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LVIII. *Influence of Proximity of Substances upon Voltaic Action.* By Dr. G. GORE, F.R.S.*

IN the year 1849 I made some attempts to discover an effect of gravity upon voltaic action at about the same time that Faraday was seeking to demonstrate by experiment a connexion between gravity and electricity. Recently I have shown (see "Relation of Volta-electromotive Force to Pressure," Phil. Mag. Feb. 1893, pp. 97, 98) that the difference of pressure due to gravity at the upper and lower ends of a vertical column of an electrolyte about three metres high, upon two perfectly similar electrodes of the same metal at the upper and lower ends of the column, in a series of six glass tubes, produced a very feeble electric current; and that whilst in fully one half of the experiments no current was perceptible, in forty-two instances a current occurred, and in thirty-nine of these it was in an upward direction through the liquid, the lower electrodes being positive. In my opinion these results indicated that the energy of mechanical pressure produced by gravity altered the volta-electromotive force and enabled an electric current to be produced.

It is manifest, if these experiments and statements are reliable, and the effects were really due to pressure:—1st, that gravity, by producing pressure, exerts an extremely minute influence upon chemical and voltaic action; and, 2nd, that similar effects, though excessively minute ones, must be produced by the gravitative action of a large mass of metal or other substance upon a voltaic electrode at the end of a *horizontal* column of electrolyte presented to it.

I have roughly calculated the probable amount of voltaic effect of pressure by the attraction of a massive cube of lead weighing 74 cwt., with its centre at a distance of fifteen inches from the ends of a series of fourteen horizontal tubes of liquid similar to those above referred to. Taking the weight of the earth as being about 12,500,000 million million pounds, the proportional weight of the cube to that of the earth as being about 1 to 1511,000000,000000,000000, and the proportional distance of its centre from the electrodes to that of the earth's centre from them as being about 1 to 17,000000, the proportional strength of gravitative influence of the cube to that of the earth upon them would be about 1 to 5300,000000, and after correction for the greater number of tubes in the horizontal than in the vertical apparatus the probable amount of voltaic effect would still be only about

* Communicated by the Author.

$\frac{1}{2400,000,000}$ part of that obtained with the six vertical tubes, and quite unrecognizable by means of a galvanometer, especially in the presence of a variable amount of unbalanced voltaic action which cannot be entirely excluded.

Numerical calculations, however, frequently lead to error unless they are sufficiently supported by facts; notwithstanding that the excessively feeble action of gravity, and the relatively large amount of purely voltaic action, rendered it highly improbable that any perceptible electric effect would be produced, on a number of occasions between the years 1849 and 1894, I devised and constructed various apparatus, and made numerous series of experiments and observations with them, in the hope of rendering such an effect perceptible. One was a vertical cylinder of guttapercha six feet high and six inches diameter, fitted with terminal electrodes attached to a galvanometer, filled with an electrolyte, and capable of revolving on a horizontal axis; a second was a massive wooden frame, provided with a high resistance-coil of very fine insulated copper wire leading to a galvanometer, and capable of being revolved upon a horizontal axis at a speed of more than 4000 revolutions per minute; a third consisted of two very compact and well insulated voltaic batteries of one hundred cells each, connected in opposition with a high resistance galvanometer, and separately attached to the two ends of a cord passing over a pulley fixed to a ceiling, so that one might be raised whilst the other was lowered through a distance of about twenty-two feet; and several others which need not be mentioned. The first really positive results were obtained in June 1894; and I will briefly describe some of the experiments made with three of the successful apparatus, substantially in the same chronological order in which they were made; the most perfect ones are those of the most recent date.

EXPERIMENTS WITH APPARATUS NO. 1.

In this section of experiments the apparatus consisted essentially of a massive influencing or "attracting" body; a series of fourteen tubes of electrolyte similar to those already mentioned, and a Thomson reflecting galvanometer having a resistance of 3040 ohms. The influencing mass, already mentioned, was composed of 72 pigs of lead, having a total weight of 8271 lb., or about 74 cwt., supported upon a solid brick floor and free from any perceptible vibration. The glass tubes containing the liquid were each about 75 inches long and $\frac{1}{4}$ inch internal diameter, fixed upon a perfectly horizontal and stout board which was capable of smooth

rotation upon a vertical axis at its middle part, so that either end of the series of tubes might be presented to the centre of the near face of the cube without being shaken. By omitting one of the pieces of lead a horizontal groove was left in that face of the cube, in order to increase the expected effect by permitting the ends of the tubes to penetrate about an inch within the mass. The electrodes were formed of zinc wire .072 inch diameter, all cut from the same piece, not amalgamated, and each fixed in a paraffined cork and projecting about $\frac{3}{4}$ of an inch into the tube; they were all connected in series by means of silk-covered thin copper wires.

By means of this arrangement, whilst the previous experiments with the *vertical* tubes referred to above (*loc. cit.*) included the effect of considerable difference of pressure, and almost entirely excluded the influence of difference of terrestrial gravitative attraction, those with the *horizontal* ones included the effect of difference of gravitative attraction of the lead, and completely eliminated that of difference of pressure caused by difference of attraction of the earth.

The electrolyte employed consisted of 38 ounces of thoroughly boiled distilled water and 75 grains of potassium chloride, the mixture being subsequently about $\frac{1}{16}$ saturated with washed chlorine gas. This liquid was used in all the following experiments with this apparatus, and was at all times carefully screened from the light. The use of the chlorine was to prevent the liberation of hydrogen.

After excluding or rendering negligible nearly all the numerous sources of error (which need not be here specified), the only remaining disturbances were due to unequal and variable voltaic action at the electrodes, changes of temperature, periodical movements of the tubes, and slightly to variations of terrestrial magnetism. These influences, however, were sufficiently small to permit the detection of a very minute amount of deflexion of the galvanometer needles due to the presence of the lead, provided a proper method of averaging the magnitudes of the deflexions was employed.

The usual method of manipulation adopted with this apparatus was to place the tubes in a line with the centre of the near face of the cube, close the circuit, allow any voltaic current to subside or become steady (this was often a tedious matter), take periodical observations every hour or less, and reverse the ends of the tubes once a day or more frequently. All these experiments were made in a cool room free from draughts, and the temperature of the cube and of the air of the room were recorded regularly with the deflexions.

These experiments were continued with but little inter-

mission during 37 days; and a total of 631 trustworthy observations of the galvanometer was taken, the number per day varying from 3 to 20. The ends of the tubes presented to the cube were reversed a total of 47 times, and the periods of time between the reversals varied from 2 to 52 hours. The total average magnitude of deflexion of the galvanometer needles whilst one end of the tubes was presented to the cube was greater than that of the other, and the proximity of the lead slightly increased the voltaic current when one set of electrodes was near the cube and slightly decreased it when the other set was near.

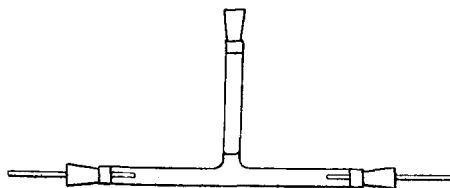
The correct interpretation I consider of these results is, that whilst nearly the whole of the deflexion of the needles in each case was due to a minute voltaic current produced by inequality of chemical action upon the two sets of electrodes and by motion of the tubes, the proximity of the lead to the ends of the tubes tended to increase the positive or decrease the negative electromotive force. (This conclusion was subsequently confirmed by results obtained with other apparatus.) The results appear to indicate a loss of energy of the mutually approaching masses of zinc and lead, attended by an extremely minute alteration of the molecular conditions of the two substances.

The chief defects of this form of apparatus were :—1st, the large mass of lead required ; 2nd, too great distance of the lead from the electrodes ; 3rd, the narrowness and considerable length of the glass tubes causing too much electric conduction-resistance ; and, 4th, the irregular differences of temperature attending the use of so large an apparatus ; I therefore designed another arrangement.

APPARATUS NO. 2.

This apparatus was essentially the same in principle as the first one ; it was, however, very much smaller, being about 18 inches long, 7 inches wide, and 6 inches high. It con-

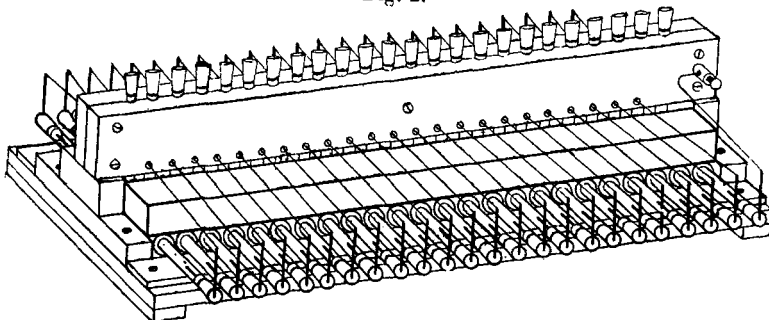
Fig. 1.



sisted of 24 **1**-shaped glass tubes, each $5\frac{1}{2}$ inches long and about $\frac{5}{16}$ inch diameter (see figs. 1 and 2), fitted with zinc

wire electrodes $\cdot 072$ inch diameter, all cut from the same piece, not amalgamated, fixed in paraffined corks, and con-

Fig. 2.



nected in series by means of silk-covered copper wire $\cdot 022$ inch diameter. The tubes were held together in a single row by means of two horizontal bars of soft wood having grooves on their inner opposed surfaces; they were arranged so as to slide to and fro through a space of $1\frac{1}{8}$ inches, into and out of leaden tubes $\frac{7}{8}$ inch long and $\frac{1}{8}$ inch thick, so as to obtain the simultaneous effects of approach and recession of the two sets of electrodes into and out of the influencing substance on each side of the apparatus. The influence of the lead tubes was reinforced by that of removable strips or bars of lead in contact with them above and beneath. The tubes and electrodes were constantly screened from daylight.

The apparatus was designed so that the electrodes and the lead might be brought very much nearer together than in the previous one. Its greatly increased compactness considerably and sufficiently diminished the disturbance caused by difference of temperature of its different parts. The electrolyte was that used in the previous apparatus; its advantages were that it did not give rise to formation of insoluble salts or bubbles of gas upon the electrodes. The same galvanometer was used as in the previous experiments; an ordinary astatic one of 1000 ohms resistance was not sufficiently sensitive. The two series of electrodes were respectively denominated "A" and "B." With this apparatus numerous experiments were made.

1st Series of Experiments.

With strips of sheet lead $\cdot 25$ inch thick and one inch wide in contact above and below with the lead tubes. The "A" electrodes happened to be feebly volta positive to the "B" ones.—Ninety-seven observations were taken during the

afternoons and evenings of 13 days, the position of the lead with regard to the "A" and "B" electrodes being usually reversed between the hours of 2 and 3 each day, and the circuit was left open every night.

In nearly all these cases the proximity of the lead to the "A" electrodes was attended by an *increase* of the deflexion, and to the "B" electrodes by a *decrease*; and whilst the average magnitude of deflexion in the former case was 21·7, in the latter it was 13·3; in some cases with the "B" electrodes the influence of the lead was sufficient to overcome the previous current and slightly reverse the deflexion. These results are consistent with the view that the proximity of the lead to either series of electrodes *increased* its electro-positive or *decreased* its electro-negative state, and they agree with those obtained with the larger apparatus (see *ante*, p. 443). In these experiments the usual period after reversal of position of the electrodes in which the effect of the lead attained its maximum was about $2\frac{1}{4}$ hours.

In some additional experiments 181 observations were made during 12 forenoons, the circuit being left open all night and closed each following morning. The average magnitude of deflexion obtained with the "A" electrodes was 27·5, and with the "B" ones 1·4. In some of these cases also the influence of the lead was sufficient to reverse the deflexion. It usually required about $2\frac{1}{4}$ hours for the effect of the lead to attain its maximum. These results agree with the immediately preceding ones.

2nd Series.—Influence of Mass of Lead, &c.

With *bars* of lead about 1 inch wide and 1 inch thick substituted for the strips, and all the other conditions remaining the same.—During the afternoons and evenings of a further period of 9 days 57 observations were made, the periods of reversal of position of the electrodes and of closing the circuit being as above.

In nearly every case the deflexions obtained in the presence of the lead with the "A" electrodes were larger than those obtained with the "B" ones, and whilst the average magnitude of those obtained with the "A" ones was 34·4, that with "B" was 16·1; *i. e.*, the proximity of the lead increased the positive condition of the "A" electrodes and decreased the negative condition of the "B" ones, and the presence of the larger mass of lead was attended by a greater amount of effect upon the electromotive force. The usual period required to attain a maximum after reversal was about two hours.

In some additional experiments the circuit was closed as
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usual each following morning, the "A" electrodes having been under the influence of the lead with the circuit open all night, and 115 observations were taken during 8 mornings.

The average amount of deflexion obtained with the "A" electrodes was 32.4 and with the "B" ones — 2.9. The usual period after the circuit was closed in which the amount of effect attained its maximum was in these cases also nearly two hours. The results agreed with the previous ones and with the further conclusion that the influence of the lead upon the electromotive force was increased by time up to a certain limit.

3rd Series.—Influence of Period of Reversal.

The hour of the day at which the reversals were made instead of being later was now changed to 9 A.M. after the circuit including the galvanometer had been closed all night, the bars of lead being still used and all the other conditions remaining the same.—Ninety-seven observations were made during $5\frac{1}{2}$ days. The average amount of deflexion with the "A" electrodes during $2\frac{1}{2}$ days was 31.0, and with the "B" ones during three days 1.4. These results confirmed the previous ones and showed that altering the period of reversing the electrodes had no conspicuous effect. The usual period after each reversal in which the effect of the lead attained its maximum was about two hours. In one instance the influence of proximity of the lead was sufficient to reverse the direction of the deflexion. The results showed that the differences of effect attending the presence and absence of the lead were not due to diurnal changes of magnetism.

Influence of Conduction-resistance.

In order to ascertain the influence of extra total resistance upon the time required for the lead to produce its full effect; whilst the "A" electrodes were between the bars of lead and the full effect had been attained, an extra resistance of about 6000 ohms was suddenly inserted in the circuit, and the effect allowed to develop. At the end of $3\frac{1}{2}$ hours the influence of the lead was still increasing and had not arrived at its usual maximum.

After allowing the circuit to remain closed all night the maximum effect of the lead appeared to be about the same as when the 6000 ohms were not in the circuit. The "B" electrodes were now substituted for the "A" ones and the apparatus allowed to remain undisturbed. The maximum effect was now attained in a period of about $3\frac{1}{2}$ hours.

These results, when compared with previous ones, indicated

that the larger the total resistance in the circuit, the longer was the period of time required for the lead to produce its full effect.

General Influence of Time.

In all the experiments of these three series, a short period of time elapsed before any effect of the proximity of the lead upon the deflexion was manifest ; in some cases it was distinct in less than five minutes, whilst in others it was not observable in less than a quarter of an hour. (N.B. In later experiments with apparatus "No. 3" offering very much less resistance, the visible effect commenced at once.) As the delay could not be attributed to any other cause, and as in all cases the maximum effect with the total amount of resistance in the circuit was usually only attained in about two hours, I conclude that a state of *strain* of the superficial molecules of the electrodes and lead bars was probably produced, and required that period of time to be completely overcome.

Both with the lead bars and with the plates, by leaving the circuit open all night (equal to about 15 hours), with the electrodes in proximity to the bars, the effects of the lead had disappeared, and it required about two hours to entirely recover after the circuit had again been closed through the galvanometer. As the bars produced a much larger maximum effect than the thin plates (see *ante*, p. 444), and produced it in about the same period of time, viz. two hours, they must have produced it at a much faster rate.

Effect of Short-circuiting the Apparatus.

As the maximum effect of the lead was more quickly attained the smaller the total amount of resistance in the circuit, the effect of short-circuiting the pile alone whilst the electrodes were under the influence of the lead was tried. In four separate experiments, by short-circuiting the apparatus, with an external resistance of only 60 ohms and no galvanometer in the circuit, during ten minutes, and then at once including the galvanometer, the maximum effect was attained in about 25 minutes ; this result indicated that the retardation was largely due to the total resistance.

Influence of Temperature, &c.

A few experiments were made with the same apparatus to examine this. A strip of lead $16\frac{1}{2}$ inches long, 1 inch wide, and $\frac{1}{8}$ inch thick was uniformly heated throughout to a

temperature varying in different cases from 5 to 16 Centigrade degrees above that of the apparatus, and placed in immediate contact with the glass tubes above the "A" and "B" electrodes separately, and allowed to remain a sufficient period of time. In each of the five trials, including a total of 28 observations, the heat made the electrodes negative; *i. e.* it decreased the electromotive force at the positive "A" electrodes, and increased that at the negative "B" ones, and thus in every case it produced an opposite effect to that produced by the lead. In one of the experiments, with the warmed strip of lead at a temperature of 16 Centigrade degrees above that of the apparatus, the difference of deflexion produced was equal to 32 degrees on the galvanometer scale; and in two instances the effect of the heat upon the current reached its maximum in about 15 to 20 minutes. The temperature of the room would not account for much of the effect, because it affected both sets of electrodes equally; a rise of it increased the current, not by increasing the voltaic action, for the reason just mentioned, but by diminishing the conduction-resistance of the liquid, and in averaging the results an allowance of five degrees of average deflexion on the galvanometer scale had to be made for each Centigrade degree average rise of temperature. These results prove that the permanent effect of the proximity of the lead upon the voltaic action was not due to heat from any source. At one period readings were constantly and regularly taken of a very sensitive thermometer placed upon the glass bulbs of the apparatus and plotted as curves, and these curves were compared with curves representing the changes of the voltaic current, and with curves of that current whilst under the influence of the lead bars. On all subsequent occasions also observations of the temperature of the apparatus were taken simultaneously with those of the amounts of galvanometric deflexion.

As in each of four different experiments the light and heat of burning magnesium, at a distance varying from three to six inches from the nearest electrodes, slightly decreased their electro-positive state, the light and heat had an opposite effect to that of the influencing bars.

[Whether temperature affects gravitation is an interesting question. "Von Sternack found, on comparing his observations in two mines, that the increase of gravity on descending was much more nearly in proportion to the rise of temperature than to the depth of descent." (H. Poynting, 'A History of the Methods of Weighing the Earth,' Proc. Birmingham Phil. Soc. vol. ix. p. 13.)]

Influence of various other circumstances.

With the object of further improving the apparatus and the method of using it, numerous experiments were made to test the influence of electrolytes of different composition, of amalgamating the electrodes, of including a very feeble voltaic cell or a thermoelectric couple in the circuit to balance the voltaic disturbance; also of tilting the apparatus, of moving the tubes to and fro during absence of the lead bars and during their presence, of comparatively rough motion of the tubes, of varying the length of the electrodes, of fixing the electrodes in the glass tubes by means of sealing-wax and of shellac, the influence of bubbles of gas or deposits of zinc oxide upon the electrodes, the use of a galvanometer of 6117 ohms resistance, &c.

It was found that a solution of zinc sulphate was better than one of potassium chloride; that whilst a small proportion of chlorine, by forming hydrochloric acid, prevented bubbles and production of zinc oxide, too large an amount caused bubbles; that a solution of ammonium nitrate produced deposits of zinc oxide; that a small proportion of hydrochloric acid caused hydrogen; that amalgamation appeared to make the electrodes and, consequently, the solution more durable (it probably also diminished voltaic disturbance); that even a suitable liquid, if constantly used, required either renewal or a fresh addition of chlorine after a period of about a month or six weeks; that motion of the tubes disturbed the electric current; that using the apparatus whilst it was in a tilted position caused no difference; and that the galvanometer of a greater resistance gave larger deflexions. The defects of "No. 2" apparatus were that it offered too much resistance, was too slow in yielding the maximum effect, contained too small a stock of electrolyte, and the liquid was too quickly exhausted by continuous use.

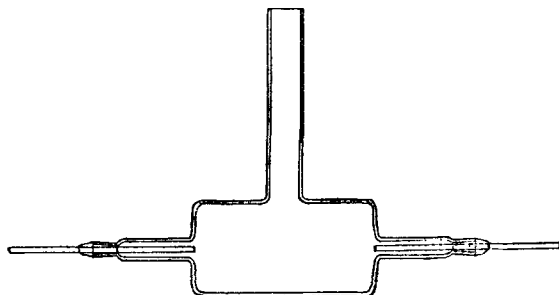
Changes of terrestrial magnetism had very little effect; the apparatus was placed east, west, north, and south, without causing any perceptible difference. The chief variations were due to voltaic change and temperature, and the effect of the bars appeared to be a constant quantity.

APPARATUS "No. 3."

As in Apparatus "No. 2" the total conduction-resistance of the electrolyte was very large, a third one was now made offering very much less. It contained 20 tubes of the annexed form (see fig. 3). Each tube was 4 inches long, with its middle part 2 inches long and 1 inch diameter. The zinc-wire electrodes, all cut from the same piece, were

fixed in the tubes by means of melted shellac, and their external portions were cotton covered and varnished. The

Fig. 3.

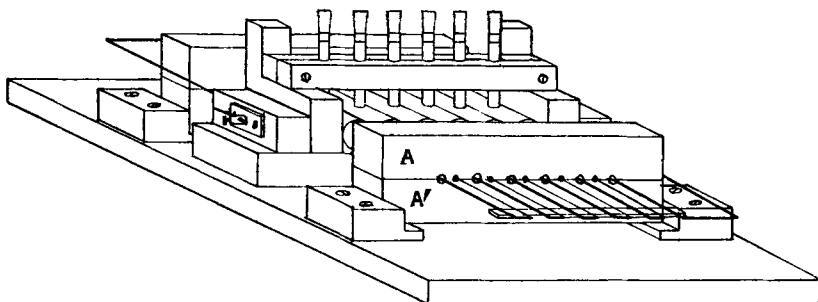


electrolyte was composed of an 18-per-cent. preboiled solution of zinc sulphate $\frac{1}{2}$ saturated with washed chlorine gas.

Description of Apparatus.

The annexed sketch (fig. 4) represents the form of apparatus, but only six tubes are included in order to

Fig. 4.



simplify the drawing. The entire apparatus was about 24 inches long, 12 inches wide, and 5 or 6 inches high. A, A' represent the bars of lead; each bar was 22 inches long, 1 inch wide, and $1\frac{1}{4}$ inch deep, and weighed about $10\frac{1}{2}$ lb. Each bar also had 40 semicircular grooves filed in one of its surfaces so as to form circular holes when in opposition, through which the glass tubes and connecting wires could freely pass without touching the lead*. The

* Subsequently, plain bars without grooves, each weighing about 31 lb., were regularly employed, and only one pair was used.

outer ends of the insulated zinc and silk-covered copper wires were fixed by means of melted sealing-wax upon a narrow strip of very thin wood for the purpose of keeping them in their proper positions. The tubes and wires were carefully adjusted so that none of them came into contact with the lead. The frame moved in parallel wooden guides, not shown in the sketch. The sliding contact-parts were coated with blacklead, so that the to-and-fro movement was very smooth.

The sketch represents the glass tubes as being midway between the bars of lead.

The inner surfaces of the two pairs of bars were 5 inches apart. The electrodes were amalgamated. The galvanometer employed in all the subsequent experiments with this apparatus was a Thomson tripod one of 6117 ohms resistance, made by Elliott. Two other forms of apparatus were constructed and employed, but they were unsuitable and need not be described.

Method of Manipulation.

Immediately the circuit was closed the amount of deflexion caused by voltaic disturbance was recorded; the image of light was then brought to zero; and this was repeated until the voltaic current either ceased or became quite steady. When the liquid had only been recently made the disturbance was considerable, and required an hour or more to subside; but after it had been in use a week or more the irregularity subsided in a few minutes. In every case, however, the image was ultimately brought to zero by means of the controlling magnet, and the experiments were then made.

Whilst sliding the movable part to and fro, great care was taken not to suddenly stop or jerk it, and to observe that neither the glass tubes nor insulated zinc wires came into contact with the lead bars; the insulated copper wires were so thin and flexible that their occasional slight contact produced no disturbance. In consequence of the extreme sensitiveness of the arrangement, considerable experience was necessary in using the apparatus so as to obtain reliable results. This great sensitiveness to movement was found to be due to bubbles of air or gas upon the electrodes and was subsequently obviated.

With this apparatus the maximum deflexion caused by motion of the tubes, either in the presence or absence of the lead bars, commenced almost immediately and was usually obtained in about fifteen minutes; whilst with Apparatus "No. 2" it required about $2\frac{1}{4}$ hours, probably in con-

sequence of the much greater total electric conduction-resistance. The amounts of deflexion were recorded at regular intervals of time, usually 2, 5, 10, 15, 30, and 60 minutes.

Causes of Variation of the Current.

Four chief causes operate to move the needles :—1st variation of the voltaic action ; 2nd, approach or recession of the influencing substance ; 3rd, change of temperature ; and 4th, diurnal variation of terrestrial and atmospheric magnetism. Of these the first and second were the most powerful. The use of cadmium electrodes might diminish the first one.

Experiments.

Several experiments, including a total of 28 observations, were made during two days, to ascertain the effect of the usual to-and-fro movements of the tubes alone in the *absence* of the lead bars, the circuit being as usual left open all night. The motion had a very nearly uniform effect of making when in one direction \longleftarrow the "A" electrodes positive, and when in the opposite direction \longrightarrow the "B" ones positive ; but in each case the electrical effect was opposite to that produced by the presence of the lead.

Similar experiments, including 46 observations, were then made during four days, with the lead bars *present*, the circuit being again left open all night. After due corrections had been made for the effects of motion of the tubes in the absence of the lead, the influence of presence of lead upon the "A" electrodes was still found to render them electro-positive, and upon the "B" ones to render them also electro-positive, and therefore to produce, or tend to produce, opposite currents with the two sets of electrodes, as in the experiments with the two previous apparatus. The disturbance caused by motion was subsequently eliminated by preventing the presence and formation of bubbles upon the electrodes.

The results of numerous additional experiments fully proved that the effect of the proximity of the lead was either to diminish or reverse the deflexions produced by the movements of the tubes alone. The opposite effect produced by the presence of the lead to that produced by its absence was not due to polarization, because the latter should have been the same in both cases. Polarization was in all cases of the research too minute to perceptibly affect the results.

After having fixed to the apparatus buffers of very elastic india-rubber, to diminish the sudden stoppage of motion, several series of experiments were made ; in one series of 81 observations the lead bars were present, and in another of

103 observations they were absent, but the results obtained only confirmed the previous ones.

Exclusion of Air-Bubbles, &c.

Bubbles of air, which had caused considerable disturbance of the current, and which, owing to the narrowness of the spaces round the electrodes, were difficult to remove, were at a later period of the research perfectly excluded by the following means :—A few minims of the liquid, sufficient only to fill the annular space, were poured into each dry empty tube before placing it in the frame, and allowed to trickle very slowly down the inclined tube and displace the air ; if this did not succeed it was run back into the bulb and poured again, and the action repeated with shaking if necessary until all air was expelled ; the opposite end was then treated similarly, and the bulb filled and the tube placed in the frame. Bubbles of hydrogen, due to corrosion of zinc, and the formation of insoluble subsalts of zinc, were prevented by employing a suitable electrolyte. The most improved liquid consisted of 750 c.c. of thoroughly boiled distilled water, 2990 grains of ordinary zinc sulphate, the solution filtered, and 25 c.c. of similar boiled water saturated with chlorine added to it.

Prevention of Leakage of Liquid.

To obviate any disturbance or want of insulation by leakage of solution, the bar of wood which supported the tubes was thoroughly varnished ; but even when a large number of tubes slightly leaked, the essential effects were clearly distinguishable. Leakage of liquid was, however, entirely prevented at a later period by the following method :—The ends of the dry tubes were coated inside with thick petroleum black varnish and allowed to dry ; shellac was then melted upon the corresponding parts of the wires and thoroughly fused when the wires were in the tubes ; and after cooling the junctions were thickly coated with the same varnish and allowed to dry ; the elasticity of the varnish prevented any cracking or separation of the rigid shellac.

Incidental Circumstances.

It was fully proved in various ways, and by several special series of experiments and observations, that the movements of the galvanometer-needles were not perceptibly due to the placing or removal of heavy bodies, nor to air-currents, the influence of light, or of magnets or articles of iron near the galvanometer, &c.

Effect of Magnetism.

In order to ascertain whether open magnetic circuits had any special degree of effect upon the electromotive force, seventy horseshoe magnets, each 8 inches long from poles to bend, 1 inch wide, $\frac{1}{4}$ inch thick, and their limbs $\frac{5}{8}$ inch apart at the poles, were clamped tightly together with india-rubber washers between them, face to face on their edges in a wooden frame by means of four brass rods and screws, in a horizontal row with all their similar poles above, thus forming a series 20 inches long, with a straight open highly magnetic space $\frac{5}{8}$ inch wide between the dissimilar poles to receive the glass tubes.

Several series of observations were made in the usual manner with the tubes between the poles, and with them removed to a distance of about 5 inches. The magnets produced precisely similar effects to the lead bars, *i. e.* they increased the electro-positive or diminished the electro-negative state of the approximated electrodes according as the latter happened to be electro-positive or negative at the time. Subjecting the electrodes to the influence of the magnets during 14 hours previous to closing the circuit had no perceptible effect.

To determine the effect of closed magnetic circuits, the magnets were taken apart and repacked in a similar manner except that each row of poles now consisted of alternately north and south ones, with a series of horizontal soft-iron armatures placed upon all of them, and as large a quantity of soft-iron filings as they would attract, thus leaving a nearly non-magnetic space between them for the tubes.

Several series of observations were made as usual under these conditions, but the effects were precisely the same as with the active magnets, and no difference of magnitude of influence due to different strength of magnetism could be detected.

Mode of Action of the Influence.

In order to ascertain whether the proximity of the influencing body acted by altering the voltaic electromotive force or by changing the conduction-resistance of the liquid, two plain rectangular bars of copper, each being 22 inches long, 2 inches wide, and 2 inches thick, were employed. They were first placed in the usual positions as near as possible to the row of electrodes which happened to be electro-positive, and the usual series of observations taken; and then placed near the negative ones and other series taken. The effect of their proximity was, as usual, to increase the

current in the first case and decrease it in the second, thus proving that the influencing bars acted upon the electro-motive force and not upon the conduction-resistance; had the whole or even the greater portion of the effect been to diminish the amount of conduction-resistance, the current would have been increased in each case. This experiment of placing the copper bars near the negative electrodes was repeated by another 36 observations on a subsequent day, and the same result—viz. diminution of the electro-negative state—was obtained.

Degrees of Influence of Various Substances.

The apparatus having been made sufficiently perfect, and the mode of treating the observations satisfactory, numerous series of experiments were made to approximately ascertain the relative magnitudes of effect of equal volumes of different substances, by employing pairs of plain rectangular bars, each bar being 22 inches long, $1\frac{1}{2}$ inch wide, and 2 inches deep, placed above each other at a distance of $\frac{5}{16}$ inch apart, so that the glass tubes might slide without friction into and out of the horizontal space between them. The substances used included copper, lead, bismuth, antimony, cast iron, wrought iron, brass, magnesium, zinc, flint glass, slate, ebony, deal, and gypsum-plaster—every one of which gave the usual kind of effect.

It usually occupied five days to obtain the final average value of effect of a substance. In order to make proper correction for the value of the voltaic current alone, which was usually the largest element (unless the solution had been recently made), an average value of that current alone was obtained on the first day; a ditto for that of the current *plus* the effect of the substance on the second and third days; for the voltaic current alone on the fourth day; and for the current *plus* influencing substance on the fifth day.

On the first day, the tubes being 5 inches distant from the bars and the circuit having been left open all night, the latter was closed in the morning, and after five minutes the spot of light, having become steady, was brought to zero on the scale. Observations were then taken every fifteen minutes, both of the temperature of the tubes and the amount of deflexions. Immediately after each observation the circuit was opened during a few seconds, the needles allowed to become steady, the deflexion again noted, the first deflexion corrected for the amount of the second one, and the true amount thus obtained. This was done about forty times, and the average value of the corrected current obtained by taking the average of all the observations.

To find the average value of voltaic current *plus* that of the effect of the substance :—On the second day, the tubes being 5 inches distant from the bars, and the circuit having been left open all night, the latter was closed in the morning, and after five minutes the spot of light was brought to zero. The tubes were then immediately slid into the space between the bars, and the observations of deflexion and temperature taken forty times during the day in the above manner.

In order to correct the average values of the currents of the first and second days for difference of temperature, an allowance of five degrees of the average deflexion for each Centigrade degree difference of average temperature of the two days was made to bring the average temperature of the one day to that of the other. The corrected average value of the voltaic current alone was then subtracted from that of the voltaic current *plus* the effect of the substance, in order to obtain the value of the latter. This was done three times for each week, and the average of the three taken as being the final value of effect of the particular substance.

In consequence of the final average number for each substance varying considerably with the age and amount of use of the solution, I was unable to obtain a reliable series of relative values of effect of all the substances ; but, by comparing the values obtained of substances immediately after each other, it was found that heavy ones usually gave greater effects than light ones, approximately in the following order :—copper ; wrought iron ; cast iron ; lead ; bismuth and antimony ; flint glass ; brass and magnesium ; zinc and slate ; ebony, deal, and plaster. This general relation of behaviour of heavy substances and light ones is not unlike that of their degrees of opacity to Röntgen rays. As the effect did not approximate very strictly to the order of the specific gravities of the substances, I venture to suggest that whilst the greater proportion of effect may be due to rays of gravity, other rays may assist in producing it ; it is also probable that the rays proceeding from one substance differ somewhat in kind from those proceeding from another and produce a different amount of voltaic change.

Effect of Mass of Substance.

With the object of ascertaining whether the influence varied directly as the mass of the substance, or proceeded only from its external surface, the effect of two sheets of copper, 22 inches long, 2 inches wide, and .013 inch thick,

was compared with that of the usual copper bars, the surfaces of each pair being $\frac{5}{32}$ inch from the axis of the electrodes. The result of this experiment was that the sheets gave somewhat less than one-half—viz. a proportion of 1·0 to 2·69—of that of the bars, but a much larger proportion than that which was due to their relative mass, which was 1·0 to 153·84, doubtless because their mean distance was much less than that of the bars, viz. as 1·0 to 8·838 from the surfaces of the electrodes. The influence therefore came from the internal mass of the influencing substance as well as from its superficial particles, and so far agrees with the action of gravity.

Influence of Distance.

The only experiments on the influence of distance of the bars from the electrodes were made with a pair of bars of wrought iron of the usual dimensions. With the nearest surfaces of the bars at a distance of $\frac{5}{32}$ inch from the axis of the electrodes, and at $\frac{19}{32}$ inch, the numbers obtained were respectively 63·06 and 20·31, the latter being considerably greater than the calculated theoretical amount.

Influence of Screens.

A number of series of experiments and observations were made in the usual manner for the purpose of detecting, if possible, an influence of screens. Each series with a single pair of bars and a single pair of screens extended over five days. The bars included copper, bismuth, lead, and zinc; and the screens comprised copper, lead, zinc, and tinned iron; the bars were of the usual dimensions; the screens were 22 inches long and 2 inches wide, and the thicknesses of them were:—copper ·013 inch, lead ·009 inch, zinc ·010 inch, and tinned iron ·006 inch. The nearest surfaces of them were at a distance of $\frac{5}{32}$ inch from the axis of the electrodes, and the bars were in immediate contact with them. Copper bars were used with screens of lead, zinc, and tinned iron; lead ones with copper, zinc, and tinned iron; bismuth with copper, lead, zinc, and tinned iron; and zinc with those of lead: no screening effect was detected in any of the eleven instances. As the radiant influence was not manifestly intercepted by screens, it appears to partake so far of the nature of gravity.

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