MAGNETO-ELECTRIC MACHINES*

FEW discoveries in physical science have been more important in themselves, or richer in practical results, than Faraday's discovery of the induction of electrical currents; and with the exception of the immortal work of Newton on the properties of Light, it would be difficult to mention any other experimental investigation, as it first issued from the hands of the author, so complete in all its details, or so full of new and original facts. Œrsted's grand discovery, which linked together electricity and magnetism, had already yielded a scientific harvest of uncommon richness. It led immediately to the construction of electro-magnets vastly exceeding in power any permanent magnets which were then known or have since been made. The multiplier or galvanometer of Schweigger supplied a new and important instrument for measuring electrical currents, which, with a little modification, became the electric telegraph. Faraday discovered the rotatory character of the reciprocal action of magnets and electrical currents; and Ampère showed that all the properties of a permanent magnet could be explained on the hypothesis of electrical currents in a fixed direction circulating around the magnet. A problem which proved to be one of surpassing difficulty, and long baffled many of the most distinguished physicists of Europe—to obtain electrical currents by means of a steel magnet—was in 1831 completely solved in the exhaustive memoir by Faraday, in which he announced the discovery of the induction of electrical currents. It may be interesting to describe, nearly in his own words, Faraday's original experiments.

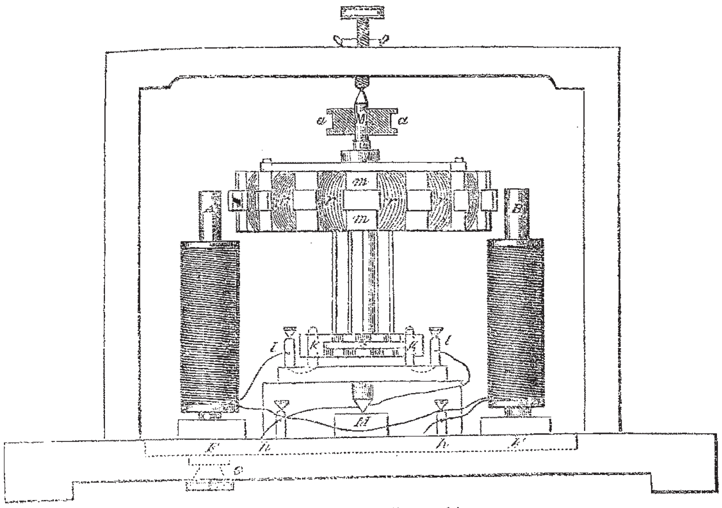

FIG. 1.—Pacinotti's Machine.

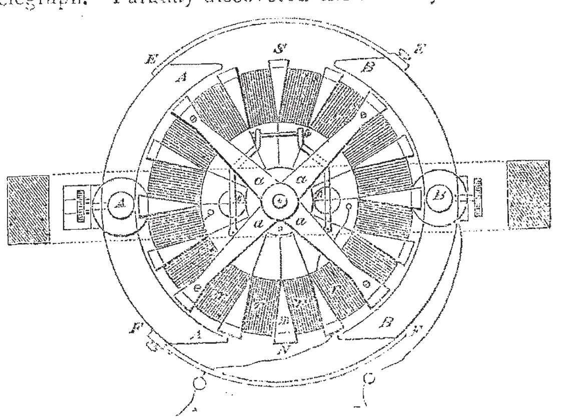

FIG. 2.—Pacinotti's Machine (Plan).

Two helices of insulated copper wire were passed round a wooden block, the ends of the wire of one helix being connected with a voltaic battery, and those of the other with a galvanometer. So long as the current from the battery passed through the first helix the needle of the galvanometer remained motionless, but on breaking the connection with the battery, a momentary current, as indicated by the galvanometer, traversed the wire of the second helix. The direction of this current was the same as that of the primary current of the battery. When the first helix was connected with the battery, another momentary current traversed the second helix, but in this case it was in the opposite direction to the primary current. Substituting for the first helix and the voltaic battery a permanent steel magnet or an electro-magnet, Faraday found that on introducing one end of the magnet into a hollow helix a temporary current was produced in the wire of the helix in one direction, and on withdrawing it another temporary current occurred in the opposite direction. For artificial magnets the magnetism of the earth may be substituted, and thus electrical currents can be obtained by induction from the magnetic conditions which everywhere prevail on the surface of this globe. The singular phenomenon first described by Arago, and afterwards elaborately investigated by Babbage and Herschel, that when a copper plate is rotated below a freely suspended magnet the latter tends to follow the motion of the plate, was shown by Faraday to arise from electrical currents induced by the magnet in the rotating metallic disc.

Soon after the announcement of these important results, Pixii constructed in Paris the first magneto-electric machine. I have still a vivid recollection of this machine as I saw it in Pixii's workshop. The currents were obtained by the rotation of a powerful horse-shoe magnet in front of an armature composed of two short bars of soft iron with a connecting crossbar, the latter being surrounded by a long coil of copper wire covered with silk. The armature had, in short, nearly the form of a horse-shoe electro-magnet. With this machine electrical sparks were obtained, and water was freely decomposed. In the rotation of the magnet the faces of the armature or electro-magnet became successively north and south poles with intermediate conditions of neutrality, and the direction of the current changed at every semi-revolution of the magnet. Hence, in the decomposition of water and other electrolytes, the ele-

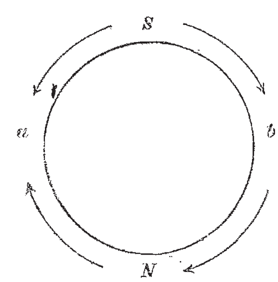

FIG. 3.

* The substance of a Lecture, with additions, delivered at the Belfast Philosophical Society, March 17, by Dr. Andrews, F.R.S., L. & E.

ments or radicles produced by the electrolysis could not be obtained separately. Pixii is said to have applied a commutator to his machine in order to obviate this defect. An important modification of Pixii's machine was soon after made by Paxton, who caused the armature to revolve instead of the permanent magnet. According to the character of the current required, armatures with longer or shorter wires were employed. A large machine of this construction, exhibited some years ago at the Polytechnic Institution in London, was capable of igniting a short platinum wire. In Clarke's machine the position of the armature was altered and an improved commutator applied. Siemens afterwards, by giving the armature a cylindrical form, rendered it more compact and better fitted for rapid rotation.

Siemens' armature was happily applied by Wilde, in 1866, to the construction of a machine of extraordinary power. Starting from a small magneto-electric machine provided with six steel magnets, each weighing one pound, and capable of carrying about ten times their weight, Wilde transmitted the direct current from this machine through the coils of an electro-magnet provided like the former with a Siemens' armature, and the direct current from the latter he in like manner transmitted through the coils of another large electro-magnet— so large, indeed, that its armature alone weighed above one third of a ton. This was also provided with a Siemens' armature. When the machine was in full action it melted a rod of iron 15 inches in length and a quarter of an inch in diameter, and gave the most brilliant illuminating effects when the discharge took place between carbon points. As nearly as could be estimated, the mechanical force absorbed in producing these results was from eight to ten-horse power. Wilde's machines have been successfully employed by Messrs. Elkington for the precipitation of copper and other metals, and he has lately proposed some important modifications to adapt them to the production of the electric light.

Some years before Wilde's experiments were published, Holmes had constructed on the Saxton principle a powerful magneto-electric machine, which has been successfully used at Dungeness and other lighthouses, and machines differing little from Holmes's are employed in some of the French lighthouses. In Holmes's original machine forty-eight pairs of compound bar-magnets were arranged for the armatures (160 in number) to revolve between the poles of the magnets, and by a system of commutators the current was obtained always in the same direction. Its amount, however, varied at almost indefinitely short intervals from a maximum to one-half of that amount. In practice these variations were wholly inappreciable.

The first suggestion of a magneto-electric machine capable of giving a continuous current always in the same direction is due to Dr. A. Pacinotti, of Florence. In the nineteenth volume of "Il Nuovo Cimento," which was published in 1865,* Pacinotti describes the model of an electro-magnetic machine constructed, some time before, under his direction, for the Cabinet of Technological Physics in the University of Pisa, whose essential feature was a novel form of armature to which he gave the name of "transversal electro-magnet." This armature was formed of a toothed iron ring, *m m* (Fig. 1), capable of rotating on a vertical axis, M M, and having the spaces between the teeth occupied by helices of copper wire covered with silk. The wire of the helices was always wound in the same direction round the ring, and the terminal end of each helix was brought into metallic connection with the adjoining end of the wire of the succeeding helix. From these junctions connecting wires were carried down parallel to the axis of the machine, and united to insulated plates of brass, of which a double row, as shown in Fig. 1, were inserted in a wooden cylinder, *c*, which was

* The date on the title-page of the volume is 1863, but it contains a letter dated Rome, Jan. 19, 1865

itself firmly attached to the lower part of the axis. The current entered through the successive brass plates as they came into contact with a small metallic roller, *k*, which was in communication with one pole of a voltaic battery. At the point of junction with the wires of the helices, the current from the battery divided into two parts, which respectively traversed in opposite directions the connected helices, each through a semi-diameter of the ring, and finally left the machine on the opposite side by a second roller, *k*, which was in connection with the other pole of the battery. When the connections were made, the iron ring began to rotate round its axis with considerable force. In a trial in which the current was supplied by four small elements of Bunsen, a weight of several kilogrammes was raised. In the apparatus as actually constructed, the poles of the electro-magnet were enlarged by the addition of two segments of soft iron, A A, B B (Fig. 2), which extended over the greater part of the iron ring. The details of the construction of the transversal electro-magnet will be easily understood from the plan given in Fig. 2.

Towards the end of the paper to which I have already referred, Pacinotti shows that the iron ring armature, or transversal electro-magnet, may be applied to reverse the conditions just described, and to obtain continuous electrical currents, always in the same direction, from a magnet, whether a permanent one, or an electro-magnet. As the original paper has not, as far as I know, been translated into English, and the scientific journal in which it was published is little known in this country, I will not make any apology for giving the following extract without abridgment.

"If we substitute for the electro-magnet A B (Fig. 1) a permanent magnet, and make the transversal electro-magnet revolve, we shall have a magneto-electric machine which will give an induced continuous current always in the same direction. To find the most suitable positions on the commutator from which to collect the induced current, let us observe that in presence of the poles of the fixed magnet, there are formed, by influence, at the extremities of a diameter, opposite poles on the moveable electro-magnet. These poles, N S (Fig. 2), maintain a fixed position when the transversal electro-magnet rotates upon its axis; and therefore, in respect to the magnetism and consequently to the induced currents, we may consider, or suppose, that the helices of copper wire move round on the ring magnet while the ring itself remains at rest. To study the induced currents which are developed in these helices, let us take one of them in the various positions it can assume. From the pole N (Fig. 3) advancing towards the pole S, there will be developed a direct current in one direction till the middle point *a* is reached; on passing this point the current will assume an opposite direction. Proceeding from S towards N, the current will maintain the same direction which it had from *a* to S, till the middle point *b* is reached; after passing *b* the direction will be again changed, and will now be the same which it had from N to *a*. Now, since all the helices communicate with one another, the electro-motive forces will be collected in one given direction, and will give to the entire current the course indicated by the arrows in Fig. 3;* and for collecting it, the most suitable positions will be *a b*; that is to say, the rollers on the commutator should be placed at right angles with the line of magnetism of the electro-magnet."

Pacinotti does not appear to have constructed specially a magneto-electric machine on the above principle, but he states that he verified the correctness of his views by turning the iron ring in the electro-magnetic machine, and observing the direction of the currents when a galvanometer was introduced into the circuit.

* Fig. 3, as given in the text, is an exact fac-simile of the corresponding figure in the original. It is obvious from the figure itself, as well as from the text, that there is an error in the engraving, and that the arrow between S and *b* should point towards S and not towards *b*.

The results he obtained were not great, but were sufficient to enable him to announce that a magneto-electric machine could be constructed which would have the advantage of giving the induced currents all in the same direction, without the help of mechanical arrangements to separate opposed currents or to make them conspire with one another.

From the foregoing analysis of Pacinotti's memoir, there can be no doubt that it contains a description of the ring armature which in the hands of Gramme has recently led to the construction of magneto-electric machines giving continuous currents of great intensity. I cannot, however, pass over without notice an extraordinary blunder into which Pacinotti has fallen, and which would render any machine constructed after his model altogether valueless. By a reference to Fig. 2, which, as well as Figs. 1 and 3, has been engraved from a photograph of the plate appended to the original memoir, it will be seen that the letters N and S are placed at the end of the diameter of the ring which is at right angles to the line A B joining the poles of the fixed magnet. That Pacinotti intended these letters to designate north and south magnetic poles is manifest from the following passage among others in his memoir:—"Osserviamo che per influenza sulla elettro-calamita mobile si formano i poli opposti alle estremità di un diametro in presenza ai poli della calamita fissa. *Questi poli* N S mantengono una posizione fissa anche quando la elettro-calamita trasversale ruota sul suo asse." It is hardly necessary to say that the positions assigned by Pacinotti for the poles in an iron ring under the influence of a fixed magnet are in reality those of the neutral points, or points of no magnetism, and that the magnetic poles of the ring are at a distance of 90° from the positions stated by him. This mistake has led to a serious blunder in the construction of his machine, the metallic rollers which carry off the induced currents being placed, not at the neutral points (as Pacinotti has himself clearly showed that they ought to be), but at the poles of the ring. That any effects at all were obtained from the model at Pisa, we must attribute to the slight shifting of the poles of the ring due to its rotation. Apart, however, from this unaccountable error, it can scarcely be disputed that to Pacinotti is due the merit not only of having devised the ring armature or transversal electro-magnet, but of having also accurately analysed its mode of action.

(*To be continued.*)

*LECTURES AT THE ZOOLOGICAL GARDENS**

V.

Mr. Garrod on Camels and Llamas

THE Tylopoda form a group which includes the Camels together with the Llamas; the name indicating that their feet are covered with callous skin instead of with hoofs as in the typical Ruminants, from which group they also differ considerably in many other characters, to be considered seriatim.

Horns are not developed in either sex. The upper lip is hairy and partly cleft. False hoofs are wanting. The general body-proportions are not so symmetrical as in any of the Cavicornia or Deer. Osteologically several special features present themselves. In the vertebræ of the neck the canals which are developed in the transverse processes, for the vertebral arteries to run in on their way to the brain, are excavated in the sides of the spinal canal of the cervical region. In the ankle two of the bones—the naviculare, or scaphoid, and the cuboid—which are anchylosed in the true Ruminants, are independent of one another. In the upper jaw there are two teeth developed, one on the side of each premaxilla; they are therefore lateral incisors. The canines in the lower jaw are of a different shape, and are separated by an interval from the incisors. The molars form a series of five above and four below; in the Camels, but not in the Llamas, an additional small premolar, isolated in position and following the canine, is to be found in both jaws, increasing the grinder series to six above and five below on each side.

The abnormal conformation of the gastric section of the alimentary canal in the Camels has attracted the attention of many naturalists. In the Llamas the same structure maintains. As in the typical Ruminants the stomach is composed of several cavities communicating one with the other, but there is some difficulty in deciding which are the exact homologues of the *rumen*, *reticulum*, *psalterium*, and *abomasum*. The first cavity is a capacious globose sac into which the œsophagus opens. A longitudinal band of muscular fibre partly constricts it, in its course from the right side of the cardiac orifice backwards along the ventral surface, opposite the middle of which a narrow and long aggregation of "water cells" starts to continue tranversely towards the left side of the organ. This longitudinal muscular band forms one of the boundaries—the left one—of a much larger collection of deeper water cells, which embrace the posterior portion of the right side of the paunch in the concavity of their crescentic mass. From the right of this first main compartment a second smaller one is cut off by a constriction which leaves a considerable opening between the two. Its position is that of the reticulum; it is deeply honeycombed, the lining membrane of the cells being covered with villi much like those on the surface of the folds of the psalterium of the deer, &c. The cell-walls are thin and but slightly muscular. In the paunch the mucous membrane is smooth and not at all thick. The water-cells are formed on a framework of many intersecting muscular sheets arranged in layers with intervals of less than an inch between them, one half being at right angles to the other, so as to form rows of quadrilateral cavities. These are again incompletely divided up by secondary septa. The orifices of the cells are partly closed by diaphragm-like membranes at their mouths. Most probably the contraction of the aggregated muscular fibres in the same situations is capable of closing the cells completely when necessary. That the camel can store fluid in these water-cells is borne out by the experience of so many authors that doubt is scarcely possible. For instance, in his "Travels to discover the Source of the Nile," Bruce (vol. iv. p. 596) tells us on one occasion that "finding the camels would not rise, we killed two of them . . . and from the stomach of each got about four gallons of water, which the Bischareen Arab managed with great dexterity." As John Hunter remarks, there is no physiological reason why this should not be the case. A specialised structure is observed by zoologists; a special power is attributed by travellers; the function and the structure may be reasonably correlated: why should they not be so, as no other explanation suggests itself? There is no arrangement for closing the cells of the reticulum similar to that found in those of the rumen.

A muscular fold runs from the termination of the œsophagus along the superior or vertebral side of the lesser curvature of the stomach to the third compartment, which evidently directs the products of rumination into it, just as the two folds of the same region do which traverse the reticulum in the typical Peccora. Following the honeycomb-bag is a single elongate cylindrical cavity, which dilates slightly and becomes bent at its pyloric extremity. This compartment is thin-walled and longitudinally ribbed internally for its proximal five-sixths, beyond which the mucous membrane is much thickened and evidently digestive in character, especially in the neighbourhood of the angle of the inflection in that region. This section of the stomach apparently corresponds to

* Continued from p. 69.