dead weight to be propelled. One way to do this is to do away with a separate carriage and put the motor in or under the car, as cannot be well done with steam, but as will undoubtedly be done in all electric street railways.

Besides the saving in first cost and running expense, electricity will have other important advantages over horseflesh. With the electric motor there are no horses' hoofs to keep wearing out the road. If the motor is in or under a car, there is as much more room in the street as horses would have taken up, and so the chances for blockades are lessened. Electric cars can be joined in trains where desirable, but horse-cars must run singly. Electric cars can be reversed and can run backward as easily as forward, — often a most desirable thing in crowded streets. On open stretches where there are no houses and little travel the electric car can make much faster time than the poor car horse can ever make. With the simple electric brake the greater part of the manual work of running a street car is done away with. Noiseless, clean, cheap, and safe, what better motive-power can be asked for on street railways?

Electricity *v.* The Cable.

The objections to the cable system are manifold. In the first place, the cost of construction is very heavy, averaging not far from $200,000 a mile of double track. As in the electric system, a central station with stationary steam engines must be maintained, so that the relative cost of operating depends on the relative economy in transmitting power by cable and by electricity. Beringer, an engineer in the employ of the German government, has estimated the return of energy in different systems of transmission as follows: —

Distance.	Electricity.	Water under pressure.	Compressed air.	Cable.
100 metres.	69 per cent.	50 per cent.	55 per cent.	96 per cent.
500 "	68 "	50 "	55 "	93 "
1,000 "	66 "	50 "	55 "	90 "
5.000 "	60 "	40 "	50 "	60 "
10,000 "	51 "	35 "	50 "	36 "
20,000 "	32 "	20 "	40 "	13 "

Comparing the cost of the different systems, Beringer concludes that when the four system are equally applicable, the cable is the most advantageous when the distance is less than a kilometre (about three quarters of a mile), but electricity ought to be used for greater distances.

The cable is a steel wire rope running in a conduit between the rails. As in some electric railway systems it is proposed to use an almost exactly similar conduit containing a copper conductor, it becomes easy to compare the cable and electricity in point of cost. Copper costs more than steel, but it may be doubted if a small copper conductor will cost more than a steel wire rope an inch and a quarter in diameter. For such distances as most street railways cover, the loss of power in transmission, we have seen, is less by electricity than by the cable. The electric motor costs more than the grips; but on the other hand, the grips wear out quicker. The wheels or rollers on which the cable runs wear out with surprising rapidity. To provide for unequal strain on the incoming or outgoing cable a differential or compensating gear must be used. Curves are made only with great loss of power, and it may well be questioned if in the heart of such a city as Boston the cable could ever be used with economy.

Aside from cost of construction and operation, the cable is disadvantageous, because if it breaks, the entire system is crippled, unless a double cable is used, which means still greater wear and tear, and a greater investment on which dividends must be paid. Cable cars can run in but one direction. Speed is necessarily limited. It takes skilled labor to handle the grips, and recent experience on the Brooklyn Bridge has shown their dangers. In fact, except in the matter of very steep grades, electricity has all the advantages of the cable, and very few of its disadvantages.

CHAPTER VI.

ELECTRICITY ON ELEVATED ROADS.

WHEN the system of elevated railways using steam as the motive-power was established in New York City, it was thought that at last a solution had been found to the knotty problem of rapid transit in cities. Across the ocean underground railways had met with favor, but Americans preferred the overhead plan, and the results in New York have justified the preference. Since 1872, nearly five hundred million passengers have been carried on the New York elevated roads with rapidity, profit, and comparative safety. Yet even this wonderful New York system has its disadvantages, — so great that no other American city away from the metropolis has adopted it. But it is clear that to elevated railways the inhabitants of great cities must look for the most available means of the rapid transit that progress in civilization is fast making an absolute necessity. The problem is, how to obviate the evils of the present elevated system so as to make it acceptable to all classes of citizens and enable it to do the good of which it is capable. The most promising key to the problem is, *Electricity*. He would be rash indeed who maintained that electricity would be a panacea in this case. It can cure but some of the ills. That it can cure enough to make itself a veritable blessing to the community seems susceptible of proof.

If, then, one should ask, "Of what advantage will it be to use electricity as the motive-power on elevated railways?" his question may be concisely answered after this fashion: "There will be an increase of *speed*, *safety*, and *cleanliness*, a decrease in *smell*, *noise*, *cost*, and *obstruction to streets*."

Speed.— The armature of an electric motor can be revolved at a speed far greater than that any locomotive driving wheel has ever attained. The only limit to the speed of an electric car is safety. If we can increase safety, we can increase speed.

Safety.—The dangers of a railway lie in the possibility of collision and in that of jumping the track. With electricity, an almost perfect block system can be devised, so that the possibility of collision is reduced much below that in the case of a steam, cable, or compressed-air system. To lessen the possibility of jumping the track, we must either lower the centre of gravity, or in some way bind the trucks to the rails. The Riley system, to be described later on, lowers the centre of gravity. The Enos system binds the truck firmly to the track. In most electric systems the motors will be part of the cars, and thus the passengers will furnish the weight for adhesion. When desirable, electro-magnets acting on the rails can answer the purpose of increased weight in rolling stock necessary in steam systems. In all these ways safety is increased, and so speed can be.

Cleanliness.—One of the most disagreeable features of the New York elevated system is the dirt it makes along the street. Wherever coal is burned, you will have smoke; and if the furnace travels along past stores and offices and parlors and chambers, you cannot keep the smoke and its resultant griminess from getting into those places, especially if it be summer, and doors and windows must be left open. Ashes and cinders will persist in dropping down into the street, often with detriment to the purple and fine linen of the passer-by. The railway train itself when propelled by a steam locomotive is always unpleasantly grimy. Electricity is perfectly clean.

Smell.—The noxious fumes from a steam engine are objectionable to many people. The electric motor gives out no disagreeable odors.

Noise.—The lighter the train, the less the pounding on the structure, and so the less rattle and rumble. There is no steam to hiss out from the electric motor.

Cost.—The economy of electricity for general railway purposes has already been shown. Its economy for elevated railway purposes has been discussed by several eminent experts, in its bearing on the proposition to substitute electricity for steam on the New York roads.

Prof. Morton, president of the Stevens Institute of Technology, has said: —

> "I heartily concur in the general conclusion that the scheme to substitute electricity for steam as motive-power, on the lines of the Manhattan Railway, is perfectly feasible. I should not put the maximum of saving at more than thirty per cent., and the actual amount might be much less. I should say that the cost of generating steam in a stationary engine and in a railway locomotive is as one to two. The removal of smoke, dust, and some other disagreeable features of the present system would, of itself, afford adequate compensation for the change, were there no pecuniary advantage to be derived from it."

Prof. Cross, of the Massachusetts Institute of Technology, and Edward Weston, the electrician, in rough estimates made separately, agreed that to run twenty-five trains on one track at the same time, each now drawn by a forty horse-power locomotive, would take an electro-motive force of about five hundred volts, and a current of about one thousand five hundred ampères. Mr. Weston says that to give this about six dynamos, each of two hundred horse-power, would be needed, and to run these, a stationary engine of one thousand two hundred horse-power would be adequate.

> "The rule is that a stationary engine of the best kind costs fifty dollars per horse-power annually, and at that rate the entire expense would be $60,000 a year. But there is this difference between a locomotive and an electric motor: the former has only its minimum power at the start, while the latter has its maximum, and so the locomotives need to have forty horse-power, although the average power required may not exceed twenty-five."

Prof. Moses G. Farmer has said: —

> "There ought to be no difficulty in saving one hundred to one hundred and forty pounds of coal per hour on each of the forty-horse locomotives now in use, if their consumption of fuel has been correctly represented to me."

It is probable, however, that the figures on which this calculation was based were exaggerated.

T. W. Rae, C. E., has made careful estimates in the matter of substituting electricity for steam on all the New York elevated roads. He finds that the cost of electric installation equivalent to present motive equipment would be $1,879,000; the cost of motive-power per hour with steam locomotives, $216.56; with electric installation, $110.57.

Some of the estimates given above are more pleasing than accurate, but there seems no doubt that the saving from the use of electricity on elevated roads will be very considerable. Any one who cares to reckon up the saving for himself will find of help the following data, the results of a test made by Angus Sinclair of a locomotive in operation on the Third Avenue elevated road. The engine drew the usual load of a train of four cars weighing some sixty-six tons over its route of eight and a half miles, making twenty-five stops. The engine weighed twenty-four tons; cylinders, eleven by sixteen inches, average indicated horse-power, 163.4; running time, twenty minutes, stopping at stations, twenty-two minutes. The average horse-power exerted by the locomotive, including running time and stations, was 77.8; as there were sixty-three trains on the road at the same time, there was an aggregate expenditure of 4,901 horse-power. The evaporation of the boiler on the basis of all coal used, without making any allowance, was 7.4 pounds water per pound of coal; and the hourly consumption of coal was 5.8 pounds per horse-power.

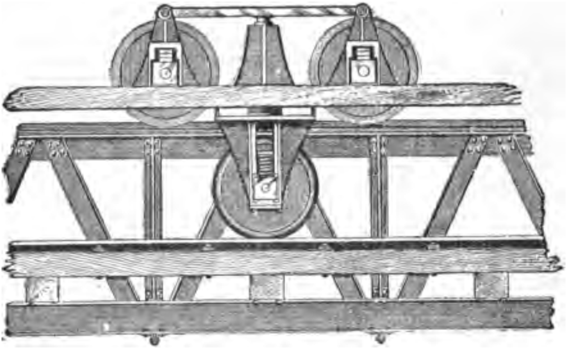
In discussing the cost it must not be overlooked that where the motors are under the cars, there will be a great reduction in the vibration and wear and tear of the superstructure, because the weight will be distributed so much more evenly. Here will be a saving in the cost of maintenance.

Obstruction of Streets.—If the present elevated road structures be used for the electric motor, the only change being the addition of a third rail, there will be no less obstruction of the streets than before. A little more light will be shut out and the view will be obscured a little more. The structure itself will be as unsightly as ever. It is only by the adoption of single-post systems, that any gain can be made in this respect. As the gain is most desirable and as it is believed that electricity is peculiarly adapted for use in single-post systems, their merits should be investigated.

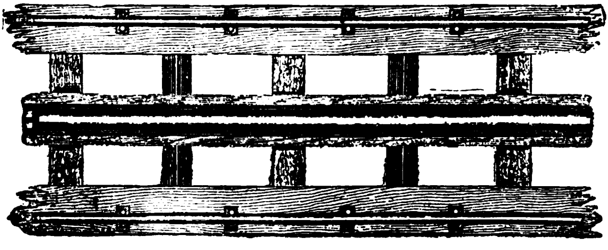
In the last sixty-five years probably more than a hundred patents have been taken out in this country and England in the line of railways supported by a single row of posts. Inventor after inventor has realized that in this direction it is probable the next important step in the art of rapid transit will be taken. Each thought to solve the problem, but not a half-dozen of the hundred ever saw their hopes realized. Some wanted to use one rail, others two, others three. Some put the car above the rails, and others put it below. Most of them failed because they could find no motive-power suitable to systems using but one line of posts. To be sure, in New York steam has been so applied, and successfully, but the roads are merely surface roads put overhead. It is claimed that in other simpler and cheaper and better systems, with the help of electricity as the motive-power, the single row of posts can be used so as less to obstruct light and view and travel, without losing any of the advantages of the single-post elevated roads now in operation. Two of these systems, known from the names of their inventors respectively as the Riley and the Enos systems, owing to their novelty and ingenuity, and their adaptability for the use of electricity as the motive-power, deserve here detailed description.

The Riley System.

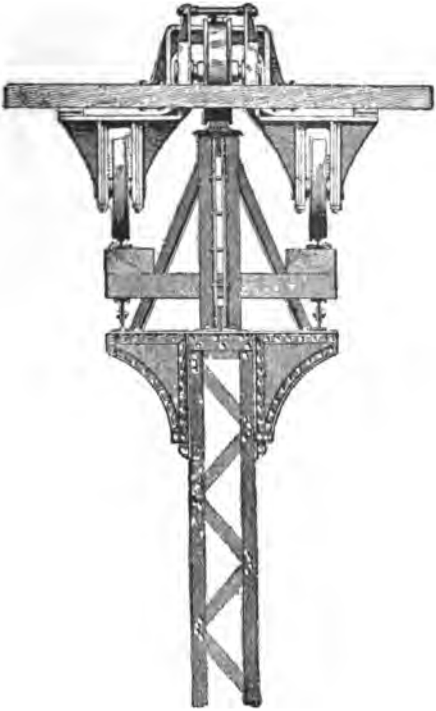
It is in the novel arrangement of rails, trucks, and wheels that the especial merit of the Riley system lies. A single row of posts supports a girder, on the top of which is a main centre bearing rail. Twenty-eight inches below this are two light rails, parallel with the centre rail, one on either side of it. Each car has two trucks, giving a wheel base of twenty-five feet for a car forty feet in length over all or thirty-three feet length of body; the car is nine feet in width over all, and weighs 16,000 pounds. Each truck has four wheels. Two of these run on the centre rail, one in front of the other, with their centres four feet apart, and are double flanged. The other two wheels are single flanged and run on the side rails below; these are also four feet apart, transversely



SIDE VIEW OF TRUCK ON IRON TRACK IN RILEY SYSTEM.



PLAN VIEW.

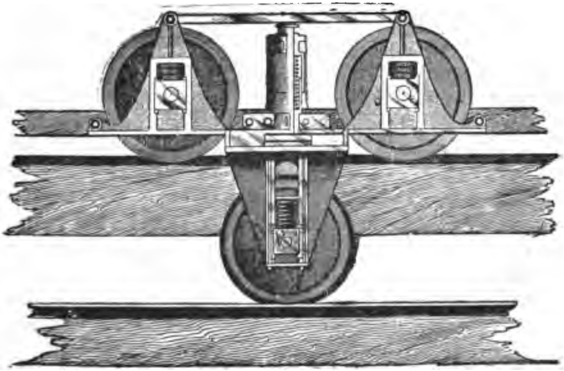


END VIEW.

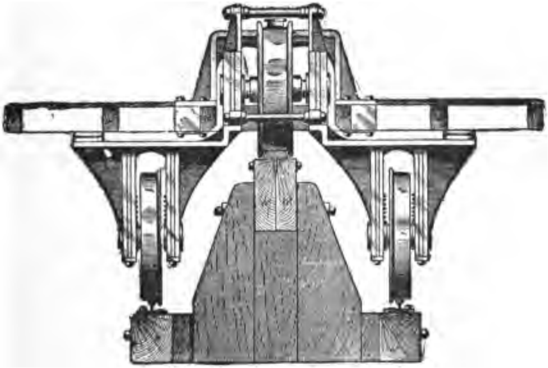
from centre to centre. All these wheels are set on the same truck, which is centrally pivoted to the car floor and adjusts itself to curves just as the ordinary bogie truck adjusts itself. The centre bearing wheels, two on each truck, are designed to support and carry seventy-five per cent. of the total load, and the other twenty-five per cent. is divided between the four side bearing wheels. The adjustment of the weight is arranged by springs, a simple and easy method. While the side bearing wheels will ordinarily have little service to perform, still they are of sufficient strength in their bearings, connections, and supports to carry the entire weight of the car if necessary. It is claimed that the Riley car truck is simple in construction, has far less detail about it to watch and keep in order, is cheaper and much lighter than the ordinary car truck; that it will ride much easier, and go round curves of very short radius with less fricton and strain than in the old truck system where the wheel base is greater and the axles are all connected.

One great advantage of the Riley system is that by bringing the car floor down to within four inches of the centre rail, the centre of gravity is much lowered. Stations will not have to be so high, and steps thereto will not be so many. As the car floor is lowered, the centre wheels must come up into the body of the car. The seats are arranged back to back lengthwise through the centre of the car, with two sliding doors at each end, so that the centre wheels and their connections form no objection, for they occupy no useful space; or the seats over trucks can be placed back to back and the balance of the car can have the regular side seats next to the windows.

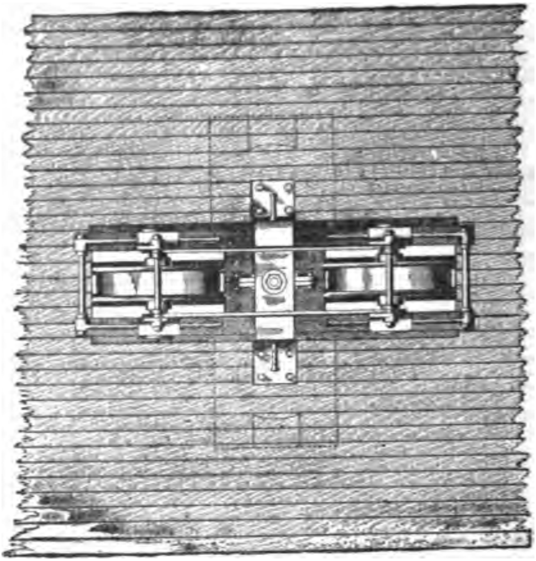
It is now intended to apply the electric power to both the centre wheels of the forward truck of the forward car in a train of three cars. The power car will be of the same length as the others, but eight feet of the forward end will be partitioned off for the motor and the devices for regulating it. The axles of the two centre wheels will be extended to form the armatures of the four Daft motors. These will, of course, be on the truck, and will come up into the car; but as this truck is centrally pivoted, curves will not affect the running of the motors.



Side View of Truck on Wooden Track.

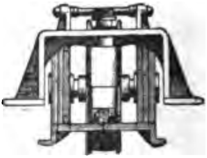


End View.



PLAN VIEW OF TRUCK.

SECTION OF IRON GIRDER.



DETAIL OF TRUCK.

As the driving wheels can be of any diameter desired, it will be easy to fix on the size that shall give the speed desired on any particular road, with the best electric efficiency, without the necessity of using gearing.

It is estimated that each car loaded will weigh thirteen tons, or not more than forty tons to the train of three cars. An empty car of the Manhattan road weighs almost twelve tons, and with a load of eighty passengers it weighs nearly nineteen tons. The loaded train of the Riley system will weigh just half as much as a loaded train of the Manhattan road without its locomotive; it will have three cars where the Manhattan has four cars and a locomotive. Thus the saving in weight will be very considerable, and there will still be enough left for traction, as when the motor car is loaded there will be five tons concentrated on its driving wheels. In the locomotives of the Manhattan road fifteen tons are carried by the drivers, and so are effective for tractive power. If it is desired to have a larger weight for traction in the Riley system, it can be had either by loading the motor car with dead weight, or by using electro-magnets acting on the rails. Probably neither of these methods will ever have to be resorted to; but even if they should be found necessary, the weight for straining and wearing out the supporting structure will never be so great as in the present New York elevated system.

A minor advantage of the Riley system, yet one that should not be overlooked, is the fact that a perfect footwalk for truck walker is provided, as well as a way of escape from passing trains. This makes track inspections easy and safe.

The Enos System.

John A. Enos, of Peabody, Mass., has very ingeniously combined in one system many of the merits of surface and elevated roads, at the same time doing away with the most obnoxious features of each. His idea is to suspend the cars, — not a wholly novel idea, but one that has never before been so carefully worked out. Previous inventors have generally aimed at suspending panniers or very small cars from elevated rails; but Mr. Enos has gone far beyond this, and intends to suspend large passenger cars at any height that may be wished, either so that their bodies will be as near the ground as those of ordinary street cars, or so that they will be as high as the structure of the ordinary elevated road. Thus the road may have all the advantages of a surface road, without the disadvantages of surface rails and horses; or it may be like an elevated road, with a saving of some of the steps and a great deal of the cumbersome structure so obnoxious in all elevated systems now in operation.

In this system a single line of posts will support by means of brackets at right angles to the road a lattice girder four feet in height. This structure is so open and light that it will not darken the street, obstruct the view, or present any serious objection whatever to property-owners. On the top of the girder runs the carrying rail; on the bottom, the steadying rail. Each car has four wheels, two running above the upper rail and two below the lower rail. With the framework connecting them, they form a sort of truck from which the car hangs. One upper and one lower wheel will be over the front half of the car, and the two others will be over the back half. The framework suspending the car is so supplied with springs that it can sway enough to prevent undue strains in starting, going round curves, and stopping. The flanges on the upper and lower wheels make it absolutely impossible for the car to jump the track. Thus the car is freed from the law which governs ordinary railway systems, viz., the greater the speed, the greater the weight necessary to keep the car on the track; it follows that the rolling stock of the Enos system can be very light. As every car is equipped with a motor, every passenger adds to the weight available for traction, and there is no need of heavy rolling stock for this purpose. With the very light cars and the single rail, curve resistance is reduced to a minimum. With all these advantages, it is thought that the speed could easily be run up to a hundred miles an hour, if it should be wished.

The motor is placed on the truck above the girder. Its arrangement was devised by Mr. Enos, and has won the hearty commendation of Leo Daft. It consists of four field magnets, one on either side of the two driving wheels. The shaft of each driving wheel is prolonged to form the armatures, so that really there are four armatures. Any or all of these field magnets can be thrown in or out of the circuit at will, so that one can do all the work, or two, or more, just as the man in charge of the car pleases. By means of a simple switch, reversing can be accomplished almost instantaneously with no hurt to the machine; full speed is secured with wonderful quickness. There is very little jar or jerk in starting or stopping the car.

One beauty of this system is the almost perfect method of conduction furnished by the upper and lower rails. They are out of harm's way, can be easily insulated, and can do neither man nor beast any injury. No extra rail is needed, as is the case on the New York elevated roads.

Perhaps electrically the most important feature of this system is the very small driving wheel used. It has been pointed out that the greatest difficulty electric railways have to surmount is the necessity of gearing between the motor and the driving wheels. As the smaller the driving wheel the more its revolutions to propel a car a given distance in a given time, the difficulty is greatly lessened by reducing the diameter of the driving wheels. In the cars now being made for the Enos system the driving wheels are but six inches in diameter, and it is perfectly practicable to use four-inch wheels. With a four-inch wheel the car would move a foot at each revolution. As dynamos can easily be made that shall do economical work at six hundred revolutions a minute, it is easy to see that using no gearing at all the Enos cars can maintain a speed of six hundred feet a minute, or about seven miles an hour, and do it with the most economical efficiency in the electric transmission. Of course, the size of the driving wheels can be increased as much as desired, or the speed of the motor can be increased. Using either means, or both together, any amount of speed can be made possible.

In this system there is no gearing to waste power. As the wheels are few, the loss from friction is reduced to a minimum. The simplicity of the whole structure makes its first cost light and the running expense small. The owners of the system believe a road can be built and equipped for much less than $15,000 a mile, and many horse-car roads have cost as much as that. Mr. Enos estimates that one of his cars can be run with a maximum speed of ten miles an hour with the average number of stops and starts, for a dollar a day of sixteen hours.

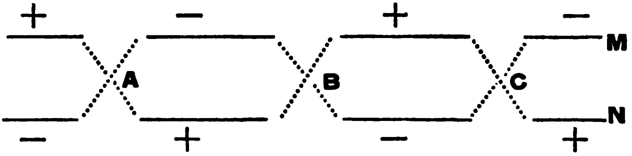
Another advantage claimed for this system by its inventor is, that as he especially devised it for the use of electricity as the motive-power, and no other, it is naturally better adapted for that purpose. The motor, too, was especially devised for this system. As the cars are small and light, and as each has its motor, only such sizes of motors will be required as have been in constant use for a long time. Small motors are almost as nearly perfect as they ever will be, and so there is no need of experimenting with them.

CHAPTER VII.

TELPHERAGE.

ALL the elevated railway systems so far spoken of have been devised for the transportation of passengers. The subject of freight transportation has received less public attention, but certain phases of it have been well studied by ingenious men, who have seen in them a chance for the useful application of electricity as a motive-power. No attempt has been made to use electricity on long lines for heavy freight. The only idea so far developed is for the transportation of freight that can be divided into small parcels or lots. A system for this purpose was devised in England by the eminent electrician, Prof. Fleeming Jenkin, now dead. He gave it the name of "telpherage," and called his road a "telpher" line. Telpherage has been defined as "the transmission of goods and passengers by means of electricity, without driver, guard, signal-man, or attendants." The first telpher line in England was opened on the 17th of October, 1885, Viscountess Hampden performing the simple ceremony. This first application of the "new departure in electro-technology" is in the carrying of clay from the clay-pits at Glynde, in Sussex, to the railroad. The line is nearly a mile long, and is composed of a double set of steel rods, each sixty-six feet long, three fourths of an inch in diameter, and eight feet apart, supported on wooden posts standing about eighteen feet above the ground. The trains consist each of an electric locomotive and ten buckets, which hang by their travelling wheels from the steel line. Each bucket weighs one hundred and one pounds, and carries from two hundred and fifty to three hundred pounds of clay. The speed is four to five miles an hour, and the train is under control of a workman, who, by touching a key, can start, stop, or reverse the train at pleasure. The trains are governed automatically, so as to run up and down an incline at the same speed. Of course, between the posts the rods sag considerably, but each train is a little longer than the distance between two supports, so part is always going up while the other goes down, thus neutralizing the effects of the sag on the mechanical resistance of the train. The electric resistance of the rods carrying the current is small compared with that of the dynamos and motors. The result is that whether the motors are near to or far away from the generating station, the variation in the electro-motive force is inappreciable in its effect on the speed of revolution of the axle.

In this telpher line there is embodied one of the most ingenious ideas any electrician has of late evolved. Of course, the same wire cannot be used as both a positive and negative conductor, and the motor of a train on a single wire would not move unless it had connection with some other conductor. The telpherage electricians have obviated this difficulty by arranging their wires in this fashion:—



M is the up track; N the down track. At A, B, and C are standards which support the rods. The rods carry the electricity and the cars hang from them. Their ends do not meet at the standards, but are insulated, connection being made by wires, as shown by the dots, so that all the rods marked + are connected and carry the positive current, and those marked — are connected and carry the negative current. The two wheels of the motor carriage are separated by a connecting rod a little longer than the distance between any two standards. Thus, when the front wheel rests on a rod bearing a positive current, the back wheel rest on one bearing a negative current, and *vice versa*. Now, a singular fact about the dynamo is that the wheel turns in the same direction, no matter which way the current comes, and the reversal of the current does not hurt the dynamo. So, as the telepher train moves along, the current through the dynamo is reversed at every standard, inertia carrying the train over the insulated pieces.

The *Electrical Review* (London) is authority for the statement that a line like that at Glynde could now be erected, at short notice, for a total cost of about $6,000, including engine, dynamo, permanent way, stiff ends, and five trains with locomotives, to carry over a hundred tons daily. The working cost, including coal and wages of fireman and electricians, and twelve and one half per cent. on cost for interest and depreciation, would be less than six cents per ton of material carried, the buckets being empty on their return journey. The Telpherage Company in London estimate the cost of the line at about $1,700 a mile; the trains at about $450 each. The estimated net cost of building a road ten miles long, to carry 30,000 tons in a year, is just a little over $50,000; five miles long, $30,000; the cost of working, at the rate of about five and one half cents for each ton carried one mile. The larger part of the cost is due to plant, so there is a very moderate increase in the rate per ton per mile when the traffic is increased. A single engine and plant of dynamos and trains might work many circuits radiating from one centre, and thus it would pay to erect lines intended to be worked to their full capacity only an hour or two a day, or one day in the week.

The whole structure need be little more cumbersome than the telegraph-pole system. It can be movable so as to be put up or taken down at short notice whenever and wherever it may be desired. It can easily be carried over uneven ground, across streams and ditches, where a railway would cost heavily. It can be run over fields and pastures without disturbing agricultural operations in the slightest. Its power can be tapped at any point, as, for instance, was done when the Glynde line was opened, a motor being set to work cutting turnips. A farmer could do his ploughing or shear his sheep by power from the line crossing his farm.

It is claimed that such a system will find its application in all cases where the traffic is sufficient to pay interest on a small outlay, and is insufficient to pay for the construction of even the cheapest form of railway. Furthermore, it will be of use in cities for such purposes, for instance, as that of carrying the mails between the post-office and the railway stations, or of carrying express packages from central to suburban offices. In mountainous regions it will be of great value in carrying ore from the mines to the railroads. At the sea-shore it will be of use in carrying freight from ships to warehouses. In mill yards it will carry cotton or wool from building to building. In short, just as steel railway electric systems are to supplant the car horse, this electric system is to supplant the dray horse.

In connection with this subject, it may be suggested that large pneumatic tubes used for postal purposes can be replaced by tiny automatic electric railways. Charles Bontemps has demonstrated that if at any given moment forty little electric trains, each weighing with its despatches thirty-three pounds, were travelling at a rate of fourteen miles an hour, the total work required for the transportation of the despatches upon all the subterranean systems of Paris would be only twelve horse-power, while by the pneumatic tubes this work requires one hundred and twenty horse-power.

CHAPTER VIII.

IN CONCLUSION.

An important feature of electric railways will be the use of their power for many minor purposes. Not the least valuable of these will be the lighting of the cars by electricity. There is no need to dwell on the imperfections of the present system of lighting railway cars. In a few drawing-room and sleeping cars the electric light has been tried with success, only moderate, because the batteries will not run many hours, and dynamos stop when the train stops. Accumulators are necessarily bulky, and though some progress in their use has been made abroad, little or nothing has been done with them here. In an electric railway the use of the power necessary for making the cars almost as light as day will hardly be noticed at the central stations. Electric head-lights are coming into use; their advantages will be gained at less cost on electric railways. The possibility of heating cars by electricity has been discussed, but nothing has yet been accomplished toward making the cost anywhere nearly as cheap as coal. It is probable, however, that there will be great advance in this direction. When we have electric heating apparatus, the danger from fire in case of accident, already greatly reduced by the use of electric lights and fireless locomotives, will be at a minimum.

The power from the rails can also be utilized with profit for running elevators at elevated road stations, as well as for lighting both elevated and surface stations and their approaches. In freight depots the power can be applied, as in Paris electricity already has been applied, for the purpose of handling freight. In the freight depot of the Chemin de fer du Nord, a sort of travelling crane has been erected. To the beams of the freight depot grooved iron rails are suspended, which work a sort of truck, containing a motor connected with a windlass. Above this arrangement run copper tubes inclosing sliding travellers for conducting the electricity. By means of a chain the current is sent into the machine, and this is connected sometimes with the windlass, which is then used to raise burdens, sometimes with the wheels of the truck, which then carry it along from the loading to the unloading place, or in the opposite direction. The electricity is supplied by two dynamos about eleven hundred feet away, and the working of the plan is completely satisfactory.

The electric power can with profit do the work of the costly galvanic batteries now used for signal systems, and perhaps it can run all the railway telegraph instruments. Possibly little electric motors can be set to work lowering and raising gates, and turning drawbridges. This calls to mind another important feature of electric railways, viz., the perfect safety from the dangers of broken bridges, for if a bridge breaks the current is broken and the trains stop. If the rails be used for conductors, a broken rail will by the act of breaking prevent any damage to approaching trains.

Not only will electricity decrease the dangers of railway travelling, it will also increase its pleasures. When the electric motor glides noiselessly over the land, there will be no clouds of smoke belching forth from roaring smoke-stacks to blot fair landscapes. There will be no puffing, wheezing locomotives to make conversation arduous. There will be no cinders to vex the eyes of passengers who wish in summer to breathe pure air or be fanned by the cooling breeze. There will be no smut and grime to blacken hands and soil linen.

Nothing brings out the bad qualities of a steam locomotive like a tunnel. Anybody who has tried standing on the platform while a train is passing through a tunnel knows the almost insufferable nuisance of the smoke and the cinders and the fumes. There will be none of this with electricity as the motive-power. In tunnel or in open there will be nothing to annoy but the jar and jolt that must always accompany the swift motion of railway trains, and even this will be diminished by the use of the lighter cars made possible by the electric railway. When smoke and cinders are gone, when dirt and noise and jolt are lessened, will not the charms of railway travelling then be doubled?

All these pleasant things are not coming in a day or a year. Grand results are not so quickly achieved. Electrical inventors have made them possible. As Edison has said of the application of the electric motor to the New York elevated roads, it is now only a question of mechanical engineering or the draughtman's work. Already the beginning has been made. The infant art is taking its first steps, — short, weak, tottering, to be sure, yet full of promise of the growth to come. Will the public stretch out a helping hand? Will the public nourish the child, not for what it is, but for what it may be in future years?

Children born of the brains of inventors have to fight for life. Could they spring Minerva-like from the brain of a Jupiter, they might not have to engage in this struggle for existence; but there are no Jupiters in this prosaic age, and even the wisest ideas must be conceived and brought forth like an infant, must grow like a child, and can reach the full strength of manhood only after they have won in the fight that ends in the survival of the fittest. Yet the people can if they choose either stimulate or retard the growth of the child. They can early recognize its right to existence, or bring to it a tardy recognition of its merits. So it will be with the electric railway. If it deserves life, it will live and grow and eventually do the good of which it is capable. But prejudice may hamper its growth. Already the repressing influence of conservatism is at work.

The representative of one of the English electric railway companies writes to me from London that their system "has not been put into actual work at present, owing to the opposition met with in England to any new scheme, and the difficulty of obtaining permission from the local authorities." We on this side the water pride ourselves on our progressive spirit, yet on this point at least we are the equals of our English brethren in conservatism. Shall we let Germany teach us a lesson in progress?

The steam railway had a harder fight to make than the electric railway has so far had. By its own merit it triumphed at last. The child survived, and now as a man is doing a good share of the work of the world. Another child promises in time to come to do that work better. Shall we not give it a speedy chance to fulfil the promise?