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R. Shida M.E.

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XII. *New Instrument for continuously recording the Strength and Direction of a Varying Electric Current.* By R. SHIDA, M.E., Professor of Natural Philosophy in the Imperial College of Engineering, Tokio, Japan.

[Plates II. & III.]

To Sir William Thomson, F.R.S., LL.D., &c.

DEAR SIR WILLIAM,

I ENCLOSE herewith a paper which I have just drawn up and which is a description of a new instrument I have devised and constructed for continuously recording the strength and direction of a varying electric current. My chief aim in designing such an instrument was to use it for making observations of both regular and irregular variations of earth-currents which are present in the telegraph-wires of this country, just as they are present in the telegraph-wires of any other country. The importance of carrying on careful observations of earth-currents has been felt more and more since you showed it before the Society of Telegraph Engineers and Electricians, about eleven years ago, in your presidential address. Indeed, so great an importance is now attached to such observations, that it was one of the main subjects discussed by the International Electric Congress which met at Paris last year. Now, since both regular and irregular earth-currents are so variable, that their strength and direction change, not only from day to day, but from hour to hour, or from minute to minute, or even from second to second, observations will be of very little value unless they are continuously made; hence the importance of a method of continuously registering the strength and direction of varying electric currents. The photographic method, such as is used in the Kew Observatory, is, of course, very satisfactory and accurate. But this method, besides requiring an elaborate arrangement of several pieces of apparatus, has a serious disadvantage, namely, that the observations must be made in a dark room. I have therefore felt for a long time the want of a method which, though not so accurate as the photographic method, is simple and convenient. It was thus that I was led to devise the apparatus described in the accompanying paper.

As will be seen from the description given in the paper, the galvanometer-part of the apparatus is, in the main, the same as that of the more recent one of your Siphon Recorders; that is to say, a coil containing a great number of turns of fine wire is suspended in a strong magnetic field produced by

permanent magnets. There is, however, one point in the apparatus which is quite new, at least quite new to my knowledge: that is, that the advantage is taken of a singular property of matter, "surface-tension of liquids." We know very well that a mercury-drop is often used for the purpose of making and breaking an electric circuit. But nobody has used a water-drop or an acidulated-water drop for the same purpose. The advantage of a water-drop over a mercury-drop, when employed for opening and closing an electric circuit, is that the former offers a far smaller resistance than the latter to the moving body which comes in contact with it. Now, in the instrument I am speaking of, a water-drop or, what is equivalent to it, a thin column of water drawn up between two narrow plates partly immersed in water, is used for the purpose of making and breaking the circuit, as will be seen from the description given in the paper.

For the further details of the apparatus I ask you to be good enough to refer to the paper itself.

The Instrument, I might mention, may of course be used as a "coulombmeter," because since in the paper ribbon, on which a record is obtained, the abscissas represent times and the ordinates represent currents, the area included by (the abscissa) the line of no current, and the ordinates corresponding to any two times and the curve of current, represents the quantity of electricity passed through the apparatus during the interval between the two times.

* * * *

R. SHIDA.

ONE of the principal subjects discussed by the International Electric Congress held in Paris in 1884, was that of Earth-currents; and the result of the Congress as regards earth-currents was "that the Conference expresses the wish that observations of earth-currents be pursued in all countries." This resolution, together with the others, has been communicated to the various Governments; and our Government having conformed to the wish of the Conference, it was decided that the observations of earth-currents be made by the Telegraph Department, in which I am a chief engineer. It thus devolved on me to take the subject up. A little consideration, suggested by the results of preliminary observations I have made of earth-currents, revealed to me that in order to carry out systematic observations of earth-currents, which, from time to time, vary in strength and direction, it is almost necessary, or at least extremely convenient, to have at our disposal a simple instrument which will continuously record

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the strength and direction of a varying electric current. In view of this, I have designed and constructed an instrument the description of which I have now the pleasure of communicating. In order that an instrument may continuously record a varying electric current, it is necessary that it should fulfil the two following conditions:—

1. That the motion of the needle of the galvanometer (which is a part of the instrument) be such that the same position of the needle always corresponds to the same strength of current, that is to say that the motion be non-oscillatory.

2. That the position of the needle of the galvanometer at any moment be recorded.

I shall first explain generally how these two conditions are satisfied in the new instrument I am going to describe.

As regards the first condition. This condition is satisfied by having a galvanometer whose needle consists of a coil of fine wire suspended in a powerful magnetic field, after the manner of the Siphon Recorder of Sir William Thomson. It is easy to show mathematically that in the case of an ordinary galvanometer, which consists of a magnetic needle suspended inside, or in the neighbourhood of a coil of wire, this condition cannot conveniently be fulfilled without diminishing its sensibility. On the other hand, in the case of a galvanometer consisting of a coil hung in a strong magnetic field as above described, it is easy to obtain a great sensibility and, at the same time, a non-oscillatory motion of the needle, as will be seen from the following investigations:—

Let α be the angle of deflection of the coil at any time t , and let T be its period of oscillation when no current is circulating through it; then we have for the equation of the motion

$$\frac{d^2\alpha}{dt^2} + \frac{4\pi^2}{T^2} = 0.$$

But when a current circulates through the coil, the equation of the motion will be altered owing to a retardation of the motion due to the current induced in the coil. Let us consider the magnitude of this retardation. If I be the intensity of the magnetic field which the coil occupies at time t , A the area included in all the turns of the coil, and if we neglect the self-induction of the coil on itself (which I think we can confidently do); then, plainly, N , the number of lines of force which pass through the coil at time t , is

$$N = IA \sin \alpha;$$

hence

$$\frac{dN}{dt} = IA \cos \alpha \frac{d\alpha}{dt}.$$

But $\frac{dN}{dt}$ is the E.M.F. due to the inductive action ; hence, if R be the resistance of the circuit and α be small, the current induced in the coil at any time t , is approximately

$$c = \frac{IA}{R} \cdot \frac{d\alpha}{dt}.$$

Now the couple or torque due to the action of the field on the circuit is cIA ; and therefore the retardation of the angular velocity of the coil at any time t is

$$\frac{I^2 A^2}{\mu R} \cdot \frac{d\alpha}{dt},$$

where μ is the moment of inertia of the coil. Hence we have, for equation of the motion of the coil,

$$\frac{d^2\alpha}{dt^2} + \frac{I^2 A^2}{\mu R} \cdot \frac{d\alpha}{dt} + \frac{4\pi^2}{T^2} \alpha = 0.$$

The motion represented by this equation will be oscillatory or non-oscillatory according as $2\pi/T$ is greater or less than $I^2 A^2 / 2\mu R$, so that in order to make the motion of the coil non-oscillatory, all that is necessary is to have the magnetic field so strong that $I^2 > \frac{4\pi}{T} \cdot \frac{\mu R}{A^2}$.

Now as regards the second condition. The method commonly used of recording the motion of the needle of a galvanometer is the photographic method, which is, undoubtedly, very satisfactory. But this method, besides requiring an elaborate arrangement of several pieces of apparatus, has a serious disadvantage, namely that the observations must be made in a darkened room. The method adopted in the new instrument is one which, though, perhaps, not so accurate as the photographic method, possesses the advantage of being very simple and convenient. In this method, which may be called the electrical method, there are several electrical circuits, each of which is closed when, and only when, the coil or the needle comes to a certain definite position corresponding to it, and each circuit, when closed, makes a mark on a moving paper ribbon chemically prepared, somewhat in the same way as in the Bain's Telegraphs. If the coil turns round in one direction, it successively closes those circuits which make marks on one side of the centre of the ribbon, and if in the opposite direction, those circuits which make marks on the other side ; and further, the distance of the mark from the centre of the ribbon is greater or less according as the turning round of the coil is greater or less.

How these electrical circuits are exactly arranged will be seen later on with reference to the diagrams of the actual instrument. At present it suffices to explain how the coil or needle closes each electrical circuit separately, and without its motion being checked or impeded. This is effected by taking advantage of one of the well-known properties of matter, "surface-tension of liquids." When a capillary tube is partly immersed in a liquid which wets the tube, like water, the liquid ascends in the tube, and the smaller the diameter of the tube the greater the height to which the liquid ascends, and *vice versâ*. In fact, it can be shown that if θ be the angle of capillarity, r the radius of the tube, w the weight of unit volume of the liquid, T the surface-tension per unit length of the liquid in contact with air, then h , the height to which the liquid rises, is

$$h = \frac{1}{r} \cdot \frac{2T \cos \theta}{w}.$$

But the liquid is drawn up in the same way in the space between two parallel plates. In this case, if d be the distance between two plates, then

$$h = \frac{1}{d} \cdot \frac{2T \cos \theta}{w};$$


which shows that the height to which a liquid rises between two parallel plates is equal to the height to which it rises in a tube whose radius is equal to the distance between the plates.

Imagine now that there is a large number of capillary arrangements, each consisting of two very narrow plates standing in a vessel containing water at small distances from one another, and arranged in an arc of a circle, while the needle of the galvanometer is disposed in such a manner that, as it turns round, it successively comes in contact with the column of water drawn up between the plates of each of those capillary arrangements and thus closes several circuits in order; or else, that there is one such capillary arrangement, while the needle carries a large number of points so disposed that, when it turns round, these points successively come in contact with the column of water in the capillary arrangement, and thus close several circuits in order. Either of these arrangements affords us the means of closing each circuit separately, and without the motion of the needle being checked. In the new instrument the latter plan is used, as will be more clearly seen with reference to the diagrams (Plates II. and III.).

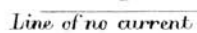
Having now explained briefly the principles upon which

Fig. 1.
1st full size.

Fig. 4.



The graph shows a periodic oscillation of the magnetic field H as a function of distance x . The curve crosses the horizontal axis, which is labeled "Line of no current". The oscillations are irregular in amplitude and frequency, with several peaks and troughs visible across the horizontal range.



A diagram of a ZC chain. It consists of a horizontal line with 10 vertical bars (sites) attached to it. The leftmost bar is labeled 'Z' and the rightmost bar is labeled 'C'.

the action of the apparatus depends, I shall proceed to describe the construction and action of the apparatus. Fig. 1 (Pl. II.) shows the general view of the apparatus; while figs. 2, 3, and 4 (Pl. III.) shows the details of the arrangement of the coil, magnet, &c. N and S are the poles of a powerful horseshoe magnet consisting of a bundle of square bar-magnets made of very hard-tempered steel. Between the poles N and S there is suspended, by means of a fine silk thread, a coil (C), which contains a great many turns of a very fine insulated wire, and whose plane is at right angles to the line joining the two poles of the magnet; m is a piece of soft iron fixed inside the coil, nearly filling, but nowhere touching, it, and serves to intensify the magnetic field in which the coil hangs. When an electric current passes, the coil tends to turn round a vertical axis in one direction, or in the opposite direction, according as the current is positive or negative. The two weights, w , w , hanging from the coil can slide up and down the inclined plane (P). These weights resist the tendency of the coil to turn round caused by the passage of a current through it, and serve to bring the coil to its original position when the current ceases. The cords by which these weights are suspended pass through small holes in a piece of brass (x), whose distance from the coil can be varied by moving it up and down along the vertical plane (P'), and thus the sensibility of the apparatus can be altered. The strength of the field is so great that the motion of the coil caused by the passage of a current is almost non-oscillatory.

Attached to the coil (C) there is a thin circular disk of ebonite (D), whose axis coincides with the vertical axis about which the coil is free to turn, so that any angular motion of the coil causes exactly the same angular motion of the disk. This disk carries, on its underside and near to a portion of its circumference, a number of platinum teeth, t , t , t , &c. Directly underneath these teeth, and rigidly fixed to the framework of the instrument, is a vessel (V), containing acidulated water, and in this vessel is provided a capillary arrangement which consists of two very narrow platinum plates p p (fig. 3) (which shall, hereafter, be called capillary plates), standing vertically up, side by side, from the central part of the vessel, and drawing up the water of the vessel between them. The position of these capillary plates, when everything is in its normal position, is such, that the platinum tooth midway between the ends of the series $t \dots t$ is in contact with the column of water between the capillary plates, and that when the coil, and therefore the disk, is deflected to the right or left, the other platinum teeth on the left or right

successively come into contact with the column of water between the capillary plates. Every time any one of the platinum teeth comes in contact with the water, it closes an electric circuit (to be described) corresponding to it, so that these platinum teeth may be called "circuit-closers."

(L) is a cylinder of wood lacquered all over. It is covered with platinum sheet, and on this sheet is rolled a ribbon of white paper nearly as wide as the length of the cylinder. A portion of this cylinder is in the rectangular box (B), which contains a chemical solution, consisting of ferrocyanide of potassium, nitrate of ammonium, and water mixed in a certain proportion. Further, the cylinder (L) is made to revolve with uniform velocity by means of a clockwork arrangement placed inside the box (H). Thus the paper on the cylinder, as it rotates, comes out moistened with the chemical solution. Resting on the cylinder (L), and fitting tightly in a rod of ebonite (*r*), there are a number of platinum needles *n, n, n, &c.*; these needles may be called "marking-needles," for, if an electric current passes between any of these platinum needles and the revolving paper, a bluish mark is made on the paper directly underneath that needle.

These marking-needles are electrically connected, each to each, with the circuit-closers in order, there being as many needles as there are circuit-closers; that is to say, the first needle (on the right or left) is in connection with the first circuit-closer (on the right or left), the second needle with the second circuit-closer, the third with the third, and so on. The small terminal screws, *a, a, a, &c.*, on the ebonite plate (E), which is fixed to the framework of the apparatus, and also the screws, *b, b, b, &c.*, are provided for facilitating these connections. The exceedingly fine wires (insulated) connect the screws *a, a, a, &c.*, with the circuit-closers, and they all hang down from the screws in the form of spiral springs, meeting together in the common axis of the disk (D), and the coil (C), and thence go to the circuit-closers; so that it is to be understood that the resistance these wires offer to the motion of the disk and coil is so small as to be negligible.

Now, the platinum sheet on the cylinder (L) is in connection with one pole (Z) of the battery (CZ), by means of a platinum spring (*s*) resting on it; while the other pole (C) of the battery is in connection with the capillary plates (see fig. 3). Consequently, when there is no current passing through the coil, the positive current flows from the copper pole of the battery through the capillary plates, and the circuit-closer in the centre, and thence through the corresponding marking needle (the centre one), rotating paper, and platinum sheet,

and back to the zinc pole of the battery, making a blue mark on the rotating paper just underneath that needle ; while if a current passes through the coil it is deflected to the right or left according to the direction of the current, the circuit-closers on the left or right of the centre successively coming into contact with the column of water between the capillary plates in order, the result being that the corresponding needles make blue marks on the rotating paper. But since the paper revolves with uniform velocity, it is evident that the longer the time of contact between a circuit-closer and the water between the capillary plates, no matter which circuit-closer it is, the longer the length of the mark on the paper underneath the needle corresponding to that circuit-closer ; and the shorter the shorter.

From the preceding description it will be clear that when an electric current, varying from time to time in strength and direction, passes through the coil (C), we shall get a curve made up of dots, or of dots and lines, on the moving paper ribbon, the nature of the curve determining the strength and direction of the current at any moment. Fig. 4 shows one of such curves experimentally obtained by allowing a varying current to pass through the coil. Now since the motion of the paper ribbon is uniform, it is easy to find out the point in the curve, or the position of the coil, corresponding to any moment; and since the motion of the coil is non-oscillatory, each position of the coil corresponds to a certain definite strength of current, which can easily be determined by a simple experiment. So that by an examination of the curve thus obtained, it is easy to find out what was the strength of the current passing through the coil at any moment.

To give a rough idea of the sensibility of the apparatus, it may be mentioned that when the record shown in fig. 4 was obtained the apparatus was at its ordinary sensibility, which was such, that the superior and inferior limits of the current which it could record were respectively about 4 milliampères and $\frac{1}{6}$ of a milliampère. But of course the sensitiveness of the apparatus can be varied within a considerable range in very much the same way as in Thomson's Siphon Recorder.

One defect of the instrument, it may be argued, is the fact that it does not record any current which produces such a deflection of the coil that no one of the circuit-closers is in contact with the water between the capillary plates. This defect, however, is not a very serious one, for since the instrument is intended to be used for recording varying currents which give rise to a curve made up of dots, or of dots and lines, on the moving paper ribbon, it is easy, by examining

the positions of dots and lines, to complete the curve to a certain degree of approximation. If, however, a greater accuracy be needed, all we have to do is to diminish the angular distance between the circuit-closers, and to increase their number. In the next instrument to be made, I am going to introduce a few improvements, of which the most important is the mode of arranging the circuit-closers and capillary plates. Instead of having the circuit-closers movable with the coil, and capillary plates fixed, we may arrange so that the capillary plates move with the coil, while the circuit-closers are kept stationary; and by this means, it is possible to diminish the angular distances between the circuit-closers, and to increase their number without increasing the moment of inertia of the needle, and thus to obviate the above defect to a great extent, and, at the same time, to give to the instrument a greater sensibility.

XIII. *Electrochemical Researches*. By W. OSTWALD, Professor of Chemistry in the Polytechnic School, Riga*.

ALL reactions of acids, dependent on the characters, rather than on the nature of the constituents, of the acids, occur with an intensity which is different in each case, but is always proportional to an affinity-constant which is itself dependent only on the character of the acid and not at all on the nature of the reaction. This fundamental fact, which throws new light on the old conception of affinity-constants, has been proved by the author for various reactions; viz. the formation of salts in aqueous solutions, the actions of acids on insoluble salts, the change of acetamide into ammonium acetate, the catalytic decomposition of methylic acetate, and the inversion of cane-sugar†. These reactions, some of which are statical and others kinetical, led to the same numerical values for the affinity-constants of the acids examined.

Adopting Clausius's theory of electrolysis, and Williamson's theory of chemical change, a distinct connection must exist between the reactions of acids and the electrical conductivity of these acids. The theory of Williamson supposes that a continual exchange of atoms is occurring among the reacting molecules; the velocity of a chemical action must therefore depend on the velocity of the atomic interchanges. The theory of Clausius says that electrolytic conduction is effected so that the free ions continually displace equivalent elements or

* Abstract of Prof. Ostwald's recent work, prepared by himself, and communicated by M. M. Pattison Muir, Cambridge.

† See Pattison Muir's 'Principles of Chemistry,' p. 418 *et seq.*