ELECTRIC LIGHTING.

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A few months ago, when the author accepted the invitation of the Council of this Association to read a paper on the application of electricity to lighting purposes, it never occurred to him how difficult would be the task to deliver an interesting paper on so special a subject, or a paper that would be of value to an Engineering Association.

The paper is divided into several parts :—

1st. An explanation of the principles involved in the production of electrical energy, and its conversion into heat and light.

2nd. A description of the apparatus used for the generating the current for the light.

3rd. A description of the lamps used, their regulators, and also the manufacture of same, together with other appurtenances, such as leads, safety plugs, etc. ; also,

4th. A reference to the cost of the light and its advantages.

Electricity exists in two distinct forms, the static and dynamic, but the word " static " is somewhat misleading, because electricity, like heat, is now recognised to be a form of matter in motion.

Electrical potential, or that which produces an electrical current—just as a head of water produces a water current—is measured in units called Volts. One Daniell's cell produces 1·1 volts.

All substances resist the passage of an electrical current. The unit of this resistance is called an " Ohm." The ohm is the resistance of a column of mercury of a square millimètre cross section, and 106 centimètres in length, at the temperature of melting ice.

The ampère is the unit of current, which is produced by an electro-motive force of one volt through a resistance of one ohm.

In all systems of artificial lighting, of whatever kind, the light is produced by the incandescence or glowing of solid particles of matter, and the heat required to produce this is produced in different ways. Ordinary coal gas consists of a combustible gas richly charged with very small particles of solid carbon, which being made white hot by the combustion of the gas, glow and produce the light required.

If these solid particles are removed the combustion of the gas produces no light. It will therefore be seen that to produce a light we must heat a solid body to incandescence.

To produce a given light with the smallest possible expenditure of heat—that is of fuel and cost—the heat must be concentrated on a solid body of the smallest possible size, so that, that may be raised to the highest possible temperature.

There is a class of substances called *conductors*, along which a current of electricity can be made to pass. Substances along which the current will not flow are called *insulators*.

No substance is perfect, either way; the best conductors offer some resistance to the currents, and the best insulators allow a little electricity to pass through them.

Conductors differ greatly in the facility with which they conduct electricity.

A platinum wire offers between five and six times the resistance to the flow of electricity as a copper wire of the same length and diameter, and the resistance of a given length of a given wire is greater when the wire is thinner, being inversely proportional to its cross section. With the same cross section it is directly proportional to the length.

Let it now be supposed that by means of a steam engine turning an electric generator a current of electricity is being forced through a long copper wire of large diameter, the only force opposing the flow will be the resistance of the wire. To overcome this a certain quantity of heat has to be expended in the steam engine working the electric generator, and by the resistance the wire will be more or less heated.

The relative amounts of work expended and heat produced in sending a current through a thick and a thin wire of the same length and material are inversely proportional to the cross sections of the wires.

As long as the wire is of the same diameter and of the same material throughout, the resistance will be the same in all parts, and the heating will be uniform all along the wire. If, however, the copper wire is divided at one place and a spiral of very fine platinum wire is interposed, a great deal of resistance will be concentrated at one spot, and instead of the heating being uniform all along the wire, by far the greater portion of the total heating will take place in the spiral. See figure A.

Thus this arrangement of the electric current provides a means of taking heat from the engine fire and conveying it to any one place, at a distance, viz., the place where the spiral has been put.

It will therefore be seen that, when at the place where it is desired to concentrate the heat, a body of sufficiently high resistance is fixed, and a sufficiently strong current is passed through it, it can be made so hot that it will glow and give light.

This is the principle of all electric lamps, of whatever kind.

As to the generators of electricity, there are many kinds of batteries used, and for such instruments as electric bells or telephones the Leclanche battery is the most suitable. The batteries, however, do not maintain a current of constant strength, which is essential for the production of electric light.

The Bunsen, Daniells, and Bichromate batteries are also generally used.

The method of producing electricity by means of the battery is too expensive to be largely used for supplying the electric light, though useful in exceptional circumstances and for experimental purposes. To afford illumination on a practical scale the plan of converting mechanical into electrical energy, by the machines termed magneto-electric or dynamo-electric generators, has been adopted.

In order that the principle of the action of these machines or generators may be understood, it is necessary to trace the connection between what are called magnets, and conductors conveying electric currents.

Lodestone or magnetic oxide of iron is found in a natural state in many parts of the world. A bar of this material has the property of attracting iron and steel, and when suspended in a suitable manner, of placing itself north and south, and is called a *natural magnet.*

A piece of hardened steel, rubbed with lodestone, permanently acquires similar properties, and is called an *artificial magnet.* A piece of soft iron whilst held under the attractive influence of a natural or artificial magnet is found to acquire *temporarily* magnetic properties, which vanish when the iron is removed from the influence of the magnet, This phenomena is called "*magnetic induction.*"

The attractive power of a magnet is not eqally distributed throughout its bulk, but is found to be much more intense at some points than at others.

In a magnet in the form of a straight bar, the greatest attractive power is found to be located at two points at short distances from the ends. A bar magnet dipped into iron filings will be found to attract large quantities at its ends, leaving the centre bare. See figure B.

The end of a magnet which points to the north, it is well known, is called the north seeking pole, and that which points to the south, the south seeking pole. For certain experiments a compass needle is a very convenient form of magnet. If the north seeking pole of a magnet is brought near the north seeking end of the needle, it will be repelled, and the south seeking end attracted. In other words, like poles repel and unlike poles attract each other.

The attractive power of a magnet is greatest close to its ends, and falls off rapidly as the distance from the poles is increased.

For example, a magnet will attract any magnetic object one inch distant with four times the power exerted at two inches, or nine times that at three inches distance.

This will be well understood when it is known that the area round a magnet is pervaded by a magnetic influence, which is called the *magnetic field,* and the lines of force may be considered as running from one pole to the other in curved lines. See figure C.

The direction of these lines of force may be ascertained by placing a sheet of paper over an ordinary bar magnet and sprinkling it with iron filings, which will arrange themselves in curved lines, as shown in figure D.

These lines show the direction in which a small magnetic needle would place itself at any given point under the influence of the attracting and repelling forces of the magnet poles. It is convenient to consider the lines of force to flow from the north seeking pole to the south seeking pole, or in the same direction that a free north seeking pole would travel.

There is a limit to the size and strength of magnets formed by rubbing with a lodestone or permanent magnet, and therefore it has been found necessary to use another kind of magnet in the electric light generators, which is more powerful, although permanent magnets are still used in some machines.

A more suitable mode of imparting magnetic power is to pass a current of electricity through an insulated wire, wound round a piece of soft wrought iron. See figure E.

The iron will be converted into a magnet whilst the current is flowing, but will lose its magnetic power as soon as the current is taken off.

A magnet formed in this way is called an *electro magnet.*

The strength of an electro magnet depends on the number of turns of wire in the coil, and the strength of the current sent round it. A cylindrical coil of wire, through which a current is passed, itself becomes magnetic, and is called a solenoid.

A conductor conveying a current is surrounded by lines of force, just as a magnet is. The direction of these lines of force varies with the direction of the current. If a conductor is looked along in the direction in which a current is flowing, the lines of force will flow round it in the same direction as that in which the hands of a watch revolve. As like magnetic poles repel and unlike poles attract each other, so will lines of force flowing in the same direction repel, and those flowing in opposite directions attract one another.

If a loop of stout wire be arranged to rotate upon its own axis between two magnetic poles, and a current be passed through it down one side and up the other side, it will be found to turn so as to place itself at right angles to a line joining the two magnet poles, and by means of a suitable apparatus for reversing the direction of the current at every half-revolution, a continuous rotation of the wire loop can be effected.

It has been shown how the mechanical rotation of a wire conductor can be produced by passing a current through it whilst in a magnetic field. The converse of this also holds good, that is to say, if a loop of wire is mechanically rotated in a magnetic field a current will be produced in it. If the wire loop is made to rotate between the magnetic poles N.S. in the same direction as the hands of a watch, a downward current will be produced in each side of the loop as it passes before the north pole, and an upward current when it passes before the south pole, the direction of the current being reversed at each revolution.

Whenever a conductor is moved near a magnet, so as to cut through lines of magnetic force, a current is generated (the effect is the same whether the conductor is made to approach the magnet, or the magnet the conductor). Currents produced in this manner are called *Induced Currents.*

It will be understood that to induce a current in a conductor it is only necessary to move it so as to cut through lines of magnetic force. The direction in which the current will be induced will be understood by imagining a person to be looking along horizontal lines of force in their positive direction, *i.e.*, north to south.

Then if a vertical conductor be moved from the left to the right hand of the person, so as to cut the lines of force, the induced current in the conductor will be in an upward direction, and in a downward direction if the movement be from right to left. If the conductor be in the form of a ring, and is rotated on its axis at right angles to the direction of the lines of force; the current induced will be in an upward direction at one side of the ring, and in a downward direction on the other side—producing a continuous current round the ring. There is an important difference to be observed between the case of the lines of force of the current and that of the lines of force of the magnet. The lines of force of the magnet *are* the magnet so far as the magnetic forces are concerned, for a piece of soft iron laid along the lines of force thereby becomes a magnet, and remains so as long as the lines of force pass through it. But the lines of force crossing through a circuit are not the same thing as the current of electricity that flows round the circuit.

A loop of wire may be taken, and the poles of a magnet put on each side of it, so that the lines of force may pass through it from one face to the other; but if they are kept there for any period the presence of these lines of force would not create an electric current, even of the feeblest nature. There must be *motion* to induce a current of electricity to flow in a wire circuit.

When a coil of wire surrounds a soft, wrought iron core, a current can be induced in it each time a magnet is made to approach to or recede from the core. This result is due to the magnetism alternately developed and destroyed in the core. In the same way, if the magnet, surrounded by a coil of wire, is brought near an armature or piece of iron, its magnetism is affected, and a current is produced in the coil.

The very close connection that exists between magnets and conductors conveying electric currents, and the reversibility of their mutual action will be understood, and it is necessary to remember that to induce a current in a coil of wire by means of a magnet, there must be relative motion between coil and magnet. Approach of a magnet to a coil, or of a coil to a magnet, induces currents in the opposite direction to that induced by recession.

The stronger the magnet the stronger will be the induced currents in the coils.

The more rapid the motion the stronger will be the momentary current induced in the coils, but the time it lasts will of course be shorter.

The greater the number of turns in the coil the stronger will be the total current induced in it by the movement of the magnets.

By using a suitable collector or commutator, the currents, direct and inverse, can be sent through the external circuits in same direction.

All electric generators may be considered as machines for moving magnets past coils of wire, which coils may or may not have iron cores, or coils of wire past magnets, the connections being so arranged that the electro-motive forces generated may produce currents.

The motion is always circular, *i.e.*, the coils are attached to the rim of a wheel, so that as the wheel revolves they pass the magnets again and again. There are a number of dynamo machines of different forms, but they may all be placed under two heads, viz. :—

The "Alternating" type, where a number of coils are placed on the rim of one wheel, and a number of magnets on the rim of another concentric with it—one wheel being fixed, and the other is made to revolve. Alternating currents, or currents alternately in opposite directions, are produced in the coils, and are either used as alternating currents, or are converted into direct currents by being passed through a collector or commutator before being passed into the line.

The "Direct" type, where the wire is wound continuously round a ring of soft iron, the winding being as if the wire were wound spirally round a long iron bar, which was afterwards bent into the form a ring. In this type the ring revolves between two, or sometimes four or six, magnet poles, and although the currents are alternately in opposite directions in any portion of the wire, they are always in the same direction in the wires which are passing either pole. These currents are collected by the commutator already referred to, and are passed as "direct" currents into the circuit.

There are two classes of generators. The magneto-electric, and dynamo-electric, In the first-mentioned machines permanent magnets are used; but in the latter electro-magnets with soft iron cores, excited by passing round them an electric current, produced either by the machine itself, or by a smaller machine provided specially for the purpose called an *Exciter*.

Almost all the machines now used for electric lighting are constructed with electro magnets, with soft iron cores—the principal of which has already been explained. The gramme machine of the direct type consists of a ring of soft iron, round which wire is wound as a continuous spiral forming a closed circuit. See Figure F.

It revolves between two poles of opposite names, the lines of force from which terminate in the ring. See Figure G.

As the ring or armature, as it is called, revolves, these lines of force are cut by the moving wires, and electro motive forces are generated in two halves of the ring, *in opposite directions*, so that they meet and oppose each other at the neutral points, N.P. See Figure H.

As long as no connections are made, no current is generated. If, however, the points N.P. are connected through an external circuit, such as a number of lamps, the two halves of the ring will act like two batteries in parallel circuit, and a current will flow through. See Figure I.

The ring being in motion, a permanent connection between the line and the wire in the ring cannot be made; but this is provided for by the collector, which is made of insulating material, often wood, and on which are a number of insulated metal strips. Each of these is connected by a wire to the part of the spiral wire opposite it, and two metal brushes press or rub on these strips at the points N.P. where the opposite electro motive forces diverge and join again. These brushes convey the current to the lamps. See Figure J.

There are three forms in which direct current machines are constructed to excite their own magnets. Series, shunt, and compound wound.