

PROCEEDINGS  
OF  
THE ROYAL SOCIETY.

May 10, 1894.

The LORD KELVIN, D.C.L., LL.D., President, followed by Sir JOHN EVANS, K.C.B., D.C.L., LL.D., Vice-President and Treasurer, in the Chair.

Professor Dmitri Ivanovitch Mendelceff, who was elected a Foreign Member in 1882, signed the obligation in the Charter Book and was admitted into the Society.

Mr. Benjamin Neeve Peach (elected 1892) was admitted into the Society.

A List of the Presents received was laid on the table, and thanks ordered for them.

In pursuance of the Statutes, the names of the Candidates recommended for election into the Society were read from the Chair as follows:—

Batson, William, M.A.	Love, Augustus Edward Hough, M.A.
Battinger, George Albert.	Lydekker, Richard, B.A.
Bradford, John Rose, M.D.	Penrose, Francis Cranmer, M.A., F.R.A.S.
Callendar, Professor Hugh Long- bourne.	Scott, Dukinfield Henry, M.A., F.L.S.
Cheyne, Professor William Wat- son, M.B., F.R.C.S.	Smith, Rev. Frederick John, M.A.
Froude, Robert Edmund.	Swan, Joseph Wilson, M.A., F.I.C.
Hill, Professor M. J. M., M.A., D.Sc.	Veley, Victor Herbert, M.A., F.C.S.
Jones, Professor John Viriamu, M.A., B.Sc.	

The following Papers were read:—

It has long been known that the disease is most common in the dirty, ill-drained, ill-ventilated dwellings of the poor, and, even in records intended to prove the contagiousness of phthisis, there are few, if any, of transmission of the disease in clean, well-lighted, well-ventilated houses or hospitals, even those for consumption. Long before Koch's discoveries, and before the disinfection of sputum was practised as it is now, the conveyance of the disease, under these conditions, was recognised by many to be one of the rarest events.

If the results that we have obtained with sputum are confirmed by others, as we trust they will be, they will afford some explanation of these facts.

So far as they extend at present, they show (1) that finely divided tuberculous matter, such as pure cultures of the bacillus, or "tuberculous dust," in daylight, and in free currents of air, is rapidly deprived of virulence, (2) that even in the dark, although the action is retarded, fresh air has still some disinfecting influence, and (3) that in the absence of air, or in confined air, the bacillus retains its power for long periods of time.\*

VI. "On some Voltaic Combinations with a Fused Electrolyte and a Gaseous Depolariser." By J. W. SWAN, M.A. Communicated by LORD RAYLEIGH, Sec. R.S. Received February 28, 1894.

It is well known that fused salts behave in many respects like electrolytes in solution, and that voltaic combinations analogous to well-known voltaic cells may be formed with fused electrolytes.

The experiments of Brown† have recently illustrated this subject in relation to the Daniell type of cell. For various reasons it appeared to the writer desirable to ascertain the behaviour of a cell with fused electrolyte and a gaseous depolariser, and corresponding in this last particular to the Upward cell.<sup>2</sup>

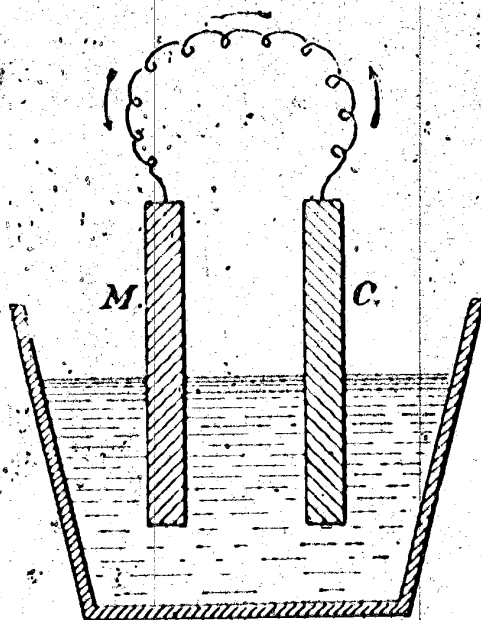
The following is chiefly a record of some of the experiments made in connection with this research.

A cell of this kind may be looked at from a theoretical point of view as follows:—A rod of metal, M (fig. 1), is immersed in a fused chloride of the same metal, MCl, and a chemically inactive conductor, C, is also immersed in the fused salt; when M and C are connected with an electrostatic volt-meter, the metallic chloride is immediately

\* A portion of the expenses of this research has been defrayed by a grant from the British Medical Association.

† 'Roy. Soc. Proc.,' vol. 52, pp. 75—91.

FIG. 1.

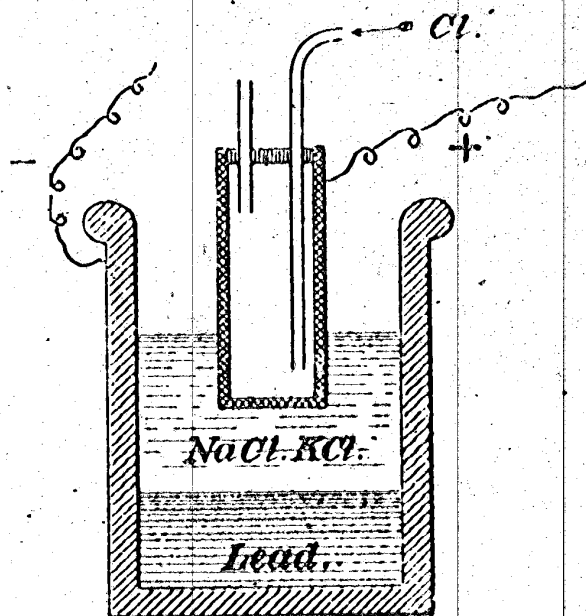


polarised, and an E.M.F. calculable from the heats of combination,  $M_2Cl = MCl$ , is developed. - If M and C are metallically connected, a momentary current passes, but the combination is immediately polarised by the opposing couple, formed by the cation of the electrolyte M and the pole C. To prevent this polarisation, chlorine has to be supplied at this pole. Complete depolarisation should occur if the pole C consisted of a solid rod of chlorine. This is impossible, but gaseous chlorine, used as a depolariser, can be made to effect more or less complete depolarisation, and should, theoretically, yield as the result of its heat of combination with lead an E.M.F. of 1.7942 volts. In experiments made with a view to realise as nearly as possible the ideal condition for preventing polarisation the cathode was always molten lead. It was found that hard gas-retort carbon had very little action upon molten alkaline chlorides and on chloride of lead, at the temperature required for their fusion. Carbon was, therefore, employed as the anode or conducting pole in most of the combinations.

The electrolyte used was either the molten chlorides of sodium and potassium mixed, or chloride of lead. As there is a continuous formation of  $PbCl_2$  during the action of the cell, and as it is a good conductor, it alone was finally adopted as the electrolyte. As a depolariser, chlorine gas was used. Many experiments were made to find a suitable way of applying the chlorine. The following are details of some of the most suggestive of them.

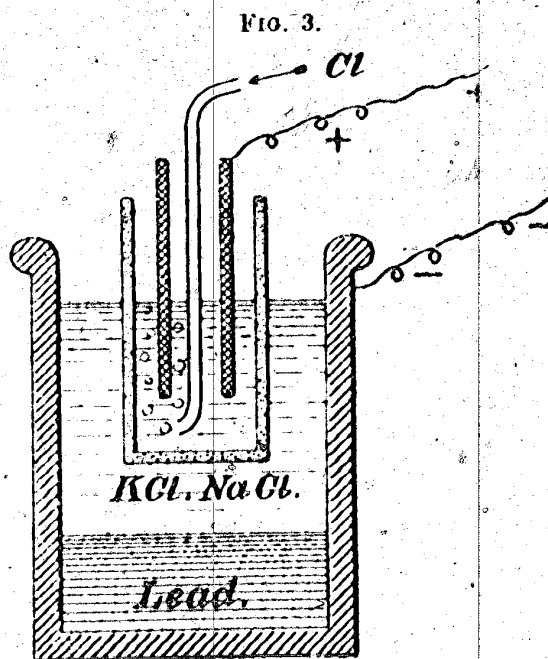
*Exp. 1.*—A cell was constructed as shown in fig. 2. The arrangement consists of an outer iron vessel, with a stratum of molten lead

FIG. 2.



covering the bottom to some depth, over the lead is a layer of NaCl and KCl previously fused, into which is immersed the lower and closed end of a carbon tube, which forms the + pole. The mouth of the carbon tube is closed by a fire-clay lid luted on, and through which pass two small clay tubes for the inlet and outlet of chlorine. The whole was heated in a small gas furnace. A binding screw on the iron vessel, which served as a connection with the lead, was used as the negative terminal, and another screw fixed on a copper ring surrounding the carbon tube, served as the positive pole connection. The first trial was made without chlorine. Short circuited through 1,000 ohms the cell developed an E.M.F. of 0.3 volt. A momentary current of more than one ampère was observed when the cell was short circuited through a low resistance ammeter. Chlorine was then passed through the tubes inside the carbon pole, but *no depolarising effect* was observed, even when the chlorine had a slightly higher pressure than the atmosphere, yet the gas passed through the exposed sides of the carbon tube and through the cement at the top. This experiment was repeated several times with carbon tubes of the smallest possible thickness, and always with the same result. It is evident, therefore, that an absorption of chlorine similar to that which takes place in the Upward cell does not occur when a molten electrolyte of the kind employed in this experiment is used.

*Exp. 2.*—As this method of applying chlorine was unsuccessful, another form of apparatus was adopted. The poles were of the same material as in the previous experiment, but the carbon pole



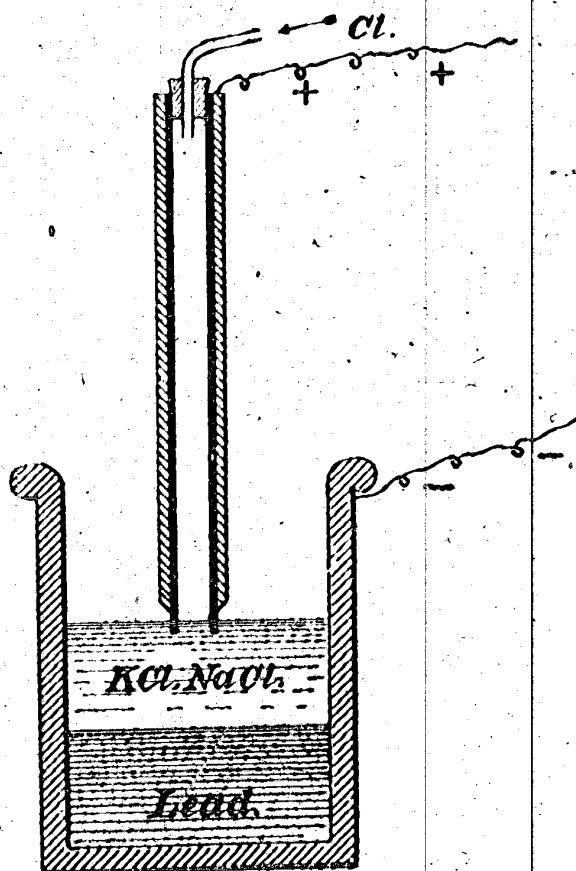
was an open tube. The electrolyte was a fused mixture of equivalent proportions of NaCl, KCl. A porous pot was introduced in order to separate the products of electrolysis set free at the electrodes. The chlorine gas was supplied through a clay tube, which passed down the centre of the carbon tube. As before, an iron crucible was used as the containing vessel for the fused lead and the electrolyte, it also served as a means of electrical connection with the lead. In relation to the depolarisation effect of the chlorine, which it was the principal object of the experiment to observe, the interfering action of the iron was found by comparison with porcelain to be practically *nil*; this no doubt is a consequence of its becoming coated by local action with a film of lead. The whole arrangement was heated in a reverberatory furnace. When the electrolyte was perfectly fused, the element was short circuited through a volt-meter of 1000 ohms resistance. An E.M.F. of 0.3 volt was observed, the outside current being from the carbon to the lead. This was the E.M.F. after polarisation. A current of chlorine was then passed through the earthenware tube; while the current of gas was slow there was no effect, but when the speed of the issuing gas was increased until the gas passed in bubbles along the side of the carbon, alternately surrounding it with chlorine and electrolyte, the E.M.F. rose to 1.25 volt. The action of the cell was then similar to a completely depolarised cell. When short circuited through a low resistance ammeter, it produced a steady current of 1.0 ampère for three-quarters of an hour. The potential difference between the poles was of course very small, while this current was passing, the exterior resistance being very small com-

pared with the interior. When, however, the circuit was opened, it almost instantly rose to 1.25 volt.

So far the experiments showed that, as chlorine is nearly or perfectly insoluble in fused chloride of lead, or in fused chlorides of sodium and potassium, it is necessary in this case that the surface of the carbon pole on which the cathion is deposited be alternately exposed to the action of the gas and electrolyte. Many experiments confirmed this conclusion. The exposed surface of the carbon tube in this experiment amounted to only 10 or 12 sq. cm.

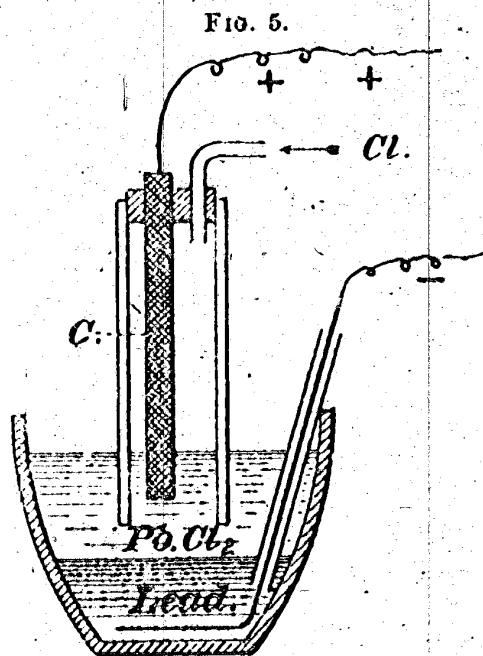
*Exp. 3.*—As in the arrangement last described, the use of a porous pot and a clay tube was found to be objectionable, through the action of the electrolyte upon them, an arrangement was devised by which the use of the porous pot and tube were avoided. The details are seen in fig. 4. The carbon tube serves as an electrode, and also for conveying the chlorine to the electrolyte. To render it impervious to the gas, it was surrounded by a close-fitting porcelain tube. This tube was closed at the top by a paraffined cork, through which a glass tube in connection with the chlorine supply was passed. The remainder of the apparatus was the same as in Experiment 2, but

FIG. 4.



without the porous pot. This arrangement gave the following results. The E.M.F. when short-circuited through a voltmeter (300 ohms) gave 1.4 volt, the chlorine entering rapidly. When short-circuited through 1 ohm, it gave a constant current of 0.6 ampère with a P.D. of 0.9 volt. The rather large interior resistance of 1.3 ohm is due not to the electrolyte, but to the greater length of the carbon tube, and bad contacts produced by the corrosive action of the chlorine. No good results were obtained until the chlorine gas bubbled out of the carbon tube, thus realising the conditions before mentioned, as necessary for the production of any large electrical effects.

*Exp. 4.*—With a view to obtain larger effects, another form of cell was tried, as shown in fig. 5. The carbon pole C consisted of a thin rod of electric light carbon, 5 mm. diameter and 15 cm. long. It was passed

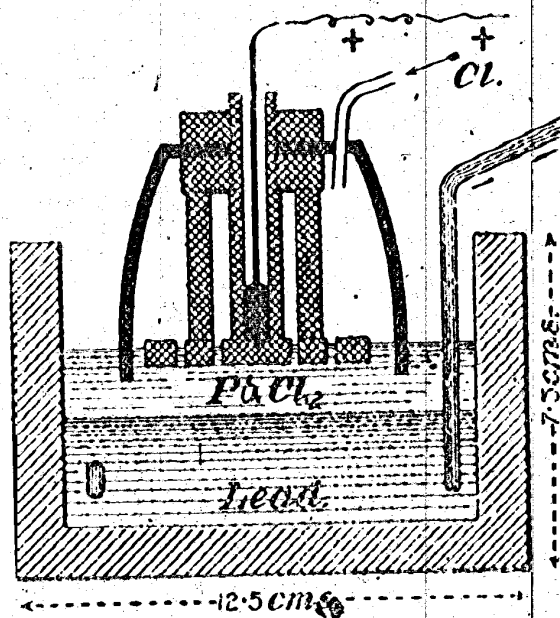


through a cork fitted in a porcelain tube, 2.5 cm. diameter. A glass tube bent at right angles was passed through the same cork, to serve for the delivery of the chlorine. The end of the carbon rod was a little short (about 3 mm.) of the end of the porcelain tube. The containing vessel was a Berlin porcelain crucible, 7 cm. diameter. The conductor from the lead was an iron wire, protected from the action of the electrolyte by a surrounding porcelain tube. The electrolyte was chloride of lead. The whole was arranged as shown in fig. 5. When the chlorine issued from the porcelain tube, the necessary conditions for depolarisation were in a large degree realised, the contact between the electrolyte and the carbon being at times almost broken,

and at other times the chlorine forming a nearly complete envelope round the carbon, these conditions following in rapid alternation. The highest E.M.F. observed was 1.25 volt. The largest current given was 0.9 ampère with a P.D. of 0.25 volt. The current was fluctuating, owing to the varying conditions at the carbon pole.

*Exp. 5.*—The following figure shows a construction almost identical with the last, differing only in a few practical details, occasioned by this cell being made larger than the last. The porcelain tube previously used was replaced by an inverted porcelain crucible, having two holes drilled in the bottom; the larger hole afforded a passage for the conductor from the carbon pole: through the smaller one there passed a porcelain pipe for the chlorine supply. The carbon pole was composed of a disc of gas retort carbon, pierced with holes, as shown in the figure. In the middle of the disc was screwed a tube of carbon, which passed up through the larger hole in the bottom of the crucible and was secured in this position by nuts of retort carbon. The bottom of the carbon tube was filled with fused lead, into which dipped a thick copper wire that formed the positive pole connexion.

FIG. 6.



The connexions between the carbon and porcelain were luted with a mixture of borax and fire-clay fused at a bright red heat. The other vessel consisted of a short cylindrical plumbago crucible. The fused lead was, as usual, on the bottom, connexion being made with it by means of a heavy open iron ring, with its free end turned up and bent over the rim of the crucible. The internal resistance was small, owing to the improved contact of the leading wire with the carbon.



pole. The electrolyte was fused  $\text{PbCl}_2$ . The whole was heated in a gas furnace. When the electrolyte was fused, the chlorine was passed rapidly through, so that it issued from under the porcelain crucible. The E.M.F. was then between 0.94 and 0.96 volt., and never rose higher than 0.98 volt. The lower E.M.F. was evidently due to the fact that part of the surface of the carbon pole was not subject to the action of the chlorine, but remained polarised by deposition of lead. The behaviour was much like that of a constant cell with an E.M.F. of between 0.94 and 0.96 volt. The method of observation was to alter the exterior resistance and then read the current and P.D., then break the circuit and read the E.M.F.

P.D. (In closed circuit). Volt.	y. Ampères.	Calculated internal resistance.	
		E.M.F. y.	P.D. (calculated). y. Ohm.
0.26	12.0		0.06
0.24	10.0		0.07
0.62	4.0		0.08
0.76	1.26		0.16
0.72	1.75		0.14
0.72	2.15		0.12
0.66	2.50		0.12

From these observations it will be seen that the internal resistance was calculated, col. 3, in order to find whether polarisation is greatest when a small or large current is taken from the cell. From the results it is apparent that the internal resistance, and at the same time the polarisation, *decrease* when the current *increases*. This kind of cell, therefore, differs from those in which aqueous electrolytes are used, inasmuch as the polarisation decreases with increased electrical output. The observations of P.D. and E.M.F. were taken almost simultaneously, and the variation of resistance as the gas bubbles passed out was thus avoided. As the internal resistance was very small the whole time, and remained almost constant during a variation of the current from 1.26 to 2.5 ampères, it may be said to be a constant battery, with an E.M.F. lower than the theoretical value. The reason of this lower E.M.F. is probably due to some part of the large carbon plate being covered with reduced lead, thus forming an opposing couple of smaller capacity and lower resistance than the primary elements, its effect being to reduce the main current. The E.M.F. of this opposing couple is of necessity the same as that of the main current, but, owing to its lower internal resistance, its P.D. is less; if it were not so, the cell would yield no appreciable current. This reasoning explains why the results obtained with small cells were better than those obtained with large ones.

Besides the experiments mentioned, trials have been made, with

more or less success, of many other forms of this combination, including some in which very porous hollow carbon poles were used, and through which the chlorine was forced, but the effects obtained were less than those recorded. The research has proved that it is possible to form pyro-batteries of the Upward type, although it is extremely difficult to realise the conditions required for effective action. In a future communication I hope to record the results of experiments made, with a view to utilise oxygen as a depolariser in connexion with cells with fused electrolytes.

VII. "Measurements of the Absolute Specific Resistance of Pure Electrolytic Copper." By J. W. SWAN and J. RHODIN. Communicated by Lord RAYLEIGH, Sec. R.S. Received February 28, 1894.

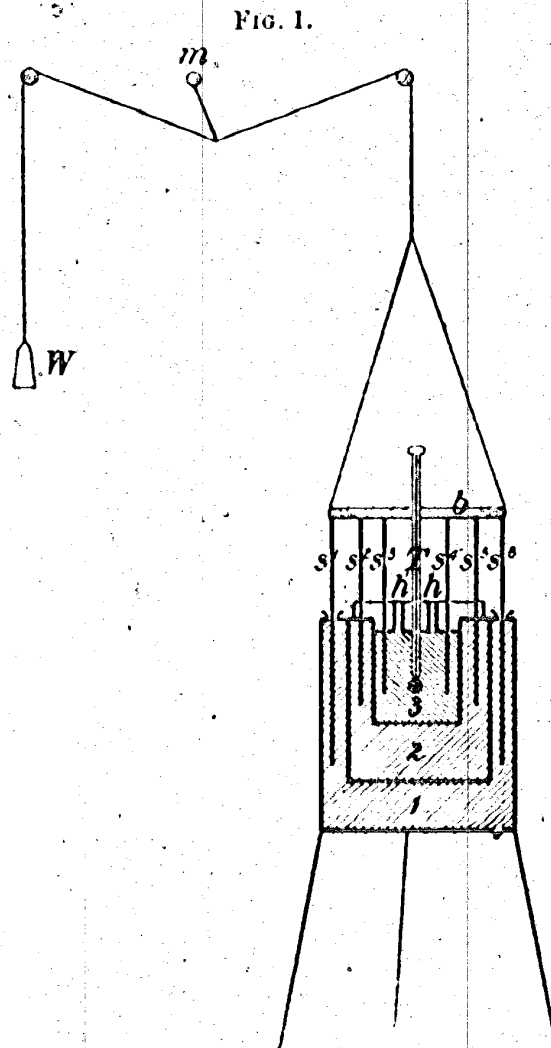
At the beginning of 1893 it was resolved to make some very careful measurements of the specific resistance of pure electrolytic copper, drawn into wire without previous fusion. Researches made during the latter end of 1892 had shown that the specific resistance of electrolytic copper varies considerably. The resistance of about thirty wires of the same length and diameter, made from specimens of electrolytic copper, prepared in different ways in the laboratory, showed differences of resistance amounting to a maximum of 1.4 per cent, both when in a hard and when in a soft or annealed state, and measured at the same temperature.

These preliminary measurements were made by means of a Wheatstone's bridge, constructed for comparing the unknown resistances of short well-conducting wires with the resistance of a standardised platinoid wire, according to Thomson's method. The accuracy obtainable by this method was 0.25 per cent. The best specimens of wire were subjected to a further and still more accurate examination.

The measurements of the specific resistance and temperature coefficient of one of these wires, and of some wire made from the same copper, after undergoing a second electrolytic refining, form the subject of this paper. It was resolved to make measurements giving an ultimate accuracy of 0.1 per cent. As they were intended to be absolute, the first problem was the determination of the exact dimensions of the wires to be measured. The measurement of the length was made by means of direct comparison with a standard metre rule; that of the diameter was determined by the specific gravity method, which consists in finding the absolute weight of a known length of wire and its density or unit volume weight as determined from its specific gravity, and then calculating its average diameter.

In the determination of the specific gravity, both the hydrostatic balance method and the picnometer method were used. The latter method was found to give more accurate results. A point of great importance was the estimation of the temperature of the specimens during measurement. To obtain as great accuracy as possible in the temperature readings, an apparatus similar to a calorimeter was employed for enclosing the coil of wire whilst it was measured. A standard thermometer divided in tenths of degrees centigrade was used, placed in the vessel containing the sample of wire. It was read at a distance by means of a telescope.

The arrangement is represented by fig. 1. It consists of three

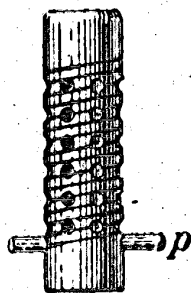


cylindrical tinned iron vessels arranged concentrically one inside the other. The section of the two outer vessels (fig. 1) is distinguished by the shading from that of vessel 3. The vessels formed three water-

tight compartments. Jackets 1 and 2 were filled with water, and the vessel 3 with paraffin oil having a flashing-point of  $150^{\circ}\text{C}$ . To stir the liquids, three circular rings of iron wire were enclosed, one in each of the compartments. These rings were suspended on the iron wires,  $s^1, s^2$ , &c. The iron wires themselves were fixed on a bar of brass,  $b$ . By means of the crank of an electromotor ( $m$ ) and strings and pulleys, the bar  $b$  could be moved up and down, stirring each of the liquids simultaneously. To make the motion easy a balance weight,  $W$ , was used. The coil to be measured was enclosed in compartment 3. This compartment was closed at the top by a hollow lid of tinned iron, pierced with holes to allow for the passage of the stirring rods, &c. This lid effectually protected the paraffin oil from surface cooling. The two holes,  $h$  and  $h'$ , made to allow the wires connecting the ends of the coil to pass out, were lined with ebonite to prevent contact with the metal of the lid. The thermometer,  $T$ , was let down through a tube in the middle of the lid. As a proof of the effectiveness of the arrangement, it may be mentioned that a small Bunsen burner when burning at its full power, and placed under compartment "1" raised the temperature of the inner one "3" only  $0.1^{\circ}\text{C}$ . in thirty seconds, a length of time more than sufficient for making a resistance determination. When the temperature in "3" had been raised to  $92^{\circ}\text{C}$ . and then allowed to cool (being constantly stirred), the temperature (in "3") only fell to  $40^{\circ}\text{C}$ . in twenty-four hours, notwithstanding the temperature of the laboratory was only  $15^{\circ}\text{C}$ .

Another important detail was an arrangement for securing the wires whilst they were measured. Fig. 2 represents this. It consists

FIG. 2.



of a piece of ebonite tube 5 cm. diameter, with a deep double screw thread cut on the outside. It was pierced all over with large holes 1 cm. diameter, to allow the paraffin oil to freely circulate in the inside, where the thermometer was inserted. A short rod of ebonite ( $p$ ) was put through and across the cylinder at the bottom. The wire to be measured was bent round this cross rod, so that equal

lengths were hanging down. The double bent wire was then wound up in the double screw thread, and secured at the top by means of string; the influence of self-induction was thus avoided. Each wire had four terminals, the main current terminals, and the shunt terminals, which were soldered to pieces of stout copper, the distance between which determined the length of the wire under examination. These reels saved the wires from being hardened or otherwise injured. The length of the wire was taken both before and after the electrical measurement. In some earlier experiments when mica strips were used for coiling the wire upon, great differences were observed. When the ebonite reels were employed hardly any difference could be observed.

The electrical measurements were made by the fall of potential method, refined as much as is possible. A D'Arsonval galvanometer was employed as an indicator of potential difference. The "dead beat" property of this instrument is an advantage which in this class of measurement cannot be over-rated. Finding in the first experiments with the D'Arsonval galvanometer, that its sensitiveness was not sufficient for our purpose, the upper suspension was lengthened very considerably. The coil was made to hang on the upper wire, the wire below the coil being left slack. By this means the required degree of sensitiveness was obtained. The galvanometer readings were made by means of a telescope and scale, a plane mirror being attached to the galvanometer coil. To gain the advantage of using very small deflections, the scale and galvanometer were widely separated, the distance between them was 8 m. The largest deflections used were 600 divisions of the scale (each division = 1/30 in.), corresponding to (at that distance from the mirror) an angle of  $1^{\circ} 40'$ , which falls within the limits for:—

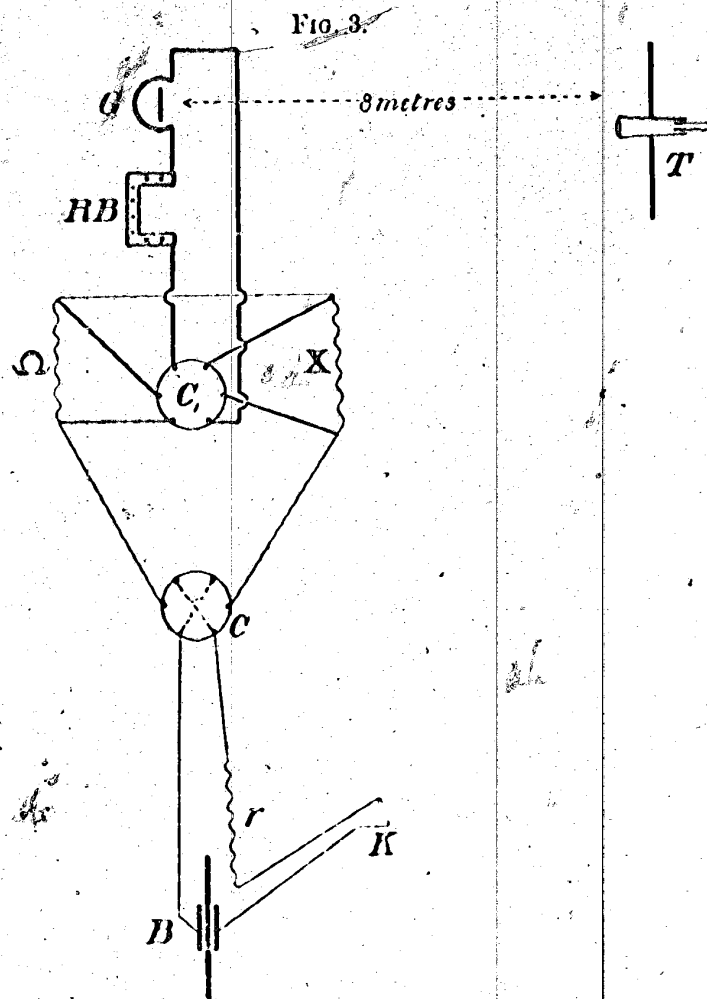
$$(1.) \quad \tan 2 \text{ angle} = 2 \tan \text{ angle} \pm 0.001 \times 2 \tan \text{ angle}.$$

The readings of the deflections were found to be proportional to the P.D. by direct and carefully made measurements, they were always read in two directions, and the sum taken as the deflection; the accuracy was thus doubled, and possible error by displacement of the zero point avoided.

The limit of sensitiveness of the galvanometer was:—

$$1 \text{ scale division deflection} = \frac{1}{30000000} \text{ ampère (approximately), or} \\ = 0.00000003101 \text{ ampère (accurately).}$$

The resistance of the suspended coil was 10 ohms. The time required for the coil to come to rest was about two seconds. The accompanying diagram shows the arrangement for making the measurements. They were made by *direct comparison* between a standard ohm and the various coils to be measured, and in such a manner that error due to the resistance of the leads was eliminated.



The following is a description of the details:—B was a single lead and lead peroxide element, of a comparatively large capacity (30 ampère hours). It was found necessary to have the capacity of the cell tolerably large to avoid the necessity of making too large corrections for the fall of potential in the cell itself between different observations. By means of a mercury contact key, K, the battery could be short-circuited through a nickel wire resistance  $r$  (of about 6 ohms), the standard ohm R and the resistance to be measured X. All these resistances were in series. (The current in the main circuit was only 0.2 or 0.25 ampère, and did not produce any sensible heating of the various resistances.) By means of the current reverser, C (a mercury switch), the current direction could be easily changed. The galvanometer, G, was connected with another mercury switch, C<sub>1</sub>, by means of which it could be put in shunt to the standard ohm and X alternately in rapid succession. In the galvanometer circuit the resistance box, RB, was inserted in order to render it possible to make the deflections nearly equal when X differed considerably from R.

The method of making a determination was as follows:—1st,  $C_1$  was placed in the position which made the galvanometer circuit a shunt of the standard ohm.  $RB$  was adjusted so as to make the deflection of a convenient amount by placing in a resistance  $R_x$  ( $R_r$  having been determined by means of preliminary experiments). Then  $K$  was pressed down and a deflection of the galvanometer " $a$ " observed. The current was then reversed, and a deflection " $b$ " observed.  $(a+b)$  was then placed in the observation table under the heading  $G_R$ . The key opened. The temperature of  $R$  observed and noted ( $T_R$ ). 2nd,  $C_1$  was then placed in the position which made the galvanometer circuit a shunt to  $X$ .  $RB$  adjusted to make the deflections of a suitable size by putting in a total resistance of  $R_X$  (determined by previous experiment). Then  $K$  was pressed down, and the deflection  $a_1$  observed, the current was then reversed, and a deflection  $b_1$  observed.  $(a_1+b_1)$  was then put down in the table under the heading  $G_X$ . The temperature of  $X$  observed and noted ( $T_X$ ).

3rd observation. No. 1 repeated.

4th " " 2 "

A set of measurements like these were made in 20 seconds, thanks to the dead-beat quality of the galvanometer; and the easy manipulation of the mercury switches. It is evident that, *if the galvanometer deflections were exactly proportional to the current, and if the resistance of the galvanometer circuit was sufficiently high to be neglected, and also if the potential difference of the accumulator did not alter between observations 1 and 2, the resistance  $X$  can be put*

$$(2.) \quad X = \frac{G_X(R_X + S)}{G_R(R_R + S)} R.$$

$S$  = resistance of the galvanometer + resistance of galvanometer leads.

The proportionality of the galvanometer deflections with the limited range employed was, as previously stated, experimentally proved. The conductivity of the galvanometer as a shunt was negligible, as is evident from the fact that it was more than 2000 ohms resistance (when a minimum), and then diminished the total resistance of the main circuit about 1/8000 ohm (it was shunted round  $\frac{1}{4}$  ohm), the resistance of the main circuit amounting to 8 ohms. The fall of potential of the accumulator was very seldom appreciable during one set of measurements. This will be seen from the identity between observations 1 and 3 and 2 and 4 respectively in the tables. When appreciable a correction was applied. When all the arrangements were completed, a determination of the specific resistance of the best specimen of copper (marked " $A$ ") was made.

*Origin of the Copper.*—The copper was deposited in a large rocking

Table I.—Specific Gravity of the Rocking Tank A Deposit. Temperature 15° C.

Description of specimen.	Weight in air + tare.	Tare.	Weight in air.	Weight in H <sub>2</sub> O + tare.	Tare.	Weight in H <sub>2</sub> O at 15° C.	Repetition of weight in air.	Specific gravity.
	grams.	grams.	grams.	grams.	grams.	grams.	grams.	
I. Pieces of the deposit as it came out of the bath.....	103.5635	2.2548	101.3087	90.1530	0.1610	89.9920	101.3080	8.9521
II. Another piece of the same .....	95.1904	2.2550	92.9444	82.7217	0.1610	82.5607	92.9445	8.9500
III. Half of I hard drawn	26.7334	2.2551	24.4783	21.9176	0.1746	21.7430	24.4783	8.9491
IV. Half of I hard drawn and afterwards an- nealed in CO <sub>2</sub> gas.....	27.5580	2.2551	25.3029	22.6514	0.1746	22.4768	25.3028	8.9533



tank from ordinary sulphate of copper solution prepared from pure crystallised sulphate of copper, pure sulphuric acid, and distilled water. The anode was a large plate of ordinary commercial electrolytic copper, and the cathode was a large polished plate of rolled copper. Before placing the cathode in the bath it was silvered by rubbing it over with a solution of cyanide of silver in potassium cyanide. This coating of silver was converted into iodide of silver by means of a solution of iodine in potassium iodide. As is well known, this treatment renders the stripping of the deposit from the cathode an easy matter. On this cathode copper was deposited to a thickness of 2.5 mm., and then the deposit was stripped off. Several deposits were made and tested roughly, as stated in the beginning of this paper. The best of them was one marked "A."

*Preparation of the Wire.*—A strip was cut from the deposited sheet of copper, filed round, and then drawn through sapphire dies to a diameter of approximately 0.02 in.

These determinations were made by means of the hydrostatic balance principle. A re-determination of the specific gravity of the copper I in the above table was made by means of a picnometer.

Picnometer	+ distilled H <sub>2</sub> O at 15° C.	= 91.2878 grams.	
"	+ specimen + " " "	= 123.3562 "	"
	Specimen .....	= 36.1012 "	"
∴ weight of displaced H <sub>2</sub> O .....		= 4.0328 "	"
	Specific gravity = 8.9519.		

As is seen from the above numbers, the specific gravity of copper when it is pure varies very little with hardness and other conditions, the variations when at a maximum only amounting to 0.0004 of the whole. The mean of the above results may, therefore, be taken as the specific gravity of this copper at 15° C. The mean is

$$8.9511 = \text{the specific gravity.}$$

This value is not the one required for the calculation of the dimension of wires; what is required is the density or absolute weight of an ideal cubic centimetre of the metal at 15° C. The weight of 1 c.c. of water at 15° C. is, according to Kohlrausch, 'Praktische Physik,'

$$0.99915 \text{ gram.}$$

The specific gravity of the copper divided by this figure gives the density:—

$$\text{Weight of 1 c.c. of copper at 15° C.} = 8.9587 \text{ grams (8.959).}$$

*Specific Resistance of Deposit "A" (hard drawn) at different Temperatures between 12.9° C. and 90.2° C.*—A hard-drawn wire of the A deposit was measured by the apparatus described. For determining

72 Messrs. J. W. Swan and J. Rhodin. *Absolute* [May 24,  
the diameter a piece 300 cm. long was taken. The weight was found  
to be—

5.6009 grams.

The ascertained density of the copper being 8.959 indicates an  
average diameter of—

$$(3.) \quad X = 2\sqrt{\frac{5.6009}{300 \times 8.959\pi}} = 0.05151 \text{ cm. at } 15^\circ \text{ C.}$$

This same wire was fitted with shunting terminals 250 cm. apart,  
and wound on one of the previously described reels, and then  
placed in the circuit. A large number of observations were made at  
different temperatures: they are arranged in Table II. The following  
are the headings of the columns:— $T_x$  = temperature of the unknown  
resistance;  $G_x$  = deflection (proportional to the current) with the  
unknown resistance;  $G_R$  = deflection when standard ohm in circuit;  
 $T_R$  = temperature of standard ohm;  $G_x$  = deflection of unknown  
resistance (supposing  $G_R$  to be always 1240);  $G_x$  (6th column) is  
deflection with unknown resistance ( $X$ ) in circuit corrected, so as to  
compare with  $G_R$  at 1240 and  $T_R$  at  $15^\circ \text{ C.}$ ; the figures in this column  
multiplied by a constant give the resistance of the wire.

Table II.

$T_x$	$G_x$	$G_R$	$G_x$ ( $G_R = 1240$ ).	$T_R$	$G_x$ ( $G_R = 1240$ $T_R = 15^\circ \text{ C.}$ )
$12.9$	1006	1250	998	$13.5$	997
$16.0$	1017	1249	1010	$13.7$	1010
$17.2$	1018.5	1245	1014	$13.9$	1014
$18.15$	1023.5	1246	1019	"	1019
$19.6$	1027	1245	1022	"	1022
$20.3$	1030.5	1244.5	1027	"	1027
$20.9$	1033	1244	1030	$13.8$	1030
$22.6$	1039	1244	1036	"	1036
$23.3$	1043	1244.5	1039	$11.5$	1038
$24.2$	1045.5	1243	1043	"	1042
$25.2$	1048.5	1242	1047	"	1046
$26.2$	1052	1242	1050	"	1049
$27.3$	1056	1241	1055	"	1054
$28.4$	1058.5	1239.5	1059	$12.5$	1058
$29.4$	1060	1238.5	1061	"	1060
$30.2$	1065	1240	1065	"	1064
$31.1$	1069.5	1239.5	1070	$12.1$	1069
$32.2$	1073.5	1239	1074	"	1073
$33.2$	1077	1238.5	1078	"	1077
$34.2$	1080	1237.5	1082	$12.5$	1081
$35.3$	1083	1237	1086	"	1085
$36.2$	1086.5	1236	1090	"	1089
$37.2$	1090.5	1237	1093	"	1092

Table II—continued.

$T_x$ .	$G_x$ .	$G_R$ .	$G_x$ ( $G_R = 1240$ ).	$T_R$ .	$G_x$ ( $G_R = 1240$ $T_R = 15^\circ C$ ).
$C^\circ$ .				$C^\circ$ .	
38·2	1093	1236	1097	12·5	1096
39·2	1097	1236	1101	"	1100
40·1	1101	1237	1104	"	1103
41·2	1106	1237	1109	"	1108
42·2	1108	1235	1112·5	"	1111
43·5	1111	1234	1116·5	"	1115
44·2	1114·5	1234	1120	"	1119
45·2	1119·5	1235	1124	"	1124
46·2	1123	"	1128	"	1127
47·2	1128	"	1133	"	1132
48·2	1133	1236	1137	"	1136
50·2	1140·5	"	1144	12·8	1143
51·2	936·5	1013	1146	14·5	1146
52	939·2	"	1150	"	1150
53·1	943	"	1154	"	1154
54·1	945·2	1012·7	1157·5	"	1157·5
55·2	949	1013	1162	"	1162
56·2	951·5	1012·5	1165	15·2	1165
57·2	955	1012·5	1169·6	"	1169·6
58·2	958	1013	1173	"	1173
59·2	960·5	1011·5	1177	"	1177
60·2	963	1011	1181	"	1181
61·2	966·5	1011·5	1185	15·5	1185
62·2	969·2	1011	1189	"	1189
63·2	973	"	1193	"	1193
64·2	976	"	1197	"	1197
65·2	979	"	1200	"	1200
66·2	982·5	1012	1204	"	1204
67·2	985·2	1011	1207·4	"	1207·4
68·2	988·5	1011	1212·4	"	1212·4
69·2	991	"	1215·5	"	1215·5
70·2	994	"	1219	"	1219
71·2	997·5	1010	1225	"	1225
72·2	1000	"	1228	"	1228
73·2	1003	"	1231·5	"	1231·5
74·2	1006	"	1235	"	1235
75·2	1010·5	"	1240·5	"	1240·5
76·2	1013	"	1244	"	1244
77·2	1017	"	1249	"	1249
78·2	1020	"	1252	"	1252
79·2	1023·2	"	1256	"	1256
80·1	1027	1011	1260	"	1260
81·2	1031	1010·5	1265	"	1265
82·2	1034	1010·5	1269	"	1269
83·2	1037	1011	1272	"	1272
84·2	1039·5	1010	1276	"	1276
85·2	1043	1010	1280·5	"	1280·5
86·2	1047	1010	1285	"	1285
87·2	1050	1009·5	1290	"	1290
88·2	1052	1009	1293	"	1293
89·2	1056	1009	1298	"	1298
90·2	1060	1009	1303	"	1303

The absolute specific resistance in C.G.S. units was calculated from the above numbers as follows. The resistance in ohms of the measured wire at any temperature is found by using Equation No. 2:—

$$(4.) \quad X = \frac{G_X(R_X + S)}{G_R(R_R + S)} R.$$

From the definition of the  $R$ , and that of specific resistance in C.G.S. units, formula 5 is deduced:—

$$(5.) \quad \sigma = X \frac{\pi r^2}{l} 10^9,$$

where  $r$  = radius of the wire in centimetres.  
 $l$  = length " " "

If the value of  $X$  as given in Equation No. 2 is substituted in Equation No. 5, the following is obtained:—

$$(6.) \quad \sigma = \frac{G_X(R_X + S)}{(R_R + S)} \frac{R}{G_R} \frac{\pi r^2}{l} 10^9.$$

In the previous table if  $G_X$  is read as in the last column, the following will be the values for the various elements of Equation No. 6:—

$R_R = 8000$  B.A. units for all observations.

$R_X = 2000$  " " "

$S = 17.3$  " " "

$R = 1$  ohm.

$G_R = 1240$ . Scale divisions for all observations.

$2r \approx 0.05151$  cm.  $\left\{ \begin{array}{l} \text{At } 15^\circ \text{ C. But, according to Mat-} \\ \text{thiessen, no correction is made} \\ \text{for the variation of these con-} \\ \text{stants.} \end{array} \right.$

In Equation No. 6 everything is constant except  $\sigma$  and  $G_X$ , and the equation results in the following, when the numerical values as above are substituted for the general expressions:—

$$(7.) \quad \sigma = 1.6906 G_X \left( \begin{array}{l} G_R = 1240 \\ T_R = 15^\circ \text{ C.} \end{array} \right)$$

$$\log 1.6906 = 0.2280258.$$

The specific resistance in C.G.S. units of the hard-drawn rocking tank A deposit at any temperature can therefore be calculated by making use of the values given in the above table. In order to find the specific resistance at  $0^\circ \text{ C.}$  it is necessary to calculate the temperature coefficient ( $\Delta_t$ ) from the above observations. The method of

least squares is the one which naturally suggests itself in calculating this coefficient, but the calculation would be too laborious in comparison with the value of the figure arrived at. Therefore, in order to ascertain which values could be used for calculating the temperature coefficient ( $\Delta_t$ ), the above observations were plotted in the usual way, the co-ordinates being  $x =$  temperature and  $y =$  specific resistance in C.G.S. units.

As previously stated, the values in column 6 of Table II have to be multiplied by 1.6906 to give the specific resistance in C.G.S. units; to save labour the multiplication was done graphically (Graphic Table No. 1).

The resistances in column 6 of Table I reduced to C.G.S. units by means of the graphical Table 1 are tabulated in another table (Table III).

The graphic Table No. 2 is a reproduction of Table III, and gives the results of the above measurements.

As the values formed so very nearly a straight line, two only are selected :--

1707 C.G.S. units at 16.0° C.  
1937    "       "       51.2° C.

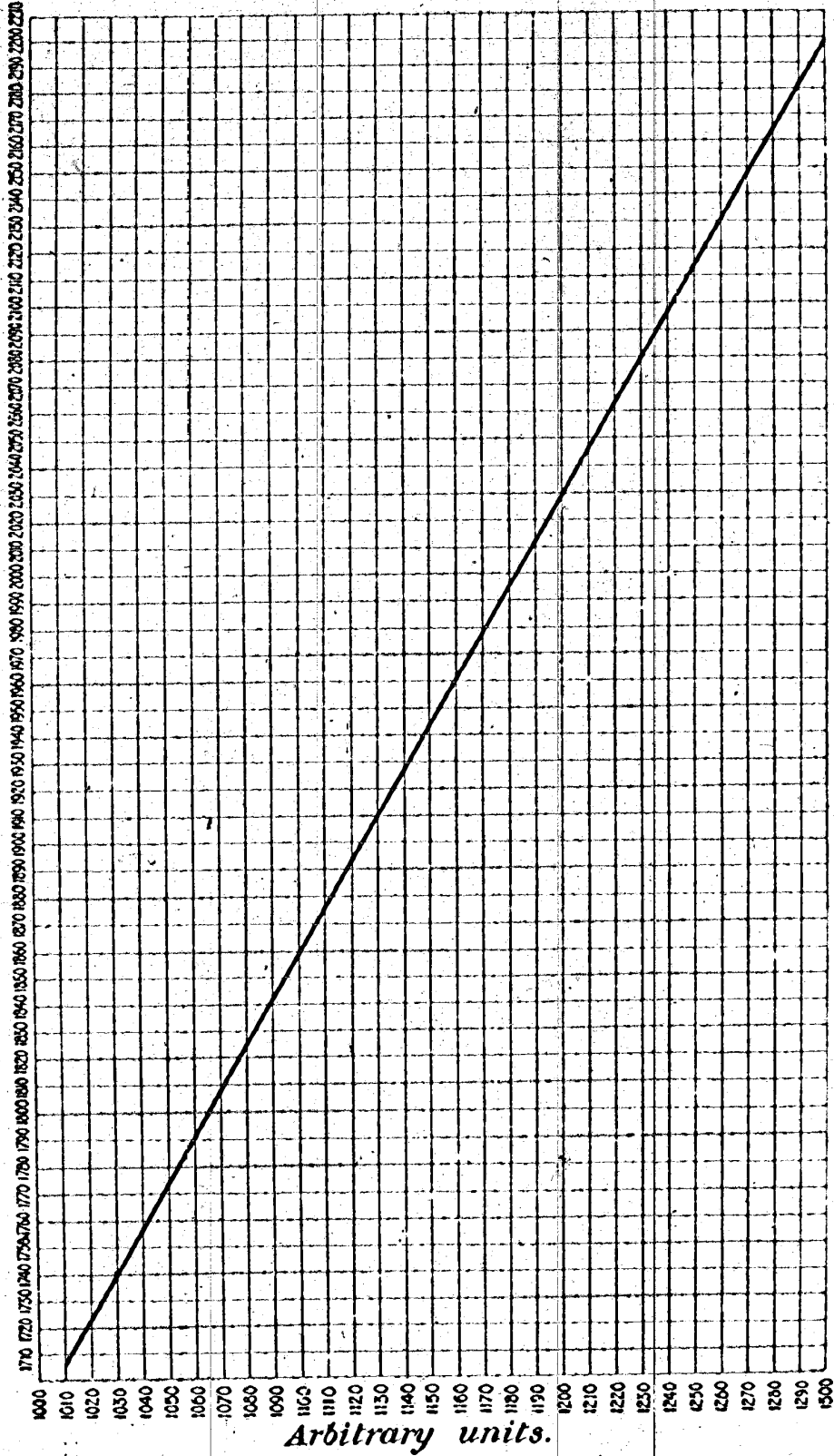
These gave the following equations :--

$$\begin{aligned} 1707 &= x(1 + 16y) \\ 1937 &= x(1 + 51.2y), \text{ from which} \\ x &= 1603 \text{ C.G.S. units} \\ y &= 0.001077. \end{aligned}$$

$x$  is the specific resistance of the A deposit (hard drawn) at 0° C., and  $y$  is the temperature coefficient. By means of these values an extrapolation was made from 0° to 16° C. in the graphic Table No. 2.

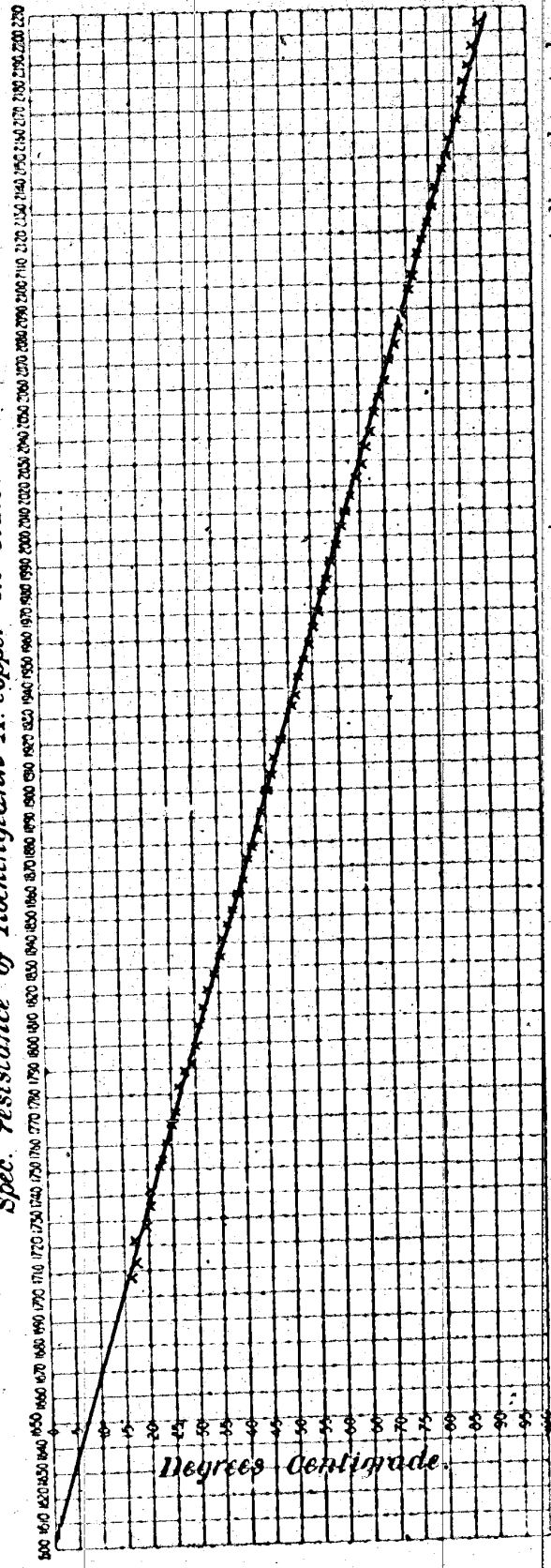
Graphic Table i.

*C.G.S. units.*



Reduction of column 6, Table II, from arbitrary units.  
To C.G.S. units by graphic method (multiplication by 1.6906).

Graphic Table 2.  
Spec. resistance of Rockingtank A. copper in C.G.S. units.



Shows the result of the measurements of the specific resistance of Rocking tank A copper (hard-drawn). The crosses indicate the actual observations reduced to the C.G.S. system.

Table III.  
Rocking Tank A Copper. Hard drawn.  
Specific Resistance.

Temperature.	C.G.S. units.	Temperature.	C.G.S. units.	Temperature.	C.G.S. units.
C°.		C°.		C°.	
16·0	1707	47·2	1913	79·2	2123
17·2	1713	48·2	1920	80·1	2130
18·1	1722	50·2	1932	81·2	2138
19·6	1727	51·2	1937	82·2	2145
20·3	1735	52·0	1944	83·2	2150
20·9	1741	53·1	1951	84·2	2157
22·6	1751	54·1	1957	85·2	2164
23·3	1754	55·2	1964	86·2	2172
24·2	1761	56·2	1970	87·2	2180
25·2	1768	57·2	1978	88·2	2186
26·2	1773	58·2	1983	89·2	2194
27·3	1783	59·2	1990	90·2	2203
28·7	1787	60·2	1996		
29·7	1792	61·2	2003		
30·2	1799	62·2	2010		
31·1	1807	63·2	2016		
32·2	1814	64·2	2023		
33·2	1821	65·2	2029		
34·2	1827	66·2	2035		
35·3	1834	67·2	2041		
36·2	1841	68·2	2049		
37·2	1847	69·2	2055		
38·2	1853	70·2	2061		
39·2	1860	71·2	2070		
40·1	1865	72·2	2076		
41·2	1873	73·2	2082		
42·2	1878	74·2	2088		
43·5	1885	75·2	2097		
44·2	1892	76·2	2103		
45·2	1900	77·2	2111		
46·2	1906	78·2	2117		

*Measurements with Rocking Tank A Copper, Soft.*

A similar wire to that used in the previous measurements was annealed in a tube of hard glass, through which was passing a current of dry CO<sub>2</sub> gas, in order to prevent oxidation. The following measurements were made with it:—

Density at 15° C., 8·959 (see previous table).

Absolute weight of 300 cm. of the wire, 5·5746 grams.

Diameter.

$$X = 2r = 2 \sqrt{\frac{5\cdot5746}{\pi \cdot 8\cdot959 \times 300}} = 2 \times 0\cdot025694 = 0\cdot051388 \text{ cm.}$$



250 cm. of this wire were compared with the standard ohm, according to the method described. The following are the observations:—

Table IV.

$T_x$	$G_x$	$G_R$	$G_x$ ( $G_R = 1210$ )	$T_R$	$G_x$ ( $G_R = 1210$ $T_R = 15^\circ C.$ )
16.8° C.	820.	1023	994	20° C.	—
	819.5	1023	993	..	994
19.95	829.	1020	1008	..	1008
	828.5	1020	1007	..	1008
48.0	916.	1019	1114	..	1115
..	916.	1019	1114	..	1115

From the numbers in column 6 the values of the specific resistance of this sample can be obtained by multiplication with the constant 1.6826 obtained in the same manner as the value for the hard variety, the difference being due to the difference in the diameters. All the other constants of the measurements were the same. The results by calculation give the following values:—

Specific resistance of rocking tank A copper, annealed in CO<sub>2</sub> gas:—

At 16.8° C.	=	1672.4	C.G.S. units.
.. 19.95	=	1696.0	.. ..
.. 48.0	=	1876.0	.. ..

The temperature coefficient, calculated from the following formula:—

$$(8.) \quad R_t = R_0(1 + \alpha t),$$

gives the value 0.00118 at ordinary temperatures.

Applying this value of  $\alpha$  to the amount of specific resistance at 16.8° C., the following is obtained as the specific resistance of this special sample of annealed rocking tank A deposit:—

$$\sigma_{0^\circ C} = 1566 \text{ C.G.S. units.}$$

*Specific Resistance of Soft Annealed Copper Wire made from Deposited Sheet Copper named B, the Deposit being obtained from a Solution of Rocking Tank A Copper Dissolved in Pure Diluted Sulphuric Acid, using an Anode of the Tank A Copper.*

*Origin of the Copper.*—A solution of sulphate of copper was prepared by using a piece of rocking tank A copper, as the anode in a

PROCEEDINGS

OF THE

ROYAL SOCIETY OF LONDON.

*From November 18, 1897, to February 24, 1898.*

VOL. LXII.

LONDON:

HARRISON AND SONS, ST. MARTIN'S LANE,

Printers in Ordinary to Her Majesty.

MDCCCXCVIII.



We have shown that the colour was in proportion to the amount of copper present, and that the colourless leucocytes contained only traces of that metal. The deposition of the copper in this large quantity appears to us to represent a degenerative reaction; it was accompanied by a most striking increase of leucocytes, which tended to distend the vessels and to collect in clumps, phenomena which are abnormal in our experience in the oyster. The presence of the copper in the leucocytes in these cases might be compared to that of the iron which is met with in some of the leucocytes in cases of old hæmorrhages, pernicious anæmia, or in other cases where iron is set free. We are not prepared to state whether copper in the food can bring about the condition, but certainly we have abundant evidence to show that it can occur where no copper mines or other evident sources of copper are present.

We are inclined to suggest that the increase of copper may be due to a disturbed metabolism, whereby the normal copper of the hæmocyanin, which is probably passing through the body in minute amounts, ceases to be removed, and so becomes stored up in certain cells.

Our results also show that hæmatoxylin is a most valuable reagent, not only as Macallum has shown in the case of iron, but also in that of copper, and that care must be taken to distinguish between the two reactions; and this must be especially the case in those invertebrata where copper plays an important rôle in the physiology of the blood.

“Stress and other Effects produced in Resin and in a Viscid Compound of Resin and Oil by Electrification.” By J. W. SWAN, F.R.S. Received May 17,—Read June 17, 1897.

(PLATES 1—4.)

While making an experiment with the object of finding the degree of resistance to puncture offered by paper coated with a soft compound of resin and oil, when placed between the secondary terminals of an induction coil, the tension being regulated by a spark-gap in a parallel branch of the circuit, observed that on the passage of a spark at the spark-gap, while no spark passed between the paper-separated terminals, a sudden roughening or puckering of the previously smooth surface of the coating took place.

A number of experiments were made with the object of ascertaining the nature of the action which produced this effect, and these led to further experiments and to results which, though closely related to well-known phenomena, possess features of novelty and interest.

It was found that clear Bordeaux resin in a viscid state (viscosity being brought about either by heat or by the addition of resin oil) is responsive to the mechanical stress consequent on electrification by non-luminous discharges; and if it is so acted upon while in the solid state, and afterwards superficially softened by heat, there results a new kind of electric discharge figure, analogous to the dust figures of Lichtenberg and Lord Armstrong, but showing some remarkable peculiarities which throw additional light on the mechanism of air-conveyed electrical discharges, and on the location and nature of the stresses imparted to the dielectric. I ascertained that a smooth surface of resin is retentive of an electric charge to an extraordinary degree, that after more than two months the lines of an electric discharge figure, as developed by heat, and as further developed by the accidental attraction of atmospheric dust to the electrified parts of the surface, were still attractive of dust in a discriminative manner, no change being observable upon re-dusting either in the arrangement or definition of the lines of electrification as originally developed.

The apparatus employed consisted of an induction coil or a Wimshurst machine, and a supporting stand, the rod of which carried two clips and a stage, the supporting part of the stage being made of strips of thick plate-glass, and the rest of wood. The clips held conducting wires, which passed through bent glass tubes, and went to the secondary terminals of the induction coil, or to the conductors of the Wimshurst machine; the discharging arms in either case constituted an adjustable spark-gap in parallel with the wires ending above and below the stage. The stage terminals were balls, discs, or points; the pairs employed in different experiments varied in size and form, and the pair used together were sometimes dissimilar. The resin was the colour of amber; in some of the experiments it was used in a solid state, but fused to the form required for experiment; in other experiments it was softened to semi-liquidity by the addition of 20 per cent. or more of resin oil, the mixture being made by fusion together of the resin and oil. The compound with 20 per cent. of oil has the consistency of treacle at a temperature of 20° C.; at 12° C. it is nearly solid, yet plastic enough to yield to the mechanical stress-action generated by the projection upon its surface of an electric discharge of the kind employed in the experiments. At the higher temperature the viscid liquid is well suited for showing the great disturbance produced by repeated discharges, and when at the lower temperature it is convenient for observing the more persistent forms of the figures produced on the surface by single discharges under various conditions. When it was required that the stress figures should be permanent, resin either alone or with not more than 2 or 3 per cent. of resin oil was used.

The dielectric was either contained in glass basins or spread as a coating of 0.5 to 1 mm. thick upon glass or mica plates, and in a few cases on copper plates. Also plates consisting wholly of resin were in some instances used.

The effect of a spark passing at the spark-gap, when one of the stage terminals is suspended over, and at a certain distance from the viscid resin and oil mixture contained in a basin, the other being in contact with a metallic disc under it, is to produce an evanescent figure on the surface.

The character of the figure depends on:—

1. Whether the terminal over the dielectric surface is positive or negative.
2. The form and size of the + and - terminals.
3. The distance of the upper terminal from the surface of the dielectric.
4. The potential and character of the spark at the spark-gap.

*Typical Effects.*—The most regular and characteristic stress figures are obtained when the spark-gap is adjusted so as to prevent the passage of a spark or visible brush through or over the dielectric, but allow a non-luminous discharge to take place of only slightly less strength than would be necessary to produce a brush discharge visible in the dark. A typical effect is obtained when the spark-gap is 25 mm., and the positive branch from it terminates in a brass ball of 8 mm. diameter hanging centrally over, and 4 mm. from the surface of the dielectric (80 per cent. resin and 20 per cent. resin oil at 20° C.) contained in a glass basin 150 mm. diameter and 15 mm. deep, the negative wire being brought to a disc of metal 100 mm. diameter under the basin, or to a disc of tinfoil attached to the underside. On breaking the primary circuit by means of a mercury break with a trigger action (the spark-gap having been momentarily short-circuited while the primary circuit was closed), and the consequent passing of a single spark at the spark-gap—no visible discharge occurring between the ball and the dielectric—there suddenly breaks out on the surface of the viscous liquid a star-shaped figure formed of deeply furrowed, closely clustered, outward-branching rays, extending from a circular frill near the centre to the margin of the liquid. The figure gradually dies down, and on the surface becoming smooth it can, with slight variations, be reproduced again and again by repeated breaks of the primary circuit.

If the commutator is reversed (the spark-gap being momentarily closed while the primary circuit is re-made), then on breaking the primary circuit as before, a figure characteristic of the negative convective discharge is produced. This figure is much smaller and weaker than the positive one; most frequently it consists of a

circular, or nearly circular, band or ring, more or less indented in outline, enclosing leaf-like rays which tend towards the centre. These are relatively broader and less branching than the rays of the positive figure, and they are characterised by having their outlines in relief, while the rays of the positive figure are sunk below the plane of the surface. When the electrification is strong, the ring enclosing the rays stands up as a frill in considerable relief.

*Effect of the Form of the Terminal.*—The character, both of the positive and negative figures, is greatly affected by the form of the discharging electrodes. When the upper terminal is a metallic disc of 25 mm. diameter, hanging in a plane parallel to, and 2 mm. above, the dielectric surface, and the other terminal is a 50-mm. metallic disc supporting the basin, complicated, but nearly symmetrical, figures of great beauty are obtained. A metal point opposed to a metal point, or a metal point above and a small metal ball below, give smaller figures of more elementary forms, having the general characteristics of the larger figures.

Balls and points as terminals tend to produce circular figures in which the rays converge to, or diverge from, one centre. This rule applies with fewer exceptions to the + figure. The negative figure, even when produced by a discharge from a brass ball, is frequently a combination of sectors, whose centres are not far apart, and are concentric with the centre of the group. The effect of this is to produce a figure of nearly circular outline broken by more or less regular indentations.

If the ordinary vibrating contact-breaker be employed instead of the trigger-break used in the foregoing experiments, the rest of the arrangement remaining as described, larger and more complicated effects are obtained. When the ball above the liquid is positive, the resin and oil being at a temperature of 20° C., on breaking the primary circuit the first effect of the make-and-break is the production of the characteristic star with arborescent rays; the repetitions of the impact which instantly follow indent the lines of the figure more and more deeply, and result in the effacement of the more regular figure, and the development of a large and turbulent movement of the liquid, tending to its division into two masses: a central mound with a flat or concave top and a concentric ring. At first the two masses are joined by radial ridges, but these gradually thin, and (if the discharges at the spark-gap are continued) eventually break down and leave the central mound and the embracing ring completely separated. During the progress of the action the ring portion is driven outwards, and when the limit of outward movement is reached, there is a subsidence of the more violent agitation, the outer ring becomes somewhat smoother and flows inwards; this is followed by a recurrence of the repellent action, and a repetition of the last

phase of the phenomena described. Figs. 1 and 2 represent in profile the appearance at the middle and final stage of the action.

FIG. 1.—*Positive*. Nearly Maximum Effect.



FIG. 2.—*Positive*. Maximum Effect.



If a metal ring (of 90 mm. diameter) is substituted for the disc, similar but more sharply defined effects are obtained. When the arrangement described is varied by making the ball over the basin negative, instead of positive, on breaking the primary circuit there is less displacement of the viscid material consequent on repeated interruptions of the circuit. To obtain a characteristic effect of repeated negative discharges, the spark-gap should be widened to 50 mm., and to prevent sparking over the edge of the basin, it should be at least 150 mm. diameter. There is then formed, immediately under the ball, a concavity the counterpart in size and curvature of the ball, and outside this there is the general figure, somewhat faint and tremulous, which seems to be a complication of the positive and negative figures, the characteristic positive figure encircling the more distinctly negative portion. Fig. 3 is a profile view of the negative displacement. The extent of the effects described is considerably modified by the degree of viscosity of the liquid, and this can be controlled by temperature.

FIG. 3.—*Negative*. Maximum Effect.



Corresponding but modified phenomena are produced by means of the Wimshurst induction machine. When, for example, an 8 mm. metal ball connected to the + arm of the discharger hangs 15 mm. from the surface of the resin and oil mixture of the consistency of treacle contained in a large basin, and the - arm of the discharger is connected to a metal disc of 100 mm. diameter under the basin, the discharger balls being 75 mm. apart, the result of continuously working the machine is the production of a turbulent motion, attended by the

formation of vortices into which the upper stratum of the liquid pours downward, carrying adherent air with it, while an equal and opposite movement takes place from below, producing worm-like eruptions of spirally twisting or wriggling jets of liquid at the surface. If the margin of the dish beyond the surface of the liquid is thinly smeared with the viscid liquid, the film breaks up into dew-like beads.

With a metal ball of 150 mm. diameter, 6 mm. above the surface of the liquid and a proportionately larger disc basin and depth of liquid, acted upon by a machine of moderate power, the spark-gap being adjusted so as to prevent sparks passing from the ball to the liquid, and the tension such as to keep up a strength of electrification of the surface only slightly less than that which would cause disruptive discharges to pass, a column of liquid rises and connects the overhanging ball and the surface of the liquid in a manner strongly suggestive of water-spout phenomena. The ascent of the column of liquid is followed by the descent of numerous thin surrounding streams, and these keep up a regular system of upward and downward circulation.

*Elevation of Characteristic Effects.*—In order to fix the various forms produced in the viscous mixture of oil and resin, an experiment was made with nearly pure resin, rendered plastic by heat, and cooled to solidity while under the action of electric discharges. It was found to be difficult to carry this out in a satisfactory manner, but it suggested a reversal of the procedure, viz., the electrification of a surface of resin in a solid state, and the subsequent development of the stress effect by rendering the surface superficially plastic by heat. This mode of operation resulted in the production of permanent relief and intaglio figures, corresponding to Lichtenberg's dust figures, to Brown's photographs,\* and to the dust figures and photographs more recently described by Lord Armstrong.†

The preparation of the resin surface for the production of the permanent figures requires care. The method I employed is as follows:—A thin glass basin was filled with a mixture of resin and 5 per cent. resin oil, the oil being added to lessen the tendency of the resin to fracture on sudden change of temperature. The resin, melted in a metal pan, was poured through a filter of muslin into the basin, while embedded in small shot and raised to the fusion temperature of resin. On slowly cooling, the basin being meanwhile covered with a plate of glass or an inverted basin, the resin solidifies with a smooth bright surface. The resin-filled basin was partly covered, on the bottom, by a disc of tinfoil, and was placed centrally

\* 'Phil. Mag.,' vol. 26, p. 502.

† 'Electric Movements in Air and Water, with Theoretical Inferences,' by Lord Armstrong, C.B., F.R.S. London: Smith, Elder and Co., 1897.



on a metal disc in contact with one of the wires from the spark-gap of the induction coil, the other wire, ending in a point, disc, or ball, overhanging the surface at the distance of a few millimetres as in the experiments with the viscous material described. On the production of a single spark at the spark-gap by means of the trigger-action mercury contact-breaker, a charge is conveyed to the resin. The peculiar distribution of this charge, and that it is attended by strong and enduring mechanical stress, can be made manifest either immediately, or many hours afterwards, by slightly warming the surface of the resin. The result is a deeply impressed figure, having the same character as the figure produced on the viscid dielectric. These solid figures, if carefully developed, show much fine detail; unfortunately, this is not capable of complete illustration by photographs. Difference of depth in the grooves is not fully indicated, neither is there represented adequately a peculiar burring of the margin of the grooves, especially in the negative figures, their edges rising slightly above the plane surface, as though the resin had been finely carved.

*Persistency of the Stresses.*—The persistency and fixity of the electrification of the resin surface, determining the form and character of the eventual figure, are very remarkable. If the development of the effect of the charge is delayed for twenty-four hours there is but little difference in the result from that which follows immediate development.

*Dust Figures and Stress Figures combined.*—It was found that the heat-developed figures attracted dust from the atmosphere, and thus formed, accidentally, a combination of a stress figure and a dust figure. The attracted dust gave clear indications of electrification beyond the limit of the stress figure, and brought out features of detail which helped to explain the nature of the electrification. Analysis of the character of the figures in this respect is still further helped by combining a modification of the dust process of Lichtenberg with the stress effect described in this paper. The modification referred to consists in allowing the dust—the mixture of red lead and sulphur proposed by Lichtenberg—to be drawn up to the electrified surface from a cloud of dust. This assists in the selective appropriation of the two substances, giving a redder colour on the negatively electrified portions of the figure, and a yellower colour on the positive portions; and showing what the stress figure alone does not show with equal clearness, how inseparable are the + and - actions. The best effect is obtained by applying the dust process before development by heat. Figs. 4 and 5 (Plate 1) represent characteristic forms obtained by positive and negative discharges with a metal ball electrode above the surface and a metal disc below, fig. 4 being + and fig. 5 -. Figs 6 and 7 are corresponding figures obtained with discs above and below, fig. 6 being + and fig. 7 -.

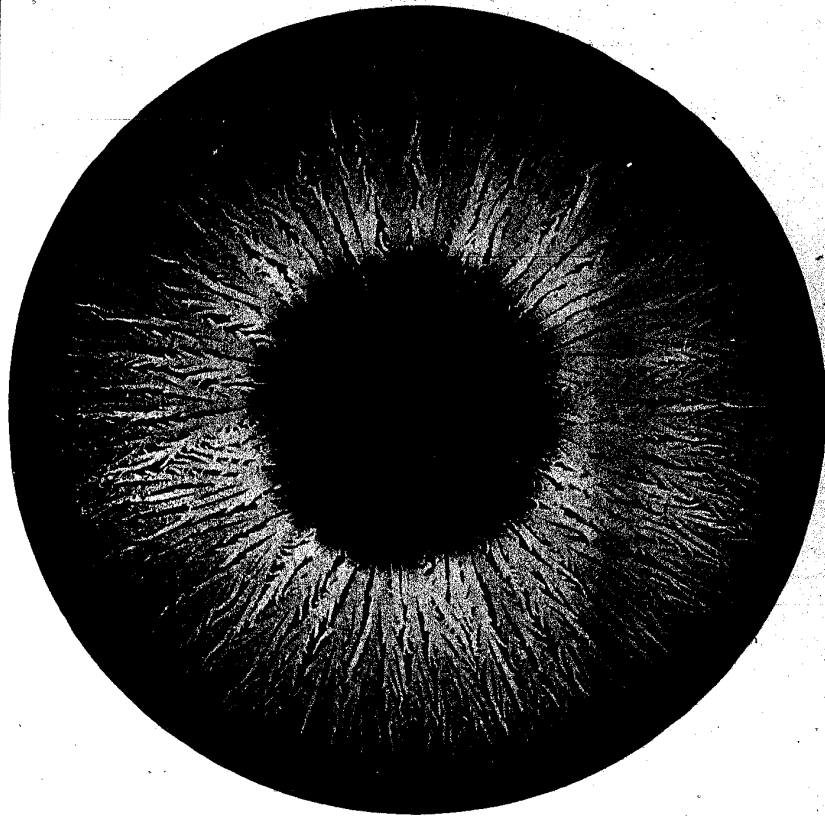


Fig. 4.

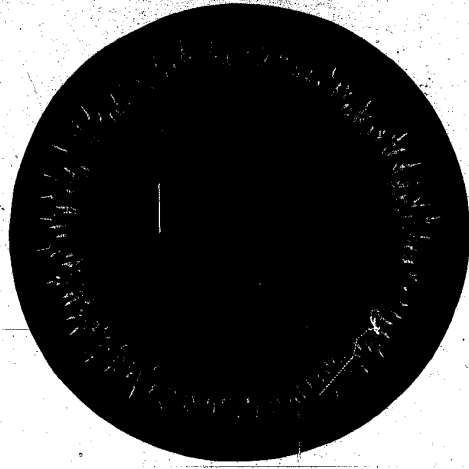


Fig. 5.

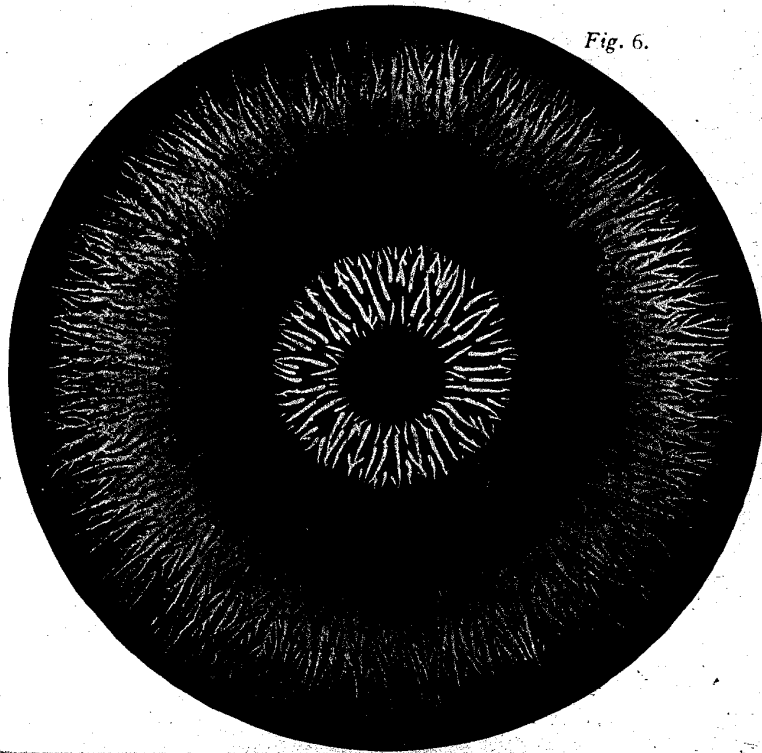


Fig. 6.