plying the method so as to obtain in a compact form and at a small cost a dispersive power exceeding that of any spectroscope on the old plan, and free from the defects inherent in a complicated instrument.

In conclusion, I may allude to an application of the remarkable property of the half-prism which may perhaps prove of practical use. From what precedes it will be clear that the half-prism, as far as its magnifying-power is concerned, is equivalent to a combination of an object-glass and cylindrical eyepiece, the peculiarity being that it magnifies the angle between two pencils of parallel rays without affecting the parallelism of the rays in each pencil. The half-prisms which have so far been considered are constructed so as to give great dispersion, and the sun is seen through them as if through a telescope with an object-glass formed of a convex flint lens and a concave crown. But it is obvious that an achromatic prism may be formed on the same principle as the achromatic object-glass, giving cylindrical magnifying-power without dispersion. If two such prisms be crossed at right angles, one behind the other, the magnifying-power will be the same in both directions, and the combination will act as an achromatic telescope with the advantage of great compactness, since the eye can be applied close to the second prism. Whether, however, this advantage would compensate for the greater quantity of glass required and for the loss of light is a matter for practical consideration; and I therefore defer the discussion of the achromatic half-prism till I have satisfied myself that it has some practical utility, even though it may never replace the refracting telescope for general use.

Royal Observatory, Greenwich,
1877, Jan. 17.

March 8, 1877.

Dr. J. DALTON HOOKER, C.B., President, in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read:—

I. "On Magneto-electric Induction in Liquids and Gases.—Part I. Production of Induced Currents in Electrolytes." By J. A. Fleming, B.Sc. (Lond.). Communicated by Prof. Stokes, Sec.R.S. Received February 6, 1877.

(Abstract.)

This paper contains an account of an experimental inquiry into the production of induced currents in liquids by magneto-electric induction. Faraday examined one such case of induction, in which a conducting liquid was used as a secondary circuit. He coiled round the armature of an electromagnet an india-rubber tube filled with dilute sulphuric acid, and found, on making and breaking the primary circuit, the induced currents generated in it, as in the case of metallic conductors; but he could not obtain any effect when brine, sulphuric acid, or other solutions were rotated in basins over a magnet, or enclosed in tubes and passed between the poles. He failed also to detect any magneto-electric current in water flowing across the earth's lines of magnetic force (viz. in the river Thames).

Since the reason for these negative results is not at once obvious, it seemed desirable to repeat and extend them to other cases, so that, if possible, the analogy ~~of electrolytic~~ with solid conductors might, in respect to magneto-electric induction, be completed. In addition, the subject involves the interesting question of the magneto-electric phenomena accompanying the flow of ocean-currents and other large masses of water.

Three cases of induction in liquids flowing in a magnetic field or traversed by lines of magnetic force have been examined.

1. *Production of induced current in a liquid stream flowing uniformly in a constant magnetic field.*—When a stream of conducting fluid flows vertically down between the poles ~~of a magnet a transverse~~ current is produced in a direction at right angles to the lines of force and line of flow. This was obtained in the following way:—A glass tube, about 200 centims. long and 2 centims. wide, had platinum plates 15 millims. wide placed along its inside and at opposite sides, with their lengths parallel to the axis of the tube. Platinum wires welded to these plates were sealed through the glass. The plates were curved to lie closely against the sides of the tube. This tube was placed vertically between the poles of a large electromagnet, the line joining the platinum plates being at right angles to the line of the poles.

To the upper end of the tube was attached another, leading to a reservoir of dilute sulphuric acid placed high above the floor; to the lower end a tube leading to a receptacle on the floor. The platinum plates were then connected with a distant galvanometer. When the magnet was not excited, no flowing of the liquid had any effect on the galvanometer; but when it was excited, at the moment the flow began the galvanometer showed a deflection of 10° to 15°. Since the only part of the galvanometer circuit in motion is the liquid, this deflection was due to the magneto-electric current generated in it by its movement. It was noticed that the plates were *polarized* by the currents so created. As a consequence of this, the deflection of the needle soon fell to zero; and on the liquid flow being stopped, a polarization current in the opposite direction was obtained. This proved that in experiments on induction in liquids, in order to obtain any constant current, non-polarizable electrodes must be used.

2. *Production of induced current in a mass of liquid rotating over a magnetic pole.*—In this case radial currents should be produced. They were obtained as follows :—Flat porous cells were placed round the circumference of a large basin, and in the centre a cylindrical one. These were filled with a solution of cupric sulphate, and contained copper plates. The basin was filled with dilute sulphuric acid. The centre copper plate was connected with one pole of the galvanometer, and the circumferential ones with the other. The whole was placed over the pole of the electromagnet. On exciting the magnet and rotating the dilute acid, a constant current was obtained, flowing from centre to circumference or the reverse according to the direction of rotation. With platinum electrodes the effect cannot be obtained, but with non-polarizable electrodes it is easily produced. Mercury was likewise tried with still better results.

3. *Production of induced current in a liquid at rest in a variable magnetic field.*—If a flexible tube filled with conducting liquid is wound round an electromagnet, and into the ends electrodes placed so as to include a galvanometer in the circuit, then induced currents are obtained whenever the strength of the magnet varies. This is the case examined by Faraday. His experiment was repeated by MM. Logeman and Van Breda (Phil. Mag. [IV.] vol. viii. p. 465), who noticed that the electrodes were left polarized after the induced current had passed. These experiments were repeated with more powerful apparatus, using a soft iron wire core within the inducing helix instead of solid iron, and employing a condenser in the primary circuit. Very strong induced currents were obtained, and correspondingly great polarization of the electrodes placed in the ends of the coil of acid. It was hoped that the currents might produce visible inductive electrolysis, but even this improved arrangement did not yield that result. Other saline solutions were tried with similar results.

Lastly, the phenomenon observed by Arago, of the retardation in the vibrations of a magnetic needle oscillated near the surface of liquids, is examined. Evidence is brought forward to show that this is *not*, as in the case of solid plates, due to induced currents created in the liquid—(1) because the retardation is, *cæteris paribus*, not proportional to the conductivity of the liquid but dependent on its volatility; (2) because it takes place equally when a light brass needle, oscillated by torsion, is substituted for the magnet, provided the needle is light and the period of oscillation not very small. Thus a magnetic needle which required 4 min. 20 sec. to suffer a decrement of 25° in the semi-arc of vibration when in air, required over dilute sulphuric acid 3 min. 30 sec., over ether 2 min. 25 sec. A brass needle of the same dimensions exhibited similar effects.

In conclusion the magneto-electric induction taking place in moving masses of water on the earth's surface under the influence of terrestrial magnetism is briefly discussed.

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Auteur	Royal society (GB)
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Notes	Irrégulier. Le titre change, (à partir du vol. 5, daté de 1851) et devient : "Abstracts of the papers communicated to the Royal society of London" ; (à partir du vol. 7, daté de 1856), devient : "Proceedings of the Royal society of London" ; enfin (à partir du vol. 76, daté de 1905), devient : "Proceedings of the Royal society of London. Series A, containing papers of a mathematical and physical character". Ed. par Taylor and Francis (à partir du vol. 6), par Harrison and sons (à partir du vol. 27), puis par Cambridge University Press (à partir du vol. 159)
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Fascicule	N056120. 1878. 1. Vol. 26

families are also comparatively few. The families so contributing are, however, among the most important and widely distributed in the vegetable kingdom; as also are some of the plants they contribute. As prominent examples may be mentioned, the *Gramineæ*, affording the cereal grains, a large proportion of the mixed herbage of grass-land, and other products; also the *Leguminosæ*, yielding pulse crops, many useful herbage plants, and numerous other products. As we have said, there does not seem to be an unsolved problem as to the sources of the nitrogen of other of our agricultural plants than those of the leguminous family. Obviously, however, it would be unsafe to generalise in regard to individual families as a whole, from results relating to a limited number of examples supplied by their agricultural representatives alone. Still, there is nothing in the evidence at present at command, to point to the supposition that there is any fundamental difference in the source of the nitrogen of different members of the same family, such as is clearly indicated between the representatives of the leguminous, and of the other families, supplying staple agricultural products. On the other hand, existing evidence does not afford any means of judging whether or not similar, or allied agencies to those now under consideration, or even quite different ones, may come into play in the nitrogen assimilation of the members of other families which contribute such a vast variety of vegetation to the earth's surface.

We have pleasure in stating that the conduct of the investigation has largely devolved upon Dr. N. H. J. Miller. He has been almost wholly responsible for the analytical work, as well as for the photographing, by which a permanent record, not only of the above-ground growth, but of the root-development of the experimental plants has been secured. It should be added, that Mr. J. J. Willis has materially assisted in the observation and noting on growth; also in the separation of the roots, mounting them for observation and for photographing, and in noting upon them.

II. "On Electric Discharge between Electrodes at different Temperatures in Air and in High Vacua."

By J. A. Fleming, M.A., D.Sc., Professor of Electrical Engineering in University College, London. Communicated by Professor G. C. Foster, F.R.S. Received December 16, 1889.

(Preliminary Notice.)

It has been known for some time that if a platinum plate or wire is sealed through the glass bulb of an ordinary carbon filament incandescent lamp, this metallic plate being quite out of contact with the carbon conductor, a sensitive galvanometer connected between this insulated metal plate enclosed in the vacuum and the external *positive* electrode of the lamp indicates a current of some milliampères passing through it when the lamp is set in action, but the same instrument when connected between the *negative* electrode of the lamp and the insulated metal plate indicates no sensible current. This phenomenon in carbon incandescence lamps was first observed by Mr. Edison, in 1884, and further examined by Mr. W. H. Preece, in 1885.[*] The primary object of the experiments described in this paper was the further examination of this effect, but the inquiry has extended itself beyond this range and embraced some general phenomena of electric discharge between electrodes at unequal temperatures, and in particular has revealed some curious effects in the behaviour of an electric arc taken between carbon poles towards a third insulated carbon on metal poles.

The first series of experiments had reference to the nature of the effect observed in the incandescence lamps having an insulated wire or plate placed in the vacuum.

If a platinum wire is sealed through the glass bulb of an ordinary carbon filament lamp and carries at its extremity a metal plate, so placed as to stand up between the legs of the carbon horseshoe without touching either of them, then when the lamp is actuated by a continuous current it is found that :—

(1.) This insulated metal plate is brought down instantly to the potential of the base of the negative leg of the carbon, and no sensible potential difference exists between the insulated metal plate and the negative electrode of the lamps, whether the test be made by a galvanometer, by an electrostatic voltmeter, or by a condenser.

(2.) The potential difference of the plate and the positive electrode of the lamp is exactly the same as the working potential difference of the lamp electrodes, provided this is measured electrostatically, *i.e.*, by a condenser, or by an electrostatic voltmeter taking no current,

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[*] See 'Roy. Soc. Proc.,' vol. 38, 1885, p. 219. "On a Peculiar Behaviour of Glow Lamps when raised to High Incandescence."—In this paper Mr. Preece describes a very careful series of observations carried out with Edison incandescence lamps, and which cover the same ground as a portion of the experiments here described. The results given in (4), (7), and (11) confirm the facts which were first ascertained by him. He also arrived at the general conclusion that the phenomena so observed are due to an electric convection by matter projected from the incandescent carbon. By carrying up the working electromotive force of the lamp to a point productive of very high incandescence, he was able to measure the resulting current through a galvanometer connected between the positive lamp electrode and the middle plate corresponding to every degree of incandescence, and showed that, whilst increasing up to a certain point, the galvanometer current fell off rapidly soon after a certain critical temperature was reached, which corresponded to the appearance of a blue light or haze in the glass receiver.—[Jan. 14th, 1890.]

but if measured by a galvanometer the potential difference of the plate and the positive electrodes of the lamp is something less than that of the working lamp electrodes.

(3.) This absolute equality of potential between the negative electrode of the lamp and the insulated plate only exists when the carbon filament is in a state of vivid incandescence, and when the insulated plate is not more than an inch or so from the base of the negative leg. When the lamp is at intermediate stages of incandescence, or the plate is considerably removed from the base of the negative leg, then the plate is not brought down quite to the same potential as the negative electrode.

(4.) A galvanometer connected between the insulated plate and the *positive* electrode of the lamp shows a current increasing from zero to four or five milliampères, as the carbon is raised to its state of commercial incandescence. There is not any current greater than 0·0001 of a milliampère between the plate and *negative* electrode when the lamp has a good vacuum.

(5.) If the lamp has a bad vacuum this inequality is destroyed, and a sensitive galvanometer shows a current flowing through it when connected between the middle plate and either the positive *or* negative electrode.

(6.) When the lamp is actuated by an *alternating* current a *continuous* current is found flowing through a galvanometer, connected between the insulated plate and *either* terminal of the lamp. The direction of the current through the galvanometer is such as to show that negative electricity is flowing from the plate through the galvanometer to the lamp terminal. This is also the case in (4); but, if the lamp has a bad vacuum, then negative electricity flows *from* the plate through the galvanometer *to* the positive terminal of the lamp, and negative electricity flows *to* the plate through the galvanometer from the negative terminal of the lamp.

(7.) The same effects exist on a reduced scale when the incandescent conductor is a platinum wire instead of carbon filament. The platinum wire has to be brought up very near to its point of fusion, in order to detect the effect, but it is found that a current flows between the positive electrode of a platinum wire lamp and a platinum plate placed in the vacuum near to the negative end of that wire.

(8.) The material of which the plate is made is without influence. Platinum, aluminium, and carbon have been indifferently employed.

(9.) The active agent in producing this effect is the *negative* leg of the carbon. If the negative leg of the carbon is covered up by enclosing it in a glass tube this procedure entirely, or nearly entirely, prevents the production of a current in a galvanometer connected between the middle plate and the positive terminal of the lamp.

(10.) It is a matter of indifference whether a glass or metal tube is employed to cover up the negative leg of the carbon; in any case this shielding destroys the effect.

(11.) If, instead of shielding the negative leg of the carbon, a mica screen is interposed between the negative leg and the side of the middle plate which faces it, then the current produced in a galvanometer connected between the positive terminal of the lamp and the middle plate is much reduced. Hardly any effect under the same circumstances is produced when the mica screen is interposed on that side of the metal plate which faces the positive leg of the carbon.

(12.) The position of the metal plate has a great influence on the magnitude of the current traversing a galvanometer connected between the metal plate and the positive terminal of the lamp. The current is greatest when the insulated metal plate is as near as possible to the base of the negative leg of the carbon, and greatest of all when it is formed into a cylinder which embraces without touching the base of the negative leg.

The current becomes very small when the insulated metal plate is removed to 4 or 5 inches from the negative leg, and becomes practically zero when the metal plate is at the end of a tube forming part of the bulb, which tube has a bend at right angles in it. Copious experiments have been made with metal plates in all kinds of positions.

(13.) The galvanometer current is greatly influenced by the surface of the metal plate, being greatly reduced when the surface of the plate is made small, or when the plate is set edgeways to the negative leg, so as to present a very small apparent surface when seen from the negative leg. In a lamp having the usual commercial vacuum, the effect is extremely small when the insulated metal plate is placed at a distance of 18 inches from the negative leg, but even then it is just sensible to a very sensitive galvanometer.

(14.) If a charged condenser has one plate connected to the insulated metal plate, and the other plate connected to any point of the circuit of the incandescent filament, this condenser is instantly discharged if the positively charged side of the condenser is connected to the insulated plate, and the negative side to the hot filament. If, however, the negative leg of the carbon horseshoe is shielded by a glass tube, this discharging power is much reduced, or altogether removed.

(15.) If the middle plate consists of a separate carbon loop, which can itself be made incandescent by a separate insulated battery, then, when this middle carbon is rendered incandescent and employed as the metal plate in the above experiment, the condenser is discharged when the negatively charged side of it is connected to the hot middle carbon, the positively charged side of it being in connexion with the principal carbon horseshoe.

(16.) If this last form of lamp is employed as in (4) the subsidiary carbon loop being used as a middle plate, and a galvanometer being connected between it and either the positive or negative main terminal of the lamp, then when the subsidiary carbon loop is cold, we get a current through the galvanometer only when it is in connexion with the positive main terminal of the lamp, but when the subsidiary carbon is made incandescent by a separate insulated battery, we get a current through the galvanometer when it is connected either to the positive *or* to the negative terminal of the lamp. In the first case the current through the galvanometer is a negative current, flowing from the middle carbon to the positive main terminal, and in the second case it is a negative current, from the negative main terminal to the middle subsidiary hot carbon.

(17.) If a lamp having a metal middle plate held between the legs of the carbon loop has a galvanometer connected between the negative main terminal of the lamp and this middle plate, we find that when the carbon is incandescent there is no sensible current flowing through the galvanometer. The vacuous space between the middle plate and the hot negative leg of the carbon possesses, however, a curious unilateral conductivity. If a single Clark cell is inserted in series with the galvanometer, we find that this cell can send a current deflecting the galvanometer when its negative pole is in connexion with the negative main terminal of the lamp, but if its positive pole is in connexion with the negative terminal of the lamp, then no current flows. The cell is thus able to force a current through the vacuous space when the direction of the cell is such as to cause negative electricity to flow across the vacuous space from the hot carbon to the cooler metal plate, but not in the reverse direction.

(18.) If a vacuum tube is constructed, having at each end horseshoe carbon filaments sealed into it, and which can each be made separately incandescent by an insulated battery, we find that such a vacuum tube, though requiring an electromotive force of many thousands of volts to force a current through it when the carbon loops are used as electrodes and are *cold*, will yet pass the current from a single Clark cell when the carbon loop which forms the negative electrode is rendered incandescent. It is thus found that a high vacuum terminated electrically by unequally heated carbon electrodes possesses an unilateral conductivity, and that electric discharge takes place freely through it under an electromotive force of a few volts when the *negative* electrode is made highly incandescent.

(19.) These experimental results above described led the writer to investigate, in the same manner, the electric arc between carbon poles taken in air. If an electric arc is formed, in the usual way, between carbon poles, and a third insulated carbon pole is allowed to dip into or touch the electric arc, or, better still, has the electric arc projected against it by a magnet, it is found that this third or insulated pole is brought down almost to the potential of the negative carbon of the arc, and that a galvanometer connected between the third insulated carbon and the negative carbon of the arc indicates no current, but that if joined up between the positive carbon and the middle carbon a strong current of about an ampère or so is found to be passing. If an electric bell or an incandescent lamp is joined up between the third carbon and the *negative* carbon of the arc, they do not work; but if the bell or the lamp is joined between the *positive* carbon of the arc and the third carbon, they are set in action by a strong current passing through them. These effects are produced, although the third carbon (which is best held at right angles to the other two forming the arc) is half or three quarters of an inch away from the positive and negative carbon, the sole condition being that the flame of the arc must touch or be projected by a magnet so as to touch this third carbon. We have, therefore, similar phenomena in the case of the arc and incandescence lamps.

(20.) When the electric arc is being projected against the third carbon, and has brought it down to the same potential, a galvanometer joined in between the two carbons shows no current; but this space between the negative carbon of the arc and the third carbon possesses a unilateral conductivity, and will pass the current from a small battery of secondary cells one way, but not the other. The secondary battery when joined in series with the galvanometer sends a current, if its negative pole is in connexion with the negative carbon of the arc, and its positive pole, through the galvanometer, with the third carbon; but if the secondary battery is reversed in position it sends no current. Negative electricity can pass along the flame-like projection of the arc *from* the hot negative carbon *to* the cooler third carbon, but not in an opposite direction.

(21.) If the arc is projected by means of a magnet for a long time against the third insulated carbon, it *craters* it out in the same fashion as the crater of the positive carbon, and the tip of this third carbon, where it has received the flame-like blast of the arc, is converted into graphite.

The same effects are observed if an iron rod is used as a third pole, and in this case the end is converted into *steel*, and rendered so hard as to be scarcely touched by the file when it has been quenched in water.

In seeking for an hypothesis to connect together these observed facts, the one which suggests itself as most in accordance with the facts is as follows:—

In the case of a carbon incandescence lamp when at vivid incandescence, carbon particles are being projected from all parts of the filament, but chiefly from the negative half of the loop. These carbon molecules carry *negative* charges of electricity, and when they impinge upon a metal plate placed in the vacuum they can discharge themselves if this plate is positively electrified, either by being in metallic connexion with the positive electrode of the lamp or with a separate positively charged body. When the plate is simply insulated the stream of negatively charged carbon molecules brings down this insulated plate to the potential of the base of the negative leg, or to the potential of that part of the carbon conductor from which it is receiving projected molecules. These carbon molecules projected from an incandescent conductor can carry negative charges, but either cannot be positively charged, or else lose a positive charge almost instantly when projected off from the conductor.

In the case of the electric arc we must suppose that the negative carbon is projecting off a torrent of negatively electrified carbon molecules, and these, impinging against the positive carbon, wear out a crater in it by a sand-blast-like action.

The higher temperature of the positive carbon in a continuous current arc is thus explained as due to the impact of the carbon molecules projected from the negative carbon.

If the electric arc is diverted against a third insulated lateral carbon, the carbon blast from the negative carbon wears out a crater in it and brings it down to the same potential as itself. The actions going on in an electric arc may be considered to be somewhat as follows:—When the carbons are first put together, the resistance at the point of contact renders the extremities incandescent. When thus incandescent and separated, the electrification of each carbon is sufficient to begin the projection of molecules from both positive and negative carbons, probably most largely from the latter. The impact of the molecular stream from the negative pole raises the temperature of the positive carbon, and this again by radiation raises the temperature of the negative carbon end. The electromotive force is thus able to keep up a projection of negatively charged carbon molecules from the end of the negative carbon, which molecules are loosened from the mass by heat, and then move away by electric repulsion from the surface in virtue of the electric charge which they retain. It would seem as if a hot carbon molecule cannot retain a positive charge, and hence the potential difference between a third insulated carbon and the positive carbon of the arc is nearly the same as the potential difference of the positive and negative carbons of the arc. The rise of potential along the arc takes place very suddenly just in the neighbourhood of the crater of the positive carbon.

It has often been suggested that the electric arc contains a counter-electromotive force. It is questionable whether such experiments as those of Edlund ('Phil. Mag.,' vol. 36, 1868, p. 352) are entirely conclusive on this point.

It has been shown by other experimenters[*] that for arcs of varying length, but the same current, beyond a certain small initial length, the potential difference necessary to maintain the arc is proportional to the length of the arc plus a constant. This might thus be interpreted to mean that a certain proportion of the working electromotive force of the arc was employed in detaching the carbon molecules from the mass of the poles, and that the excess alone is represented by the current produced in an arc of definite length.

In the case of the incandescence lamps the hypothesis of the projection of negatively charged carbon molecules from the incandescent conductor, to which the name of *molecular electrovection* may be given, will suffice to explain all the various different effects produced by varying the surface, position, and distance of the metal plate against which they impinge, and also the nullifying effect of shielding this plate from the negative leg of the carbon.

That this molecular discharge goes on chiefly from the negative leg is additionally proved by the greater erosion which takes place in the deposit of carbon on the negative leg when the carbon is uniform and traversed by a continuous current.

The hypothesis that a carbon molecule detached from an incandescent carbon surface in a high vacuum can only convey away a negative charge, reconciles also the above described observed effects in which a negative discharge can be made *out* of a hot surface of carbon more easily than a positive discharge. When an electromotive force is applied to two metallic terminals or electrodes sealed into a good vacuum, it is well known that a certain initial electromotive force has to be applied before any electric current begins to flow through the gas at all. It seems conclusively proved by Mr. Crookes's researches that the nature of an electric discharge through a high vacuum consists in a torrent of electrified particles proceeding from the negative electrode. If this is the case the initial electromotive force required to begin a discharge through such rarefied gas would naturally be reduced by heating the negative electrode, so as to favour and assist the detachment of the charged molecules of that electrode. The effect of heating the negative electrode in facilitating discharge through vacuous spaces has previously been described by W. Hittorf ('Annalen der Physik und Chemie,' vol. 21, 1884, p. 90—139), and it is abundantly confirmed by the above experiments. We may say that a vacuous space bounded by two electrodes—one incandescent, and the other cold—possesses a unilateral conductivity for electric discharge when these electrodes are within a distance of the mean free path of projection of the mole-

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[*] See Professors Ayrton and Perry, 'Proceedings of the Physical Society,' vol. 5, p. 201.

of gas is a mixture of these two, its refractivity will determine the proportions in which the components are present.

The observations were made by an apparatus similar in character to that already described, but designed to work with smaller quantities of gas. The space to be filled is only about 12 c.c., and if the gas be at atmospheric pressure its refractivity may be fixed to about 1/1000 part. By working at pressures below atmosphere very fair results could be arrived at with quantities of gas ordinarily reckoned at only 3 or 4 c.c.

The refractivity found for the Bath residue after desiccation was 0·896 referred to air, so that the proportional amount of helium is 8 per cent. Referred to the original volume, the proportion of helium is 1·2 parts per thousand.

"On the Changes produced in Magnetised Iron and Steels by cooling to the Temperature of Liquid Air." By JAMES DEWAR, LL.D., F.R.S., Fullerian Professor of Chemistry in the Royal Institution of Great Britain, and J. A. FLEMING, M.A., D.Sc., F.R.S., Professor of Electrical Engineering in University College, London. Received April 25,—Read May 21, 1896.

The action of the low temperature produced by liquid air upon the magnetic moment of steel magnets was studied by one of us in a few cases in a preliminary research made some time ago.* We have recently returned to the subject and made further investigations on the influence of the low temperatures thus obtained on magnetised iron and steels of very various compositions, with the object of determining the nature of the changes which take place in the magnetic moment of small magnets constructed of these metals, when cooled gradually or suddenly down to the lowest temperature obtainable by the use of boiling liquid air. The arrangements adopted in this investigation were as follows:—

A reflecting magnetometer consisting of three small magnetised needles of watch-spring steel, cemented to a concave glass mirror, suspended by a single cocoon fibre, was placed in a tube so as to be free from disturbance by draughts of air. The small magnets were 8 to 10 mm. in length. The image of a portion of the filament of an incandescent lamp was reflected by the mirror on to a divided scale placed at a distance of 70 cm. from the mirror. The edge of the very sharp image of the filament, focussed upon the scale,

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* Friday evening discourse at the Royal Institution, "On the Scientific Uses of Liquid Air," by James Dewar, LL.D., F.R.S., January 19, 1894.

enabled any angular displacement of the magnetometer needle to be easily determined. The position of this magnetometer needle was regulated by the field produced by an external controlling magnet. The small magnet, the behaviour of which at low temperatures was to be studied, was placed behind the magnetometer, with its centre at a distance of 1 to 10 cm. from the centre of the magnetometer needle and its axis in a direction passing through the centre of the magnetometer needle, and at right angles to the direction of the undisturbed magnetometer needle. The magnet to be examined was fixed to a brass wire, held in a wooden support in such fashion that the magnet under examination could be easily removed from its position behind the magnetometer, and restored to it again exactly. A large number of samples of steel and iron were then prepared in the form of small needles, generally 15 mm. long and about 1 mm. in diameter. These steels comprised nickel steels, with various percentages of nickel; chromium steels, with various percentages of chromium; aluminium steels, with various percentages of aluminium; tungsten steels, manganese steels, silicon steel, ordinary carbon steels in various states of tempering, soft-annealed transformer iron, soft-iron wire, and the same irons hardened by hammering. For most of these samples of steels we were indebted to Mr. R. A. Hadfield, of Sheffield, who kindly furnished them to one of us in the form of wires.

These short steel magnets were then all magnetised to "saturation" by placing them for a few moments between the poles of a powerful electro-magnet. One by one they were then placed in position behind the magnetometer, and the deflection produced on the magnetometer needle observed. In any particular case this deflection may be taken as approximately representing the intensity of magnetisation of the sample, although, owing to the varying sizes of the sample and distance from the magnetometer, the deflections in the case of different magnets are not comparable with one another, and cannot be taken as indicating the relative intensities of magnetisation of two different samples. This, however, was not important, as our object was not to compare the absolute values of the magnetisation of different classes of steels, but to observe the mode of variation of the magnetisation of any one sample when cooled from ordinary temperatures down to the temperature of liquid air.

The method of proceeding was then as follows:—Having adjusted the image of the lamp filament to the zero of the scale, the small magnet under observation was placed behind the magnetometer, and the deflection of the magnetometer needle observed. A small vacuum-jacketed cup, filled with liquid air, was then brought up underneath the sample, and by its aid the magnet cooled suddenly *in situ* to a temperature in the neighbourhood of −186° C. In the many cases this sudden cooling immediately deprived the magnet of a considerable percentage of its magnetisation, and the magnetic moment was reduced. This, however, was not universally the case. In some cases, as in that of the chromium steels, the first effect of this sudden cooling was an increase in the magnetic moment of the magnet; in other cases hardly any change in the magnetic moment at all. The vessel of liquid air was then removed, and the magnet allowed to heat up again, which it very quickly did, to the temperature of the room, or rather to a temperature at which the deposit of snow formed upon the needle immediately on coming out of the liquid air, fully melted. This was taken to be at about 5° C. It was found that each magnet had certain peculiarities of its own.

Taking first the ordinary carbon steel (a sample of knitting-needle steel) we observe the following facts:—

Knitting-needle Steel (a) *Tempered Glass Hard.*—The first effect of cooling this magnet was to diminish the magnetic moment by 6 per cent. On allowing the magnet to heat up again to the ordinary temperature, the magnetic moment still further diminished by about 16 per cent. On cooling again the magnetic moment increased 10 per cent., and from and after that time cooling the magnet always increased the magnetic moment, and allowing to heat up again to ordinary temperature always diminished the magnetic moment, the magnetic moment at −185° C. being about 10 per cent. greater than the magnetic moment at 5° C. The first effect, therefore, of the cooling was to permanently diminish the magnetic moment, but after a few alternations of heating and cooling, the magnet reached a permanent condition in which its moment, when cold, was greater than its moment when warm. These changes of magnetisation may be best represented as in the diagram in fig. 1, in which the firm lines represent to some arbitrary scale the moment of the magnet when at its ordinary temperature of 5° C., and the dotted lines represent to the same scale the moment of the magnet when cooled to −185° C.

Knitting-needle Steel (b) *Medium Temper.*—The same general results were obtained with knitting-needle steel tempered to a medium temper. The first effect of the cooling to the low temperature was to diminish the moment of the magnet. On allowing it to heat up again the moment of the magnet diminished still more. The next cooling caused an increase of magnetic moment, and from and after that time the steel settled down into a permanent condition in which the magnetic moment was greater at −185° C. than at 5° C. by nearly 20 per cent. of its value at 5° C. (see fig. 2).

Knitting-needle Steel (c) *Annealed Soft.*—The same general course of events was noticed in the case of the knitting-needle steel when made soft by heating to a red heat and allowing it to cool very

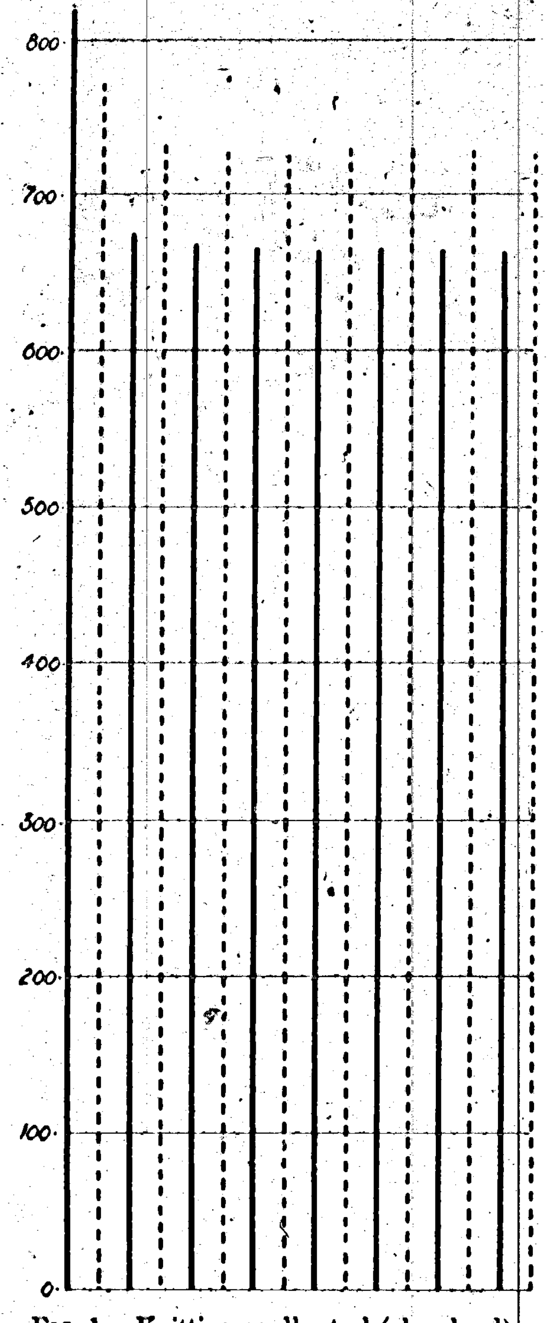

FIG. 1.—Knitting-needle steel (glass hard).

slowly. In this case, however, the first diminution of magnetic moment was still greater. On first immersion in the liquid air the magnet lost about 33 per cent. of its moment. On allowing it to heat up again to 5° C. it still further diminished in moment, and from and after that point it arrived soon at a permanent condition, in which its moment, when cold, was greater than its moment when warm by 30 per cent. of its moment at 5° C. These

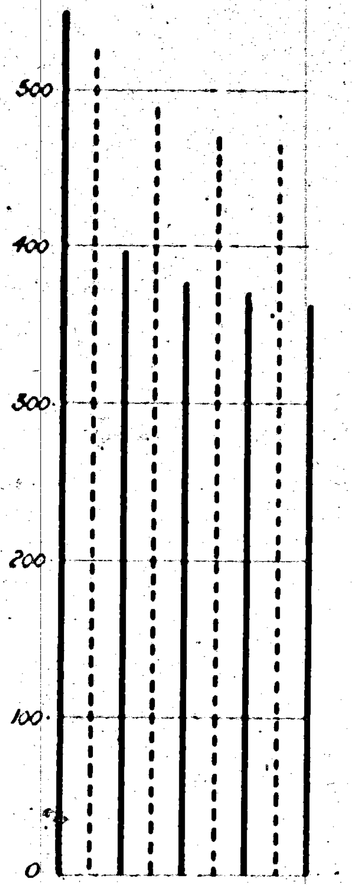

FIG. 2.—Knitting-needle steel (medium temper).

changes of the medium- and soft-tempered steel are represented by the lines in the diagrams 2 and 3, in which the firm lines are proportional to the magnetic moment of the magnet at 5° C., and the dotted lines proportional to the magnetic moment at −185° C. It will be seen that, in the case of this carbon steel, the effect of softening the steel is to make more pronounced the effect of the final temperature changes; the change of moment caused by cooling from the ordinary temperature to the temperature of liquid air, when the permanent condition has been reached, being in the case of the glass-hard steel an increase of magnetic moment of about 12 per cent.; in the case of the same steel with a medium temper about 22 per cent., and in the case of the same steel tempered very soft about 33 per cent. (see fig. 3).

Chromium Steels.—Observations were then made with the magnets of chromium steel, having respectively 0·29 per cent., 1·18 per cent., 5·44 per cent., and 9·18 per cent. of chromium. In all these cases the first effect of cooling the magnet was to cause at once an increase of magnetic moment, and the subsequent heating up again to the ordinary temperature caused a decrease of magnetic moment. These

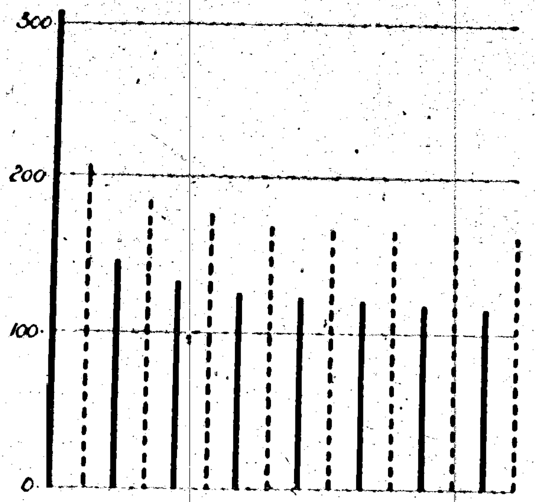

FIG. 3.—Knitting-needle steel (tempered soft).

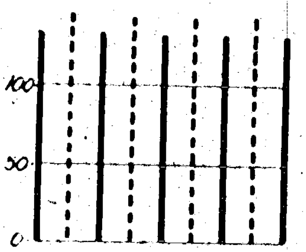

FIG. 4.—Chromium steel.

Cr = 0·29
C = 0·16
Si = 0·07
Mn = 0·18
Fe = 99·30

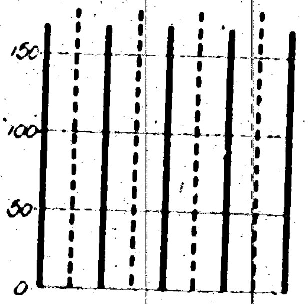

FIG. 5.—Chromium steel.

Cr = 1·18
C = 0·27
Si = 0·12
Mn = 0·21
Fe = 98·22

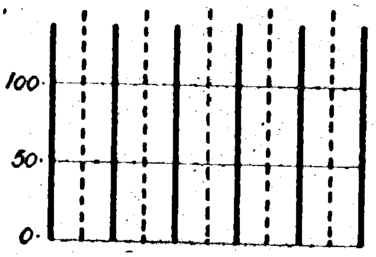

FIG. 6.—Chromium steel.

Cr = 5·44
C = 0·27
Si = 0·50
Mn = 0·61
Fe = 92·68

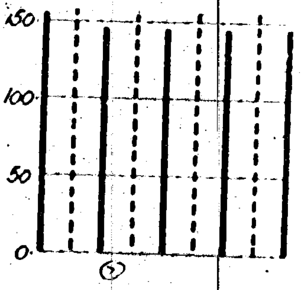

FIG. 7.—Chromium steel.

Cr = 9·18
C = 0·71
Si = 0·36
Mn = 0·25
Fe = 89·50

magnets arrived almost immediately at their permanent condition, in which the magnetic moment, when cold, was greater than the magnetic moment when warm by about 12 per cent. The variation of magnetic moment in the case of these magnets is shown by the diagrams 4, 5, 6, and 7, in which the firm lines represent the magnetic moment when the magnet is at 5° C., and the dotted lines the magnetic moment at −185° C. It will be seen, therefore, that in the case of the magnets there was no such initial decrease of magnetisation as in the case of the carbon steel magnets. The analysis of these steels was furnished to us by Mr. Hadfield, and is appended to the diagrams. These steels are all in their hard condition, and possess considerable coercive force.

Aluminium Steels.—The aluminium steels employed had the following percentages of aluminium, viz.: 0·72, 1·16, and 1·60. In all these cases the first effect of cooling the magnet made of these steels was to cause a very small diminution in the magnetic moment, but not more than about 2 per cent. (see figs. 8, 9, and 10). The subsequent rise in temperature of the magnet again to its ordinary temperature, caused a still further fall in magnetic moment, and from and after that point the effect of cooling down to the temperature of

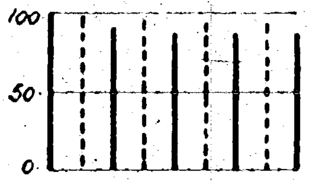

Fig. 8.—Aluminium steel.

Al = 0·72
C = 0·20
Si = 0·12
Mn = 0·11
Fe = 98·85

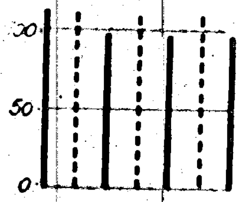

Fig. 9.—Aluminium steel.

Al = 1·16
C = 0·26
Si = 0·15
Mn = 0·11
Fe = 98·32

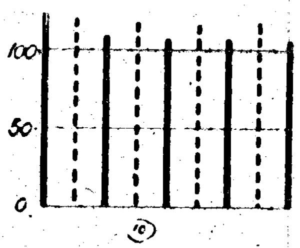

Fig. 10.—Aluminium steel.

Al = 1·60
C = 0·21
Si = 0·18
Mn = 0·18
Fe = 97·83

liquid air was to cause the magnet to possess a magnetic moment about 10 per cent. greater at −185° C. than at 5° C. It will be seen, therefore, that these steels differ from the chromium steels in this respect, that whereas in the chromium steels the effect of the first cooling is to cause an increase in magnetic moment; in the case of the aluminium steels, the effect of the first cooling was to cause a decrease of magnetic moment, although much smaller relatively than in the case of the carbon steels.

Nickel Steels.—Experiments were then made with samples of nickel steel containing 0·94, 3·82, 7·65, 19·64, and 29 per cent. of nickel. These steels exhibited some rather interesting peculiarities. In the case of the nickel steel with 0·94 per cent. of nickel, the effect of the first cooling in liquid air was to cause a very small decrease in magnetic moment (see fig. 11), and the subsequent heating and cooling brought the steel into a condition in which its magnetic moment, when cold, was always greater than its magnetic moment when warm, by about 10 or 11 per cent. In the case of the nickel steel with 3·82 per cent. of nickel, the effect of the changes of temperature was very similar (see fig. 12), and also in the case of the nickel steel having 7·65 per cent. of nickel the order of the changes was not very different—in this respect, that the magnetic moment when cold was

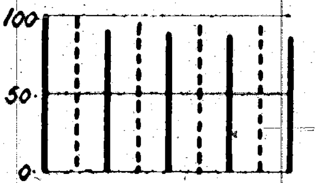

FIG. 11.—Nickel steel.

Ni = 0·94
C = 0·13
Si = 0·23
Mn = 0·72
Fe = 97·98

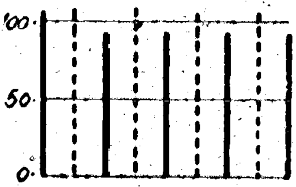

Fig. 12.—Nickel steel.

Ni = 3·82
C = 0·19
Si = 0·20
Mn = 0·65
Fe = 95·14

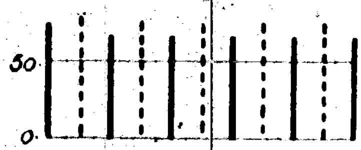

FIG. 13.—Nickel steel.

Ni = 7·65
C = 0·17
Si = 0·28
Mn = 0·68
Fe = 91·22

greater than the magnetic moment when warm, when the permanent state had been reached. But it will be noticed from the diagrams (see fig. 13) that in the case of the 7·65 per cent. nickel steel, the effect of the first cooling was to cause a slight increase in magnetic moment. A remarkable peculiarity, however, was found in the case of the 19·64 per cent. nickel steel. In this case the effect of the first cooling was to cause a very considerable reduction of magnetic moment, very nearly 50 per cent., that is to say, the magnetic moment fell instantly, on cooling in the liquid air, to about half the value that it had at the beginning of the experiment. On taking the magnet out of the liquid air and allowing it to warm up again to the temperature of the room, the magnetic moment immediately *increased* again, and from and after that time the effect of the temperature change on the magnetic moment was such that the magnetic moment, when cooled to the temperature of liquid air, was always *less* than the magnetic moment at 5° C. by about 25 per cent. of the latter value. These relative changes are shown in the diagram (fig. 14). These experiments with the 19 per cent. nickel steel were repeated a great many times, and always with the same general results. The sample of 29 per cent. nickel steel was then examined, and it was found that the magnetic changes produced in it on heating and cooling were of the same general character as in the case of the 19 per cent. sample, only less

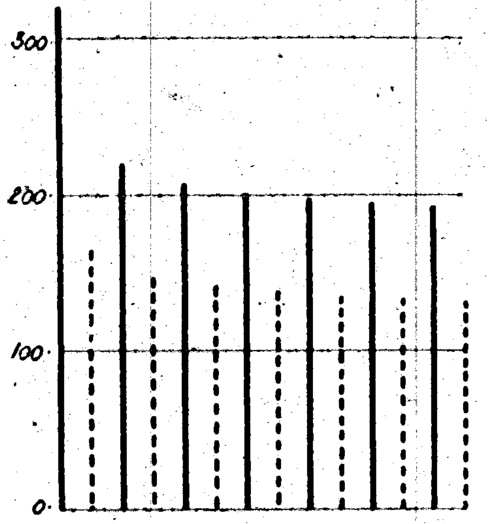

FIG. 14.—Nickel steel.

Ni = 19·64
C = 0·19
Si = 0·27
Mn = 0·93
Fe = 78·97

100·00

marked. Steels having these high percentages of nickel are, as Dr. J. Hopkinson has pointed out,[*] remarkable for the wide range of temperature within which they can exist in two states, one considerably magnetic, and one practically non-magnetic or but feebly magnetic. In these two states their mechanical and other physical properties are entirely different. In the experiments here mentioned, the nickel steel samples were in the magnetic condition. They are put into this condition by dipping for one moment in liquid air, and are only transformed back into the feebly magnetic condition by heating to a cherry-red heat. The 29 per cent. sample of nickel steel being in the magnetic condition was magnetised by contact with the poles of the electromagnet. On cooling it in liquid air it immediately lost about 20 per cent. of its moment, on warming up again to 5° C. it lost about 5 per cent. more, and from and after that point remained in a condition in which cooling the magnet to −185° C. caused its moment to become about 10 per cent. *less* than it was at 5° C. Hence the 29 per cent. nickel steel exhibits the same quality but in a less marked degree than the 19 per cent., in that its magnetic moment is decreased by cooling to −185° C., and recovers again on heating up to 5° C. In this respect the two samples of nickel steel differ from all other samples of steel which we have examined, in that they have a negative temperature coefficient for magnetic moment change with temperature, after the first change on cooling has taken place.

Pure Nickel.—In order to see if this peculiarity extended to pure nickel, we examined the behaviour of a small magnet made with Mr. Mond's pure nickel, but we found that such a nickel magnet, magnetised to saturation, behaved exactly as did a carbon steel magnet (see fig. 15). The effect of the first cooling to the temperature of liquid air was to diminish the magnetic moment. On allowing the magnet to heat up again to the ordinary temperature the moment diminished still more, and from and after that time the behaviour of the magnet was perfectly normal, that is to say, its magnetic moment when at 5° C. was less than its magnetic moment at −186° C., but only by about 3 or 4 per cent. of the latter value.

Silicon Steel.—A sample of silicon steel, containing 2·67 per cent. of silicon, behaved in a normal manner (see fig. 16). The magnet experienced a permanent diminution of moment on cooling for the first time, and after that, its magnetic moment when cold was greater than its magnetic moment when warm.

Soft Iron.—In order to determine if similar changes of magnetic moment could be produced in the case of soft annealed iron, small magnets of Swedish iron were prepared, formed of a short length, about 15 mm., of soft iron, or a small slip of annealed transformer iron. On magnetising these in a strong field, and testing them with

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[*] 'Roy. Soc. Proc.,' 1890, vol. 47, p. 138.

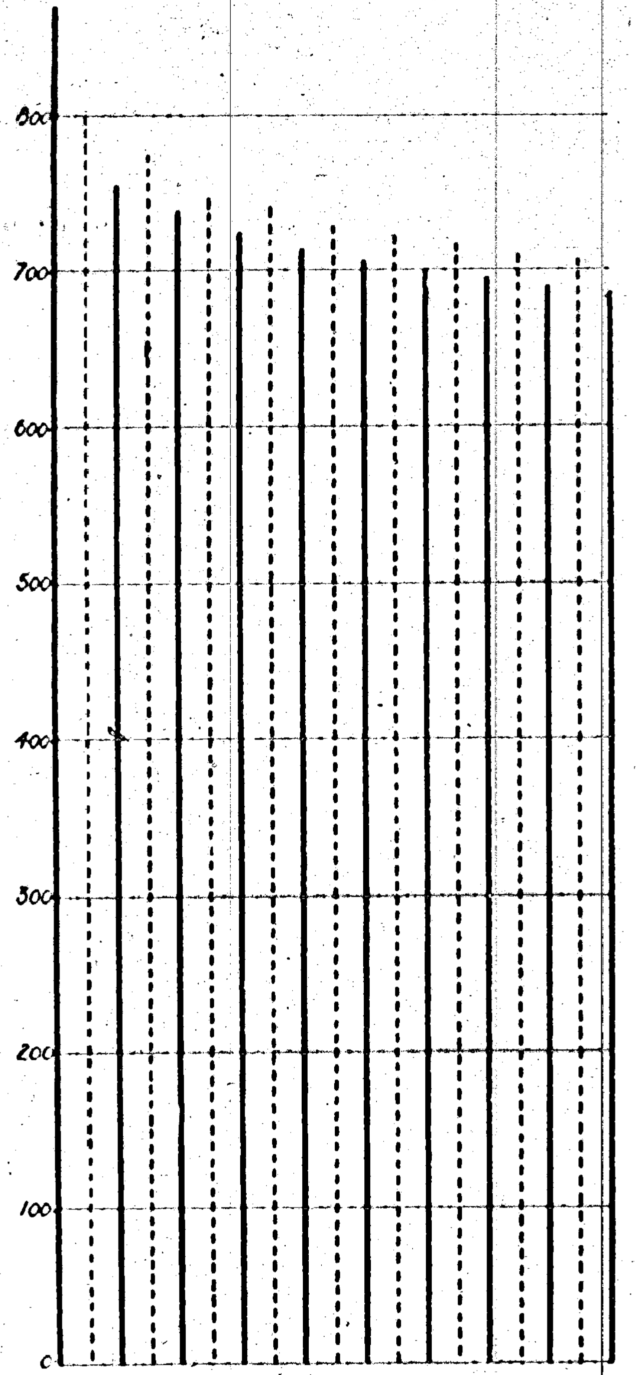

FIG. 15.—Mond's pure nickel.

the magnetometer, and cooling them by immersing in liquid air, it was found that the first effect of the cooling was to produce a small diminution in the magnetic moment, and the subsequent heating in some cases produced a further diminution of magnetic moment. In the first sample of soft iron, the wire was about 3 cm. long, and bent

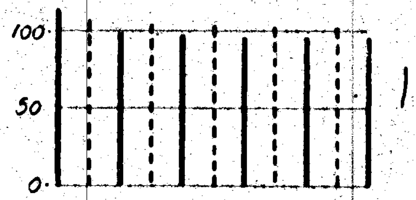

Fig. 16.—Silicon steel.

Si = 2·67
C = 0·20
Mn = 0·25
Fe = 96·88.

into a U shape, with ends about 10 mm. apart, and in this case the changes of magnetic moment, as shown in fig. 17, were similar to those in the case of the carbon steels, only with very much narrower limits of variation. The first cooling hardly produced any change whatever in the magnetic moment of the magnet. On allowing it to heat up again, the magnetic moment was very slightly diminished, and thenceforth the changes of moment were such that the magnetic moment was greater when the magnet was cold than when it was warm, by about 2 or 3 per cent. of the latter value. In the case of a straight, soft iron magnet, formed of annealed transformer iron, the curious fact was noticed that whereas a rapid cooling of the magnet by plunging into liquid air hardly produced any effect on the magnetic moment after the first initial loss of magnetism had taken place on cooling, the effect of a slow cooling down to the temperature of −185° C. was always to produce a permanent diminution of magnetic moment. Hence the magnetism of this soft iron sample could be frittered away by a process of slow cooling to −185° C., and intermediate heating up to 5° C. These changes of moment are represented in the diagram of fig. 18.

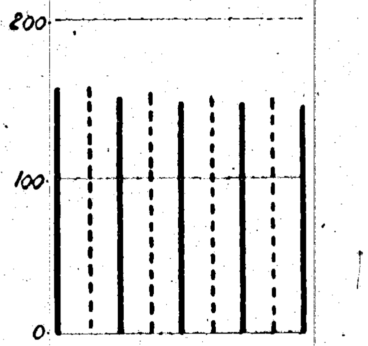

Fig. 17.—Soft iron.

Hard Iron.—A sample of the same iron, hardened by hammering, was tested, and was found to behave in a very similar manner to the

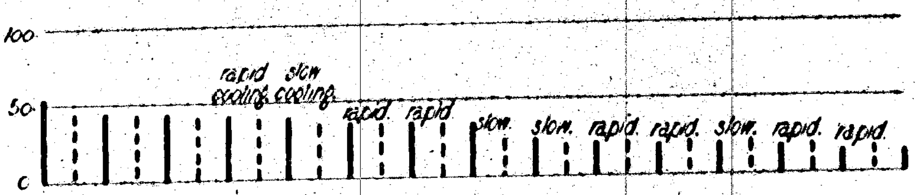

Fig. 18.—Annealed transformer iron.

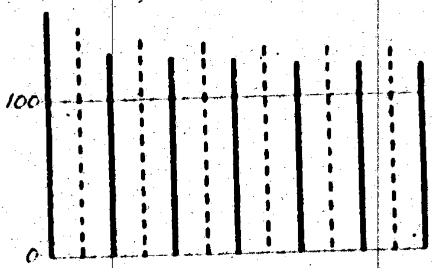

Fig. 19.—Hard transformer iron.

glass-hard carbon steel (see fig. 19), the changes in magnetic moment being relatively about the same percentage for the same temperature change: that is to say, the magnet had a moment of about 10 per cent. greater at −185° C. than at 5° C.

A series of tungsten steels were then examined, having respectively 1, 7·5, and 15 per cent. of tungsten in them.

Magnets were prepared of these steels, both in the glass-hard condition and in a carefully annealed condition. These steels were found to resemble the simple carbon steels in that the first effect of cooling the magnet to −186° C. was to cause a diminution of magnetic moment, and the subsequent warming up again to 5° C., a still further decrease in magnetic moment. From that time forth cooling the magnet always caused an increase of magnetic moment. The effect of increasing the percentage of tungsten was to cause a decrease in the variation of the magnetic moment over a given temperature range. That is to say, the hardened 15 per cent. tungsten steel temporarily lost magnetic moment to the extent of about 6 per cent. by heating up from −185° C. to 5° C. when once the initial condition had been passed. The 7·5 per cent. tungsten steel lost moment to the extent of about 10 per cent., and the 1 per cent. tungsten steel lost moment to the extent of about 12 per cent. when the temperatures rose between the same limits. As regards these tungsten steels, softening the steel caused the magnetic moment to decrease by a greater percentage when heated up from −185° C. to 5° C. than was found to be the case when the steel was in its hard condition. A sample of manganese steel containing 12 per cent. of manganese was rendered magnetic by heating for 24 hours to a dull red heat. A small magnet prepared from this steel was found capable of retaining magnetism. On cooling it to −185° C., it slightly increased in magnetic moment, and on heating up again to 5° C., its magnetic moment decreased to the extent of about 3 per cent. of its moment at −185°C. There was no initial decrease of moment in this case. In this respect, therefore, it resembled the chromium steel magnets.

Broadly speaking, the results so far obtained are:—

(1) That the sudden cooling to the temperature of liquid air usually permanently decreases the magnetic moment of short magnets made of many varieties of steel, assuming them to have been initially magnetised in a strong field.

(2) This initial decrease is found both in hardened steels having great coercive force, and also in the same steels in a soft or annealed condition, and is especially conspicuous in the case of the 19 per cent. nickel steel.

(3) In the case of most steels so far examined, the effect of cooling magnets made of them to −185° C. is to temporarily increase the magnetic moment after the permanent magnetic condition has been reached.

(4) The exceptions to the above rule so far noted are the nickel steels with percentages of nickel from 19 to 29 per cent., in which case the magnetic moment is always decreased temporarily by cooling to −185° C., after the permanent magnetic condition has been reached.

(5) It appears from these experiments that one of the best ways of *ageing* a permanent magnet is to dip it several times into liquid air. It then arrives at a constant condition in which subsequent temperature changes have a definite effect, and in which the subpermanent magnetism is removed.

Note added May 4.

Since the 19 per cent. nickel steel magnet increases in magnetic moment when heated from −185° C. to +5° C., and since it is well known that at some higher temperature it would lose magnetic moment altogether, it was considered very desirable to ascertain the temperature at which it would have its maximum magnetic moment. The magnet was accordingly heated (on April 2) in an oil bath gradually up to a temperature of about 300° C., and the deflections of the magnetometer observed at intervals, both as the temperature rose and as it fell. The result showed that this nickel steel magnet continued to increase in magnetic moment, until a temperature of about 30° C. was reached, and the magnetic moment then began to decrease.

At a temperature of +300° C., the moment of the magnet was not much greater than it was at −185° C. On cooling down again from

300° C., the moment increased, but not to the same maximum as before, and on repeating the cycle of temperature from about 15° C. to 300° C., the magnetic moment gradually varied, in the manner shown in fig. 20, and the temperature of maximum magnetic moment

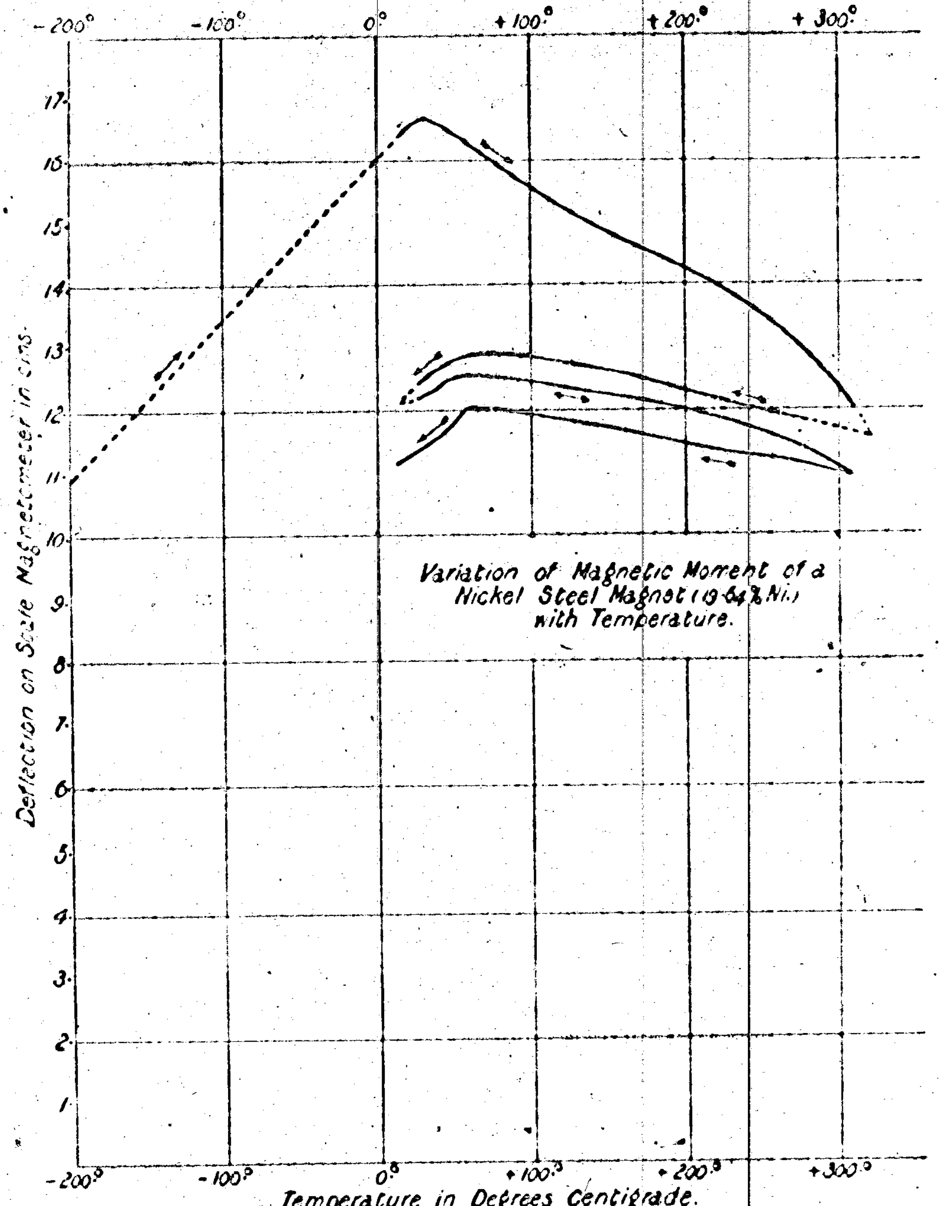

FIG. 20.

gradually shifted upwards to about 56° C. This magnet is, therefore, an interesting case of a sample of steel which, when magnetised, has a maximum magnetic moment at a certain temperature.

"On the Electrical Resistivity of Bismuth at the Temperature of Liquid Air." By JAMES DEWAR, LL.D., F.R.S., Fullerian Professor of Chemistry in the Royal Institution, and J. A. FLEMING, M.A., D.Sc., F.R.S., Professor of Electrical Engineering in University College, London. Received May 19,—Read June 4, 1896.

In the course of last year we published some observations (see 'Phil. Mag.,' September, 1895, p. 303)* on the electrical resistance of bismuth at the temperatures of liquid and solid air, in which the resistivity of certain samples of bismuth was measured at various temperatures down to the temperature at which air solidifies. These observations showed some anomalous results. In the case of two samples of bismuth used by us, and prepared by different chemical means, it was found that the resistivity reached a minimum value at a temperature of about −80°, and that after that point further cooling increased the electrical resistivity of these samples of the metal. In the case of another sample of commercial bismuth, the resistivity curve was a curve of double curvature. These results, together with the high absolute value of the resistivity of the samples, caused us to feel a strong conviction that different results would be obtained with bismuth prepared by an electrolytic method. Some observers, particularly M. van Aubel, who have investigated the electrical properties of bismuth, have expressed the opinion that bismuth cannot be prepared in a state of perfect purity by any chemical means. Finding the chemical methods of doubtful utility, we accordingly solicited the assistance of Messrs. Hartmann and Braun, who have devoted a large amount of attention to the preparation of pure electrolytic bismuth for the purposes of constructing spirals of bismuth for measuring the strength of magnetic fields. They kindly prepared for us at our request a considerable quantity of bismuth by an electrolytic method, which examination showed to be exceedingly pure, and this metal was pressed into a uniform wire with a diameter of about half a millimetre. This electrolytic bismuth is very soft, and in the form of wire can be bent without difficulty. Resistance coils were accordingly constructed of this wire, of a form suitable for use when measured in liquid air and at low temperatures. In the case of one resistance coil, which may be denoted as electrolytic bismuth No. 1, the length of the wire employed was 80·85 cm.; the diameter of this wire was carefully measured with a microscopic

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* "The Variation in the Electrical Resistance of Bismuth when cooled to the Temperature of Solid Air," Dewar and Fleming, 'Phil. Mag.,' September, 1895, p. 303.

micrometer in twenty to thirty places, these diameters having very nearly equal values, and a mean value of 0·05245 cm. The bismuth wire so prepared was mounted on a suitable holder, and its resistance was taken at several different temperatures and in liquid air, the temperatures being in all cases measured by our standard platinum thermometer P_1.*

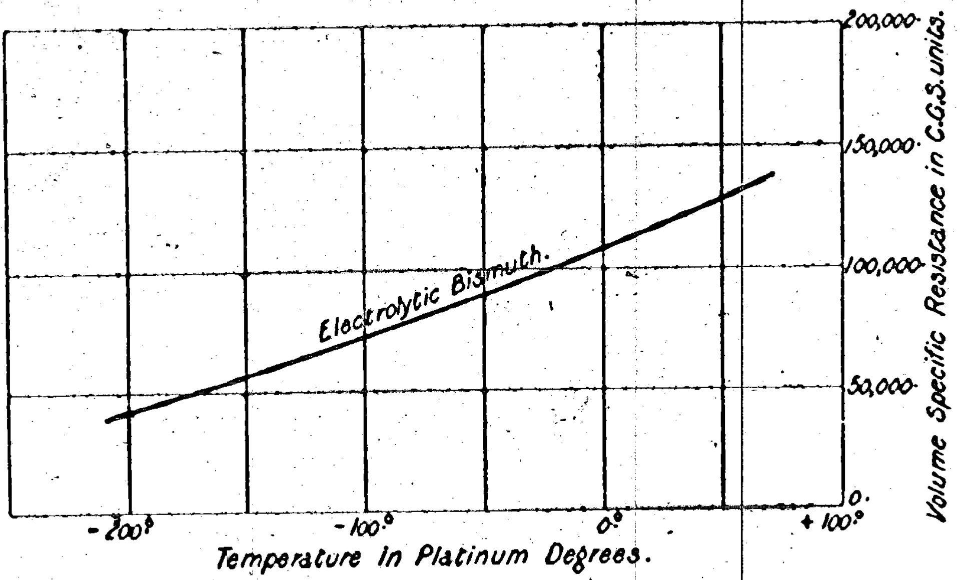
The results of these measurements were as follows:—

Resistivity of Electrolytic Bismuth. No. I.

Temperature in platinum degrees.	Observed resistance in ohms.	Resistivity in C.G.S. units per cubic centimetre.	Remarks.
+60°·5	4·9857	133250	At ordinary temperature.
+19°	4·3464	116180	" "
−61°·2	3·1275	83590	In ether cooled with solid carbonic acid.
−202°·2	1·5256	40780	In liquid air.

The curve of resistivity plotted from these data is shown in fig. 1, and in the table the value of the resistivity of bismuth in C.G.S. units per cubic centimetre is given above. These values of the resistivity show that in the case of this pure electrolytic bismuth

Fig. 1.



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* For details of this thermometer, see Dewar and Fleming on the "Thermo-electric Powers of Metals and Alloys at the Boiling Point of Liquid Air," 'Phil. Mag.,' July, 1895, p. 100.

there is no tendency of the resistivity curve to a minimum value. Down to the lowest temperatures reached in these experiments, the resistivity of bismuth continues to decrease in a perfectly regular manner, and in such a way as to show that it would be no exception, in all probability, to the ordinary law, that resistivity of pure metals vanishes at the absolute zero of temperature. On comparing the results of these measurements with those in the former experiments made with chemically prepared bismuth, it is seen that the electrolytic bismuth used by us has a very much lower resistivity at 0° C., viz., 108,000 units, and it has a lower value than that given by Matthiessen for pure bismuth, which is 129,700. We have, then, an additional indication that the bismuth used by us in the experiments in 1895 must have contained sufficient, though slight, impurity to markedly alter its resistivity, and to change entirely the character of the resistivity curve. With this electrolytic bismuth we have repeated the experiments which we made last year, on the variation of the electrical resistance of bismuth when placed transversely to the direction of the force in a magnetic field, and when cooled to the temperature of liquid air. For this purpose we constructed a flat spiral of the electrolytic bismuth, so arranged that its resistances could be measured at ordinary temperatures, and at the temperature of liquid air, by immersing it in a flat vacuum-jacketed test-tube, both when in a powerful magnetic field, and when merely in the terrestrial field. With this electrolytic bismuth we have confirmed the observation which we made last year, with a small sample of electrolytic bismuth, viz., that the effect of a given transverse magnetic field in increasing the resistivity of bismuth is immensely increased by cooling the bismuth to the temperature of liquid air. The figures in the following table will show the actual results obtained in these last experiments:—

Variation of Electrical Resistance of Electrolytic Bismuth in Magnetic Fields of different Strengths.

Temperature in platinum degrees.	Magnetic field strengths in C.G.S. units.			Remarks.
	Zero.	1400 units.	2750 units.	
	Resistance of bismuth coil.			
+20°	ohms. 1·679	ohms. 1·700	ohms. 1·792	At ordinary temperature.
−202°	0·5723	1·4435	2·6801	In liquid air.

It will thus be seen that whereas the immersion of the electrolytic bismuth wire, at ordinary temperatures, transversely in a magnetic field of strength 2,750 C.G.S. units, only increased its resistance by about 6 per cent., the immersion of the same wire in the same magnetic field increased its resistance to more than four and a half times when it was cooled to the temperature of liquid air, and the effect of the cooling with liquid air is more than nullified by the field, so that the bismuth cooled in liquid air and at the same time placed in the field has a resistance of 50 per cent. greater than it was when not cooled and not in the field. We are engaged in extending these observations to stronger fields.

The behaviour of electrolytic bismuth in fields of various strengths and at various temperatures, from 0° C. to 100° C., has been studied by Mr. J. B. Henderson (*see* 'Phil. Mag.,' vol. 38, 1894, p. 488), and he has given a series of curves showing the variation of resistance of bismuth between these temperatures for fields of strength varying from zero to 22,700 C.G.S. units. Our observations at low temperatures are quite consistent with Mr. Henderson's curves. His curves indicate that at lower temperatures the effect of any given field in increasing the resistance of the bismuth becomes more marked.

Pressed to its limit it would appear that pure bismuth, which would in all probability be made a perfect conductor by reducing to the absolute zero of temperature, would be then converted into a non-conductor if at the same time immersed in a magnetic field of sufficient strength. Both M. van Aubel and Mr. Henderson have pointed out that the temperature coefficient of bismuth at any given temperature is quite altered by placing it in a magnetic field, and it will therefore be a matter of great interest to examine the effect of an exceedingly strong magnetic field as bismuth when cooled to the temperature of solid air.

By enclosing a bismuth wire and a platinum thermometer wire in the same mass of paraffin wax we have been able to measure the variation of resistance of the bismuth from the temperature of liquid air up to ordinary temperatures at a number of intermediate points, and to determine the resistance both in a zero magnetic field and in one of known strength, but the results we wish to reserve until we have had the opportunity of repeating them with stronger magnetic fields.

"On the Electrical Resistivity of Pure Mercury at the Temperature of Liquid Air." By James Dewar, LL.D., F.R.S., Fullerian Professor of Chemistry in the Royal Institution, and J. A. Fleming, M.A., D.Sc., F.R.S., Professor of Electrical Engineering in University College, London.

Received May 19,—Read June 4, 1896.

Although the electrical resistivity of mercury at ordinary temperatures has been carefully examined by many observers, and accurate determinations made of the specific resistance[*] and temperature coefficient, and in addition an examination made of the variation of resistivity in mercury when cooled to temperatures as low as $-100°$ C.,[†] we considered it would be of interest to examine the behaviour of pure mercury in respect of change in electrical resistivity when cooled to the temperature obtained by the employment of boiling liquid air. With this object we prepared a sample of very pure mercury in the following manner: Ordinary distilled mercury was shaken up with nitric acid in the usual manner to free it from other metals, and then carefully dried. It was then introduced into a bent glass tube formed of hard glass. This bent tube had both ends sealed, and a side tube connected in at the bend, by which it could be connected to a mercury vacuum pump. Two or three hundred grammes of the mercury was then introduced into one bend, and a high vacuum made in the tube. The side tube was then sealed off from the pump, and the mercury distilled over from one leg into the other. For this purpose, one leg of the bent tube was placed in ice and salt, and the other submitted to a gentle heat just sufficient to make the mercury distil under reduced pressure without ever bringing it into active ebullition. In this way the mercury is distilled over at a very low temperature, and the portion condensing in the cooler limb of the bent tube is entirely free from any contamination with silver, lead, zinc, or tin. By performing this distillation two or three times successively on the same mercury, a small quantity of mercury is at last obtained in an exceedingly pure condition. A glass spiral tube was then formed of lead glass, consisting of a tube having an internal diameter of about 2 mm., and a length of about 1 metre. This tube was bent into a spiral of about twelve close turns, each turn being nearly 2·5 cm. in diameter, and the ends of this spiral provided with enlarged glass ends formed of wider tube. The spiral,

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[*] "The Specific Resistance of Mercury," by Lord Rayleigh and Mrs. Sidgwick (*Phil. Trans. R. S.*, Part I, 1883). See, also, Mr. R. T. Glazebrook (*Phil. Mag.*, Oct., 1885), for other values.

[†] Cailletet and Bouty (*Compt. Rend.*, 100, 1188, 1885).

after being cleaned, was then very carefully filled with the purified mercury, and by running the mercury through a spiral several times, all air bubbles and air film were finally removed. Into the wider ends of the spiral, amalgamated copper electrodes were introduced, consisting of copper wire 4·4 mm. in diameter; the wider terminal ends of the spiral were then closed by paraffined corks to keep the copper electrodes in position. This spiral, full of mercury, was placed in a test-tube, and paraffin wax cast round it so as to enclose it entirely, leaving only the copper electrodes protruding. In order to determine the temperature of the mercury in the glass spiral tube, a platinum wire, the resistance of which was known at all temperatures down to the temperature of liquid air, was also embedded in the paraffin wax closely in contact with the glass spiral, and proper electrodes brought out to enable the resistance of this platinum wire to be determined. This mass of paraffin wax was then cooled down in a vacuum vessel kept filled up with liquid air until the whole mass reached the temperature of the liquid air. The glass spiral and thermometer enclosed in wax was then removed from the bath of liquid air and placed in a vacuum-jacketed test-tube, in order that it might warm up with extreme slowness to the ordinary temperature of the air.

Having in this manner cooled the mass of paraffin enclosing the glass spiral filled with mercury and the platinum resistance wire entirely to the temperature of liquid air, a series of observations were taken with the aid of two observers, one measuring the resistance of the mercury by a Wheatstone's Bridge, while at the same time the other observer at another slide wire bridge measured the resistance of the platinum wire, these observations being taken quite simultaneously, and continued whilst the mass heated up from −197·9° (platinum temperature) to 0°. All proper corrections were then applied to correct for the resistance of the connecting wires and the bridge temperature; and the observed resistance of the platinum wire employed was corrected to determine from its resistance temperatures in terms of the standard platinum thermometer employed by us in our investigations on the thermo-electric power of metals and alloys (see Dewar and Fleming, 'Phil. Mag.,' July, 1895, p. 95). This standard thermometer has always been denoted by the letter P_1. The following table shows the corrected resistance of the mercury column and the corresponding platinum temperatures, as also the specific resistance of the mercury calculated from the accepted resistivity at 0° C.:—

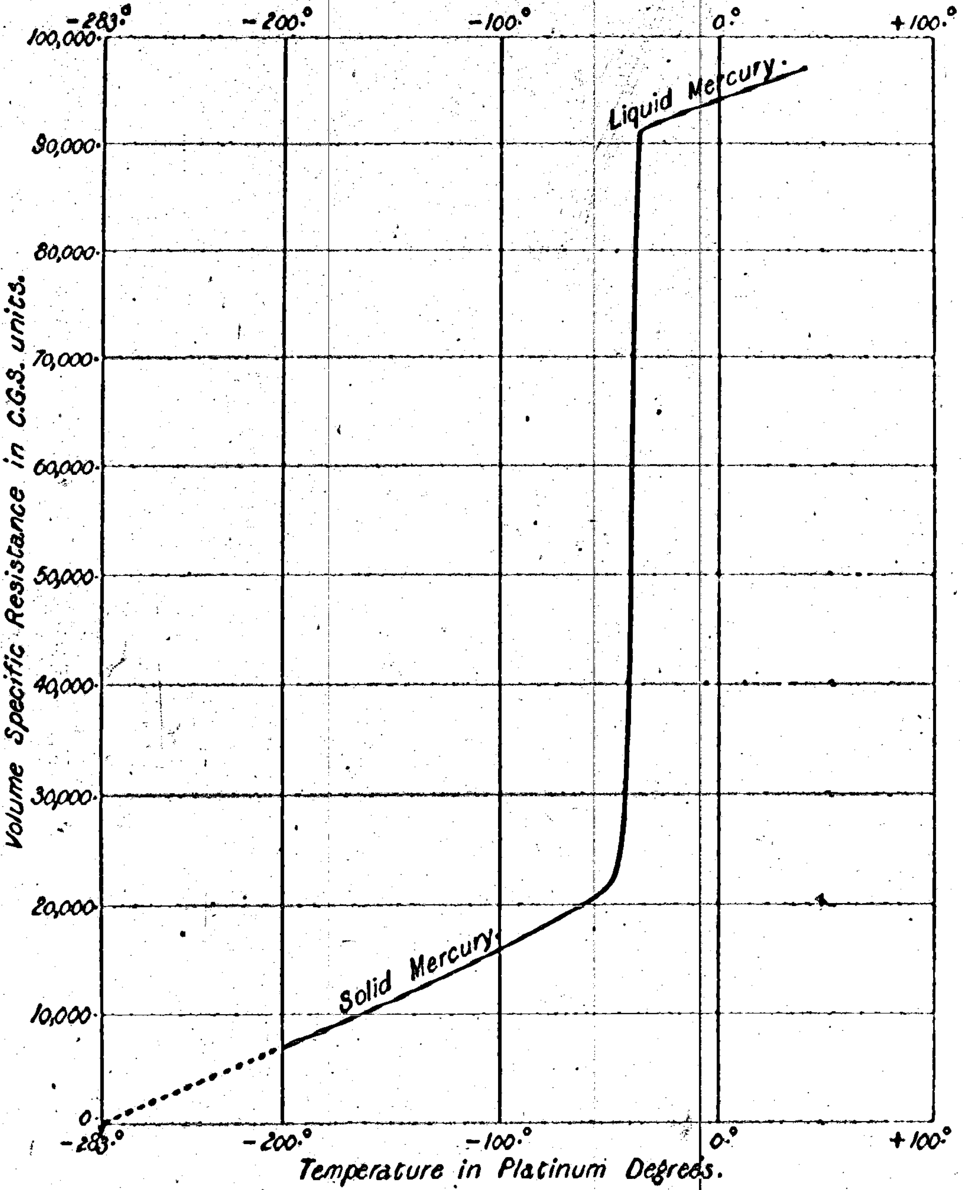
Resistivity of Pure Mercury in C.G.S. Units at various Temperatures in Platinum degrees.

Platinum temperature, *pt*, in terms of the standard platinum thermometer P_1.	Observed and corrected resistance of mercury in lead glass spiral in ohms.	Resistivity of mercury in glass in C.G.S. units.
−197·9	0·0551	6970
−197·8	0·0551	6970
−197·5	0·0551	6970
−196·9	0·0566	7160
−195·2	0·0581	7350
−191·2	0·0601	7600
−182·7	0·0641	8100
−173·2	0·0721	9120
−168·4	0·0761	9620
−165·1	0·0781	9870
−157·4	0·0836	10570
−149·7	0·0886	11200
−143·0	0·0931	11770
−131·9	0·1011	12780
−128·3	0·1041	13160
−122·9	0·1081	13670
−117·5	0·1121	14170
−108·4	0·1191	15060
−103·7	0·1231	15560
− 97·0	0·1281	16200
− 91·1	0·1331	16830
− 85·0	0·1381	17460
− 79·1	0·1432	18100
− 73·1	0·1482	18740
− 67·4	0·1532	19370
− 63·2	0·1582	20000
− 57·6	0·1632	20630
− 52·5	0·1682	21270
− 48·9	0·1753	22160
− 47·0	0·1833	23180
− 46·0	0·1883	23810
− 44·9	0·1933	24440
− 44·2	0·1983	25070
− 43·5	0·2033	25700
− 43·0	0·2183	27600
− 42·4	0·2283	28860
− 42·1	0·2383	30130
− 41·9	0·2484	31410
− 41·2	0·2584	32670
− 40·8	0·2784	35200
− 40·6	0·2884	36460
− 40·4	0·3184	40260
− 39·7	0·3585	45330
− 39·5	0·3885	49120
− 39·4	0·4185	52920
− 39·3	0·4385	55440
− 39·1	0·4785	60800
− 38·7	0·5186	65570
− 38·5	0·5486	69360
− 38·3	0·5786	73160
− 37·7	0·6086	76950

Platinum temperature, *pt*, in terms of the standard platinum thermometer P_1.	Observed and corrected resistance of mercury in lead glass spiral in ohms.	Resistivity of mercury in glass in C.G.S. units.
− 37·6	0·6387	80760
− 37·2	0·6587	83280
− 36·7	0·6787	85810
− 36·0	0·7087	89600
− 35·2	0·7208	91140
− 33·7	0·7228	91380
− 31·2	0·7248	91640
0	0·7440	94070
+ 13·1	0·7518	95060
+ 16·3	0·7540	95330
+ 35·4	0·7653	96760

Adopting the value for the specific resistance of pure mercury at 0° C., which has been recommended by the Board of Trade Electrical Committee, viz., 94,070 C.G.S. units, we have reduced the observed resistances of the mercury column at various temperatures to their equivalents in resistivity in absolute units, and placed these numbers against the observed resistances in the table above. As the specific resistance of mercury has been so carefully observed by many observers, we did not, for a moment, consider it necessary to attempt a further determination of this constant. On plotting out these values of the resistivity of mercury in the form of a curve in terms of the corresponding platinum temperatures, we find the resistivity curve has the form shown in fig. 1. It will be noticed that the resistivity of the mercury decreases gradually from the point at which the observations finished, viz., at +35° C., to the temperature −36° on the platinum scale. At this point the resistivity rapidly decreases to about one-quarter of its value in falling from −36° to −50°, and this sudden change all takes place within the range of about 14° of temperature. At the temperature of −50° on the platinum scale the resistivity curve again changes direction, and continues downwards in such a direction as to show that if produced along the same line from the lowest temperature actually observed, viz., −204° on the platinum scale, it would pass exactly through the absolue zero of temperature on this scale, which is −283° *pt*. It is also interesting to note that the part of the curve which corresponds to the mercury in the liquid state is almost exactly parallel to that part of the curve which corresponds to mercury in the solid condition, although, owing to the difference in the absolute values of the resistivities at these parts, the temperature coefficients as usually defined are very different. In the solid condition between the temperatures of −197·9° and −97°, the mean increase in resistivity is

FIG. 1.



93·14 C.G.S. units per degree rise of temperature on the platinum scale; between −108·4° and −57·6° the mean increase in resistivity in C.G.S. units per degree is 109·6; in the liquid condition between the temperature −35·2° and 0° the mean increase in resistivity in C.G.S. units per degree is 83·2; temperature measurement being on the platinum scale as above defined. It may be stated here that temperatures defined by this platinum scale do not differ by more than about 0·5° from the Centigrade scale down to temperatures of −100°, but that the temperature of boiling liquid oxygen which, on the Centigrade scale is denoted by −182°, is, on the platinum scale derived from our standard thermometer, denoted by −196·7°. This would show, therefore, that the temperature coefficient as usually defined is 0·000884 between −35° and 0°.*

These observations are specially interesting as giving additional proof that in the case of a metal of known purity the variation of resistivity, as the metal is continuously cooled, is such as to indicate that it would in all probability vanish at the absolute zero of temperature. In the case of mercury, we are able to obtain a metal in a state of almost perfect chemical purity, and which, when continuously cooled, passes into the solid condition under circumstances which are entirely favourable to the prevention of stresses in the interior of the metal, due to cooling. These measurements, therefore, afford a further confirmation of the law which we have enunciated as a deduction from experimental observations, that the electrical resistivity of a pure metal vanishes at the absolute zero of temperature.

"On the Magnetic Permeability and Hysteresis of Iron at Low Temperatures." By J. A. Fleming, M.A., D.Sc., F.R.S., Professor of Electrical Engineering in University College, London, and James Dewar, LL.D., F.R.S., Fullerian Professor of Chemistry in the Royal Institution, &c. Received May 27,—Read June 11, 1896.

Although considerable attention has been paid to the changes produced in the magnetic properties of iron, particularly its magnetic permeability and hysteresis, at ordinary and at higher temperatures, but little information has been obtained up to the present on the behaviour of iron and steel as regards magnetic properties when cooled to very low temperatures. By the employment of large quantities of liquid air we have been able to conduct a long series of experiments on this subject, the results of which we propose here briefly to summarise, leaving for a future communication fuller details and discussion of the results. The experimental work has consisted in making measurements, chiefly by ballistic galvanometer methods, of the permeability and hysteresis loss in certain samples of iron and steel, taken in the form of rings or cylinders. The first experiments were concerned with the variation of the magnetic permeability of soft iron under varying magnetic forces, the iron being kept at a constant low temperature, obtained by placing it in liquid air in a state of very quiet ebullition in a vacuum vessel.

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* This is in close agreement with the values obtained by Guillaume, Mascart, and Strecker for temperatures between 0° C. and +30° C.

"Note on the Dielectric Constant of Ice and Alcohol at very Low Temperatures." By JAMES DEWAR, M.A., LL.D., F.R.S., Fullerian Professor of Chemistry in the Royal Institution, London, and J. A. FLEMING, M.A., D.Sc. F.R.S., Professor of Electrical Engineering in University College, London. Received January 27,—Read February 25, 1897.

Of late years many careful determinations have been made of the dielectric constants of water and ice by different observers. These evaluations may be divided into two classes. Firstly, those which are, strictly speaking, determinations of the specific inductive capacity of the material, and have been made by measuring the change in the capacity of a condenser when water or ice is substituted for air as the dielectric. Secondly, those which are really measurements of the electrical refractive index of water or ice for electric waves of various lengths, and which have been generally made by obtaining the reduction in wave-length experienced by an electric wave on passing from air into water or ice. The square of this refractive index or the ratio of wave-length reduction is then taken as the dielectric constant.

In order that results thus recently obtained may be compared, we have collected into two tables (I and II) some of the values for the specific inductive capacity, and the electric refractive index of water for waves of various lengths.

The determinations of the specific inductive capacity quoted all appear to have been made by methods which, whilst excluding, or believed to exclude, error arising from the conductivity of the water, may yet be regarded as giving the value corresponding to comparatively slow reversals of electromotive force or to waves of infinite wave-length. The electric refractive index observations have been made by using electric waves of lengths in air varying from 8 mm. to 600 cm.

Two very careful determinations of the specific inductive capacity of water seem to be those of W. Nernst (80·0 at 17° C.) and F. Heerwagen (= 80·88 at 17° C.), and that of J. F. Smale is in close agreement with that of Nernst.

As regards the electrical refractive index, it will be seen that the determinations of P. Drude for waves of 70 cm., which give $\mu = 8·95$, and hence $\mu^2 = 80·2$ at 17° C., and those of Cohn and Zeeman, which give $\mu = 8·91$ and $\mu^2 = 79·39$, as a mean value for waves from 155 to 560 cm. in length, are in fairly close agreement with one another, and with the best determinations of specific inductive capacity.

Table I.—Determinations of the Dielectric Constant (Specific Inductive Capacity) (K) of Water by Various Methods.

Observer.	Reference.	Value found.	Method.
W. Nernst ...	'Zeits. phys. Chem.,' 1894, vol. 14, pp. 622—633	80·00 at 17° C.	By condensers balanced on a Wheatstone's bridge arrangement using a telephone as detector.
C. B. Thwing	'Zeits. phys. Chem.,' 1894, vol. 14, pp. 286—300	75·5	By resonance of two electrical circuits. Capacity in each adjusted to identity.
L. Graetz and L. Fomm	'Wied. Ann.,' 1895, vol. 54, pp. 626—640	73·54	By deflection of a dielectric ellipsoid suspended in water in an electric field.
T. F. Smale ..	'Wied. Ann.,' 1896, vol. 57, pp. 215—222	80·05	By using an electrometer filled with water.
F. Heerwagen	'Wied. Ann.,' 1893, vol. 49, p. 279	80·88 at 17° C.	By using a double electrometer, one filled with water. Reversals of polarity 42—85 per second.
A. Franke....	'Wied. Ann.,' 1893, vol 50, p. 163	81·65 at 17° C.	By using a double electrometer and reversals of polarity made by an induction coil.
W. K. Röntgen	'Wied. Ann.,' 1894, vol. 52, pp. 593—606	86·0	By alternate currents and condenser.
E. B. Rosa ...	'Phil. Mag.,' 5th ser., vol. 31, 1891, p. 188	75·7 at 25° C.	By attraction of plates of a condenser, alternating potentials used. 2000 to 4000 reversals per minute.

The general results show that the square root of the specific inductive capacity of water as determined by relatively slow-speed electrostatic methods is expressed by a number which is not very different from that which denotes the refractive index of water for electrical waves varying in length from 8 mm. to 600 cm. Maxwell's law is, therefore, fulfilled in the case of water under these conditions.

The general evidence at disposal does not indicate any very marked dispersive power on the part of water for electric waves varying in length between the above-named limits; though the careful results of P. Drude in 1896, for waves from 40 to 200 cm. in length, taken by themselves, indicate a slight normal dispersion, the refractive index increasing with decreasing wave-length. Change of temperature has a marked effect upon the electrical refractive index, and conclusions cannot be drawn, therefore, from the comparison of observations not made at the same temperature.

There is, however, no such good agreement between the results of these two classes of physical measurement in the case of ice.

Table II.—Determinations of the Electrical Refractive Index (μ) of Water for Electric Waves of Various Wave-lengths.

Observer.	Reference.	Value found.		Wave-length of waves used in air.	Method.
		μ.	μ^2.		
P. Drude........	'Wied. Ann.,' 1895, vol. 54, pp. 352—370	8·9	79·21	300—600 cm.	Measured reduction of wave-length on passing from air to water.
P. Drude........	'Wied. Ann.,' 1895, vol. 55, pp. 633—655	8·7	75·69	72 cm.	Measured reduction of wave-length on passing from air to water.
P. Drude........	'Wied. Ann.,' 1896, vol. 58, pp. 1—20	9·07 (11·7° C.) 8·95 (17° C.)	82·21 80·2	70 ,,	Measured reduction of wave-length on passing from air to water. Last result best.
H. Rubens and A. D. Cole	'Ver. phys. Ges., Berlin,' 1895, vol. 14, pp. 76—78	8·8 8·9	77·04 79·21	·5 ,,	Measured intensity of rays reflected from surface of water at incidence of 45° and calculated μ by applying Fresnel's formulæ.
A. D. Cole	'Wied. Ann.,' 1896, vol. 57, pp. 290—310	8·85	78·32	5 ,,	Same as above.
V. von Lang......	'Wien. Sitzungsber.,' vol. 105, Part IIA, p. 253	9·4	88·36	8·5 ,,	By interference of electric waves.
P. Drude........	'Wied. Ann.,' 1896, vol. 59, pp. 17—62	9·14 9·03 8·98	83·6 81·67 80·60	40 ,, 75 ,, 200 ,,	Measured reduction of wave-length in passing from air to water. Found μ varied with temperature. $\mu^2 = 88{\cdot}23 - 0{\cdot}4044t + 0{\cdot}001035t^2$.
E. Cohn and P. Zeeman	'Akad. d. Wissensch. zu Amsterdam,' Sept., 1895	8·91	79·39	155 ,, 350 ,, 560 ,,	Measured reduction in wave-length in passing from air to water.
A. Lampa.......	'Wien. Sitzungsber.,' 1896	8·972	80·49	8 mm.	
D. Mazzotto	'Rend. Acc. Linc.,' 5, 2, p. 301, 1896.	9·0 (19° C.)	81·0	234—1836 cm.	By use of Lecher apparatus. Measured reduction of wave-length in passing from air to water.

M. E. Bouty ('Journal de Physique,' 3 S., vol. 1, 1892, p. 454) found by a slow-speed method a value of 78·8 for the specific inductive capacity of ice at −23° C. and upwards, whilst R. Blondlot ('Compt. Rend.,' vol. 119, 1894, pp. 595—597), using electric waves and measuring the wave-lengths in air and in ice, found 1·41 for the electric refractive index of ice, and hence the number 2·0 as the value of the dielectric constant of ice at a temperature not stated, but presumably not far below 0° C.

Also A. Perrott ('Compt. Rend.,' vol. 119, 1894, p. 601, also 'Compt. Rend.,' vol. 114, June, 1892, p. 1528) found the value 1·43 for the refractive index, and hence 2·04 for the square of the electric and refractive index of ice. C. B. Thwing, working with electric resonance, and therefore very rapid reversals, gives ('Zeits. Phys. Chem.,' vol. 14, 1894, pp. 286—300) 3·36 at −2° and 2·85 at −5° C. as values for the dielectric constant of ice.

It seemed desirable to endeavour to throw light on the reasons for these differences by an examination of the dielectric constant of ice at very low temperatures.[*] We have accordingly applied the method and apparatus used by us in the latest determinations of the dielectric constant of liquid oxygen[†] for the purpose of making an examination of the dielectric constant of ice and frozen ethyl alcohol.

A condenser was constructed consisting of three very thin concentric brass tubes about 20 cm. in length. The extreme outer and inner tubes, having diameters of 3·74 and 3 cm. respectively, were connected together metallically at the bottom, and formed one plate of the condenser. An intermediate brass cylinder 3·37 cm. in diameter was suspended between the inner and outer tubes, thus forming the other plate of the condenser. This last plate was insulated and suspended from the others by providing it with small wire attachments, which were passed through the holes in six glass beads wedged in between the inner and outer connected cylinders at the top and bottom as shown in fig. 1. This condenser was contained in another brass cylinder closed at the bottom, and then had its dielectric formed of ice by filling the annular space between the cylinders with distilled water and freezing it. The terminal wires from this condenser were connected to a rapid contact maker driven by an

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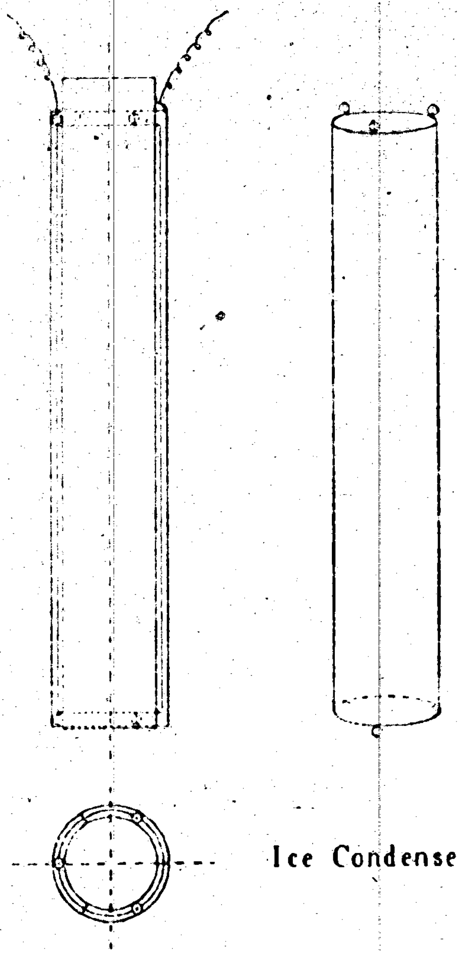
[*] *Note added February* 15, 1897. Since this Paper was presented a communication has been made to the Royal Society by Dr. J. Hopkinson and Mr. E. Wilson, in which they describe experiments on the dielectric constant of ice. These authors find that the specific inductive capacity of ice, when measured with electromotive force reversals having a period of from 1/100 to 1/10 of a second, is a number of the order of 80, but if measured with periods such as $1/10^6$ of a second it is a number less than 3. The difference they ascribe to residual charge. Hence it is clear that these observations are in accord with those of Bouty and Blondlot.

[†] Fleming and Dewar, "On the Dielectric Constant of Liquid Oxygen," 'Roy. Soc. Proc.,' 1896, vol. 60, p. 358. See note added December 18, 1896, p. 368.

FIG. 1.



Ice Condenser.

electrically controlled tuning fork. The tuning fork used made 124 complete vibrations a second, and was made, by means of a mercury cap and steel stylus dipping into it, to close an electrical circuit 124 times every second, and thus drive synchronously an electro-magnetic contact maker, which placed one terminal of the condenser alternately in connection with a battery of fifty lithanode secondary cells, and with a sensitive galvanometer. The other terminals of the battery, galvanometer and condenser, were connected together. In this way the galvanometer was traversed by a rapid series of electric charges, which have all the effect of a continuous current. The galvanometer deflection remains perfectly steady as long as the battery voltage is unaltered. Other things remaining the same, the galvanometer deflection measures the capacity of the condenser. In employing this method, the galvanometer may be arranged so as to be affected by the series of *discharges* of the condenser, or it may be placed so as to be traversed by the series of *charges* of the condenser. If the condenser has any sensible leakage or dielectric conductivity this will show itself by making the galvanometer readings in the two cases unequal. Mr. Petavel, who assisted us in these observations, and to whom our thanks are due, arranged a convenient switching device which enabled the galvanometer to have its position in the circuits instantly changed to take either the charge currents or the discharge currents of the condenser, and the equality of these readings is taken as an indication that no sensible leakage takes place across the dielectric during the passage of the contact maker from one stop to the other. This method of exchanging the position of the galvanometer also eliminates errors due to the setting of the scale, as the deflections are on opposite sides of the zero. The above-described arrangements having been made, the ice condenser was cooled down to the temperature of liquid air by immersing it in the liquefied gas contained in a large vacuum vessel.

In order to take the temperature of the condenser a platinum wire resistance thermometer was placed in the inside of the inner cylinder and in close contact with it. The ice having been reduced in temperature to −185° C., or −198° platinum temperature, the capacity of the condenser was measured. The condenser was then raised out of the liquid air and allowed to warm up very slowly, and its capacity taken at various stages as the temperature rose. Before and after the experiment with the ice the capacity of the condenser was taken when the metal cylinders were at the temperature of −185°, but the dielectric was gaseous air at that temperature instead of ice, and the results so obtained enabled the dielectric constant of the ice to be calculated.

These experiments being to a considerable extent preliminary experiments, and intended merely to explore the ground, we do not make any particular claim for the accuracy of the numbers as determinations of a physical constant. We are arranging improved methods for repeating the whole of these measurements. All we desired in the first instance to do was to examine the mode in which the dielectric constant varied with temperature and its approximate magnitude at each temperature. The following Table III shows the observed value of the dielectric constant of ice between −185° C. (−198° pt.) and about −120° (−130° pt.). The voltage used on the condenser was 24·1 volts, and kept perfectly constant during the whole time. In order to ascertain if the galvanometer deflection was really due to the sequence of capacity charges or discharges only, and not to any measurable admixture of conduction current through the ice, a resistance of 1,000 to 90,000 ohms was occasionally inserted in the galvanometer circuit, and the absence of any observed change in the galvanometer deflection was taken as a proof that sensible conduction did not interfere with the true capacity effect. The galvanometer used had a resistance of 500 ohms.

In the following table the temperatures are given in terms of platinum temperature (pt.) as defined by our standard platinum thermometer P_1.*

Table III.—Dielectric Constant of Ice at Various Temperatures. Frequency of Fork, 124.

Temperature in platinum degrees by standard thermometer P_1.	Scale reading or galvanometer deflection in centimetres.	Dielectric constant of ice.
pt.		
−198·0	5·6	2·83
−197·8	5·6	2·83
−197·6	6·0	3·03
−182·0	6·25	3·10
−176·8	6·4	3·23
−171·0	6·8	3·44
−165·7	7·2	3·64
−161·8	7·6	3·84
−159·7	8·0	4·04
−155·2	8·8	4·45
−150·8	10·0	5·05
−146·7	10·6	5·36
−143·2	11·7	5·92
−141·7	12·7	6·42
−140·0	13·4	6·77
−138·5	14·1	7·13
−137·5	15·1	7·63
−136·2	16·5	8·34
−134·5	17·7	8·94
−133·2	18·0	9·1
−131·0	21·8	11·0
−130·7	23·0	11·6

With the above frequency (124) the conductivity of the ice began to make itself felt at about −130° pt.

The above numerical results are plotted out in a curve in fig. 2. They show clearly that the dielectric constant of the ice increases progressively from a value of about 2·8 to 11·6 between the limits of −198° and −131° pt. Moreover, the trend of the curve shows that at the absolute zero the dielectric constant of the ice would probably not be far from 2·0. With the above arrangements we were not able, partly for want of time and partly because of the very moderate frequency of the tuning-fork, to take the dielectric constant at higher temperature, but this we hope to do before long, and also to examine the effect of varying the frequency of the contact maker.

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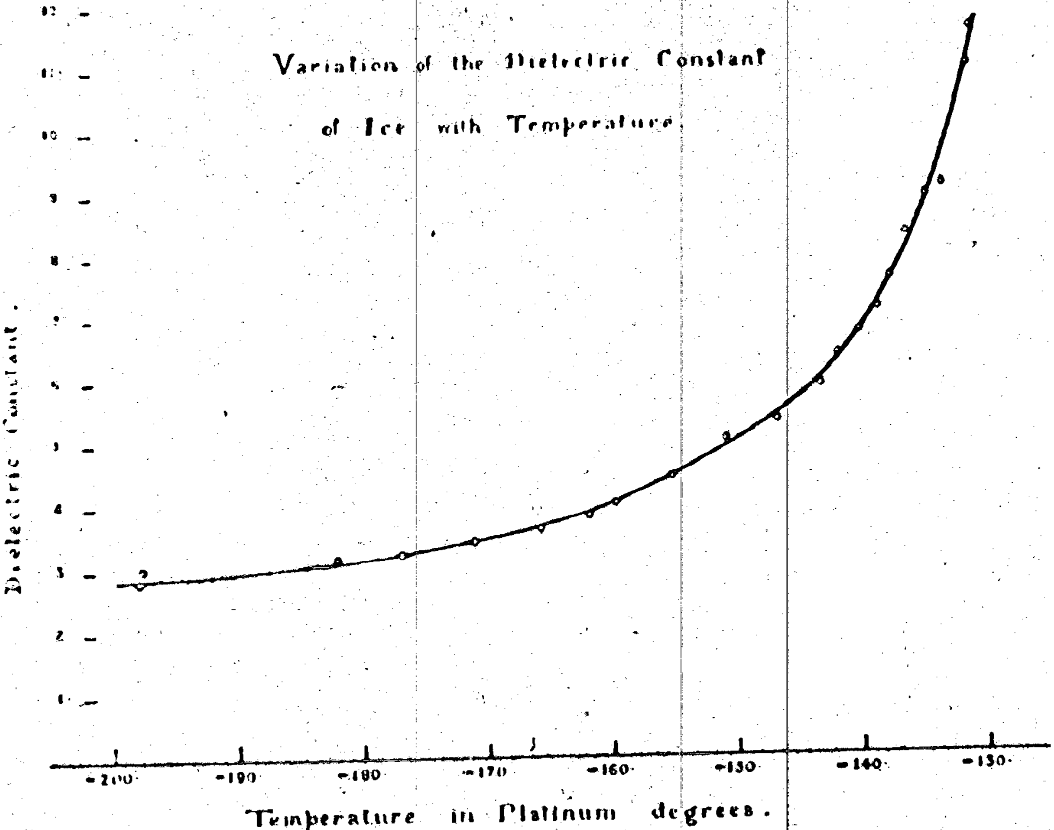
* See Dewar and Fleming, "On the Thermo-electric Power of Metals and Alloys," 'Phil. Mag.,' July, 1895, p. 100.

FIG. 2.



The broad general result which emerges from these experiments is that at a temperature of −185° C. we find a value for the dielectric constant for ice, when using relatively very slow reversals of electromotive force, which is not very different from that found by observers using reversals of many millions per second by the use of electrical oscillations or waves, when working at temperatures of 0° C. or a little below.

C. B. Thwing ('Zeits. Phys. Chem.,' vol. 14, 1894), using an electrical resonance method, has examined the variation of the dielectric constant of water with temperatures from 0° C. to 88° C., and found a maximum value of 85·2 at or near the temperature of maximum density of water.

It seems therefore to be a matter of some importance to measure the dielectric constant of ice at all temperatures from the lowest which can be reached up to 0° C., using various frequencies of alternating electromotive force, and to explore the mode of variation of the dielectric constant with temperature and with frequency throughout this range. The point which especially needs to be cleared up is whether the dielectric constant of ice is, or is not, more changed by change of frequency of the electromotive force than is the case with water. It appears certain that as far as water at 0° C. is concerned, the dielectric constant and the square of the electric refractive index is a number not far from 80, for waves having wave-lengths between 8 mm. and infinity, or for electromotive force reversals having frequencies varying from 37·5 $\times 10^9$ to zero. On the other hand, the values found for ice at or a little below 0° C. seem to indicate a dielectric constant of 78, when using very slow oscillations; and a value of about 2·0 when using oscillations having a frequency of some millions per second.

It is clear that in this matter there is still room for further investigation. It is evident, since the optical refractive index of water is a number lying between 1·3 and 1·4 for waves having a wave-length of 0·00005 cm. or reversals having a frequency of -400×10^{12} to 700×10^{12}, that water may be regarded as presenting the phenomenon of anomalous dispersion beyond the range of the visible spectrum, because the refractive index for waves of a length of 0·8 cm. and upwards is a number not far removed from 8·9, and this number is very much greater than that for wave-lengths of the order of visible light.

Within the octave of wave-lengths comprising visible light the refractive index of water, lies between 1·3 and 1·4. We know very little about the refractive index of water for the fourteen octaves of radiation lying beyond the extreme red end of the spectrum, but we know that water has very considerable absorptive power for a large range of this radiation. The next ten octaves beyond the last, include the range of the Hertz radiation or of wave-lengths from ½ to 500 cm. in length, and for all this the refractive index of water is approximately 8·9. It remains to be seen how the high value is connected with the low one, and whether this variation may be properly regarded as a case of anomalous dispersion analogous to that found in the case of an alcoholic solution of fuchsine within the range of the visible spectrum. It is evident that since the dielectric constant of any one substance, such as ice-water, is a function both of temperature and time, it can best be represented geometrically by a *surface*, which may be called the dielectric surface, and which is defined by the co-ordinates representing dielectric constant, temperature, and frequency of electromotive force reversals.

The details of two determinations of the dielectric constant of ice at −185° C. are given in Table IV.

The same readings were obtained both with 90,000 ohms and 1,000 ohms in the galvanometer circuit.

The above figures of observation require two corrections to be applied. In the first place, the pins which support the inner condenser plate, and which pass through glass beads, have a total area

Table IV.—Brass Condenser filled with Distilled Water and frozen into Ice. Ice reduced to −185° C. by use of Liquid Air.

Deflections of galvanometer when in charge circuit.	Deflections of galvanometer when in discharge circuit.	Volts on terminals of condenser.	Mean galvanometer deflection.
22·4 cm.	23·45 cm.	101·1 volts	22·93 cm.
22·3 „	23·50 „	101·1 „	22·90 „
22·35 „	23·50 „	101·1 „	22·92 „

Mean galvanometer deflection = 22·917. Frequency of contact maker 124.
Mean voltage on condenser = 101·1.

of 0·4 sq. cm., or 0·17 per cent. of the area of the condenser plate, and taking the specific inductive capacity of the glass as equal to 5·0 when cooled to −185° C., it can be seen that the glass supports form 0·85 per cent. of the effective capacity of the condenser when the dielectric is gaseous air at −185° C.

In order to determine this last capacity the brass condenser had its capacity taken at 20° C., air being the dielectric, and then it was cooled in liquid air and then lifted out into the cold gaseous air at a temperature of −185° C., lying above the liquid air, and in this condition the same readings taken. The following were the observed readings of the galvanometer:—

Table V.—Brass Condenser at 20° C., filled with Gaseous Air at that temperature. Frequency of Contact Maker, 124.

Deflection of galvanometer when in charge circuit.	Deflection of galvanometer when in discharge circuit.	Volts on terminals of condenser.	Mean galvanometer deflection.
8·32 cm.	8·31 cm.	101·0 volts.	8·315 cm.
8·35 „	8·30 „	101·1 „	8·325 „

Table VI.—Brass Condenser at −185° C., filled with Gaseous Air at that temperature. Frequency of Contact Maker, 124.

Deflection of galvanometer when in charge circuit.	Deflection of galvanometer when in discharge circuit.	Volts on terminals of condenser.	Mean galvanometer deflection.
8·30 cm.	8·48 cm.	101·1 volts	8·39 cm.

The difference between the mean galvanometer readings, viz., 8·31 and 8·39, in the two last cases, is due to the fact that the condenser capacity is changed by the cooling, owing to the fact that the plates contract. The actual difference due to the temperature of the air changing from 20° C. to −185° C. is very much smaller, and does not sensibly affect the capacity as far as the accuracy of the present measurements is concerned.

There is, however, another correction which needs to be applied, and that is for the capacity of the leads and of the contact maker. Experiment showed that this was equivalent to 4·15 mm. deflection of the galvanometer, and hence the amount has to be deducted from all mean galvanometer readings.

The final result then is as follows:—

The specific inductive capacity, K, of the ice at −185° C. is very nearly equal to the ratio of (22·917−0·07−0·415) to (8·39−0·07−0·415), or K = 2·83.

The correction 0·07 is the correction for the capacity of the glass separators, which is equal to 5×0·17 = 0·85 per cent. of the total capacity, and hence the remanent capacity of the condenser is 8·39−8·39×0·0085 = 8·39−0·07. The correction 0·415 is the correction for the capacity of the contact maker and leads.

A second determination was made at a lower voltage, the details of which are as follows in Table VII.

Table VII.—Brass Condenser filled with Distilled Water and frozen into Ice. Ice reduced to −185° C. by use of Liquid Air.

Deflection of galvanometer when in charge circuit.	Deflection of galvanometer when in discharge circuit.	Volts on terminals of condenser.	Mean galvanometer deflection.
8·35 cm.	8·60 cm.	36·1 volts	8·48 cm.
8·35 „	8·60 „	36·1 „	8·48 „

Mean galvanometer deflection = 8·48 cm.
Mean voltage = 36·1 volts.
Mean deflection for voltage of 101·1 = 23·75 cm.
Corrected value of the deflection = 23·75−0·07 = 23·68.

$$\text{Specific inductive capacity of ice at } -185^\circ \text{ C.} = \frac{23{\cdot}68-0{\cdot}415}{8{\cdot}32-0{\cdot}415} = 2{\cdot}94.$$

Hence the mean value of the dielectric constant of ice at −185 C. for slow reversals of electromotive force is a number not far from 2·9.

We have in the same manner examined ethylic alcohol frozen and reduced to −185° C.

The observations with same condenser having frozen alcohol as the dielectric are as follows :—

Table VIII.—Brass Condenser filled with Absolute Ethylic Alcohol frozen and reduced to $-185°$ C.

Deflection of galvanometer when in charge circuit.	Deflection of galvanometer when in discharge circuit.	Voltage on terminals of condenser.	Mean galvanometer deflection.
12·20 cm.	12·80 cm.	50·5 volts	12·5 cm.
12·10 „	12·50 „	„ „	12·3 „
12·10 „	12·50 „	„ „	12·3 „

Mean galvanometer deflection = 12·60.
Mean voltage = 50·5.

Galvanometer deflection corrected for capacity of glass separators and also of contact breaker, and reduced to correspond to a voltage of 101·1 = 24·665.

Since the corrected capacity of the condenser when at $-185°$ C. and filled with gaseous air at $-185°$ C. is represented by the number $7·905 = 8·39 - 0·07 - 0·415$, we have for the dielectric constant of solid alcohol at $-185°$ C. the value $24·665/7·905 = 3·12$.

In addition to measuring the dielectric constants, the same experimental arrangements enabled us to measure approximately the dielectric resistance of the ice and frozen alcohol at and from the temperature of $-185°$ C., and the following tables give the approximate total resistance of the condenser when the dielectric consisted of these substances and was slowly allowed to heat up from $-185°$ C.

Table IX.—Variation in the Resistance of an Ice Condenser heated up from $-185°$ C. $= -200°$ pt. to about 70° C. Temperatures given in platinum degrees by standard platinum thermometer P_1.

Temperature of the ice in platinum degrees.	Resistance of the ice condenser in megohms.
−200·0°	26200·0
−172·2	5670·0
−135·0	1570·0
−126·0	1130·0
−108·4	706·0
−98·8	470·0
−95·2	353·0
−93·2	282·0

Temperature of the ice in platinum degrees.	Resistance of the ice condenser in megohms.
−91·8	209·0
−88·8	118·0
−88·2	91·4
−86·3	66·5
−84·4	53·4
−82·3	46·3
−75·0	42·8
−70·7	43·4

In the same way the resistance of the frozen ethylic alcohol condenser was taken at temperatures lying between −185° C., and about −160 C., as given in the table below.

Table X.—Variation in Resistance of the Frozen Alcohol Condenser Temperatures given in Platinum Degrees.

Temperature of the alcohol in platinum degrees.	Resistance of condenser in megohms.
−200·0°	14500·0
−190·0	45·0
−186·5	9·7
−168·0	1·0

The above numbers cannot be considered as more than moderate approximations, but they are sufficient to show the mode of variation of resistance in the two cases.

The values for the resistance of the ice and alcohol have been set out in the two curves in figs. 3 and 4.

These figures show that in the case of the alcohol, as soon as a temperature of −190° pt. is reached the resistance begins to fall with great rapidity or the conductivity to go up.

In the case of the ice the same rapid increase in conductivity begins to take place at about −90°.

We have designed a form of condenser which will enable us to repeat these measurements and free them from some sources of error due to the difference between the contraction of the metal plates of the condenser and that of the dielectric; but pending such more accurate measurements the above figures may be taken as showing approximately the course of events when the ice and frozen alcohol are heated up from the temperature of boiling liquid air.

We add two tables, XI and XII, giving some recent determinations of the dielectric constant of the ethyl alcohol, the results in Table XII showing that evidence apparently exists of abnormal dis-

FIG. 3.

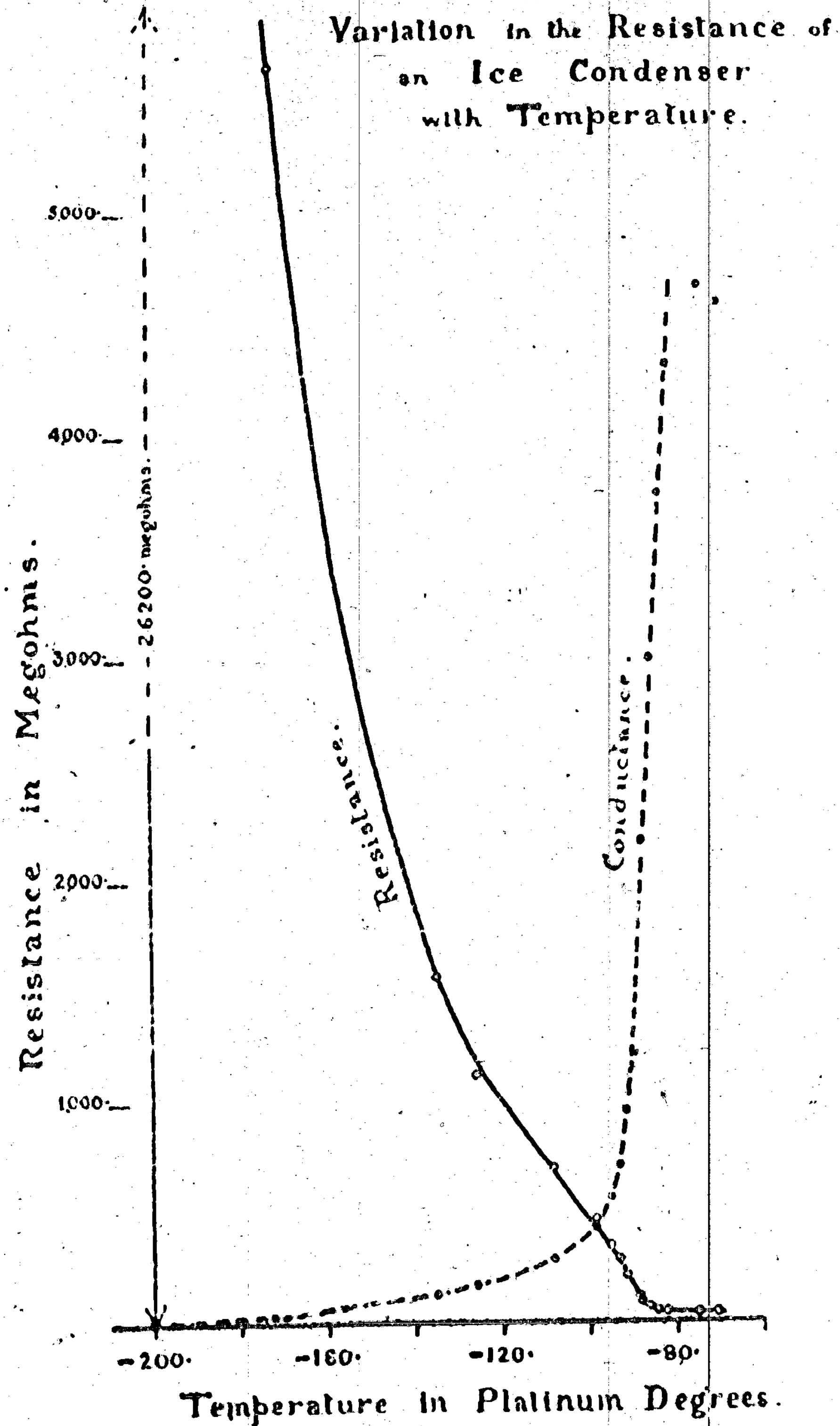
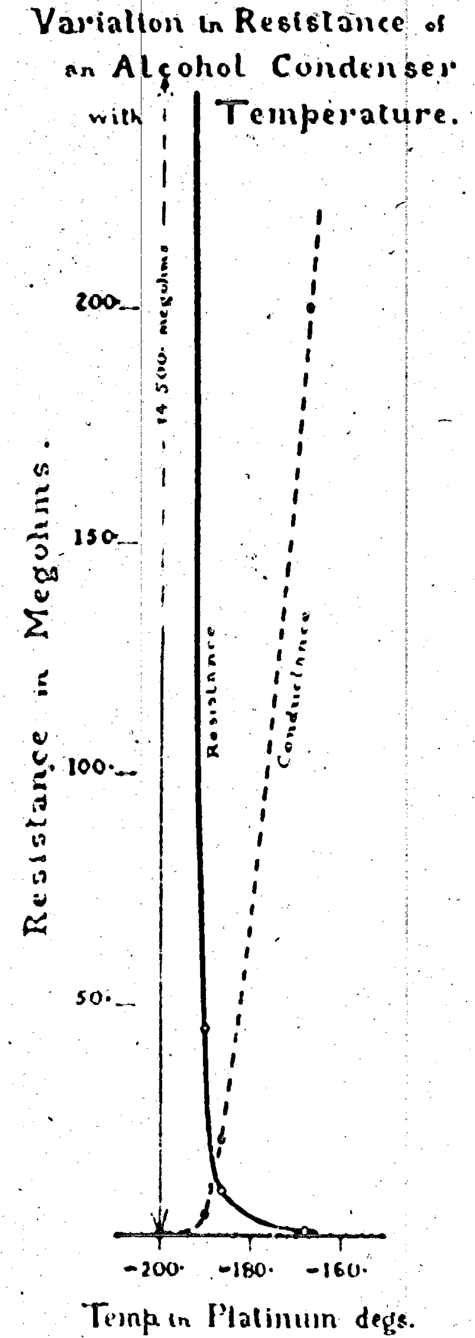

Variation in the Resistance of an Ice Condenser with Temperature.
Resistance in Megohms.
5,000
4,000
3,000
2,000
1,000
26200 megohms.
Resistance.
Conductance.
-200
-160
-120
-80
Temperature in Platinum Degrees.

Fig. 4.


Variation in Resistance of
an Alcohol Condenser
with Temperature.
Resistance in Megohms.
200
150
100
50
14 500 megohms
Resistance
Conductance
-200
-180
-160
Temp in Platinum degs.

persion in the case of alcohol for electric radiation lying within the limits of the ten octaves of waves comprised between wave-lengths of 8 mm. and 900 cm. measured in air.*

Table XI.—Determinations of the Dielectric Constant (Specific Inductive Capacity = K) of Ethyl Alcohol by Various Observers.

Observer.	Reference.	Value found per K.	Method.
W. Nernst ...	'Zeits. phys. Chem.,' vol. 14, 1894, p. 622	25·8	By comparing capacities of condensers with telephone.
J. F. Smale ..	'Wied. Ann.,' vol. 57, p. 215	25·8	By deflections of an electrometer filled with alcohol.
E. B. Rosa ...	'Phil. Mag.,' vol. 31, 1891, p. 188	25·7	By attraction between plates of condenser filled with alcohol. Reversals of E.M.F. 2000—4000 per minute.
W. C. Röntgen	'Wied. Ann.,' vol. 52, p. 593	30·5	By alternate currents and condenser (not of such weight perhaps as the others here given).

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* The different results found by A. D. Cole for long and short waves have been criticised by J. F. Mohler (see 'Physical Review,' vol. 4, p. 153), who ascribes the differences to conductivity. It has, however, been shown both by E. Cohn and L. Arons ('Ann. der Physik u. Chemie,' vol. 33, p. 13) and by G. U. Yule that the addition of salts to alcohol, which largely affect its conductivity, does not apparently alter perceptibly the dielectric constant, whether determined by slow or rapid reversals of electromotive force.

Table XII.—Determinations of the Electrical Refractive Index (μ) of Ethyl Alcohol for Electric Waves of Various Wave-lengths.

Observer.	Reference.	Value found.		Wave-length of waves used in air.	Method.
		μ	μ^2		
A. Lampa	'Wien. Sitzungsberichte'.	2·568	6·59	8 mm.	Reduction in length of waves passing into alcohol from air.
A. D. Cole	'Ver. Phys. Ges.', Berlin, vol. 14, 1895, p. 76	3·1 3·2	9·6	5 cm.	Ratio of intensities of original and reflected ray.
P. Drude	'Wied. Ann.', vol. 54, 1895, p. 352	4·74	22·46	60 "	Reduction of wave-length of waves passing into alcohol.
A. D. Cole	'Wied. Ann.', vol. 57, 1896, p. 290	5·24	26·32	259 "	Ratio of intensities of original and reflected rays.
G. U. Yule........	'Phil. Mag.', vol. 36, p. 531	5·16	26·7	900 "	Reduction in wave-length of waves passing into alcohol.
C. B. Thwing......	'Zeits. phys. Chem., vol. 14, p. 286, 1894	5·00	25·0	—	Resonance of electric circuits. Frequency not stated, but high.

Experiments on Annealed Swedish Iron.

A cylinder of iron was formed by winding up a sheet of Sankey's best transformer iron (Swedish).* The width of the strip was 4·895 cm., the thickness 0·0356 cm.; three complete layers of the sheet iron were used in forming the core. The area of cross-section of the side of the cylinder so formed was 0·5229 sq. cm. The mean diameter of the cylinder was 3·612 cm. This cylinder of iron was placed in a clay crucible packed with magnesia, the lid luted on with fire-clay, and the crucible then raised to a bright red heat in a forge, after which it was allowed to cool very slowly. The iron cylinder was thus carefully annealed out of contact with air or any material containing carbon. This soft annealed iron ring was then wound over with silk ribbon, and two windings of silk-covered copper wire placed upon it; the first or primary circuit consisted of 131 turns of No. 26 double silk-covered wire; the secondary circuit consisted of 112 turns of No. 36 silk-covered copper wire. The magnetising force to which the ring is subjected when a current is sent through the primary coil is measured by the value of $4\pi/10 \times$ the ampère-turns per unit of length of the mean perimeter of the ring, and this, in the case of the present ring, reduces to the number 14·507 times the ampère current. The magnetising force in absolute units is therefore very closely given by the number obtained by multiplying the current flowing through the primary coil in ampères by 14·5. The resistance of the primary coil at about 15° C. was 0·92 ohm, and the resistance of the secondary at the same temperature 8·98 ohms. The secondary circuit of this ring coil or transformer was then connected through appropriate resistances with a ballistic galvanometer, having a resistance of 18 ohms. The primary circuit was connected through suitable resistances and a current reverser with a circuit of constant potential. By these arrangements it was possible to reverse a definite current passing through the primary coils, and by observing the throw produced by the ballistic galvanometer, to calculate the induction in the iron core. The galvanometer was calibrated by reversing a known current passing through a long solenoid, in the centre of which was placed a secondary coil of known turns and dimensions, which was always kept in series with the secondary coil of the transformer. In this manner a series of observations was taken with gradually increasing magnetising forces. Before commencing each series of observations, the ring was carefully demagnetised by passing through the primary coil an alternating current, which was gradually reduced in strength to zero, the ring coil being thus brought into a magnetically neutral condition. An increasing

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* This sheet iron was kindly given to us by Mr. R. Jenkins, to whom our thanks are due.

series of primary currents was successively passed through the primary coil and reversed, the throw of the ballistic galvanometer being noted in each case. In the first set of observations the ring was kept at the ordinary temperature of the air, 15° C., and in the second set it was immersed in liquid air, and the following table shows the results, both for the high and for the low temperature observations.

After taking a complete magnetisation curve at the ordinary temperature, the ring was immersed in liquid air, bringing its temperature down to about –185° C., and a complete series of observations taken again in the same manner, previously having first carefully demagnetised the ring as described by an alternating current. The ring was then taken out of the liquid air, allowed to warm up again to the ordinary temperature, and another complete set of observations taken at the ordinary temperature. In this manner a series of eighteen complete sets of observations were taken, about half of them being at 15° C. and half of them at –185° C. In cooling the ring in liquid air, it was found to be important to cool it slowly by holding it some time in the dense gaseous air lying over the liquid air. If suddenly plunged into liquid air the iron becomes hardened. It was found that after the first five sets of observations, which were some-

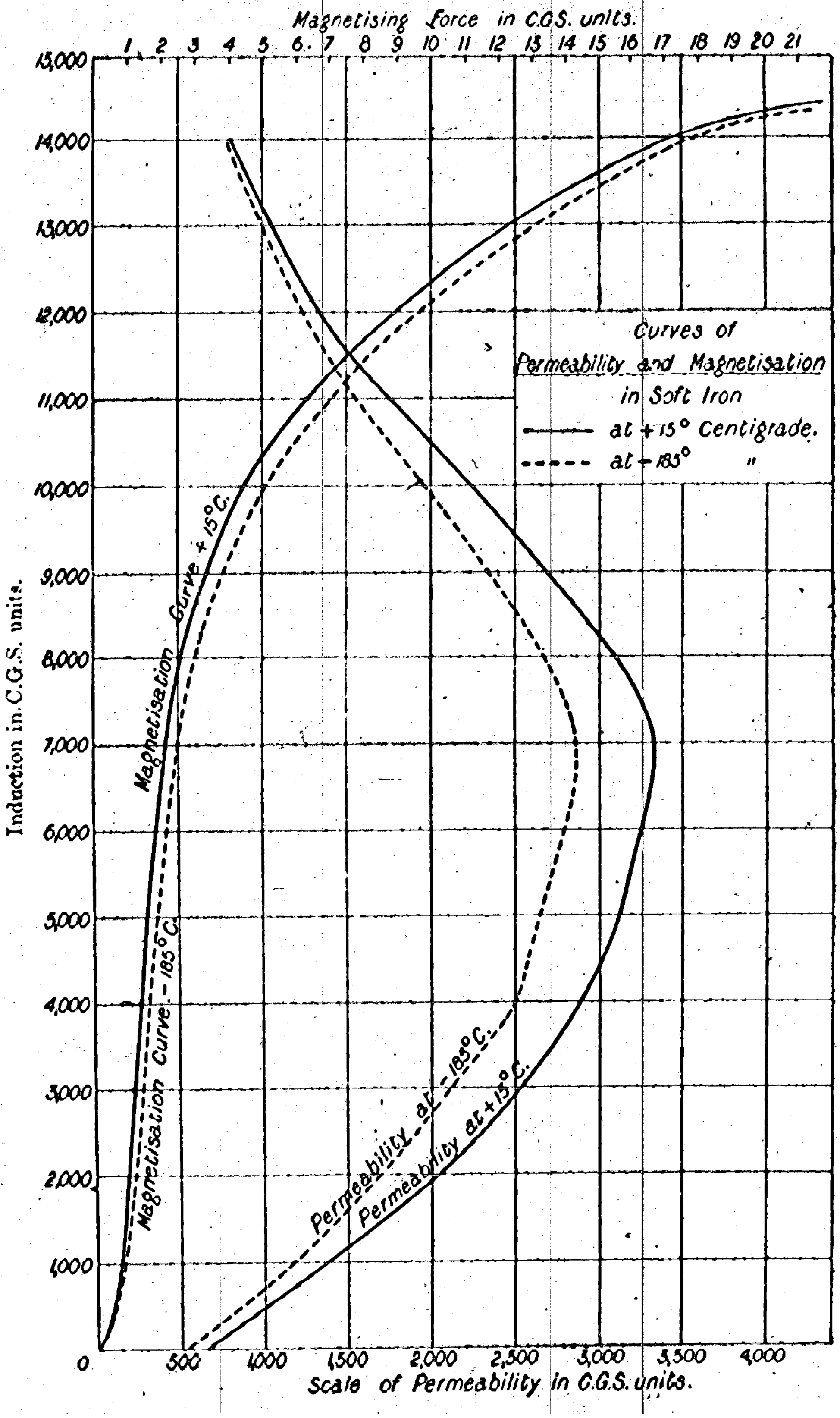
Table I.—Magnetisation Curve of Annealed Soft Iron (Sankey's Transformer Iron).

At 15° C.			At –186° C. (in liquid air).		
Magnetising force. H.	Induction. B.	Permeability. μ.	Magnetising force. H.	Induction. B.	Permeability. μ.
0·725	1000	1379	0·841	1000	1189
0·971	2000	2060	1·174	2000	1704
1·174	3000	2555	1·407	3000	2132
1·378	4000	2003	1·595	4000	2508
1·595	5000	3135	1·886	5000	2651
1·810	6000	3261	2·145	6000	2797
2·10	7000	3333	2·440	7000	2869
2·58	8000	3101	2·99	8000	2675
3·35	9000	2687	3·83	9000	2350
4·47	10000	2237	5·08	10000	1968
6·27	11000	1754	7·05	11000	1560
8·99	12000	1335	9·72	12000	1234
12·35	13000	1053	13·11	13000	992
17·22	14000	813	17·90	14000	782
22·1	14400	652	21·35	14300	670

what variable, the annealed iron ring was brought into a completely stable condition, in which the curve of magnetic induction plotted in terms of magnetising force taken at the low temperature was different from that taken at 15° C. by a perfectly constant amount, the observations at the low temperature always lying on one curve, and those at the higher temperature always lying closely on the other curve. In the diagram in fig. 1 the two magnetisation curves are shown, the firm line curve being the magnetisation curve at 15° C., and the dotted curve being the magnetisation curve taken at −185° C. in the liquid air. The figures in Table 1 are the mean values obtained from the curves plotted from the thirteen sets of closely consistent observations. These curves show that the permeability of soft annealed iron is reduced when it is cooled to about 200° below zero, for the whole range of magnetic forces between zero and 25 C.G.S. units. The permeability curves for the two states are likewise similarly shown on the same chart. The maximum permeability for this iron corresponds with a magnetising force of about 2 C.G.S. units; the maximum permeability at the ordinary temperatures for this iron is 3400, being reduced to 2700 when the iron is cooled to the temperature of liquid air. The percentage reduction in permeability becomes less as the magnetising force is increased beyond or reduced below this critical magnetising force. These experiments were repeated, as above stated, many times very carefully with this ring of annealed soft Swedish iron, and also with a second ring of the same kind, and have invariably shown the same results, viz., that the permeability of soft annealed iron is decreased by being cooled to this low temperature within the range of magnetising forces from 0 to 25. It will be seen that the highest induction reached in the case of this iron is 14,500 C.G.S. units, corresponding to a magnetising force of 25. This iron is of very high magnetic quality, and is of the same character as that which is much used for the construction of alternating current transformers in commercial use.

A series of experiments was then made with the same transformer, keeping the magnetising forces constant, but allowing the iron to rise gradually in temperature up from the temperature of liquid air to 15° C. In these experiments the transformer was embedded in a mass of paraffin wax with a platinum wire resistance thermometer also embedded in the same mass in close contact with the ring coil. The paraffin wax encasing the ring coil and thermometer having been cooled down to the temperature of liquid air by immersing it in a large bath of the liquid air, it was then lifted out and placed in a vacuum-jacketed test-tube, so as to heat up with extreme slowness, and a series of observations taken by reversing a constant magnetising force at intervals, and observing at the same instant the temperature of the ring coil as given by the platinum thermometer.

FIG. 1.


Magnetising force in C.G.S. units.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
15,000
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Induction in C.G.S. units.
Curves of
Permeability and Magnetisation
in Soft Iron
—— at +15° Centigrade.
- - - - at -185° "
Magnetisation Curve +15°C.
Magnetisation Curve -185°C.
Permeability at -185°C.
Permeability at +15°C.
500 1000 1500 2,000 2,500 3,000 3,500 4,000
Scale of Permeability in C.G.S. units.

The results of these observations are given in Table II, and these observations are set out in the curve marked soft annealed iron in fig. 2.

Table II.—Variation of the Magnetic Permeability of Soft Annealed Swedish Iron with Temperature.

Magnetising force = 1·77 C.G.S.

Temperature measured in platinum degrees by standard thermometer P_1.

Temperature.	Permeability.
0°	2835
− 20	2815
− 40	2770
− 60	2727
− 80	2675
−100	2622
−120	2560
−140	2497
−160	2438
−180	2381
−200	2332

The results show that as the temperature rises up from −185° C., or −200° on the platinum scale temperature, up to the ordinary temperature, the permeability of the soft iron for the particular magnetising force selected increases perfectly uniformly, the curve of increasing permeability with temperature being nearly a straight line.

In the next place, we have examined the hysteresis of the same soft iron ring at different temperatures and for different maximum inductions. These observations were carried out by taking a complete series of hysteresis curves with the ballistic galvanometer, gradually increasing the inductions from zero to 12,000. After the complete hysteresis curves were obtained, their areas were carefully integrated with an Amsler planimeter, and the values reduced so as to express the hysteresis loss in watts per lb. per 100 cycles per second, and these values plotted in terms of the maximum value of the magnetic induction per square centimetre of the iron core corresponding to each particular hysteresis loss. Nothing would be gained by giving the full details of all the observations by which these hysteresis curves were obtained. They were exceedingly numerous, and the tedious nature of the ballistic observations made it a matter of prolonged observation to secure the whole series necessary, but the final results are shown in Table III. The curve in fig. 3 represents the increase of hysteresis loss with induction, and the observations which

FIG. 2.

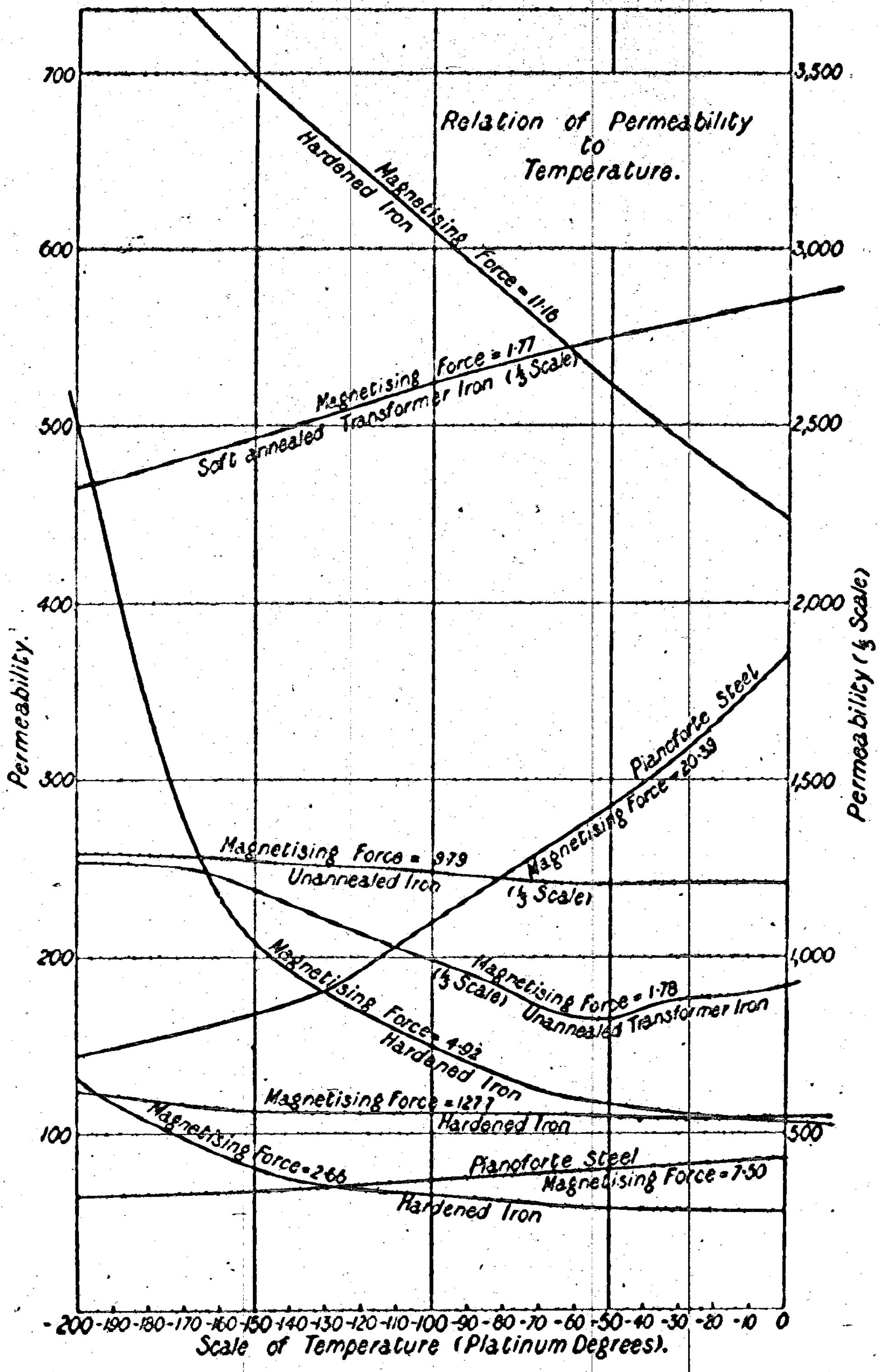

Relation of Permeability to Temperature.
Magnetising Force = 11·18
Hardened Iron
Magnetising Force = 1·77
Soft annealed Transformer Iron (⅕ Scale)
Pianoforte Steel
Magnetising Force = 20·39
Magnetising Force = 9·79
Unannealed Iron
(⅕ Scale)
Magnetising Force = 1·78
(⅕ Scale) Unannealed Transformer Iron
Magnetising Force = 4·92
Hardened Iron
Magnetising Force = 12·77
Hardened Iron
Magnetising Force = 2·66
Pianoforte Steel
Magnetising Force = 7·50
Hardened Iron
Permeability.
700
600
500
400
300
200
100
Permeability (⅕ Scale)
3,500
3,000
2,500
2,000
1,500
1,000
500
-200 -190 -180 -170 -160 -150 -140 -130 -120 -110 -100 -90 -80 -70 -60 -50 -40 -30 -20 -10 0
Scale of Temperature (Platinum Degrees).

Fig. 3.

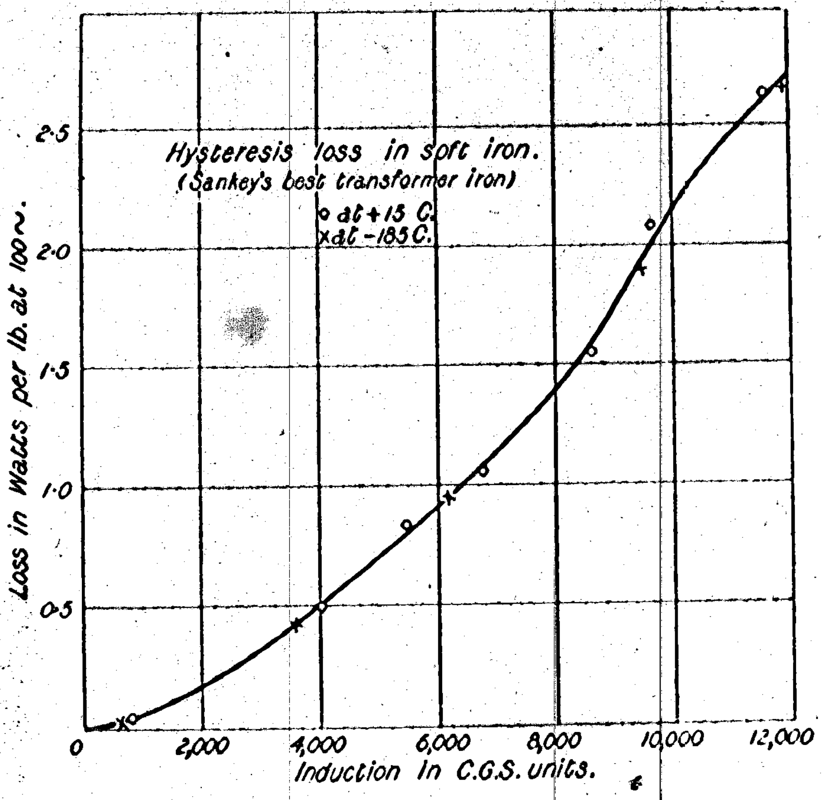
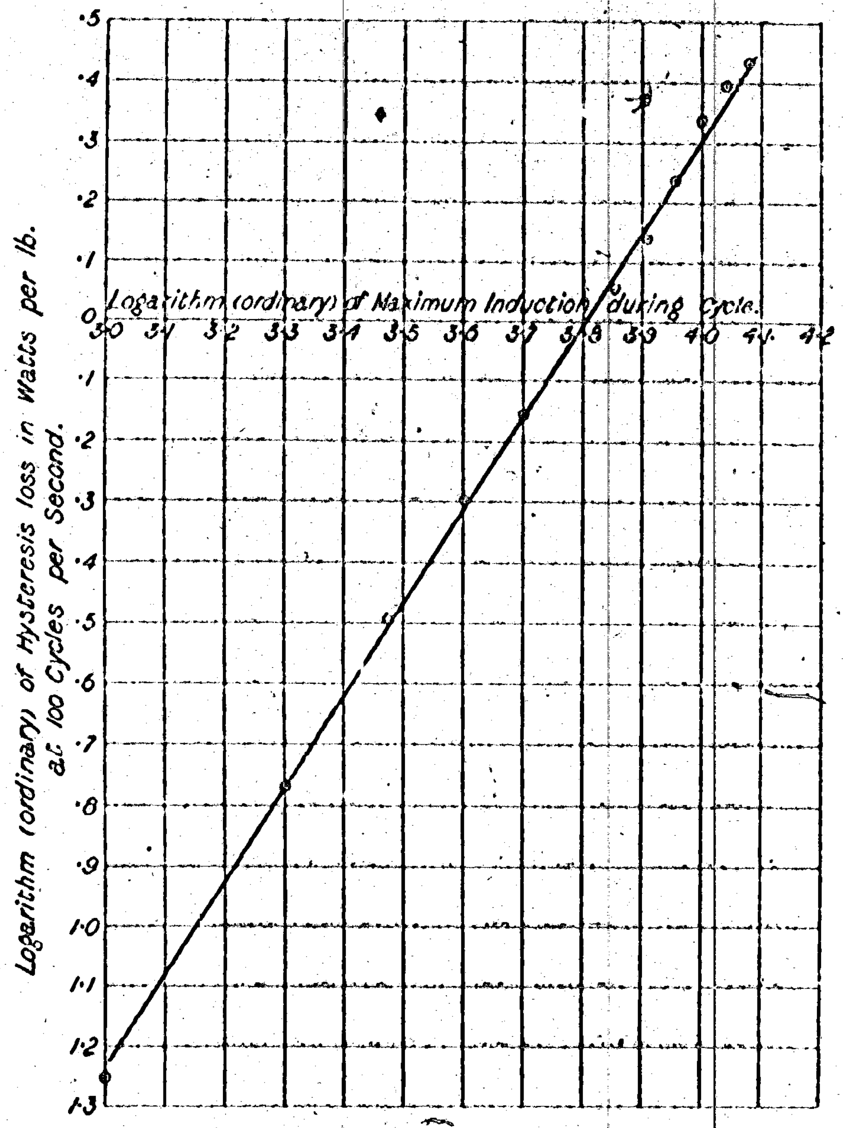


Table III.—Hysteresis Loss in Soft Annealed Swedish Iron in Watts per pound per 100 cycles per second for various maximum Inductions.

I. At + 15° C.		II. At − 185° C. (in liquid air).	
Maximum induction. B.	Hysteresis loss. W.	Maximum induction. B.	Hysteresis loss. W.
844	0·0397	688	0·02519
4026	0·4957	3603	0·4246
6743	1·062	6185	0·949
9687	2·070	9461	1·907
11618	2·632	11916	2·658
8593	1·545		
5516	0·823		

were taken at ordinary temperatures are denoted by the small circles. The observations for hysteresis loss which were taken at the temperature of liquid air are denoted by the crosses. It will be seen that substantially the circles and the crosses lie on the same curve. The results of these observations, therefore, show that there is practically no change in the hysteresis loss in soft iron by cooling it to the temperature of liquid air. If, instead of plotting the hysteresis loss and induction, the ordinary logarithms of these quantities are taken as coordinates, the curve, as shown in fig. 4, then obtained is

FIG. 4.



very nearly a straight line as far as the limit of an induction of about 9000, and from the inclination of this line it is clear that the hysteresis loss, W, in watts per lb. per 100 cycles is found to be related to the maximum induction B in C.G.S. units per square centimetre by the law $W = \frac{1156}{10^9} B^{1·56}$, or, if the hysteresis loss is reckoned in ergs per cubic centimetre per cycle = W′, then $W' = 0·002\, B^{1·56}$. These results are quite in accordance with certain conclusions of Messrs. Laws and Warren (see 'Proceedings of the American Academy of Sciences,' vol. 30, p. 490). These observers made a series of experiments on a material which was practically a very soft steel, and employing a differential watt meter, measured the hysteresis loss in the iron at varying and increasing temperatures up to 600° or 700°. They found that the hysteresis loss in this material did not begin to decrease sensibly until about 150° C.; after that it decreased regularly in accordance with the simple linear function of the temperature. In one experiment which they tried with the same material cooled to −78° C. in solid carbonic acid and ether, they found no difference between the hysteresis loss of this soft steel at that temperature and at the ordinary temperatures. Our results, which have been carried to the much lower temperature of liquid air, indicate that in the case of soft annealed Swedish iron the hysteresis loss is not changed by cooling from ordinary temperatures to the temperature of liquid air. As we know that the hysteresis loss of soft iron decreases when the temperature is increased, from the ordinary experience with transformers in commercial use, the matter that requires further investigation is to discover the temperature at which the hysteresis loss sensibly changes and begins to diminish.

Experiments on Unannealed Swedish Iron.

We have also carried out a series of experiments of the same character with unannealed iron and steel. A ring coil was constructed of sheet iron of the same quality as that forming the core of the soft iron transformer above described, but no special pains were taken to anneal the iron, and as it was "hardened" in a magnetic sense by being bent into shape, this difference in quality showed itself in the magnetic observations. A ring coil was constructed of the following dimensions:—The thickness of the strip was 0·031 cm., width of the strip 1·24 cm., the ring was formed by $23\frac{1}{2}$ layers of this sheet iron wound up closely into the form of a ring. The outside diameter of this ring was 4 cm., the inside diameter 2·13 cm., the cross-section of the iron in the ring was therefore 0·9032 sq. cm., and the mean perimeter of the ring 9·62 cm. This iron ring was not annealed in any way, but it was simply wound over with silk ribbon, and then had placed upon it two coils of wire. The primary coil consisted of 150 turns of No. 26 wire, having a resistance of 0·383 ohm, and the secondary coil consisted of 240 turns of No. 36 wire having a resistance of 8·092 ohms. As the diameter of cross-section of the ring was not very small compared with the mean diameter of the ring, it was necessary to calculate by a proper integration the mean value of the mean magnetising force in terms of the current passing through the primary coil, and it was found that the mean magnetising force to which the iron was exposed was closely expressed by the value 20·219, multiplied by the ampère current flowing through the primary coil. This coil had its secondary circuit connected up to the galvanometer, as above described, and a series of observations were taken with this coil by reversing a constant magnetising current passing through the primary coil, and observing the throw of the ballistic galvanometer connected with the secondary circuit. The ring coil, together with the platinum thermometer, was embedded, as above described, in a mass of paraffin wax, and the whole mass, after having been cooled down to the temperature of liquid air, was slowly allowed to heat up again. Observations were taken with two different magnetising forces over the range of temperature from −185° C. up to the ordinary temperature, and from the calculated induction in the ring determined for each magnetising force, the permeability was found corresponding to each particular force and temperature. The results of these observations are given in Table IV, and are delineated in fig. 2, in the form of two curves marked unannealed iron.

Table IV.—Variation of Magnetic Permeability of Unannealed Swedish Iron with Temperature.

Temperature measured in platinum degrees by standard thermometer P_1.

	Permeability.	
Temperature.	Magnetising force, 1·78.	Magnetising force, 9·79.
0°	917	1210
− 20	885	1212
− 40	857	1212
− 60	832	1208
− 80	913	1230
−100	993	1240
−120	1067	1255
−140	1153	1265
−160	1230	1280
−180	1262	1290
−200	1272	1293

The results of the observations, as indicated in fig. 2 in the curves marked Unannealed Iron, show that for this unannealed iron the permeability increases as the temperature falls, and is exactly the reverse in the case of the same quality of iron carefully annealed. The difference, also, between the two materials is very marked at low temperatures. The soft annealed iron if cooled slowly to −185° C. recovers its original permeability when heated up again to ordinary temperatures. The unannealed iron, however, after cooling to the same low temperature, retains some of its increased permeability when heated up again to 15° C. The unannealed iron cannot be taken over the temperature range again and again with the same definite permeability values at each recurrent temperature, as in the case of the soft annealed iron. The unannealed iron is more or less permanently changed in magnetic character every time it is heated or cooled.

With this transformer, a long series of observations were taken to determine the hysteresis loss corresponding to different inductions when taken at the ordinary temperatures, and the temperature of liquid air. The hysteresis cycles were taken with the ballistic galvanometer over wide ranges of maximum induction, the transformer being alternately at the ordinary temperature and in liquid air, but no constant magnetic condition could be obtained. In one set of observations, at a given maximum induction the hysteresis loss was increased when the transformer was raised in temperature, and for another series of observations at the same induction it was diminished. It is therefore impossible to make any definite statement with regard to the magnetic hysteresis loss in this unannealed iron ring coil at the two temperatures. The mere fact of immersing the unannealed iron in the liquid air changes its magnetic qualities to such a degree that it is no longer the same material, magnetically considered, after as before its immersion. One curious fact, however, was noticed very soon with regard to unannealed iron, and that is, that if the unannealed iron ring coil has a small magnetising current passed through its primary coil, the secondary coil being connected to the galvanometer, the sudden immersion of this ring coil into liquid air invariably causes a deflection of the ballistic galvanometer, even when the primary magnetising current remains perfectly constant in value, thus showing a sudden and very large increase in the permeability of the unannealed iron. Whilst the iron is in the liquid air it retains this increased permeability. If brought suddenly out its permeability again diminishes, but not with equal rapidity. This is partly accounted for by the fact that the iron is cooled with immense rapidity when it goes into the liquid air, but it heats up again much more slowly when it is brought out. The definite fact, however, remains, which has been repeatedly observed, that the cooling of this unannealed iron to a low temperature always increases its permeability, as far as we know, no matter whatever may be the magnetising force employed. One difficulty experienced in dealing with unannealed iron is the fact that in taking it up to the high magnetising forces, and by the process required to remove residual magnetism by the application of an alternating current, the iron is so altered in magnetic qualities that it is impossible to repeat two sets of observations under precisely similar circumstances. With regard to the unannealed iron, it may be noted that if an ordinary magnetisation curve is taken up to very high magnetisation forces, and the iron then demagnetised by the application of an alternating current gradually reduced, the first magnetisation curve can never be repeated exactly again on applying increasing magnetisation forces, but a curve is obtained which lies slightly inside the first curve, and which indicates that the permeability has been reduced. The subsequent repetition of this process will give a series of curves which occupy different positions, but which do not precisely repeat any of them. Hence it is impossible to repeat at a constant temperature with this unannealed iron exactly any magnetisation or permeability curve. In the case of the annealed iron it is quite different. A magnetisation curve can be obtained after having carefully de-magnetised the iron, if this magnetisation is pressed up to nearly its limit and the iron then de-magnetised by the application of an alternating and decaying magnetising force, a second magnetisation curve can be obtained on again applying an ascending magnetising force, but it will not coincide exactly with the first curve. The annealed iron can, however, be brought back into its original condition by dipping it a few times into liquid air. Under these conditions, we have been able to repeat as frequently as required the observations with the annealed iron taken at the different temperatures. In the case of the unannealed iron the changes produced in it by immersing it in the liquid air and by magnetising and demagnetising it, are such as to render it almost impossible to obtain results capable of precise repetition, with respect to the hysteresis loss and permeability for varying magnetising forces.

Experiments with Hardened Iron.

A third set of experiments were taken with a ring coil of the same dimensions as the ring coil made of soft annealed transformer iron first described. This third coil was constructed of the same sample of Sankey's transformer sheet iron as the above described soft annealed ring, but it was treated subsequently to its formation in the following manner:—

A short piece of iron gas-pipe was made red hot in a forge; the ring coil, having been constructed, was dropped into the red-hot pipe, and the ends of this pipe loosely plugged up with slag wool; the red-hot pipe was then covered over with cinders, and the mass allowed to cool. Under these conditions the ring coil was annealed in an atmosphere of carbonic oxide and in contact with hot carbon; the sheet iron was, therefore, under these circumstances, case-hardened, and will be referred to as the hardened iron ring. Having been formed into a transformer in the above-described manner, a long series of observations were taken with this coil to determine its permeability at different temperatures and with different magnetising forces. The results of these observations are shown in the Table V below, and are delineated graphically in the curves in fig. 2, marked Hardened Iron. The results show in a remarkable manner that the iron so treated undergoes a very considerable increase in magnetic permeability when it is cooled to the temperature of liquid air; for certain magnetising forces the permeability at the lowest temperature reached may be increased as much as five times. In this respect, therefore, this iron presents in an exaggerated degree the same qualities found in the unannealed iron.

Table V.—Variation of Magnetic Permeability with Temperature of Hardened Iron.

Temperature measured in platinum degrees by standard thermometer P_1.

Temperature.	Permeability.			
	H = 2·66.	H = 4·92.	H = 11·16.	H = 127·7.
0°	56·0	106·5	447·5	109·0
− 20	57·0	109·5	476·0	108·5
− 40	58·0	114·0	506·5	109·0
− 60	59·0	119·8	540·0	110·5
− 80	62·5	132·5	575·0	111·0
−100	65·5	150·0	610·0	112·0
−120	69·2	169·3	645·0	112·0
−140	75·3	192·5	680·0	112·3
−160	89·5	236·0	717·0	114·0
−180	107·5	338·0	762·0	119·5
−200	132·0	502·0	823·0	124·0

Experiments with Steel.

We have also examined the behaviour of a ring coil made of steel pianoforte wire. We have found in this case the curious result that pianoforte steel behaves in the same manner as the annealed soft iron; its permeability is decreased as the temperature is lowered. The results of the measurements with this steel-core ring are shown in Table VI, and graphically in the curves in fig. 2, marked steel.

Table VI.—Variation of Permeability with Temperature.

Pianoforte Steel.

Temperature measured in Platinum degrees by standard thermometer P_1.

Temperature.	Permeability. Magnetising force, 7·50.	Permeability. Magnetising force, 20·39.
– 0°	86·0	361·0
– 20	84·0	332·5
– 40	81·0	299·5
– 60	79·0	271·5
– 80	77·0	246·5
–100	74·0	220·0
–120	71·5	193·0
–140	68·5	174·3
–160	67·0	163·0
–180	66·0	153·0
–200	64·5	144·0

We propose to continue the examination of the anomalous behaviour so presented by iron in different states of hardening by examining in the same way the changes of permeability in the case of several iron rings of the same dimensions formed in the one case of soft annealed iron, and in another case of the same quality of iron hardened, and in the remaining cases using steel of known composition at different states of temper. We desire to add that in the conduct of this research we have been under great obligations to Mr. J. E. Petavel for rendering us very efficient assistance in taking the exceedingly tedious ballistic galvanometer observations, and in reducing them when taken.

"On the Dielectric Constants of certain Frozen Electrolytes at and above the Temperature of Liquid Air." By J. A. Fleming, M.A., D.Sc., F.R.S., Professor of Electrical Engineering in University College, London, and James Dewar, M.A., LL.D., F.R.S., Fullerian Professor of Chemistry in the Royal Institution, London. Received May 6, —Read June 3, 1897.

In a preliminary note on the "Dielectric Constant of Ice and Alcohol at very Low Temperatures"* we have described the method employed by us in determining the dielectric constants of ice and frozen ethylic alcohol at the temperature of liquid air. One difficulty which presented itself in our initial experiments was that of the construction of a suitable electrical condenser for use with frozen liquids as dielectrics. The concentric-tube pattern of condenser used by us in the first experiments on ice gave trouble by becoming deformed under the expansive force of the water on freezing, and the subsequent great contraction of the ice on cooling to the tempera- of liquid air tended to break the contact between the metal plates and the dielectric. It was, in addition, difficult to clean out.

In undertaking, therefore, a more careful study of the dielectric constants of various frozen electrolytes at and above the temperature of liquid air, the first experimental problem which arose was that of the construction of a form of condenser which could be employed with the selected frozen electrolyte as dielectric, and which should comply with the following conditions:—

1. To allow any required and actual expansion of the dielectric on freezing without deforming the condenser.
2. To permit the subsequent great contraction of the dielectric substance on cooling to the temperature of liquid air, without breaking contact between the dielectric and the metal plates.
3. To be sufficiently compact to be placed in a large vacuum tube of liquid air.
4. To be rigid and have high insulation and be able to be taken apart and put together again quickly and accurately.

After trying several arrangements, we were at last able to design a condenser fulfilling the above conditions in a very perfect way, and which has given in its latest form little or no trouble in work.

This condenser, which we call a cone-condenser, is constructed as follows:—

It consists of two hollow cones turned out of hard brass (see fig. 1), the outer cone being 14·9 cm. in length inside, 5·1 cm. in diameter

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* See 'Roy. Soc. Proc.,' vol. 61, p. 2, February, 1897. J. Dewar and J. A. Fleming.

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and M_1, M_2 are the coefficients of mutual induction of the circular ends of the sheet and the helix.

Hence the calculation of this force reduces itself to a double application of the formulæ for the coefficient of mutual induction of a circle and coaxial helix.

It is hoped that this may form a useful method of calculating the constant of current weighers designed to measure current in absolute units.

"A Note on some further Determinations of the Dielectric Constants of Organic Bodies and Electrolytes at very Low Temperatures."

By JAMES DEWAR, M.A., LL.D., F.R.S., Fullerian Professor of Chemistry in the Royal Institution, and J. A. FLEMING, M.A., D.Sc., F.R.S., Professor of Electrical Engineering in University College, London.

Received October 28,—Read December 9, 1897.

In several previous communications* we have described the investigations made by us on the dielectric constants of various frozen organic bodies and electrolytes at very low temperatures. In these researches we employed a method for the measurement of the dielectric constant which consisted in charging and discharging a condenser, having the given body as dielectric, through a galvanometer 120 times in a second by means of a tuning-fork interrupter. During the past summer we have repeated some of these determinations and used a different method of measurement and a rather higher frequency. In the experiments here described we have adopted Nernst's method for the measurement of dielectric constants, using for this purpose the apparatus as arranged by Dr. Nernst which belongs to the Davy-Faraday Laboratory. The frequency of alternation employed was 350 or thereabouts, whereas in all our formerly described experiments with the galvanometer method it was 120.

The electrical details of the arrangement employed in Nernst's method are as follows:—A Wheatstone's bridge is formed (see diagram), two sides of which consist of variable resistances, R_1, R_2, which are usually liquid resistances contained in U-tubes. The other two sides of the bridge consist of two sliding condensers of variable capacity, C_1, C_2, which are shunted by adjustable liquid resistances, R_3, R_4. The bridge circuit contains a telephone, T, as detector. The alternating currents are furnished by an induction coil, I. An experimental condenser, X, the dielectric of which can be made

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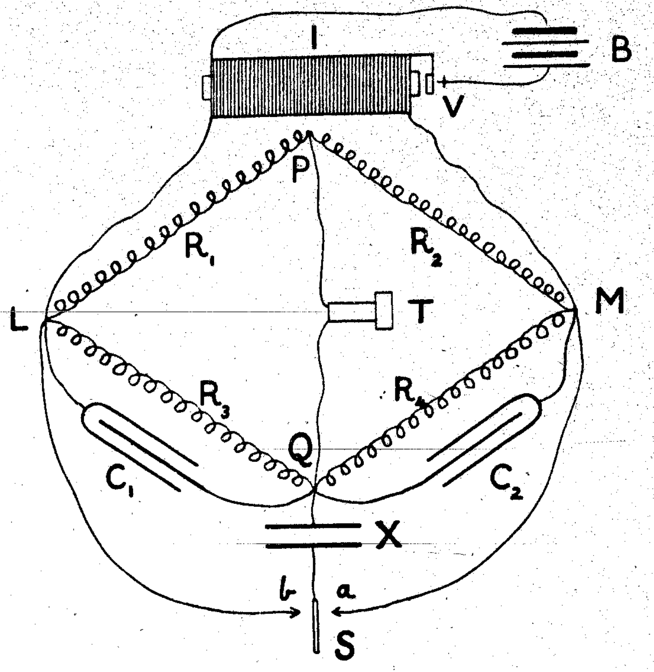
* See Fleming and Dewar, 'Roy. Soc. Proc.' (1897), vol. 61, pp. 2, 299, 316, 358, 368, and 381.



to be the substance under examination, is connected, as shown in the diagram, so that it can be placed in parallel with either of the shunted condensers forming the third and fourth arms of the bridge. The process of measurement is then as follows:—The experimental condenser is placed in parallel, by the switch S, say, with the third arm of the bridge, and the shunt resistances are first adjusted, so that the telephone gives a minimum of sound. The capacity of one sliding condenser, C_1, is then varied until complete silence in the telephone in the bridge is obtained. The experimental condenser is next shifted over into parallel with the fourth arm, and the capacity of the same sliding condenser is again adjusted to produce silence in the telephone. The change in capacity thus made in the sliding condenser corresponding to the change in position of the experimental condenser is denoted by s. The experimental condenser then has its air dielectric replaced by a liquid of known dielectric constant D_0, and the same process of change of its position effected. Let the variation of the adjustable sliding condenser then be denoted by S_0. Finally the experimental condenser has its air dielectric replaced by a liquid or frozen liquid of unknown dielectric constant D, and the process of change and adjustment a third time repeated. Let the variation of the sliding condenser in this third case be S. It is then very easy to show that the following relation holds good between D_0, D, S_0, S, and s, viz. :—

$$\frac{D_0-1}{S_0-s}=\frac{D-1}{S-s}$$

or

$$D=\frac{D_0-1}{S_0-s}(S-s)+1.$$

In order to apply this method we employed absolute ethylic alcohol as the standard dielectric substance of known dielectric constant, and took as its dielectric constant at 15° C. the value 25·8 (according to Nernst), a number closely in agreement with all the best results by other observers.

The actual capacity of the experimental condenser with air as dielectric was very small, not being more than about 0·00001 of a microfarad. Hence in the above formula $D_0 = 25·8$.

The value of s was determined to be 1·33 and 1·38 in two experiments, and the mean 1·36 was taken as the value of s.

The following liquids were then examined by placing them in the experimental condenser and keeping them at ordinary temperatures, viz., 16° C. to 20° C.

1. Solution of Potassic Hydrate in water, 5 per cent. solution.
2. Solution of Rubidic Hydrate in water, 5 per cent. solution.
3. Amyl alcohol.
4. Ethylic ether.
5. Ethylic ether, pure and dry.
6. Ethylic alcohol.

The change in capacity of the sliding condenser when ethylic alcohol replaced the air in the experimental condenser was 16·7. Hence $S_0 = 16·7$ and $D_0 = 25·8$, also $s = 1·36$.

Therefore $$\frac{D_0-1}{S_0-s}=\frac{24·8}{15·34}=1·613.$$

The following table shows the observed values of s in the several cases when the above liquids were placed in the experimental condenser, and the corresponding calculated value of the dielectric constant D, where $D = 1·613 \times (S-s)+1$.

Table I.—Determinations of the Dielectric Constants of certain Liquids at Ordinary Temperatures (15° C.) by Nernst's Method. Frequency = 320.

Substance.	S.	S − *s*.	1·613 (S − *s*).	Dielectric constant = D.
Ethylic alcohol (taken as the standard of comparison)	16·7	15·34	24·8	25·8 (assumed value)
Amyl alcohol	10·49	9·13	14·7	15·7 (calculated)
Ethylic ether........	3·98	2·62	4·23	5·23 (calculated)
Pure dry ethylic ether	3·70	2·34	3·78	4·78 (calculated)

Hence by Nernst's method, assuming the dielectric constant of ethylic alcohol to be 25·8, we find that of amyl alcohol to be 15·7 and pure ethylic ether to be 4·78.

Nernst himself found amyl alcohol to be 16·0 and ethylic ether to be 4·25 at about this temperature. Hence our values are in fair agreement with his.

In the next place we cooled the experimental condenser down to the temperature −185° C. in liquid air, after filling it with one of the above six dielectric liquids, and we repeated all the above-described operations again. The results are collected in Table II.

Table II.—Determinations of the Dielectric Constants of certain Frozen Liquids at the Temperature of Liquid Air by Nernst's Method. Frequency = 320.

Substance.	S.	S − *s*.	1·613 × (S − *s*).	Calculated dielectric constant = D.
Ethylic alcohol	2·68	1·32	2·13	3·13
Amyl alcohol	2·34	0·98	1·58	2·58
Ethylic ether	2·16	0·80	1·29	2·29
5 per cent. solution of Rubidic Hydrate	2·94	1·58	2·55	3·55
5 per cent. solution of Potassic Hydrate	5·15	3·79	6·12	7·12

The above values for the organic bodies are in close agreement with the results we obtained for the same substances by the galvanometer and switch method formerly used by us, as may be seen by a reference to Table III.

Table III.—Comparison of the Determinations of certain Dielectric Constants made by different Methods at the Temperature of Liquid Air.

Substance.	By galvanometer and switch method. Frequency = 120. Dielectric constant.	By Nernst's bridge method with telephone. Frequency = 320. Dielectric constant.
Ethylic alcohol	3·11	3·13
Amyl alcohol	2·14	2·58
Ethylic ether	2·31	2·29
5 per cent. solution (aqueous) of Potassic Hydrate	123·0	7·12
5 per cent. solution (aqueous) of Rubidic Hydrate	81·6	3·55

The results collected in the above Table III, show that the two methods give practically identical values for the two alcohols and the ether, but very different value for the two frozen dilute hydrates.

An examination was then made of several other substances, and for this purpose another condenser was constructed, which consisted of a platinum crucible about 4 cm. in diameter and 5 cm. high. This crucible was fitted with an ebonite lid, through which passed a glass test-tube, in the interior of which was placed our platinum thermometer. Round the outside of the test-tube, platinum wire was closely wound, so as to form the opposed surface of a condenser in relation to the platinum crucible as the other surface. This platinum condenser could then be filled with any electrolyte or organic liquid and frozen in liquid air.

Owing to the very small actual capacity of this last experimental condenser, and especially that of the variable part of it in comparison with the capacity of the leads and connections, no very great accuracy of measurement was looked for, or attained. The results, however, were sufficient to check the general accuracy of the experiment with similar substances by the galvanometer method. This platinum condenser was calibrated and used with the Nernst bridge, exactly as in the previous experiment.

With the experimental condenser empty the change in capacity of the variable sliding condenser in the bridge arm was 1·50 on changing over the position of the experimental condenser. Hence $s = 1{\cdot}50$.

When filled with ethylic alcohol ($D_0 = 25{\cdot}8$) the change of capacity of the sliding condenser was 6·20. We have, therefore, $S_0 = 6{\cdot}20$, $D_0 = 25{\cdot}8$, $s = 1{\cdot}50$.

Therefore
$$\frac{D_0-1}{S_0-s} = \frac{24{\cdot}8}{4{\cdot}70} = 5{\cdot}27.$$

The experimental condenser was then filled with some liquid, either at ordinary temperature or frozen at a low temperature, and the bridge measurement made, and the reading S or the change of capacity of the sliding condenser observed, as before, when the experimental condenser had its position changed.

The following Table IV gives the summary of the results obtained with several substances at various temperatures.

Table IV.—Measurement of the Dielectric Constants of various Substances at different Temperatures by Nernst's Method. Frequency = 320. S = 1·50, $\frac{D_0-1}{S_0-s} = 5·27$.

Substance.	S.	$S-s$.	$5·27(S-s)$.	Calculated dielectric constant = D.	Temperature in platinum degrees.
Ethylic ether..	2·1	0·6	3·16	4·16	+15°
Glycerine	12·15	10·65	56·2	57·2	+30
Solution of ammonia (sp. gr. = 0·880)....	4·5	3·0	15·8	16·8	−123 (?)
	5·6	4·1	21·6	22·6	−137
	13·5	12·0	63·0	64·0	−119
Distilled water or pure ice ..	0·2	0·5	2·6	3·6	−49
	11·0	9·5	50·0	51·0	−7
	14·3	12·8	67·0	68·0	+1
Oxide of copper in suspension in water....	3·95	2·45	12·9	13·9	−61
	12·8	11·3	59·7	60·7	−41

The value found for the dielectric constant of water at +1° is rather low, but, as above mentioned, the smallness of the capacity of the experimental condenser prevented the results from being more than good indications of the *order* of the dielectric constant.

We have, in addition, repeated and extended experiments made with the cone condenser on various electrolytes and dielectrics.

In the first place, we have carefully examined the effect of change of temperature on the dimensions of the cone condenser *per se* to ascertain if the dimensional change produced by cooling it in liquid air could sensibly affect the value of the dielectric constant of an electrolyte forming the dielectric between the cones, apart from the change which temperature produces in the dielectric quality of the dielectric itself.

The gilt cone condenser was accordingly connected with the tuning-fork interrupter as formerly described,* and the galvanometer scale deflection when the condenser was charged with 97·2 volts was found to be 3·85 cm. to the left and 3·88 cm. to the right, hence the mean galvanometer deflection was 3·87 cm. of the scale. This corrected to 100 volts becomes 3·98, and deducting 0·4 cm. for the capacity of the leads, gives 3·58 as the number representing the

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* See Fleming and Dewar, 'Roy. Soc. Proc.,' vol. 61, 1897, p. 299.

electrical capacity of the cone condenser as then arranged. A standard condenser belonging to the Davy-Faraday laboratory, and having a capacity of one-thousandth of a microfarad, was then substituted for the cone condenser, and gave right and left deflections of 19·1 and 19·6 cm., respectively when charged with 97 volts. This corrected for capacity of leads (= 0·4 cm.) and reduced to 100 volts becomes 19·53. Hence, since the electrical capacities are proportional to the galvanometer deflection, the electrical capacity of our cone condenser is $\frac{3·58}{19·53} \times 0·001$ of a microfarad, or 0·000183 of a microfarad.

The capacity of the gilt cone condenser was then again measured with air at 20° C. as dielectric, and the galvanometer deflection observed. The outer cone was then cooled to −185° C. by quickly applying to it a large quantity of liquid air whilst the inner cone remained at about 20° C., and the galvanometer deflection again observed. This deflection was taken again when the inner cone had fallen in temperature to −75°, and finally when both inner and outer cones were at −185° C. The following numbers giving the galvanometer deflections are then proportional to the electrical capacity of the condenser between the cones.

Table V.—Examination of the Effect of Cooling on the Electrical Capacity of the Cone Condenser.

Galvanometer scale deflection in cm. or electrical capacity of the cone condenser in arbitrary units, the dielectric being gaseous air.	Remarks.
4·22 cm.	Both inner and outer cones both at 20° C.
4·82 cm.	Outer cone at −185° C. Inner cone at 20° C., about.
4·58 cm.	Outer cone at −185° C. Inner cone at −75° C.
4·19 cm.	Outer and inner cones both at −185° C.

Hence it is clear that mere change of temperature of the metal work of the cone condenser does not affect its electrical capacity by more than 1, or perhaps 2, per cent., and any larger changes in capacity found on cooling must be due to a real change in the dielectric constant of any dielectric substituted for the air between the cones, and not to mere dimensional changes of the condenser itself produced by the cooling.

Another matter to which our attention was directed was the question whether there was any sensible or serious lag in the temperature of the resistance thermometer behind the temperature of the dielectric. Our usual custom had been to immerse the condenser when prepared for use in liquid air, and cool down the whole mass to −185° C., and then raising it out of the liquid air to take temperature and capacity readings as it warmed up. The resistance thermometer was placed in the inner cone in a thin test-tube, and fixed in with fusible metal in the inner cone. We therefore tried one experiment with pure glycerine as dielectric, in which the electrical measurements were made as the condenser was slowly cooled, instead of being made as it slowly heated up. The process of cooling from −38° *pt.* to −201° *pt.* was allowed to occupy one hour and forty minutes. The values thus found for the dielectric constant for glycerine for this range of temperature were practically in agreement with those found when the condenser capacity was measured as it warmed up instead of cooled down.

Table VI.

I. *Dielectric Constant of Pure Glycerine.*

Corrected galvanometer deflection when the condenser had air as dielectric = 3·92 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−38·0	2·85	50·5	Condenser charged with 1·434 volts. Time = 3.5 P.M.
−42·6	2·97	52·8	
−46·0	3·00	53·3	
−55·8	3·17	56·5	
−64·8	3·03	53·8	Time = 4.15 P.M.
−98·8	2·70	3·95	Condenser charged with 17·0 volts.
−119·5	2·20	3·19	Time = 4.30 P.M.
−201·0	11·05	2·82	Condenser charged with 92·4 volts. Time = 4.45 P.M.

The above values of the dielectric constant of glycerine are in very fair agreement with the values obtained by us during rising temperature.*

We have also extended our former observations made with this cone condenser and the galvanometric method to certain other frozen electrolytes, and measured their dielectric constants at low temperatures.

The results and substances are as follows :—

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* 'Roy. Soc. Proc.,' vol. 61, p. 324.

II. *Dielectric Constant of Dry Concentrated Sulphuric Acid* (H_2SO_4).

The corrected galvanometer deflection with air as dielectric was 3·92 cm. for 100 volts. The switch frequency was 120.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−200·9	14·6	3·86	Condenser charged with 94·2 volts.
−186·0	14·8	3·90	,, ,, ,, ,,
−181·8	2·5	3·82	Condenser charged with 16·2 volts.
−150·7	2·7	4·13	,, ,, ,, ,,
−129·8	2·95	4·33	Condenser charged with 16·9 volts.
−110·0	6·0	7·25	Condenser charged with 17·0 volts.

III. *Dielectric Constant of Dry Concentrated Nitric Acid* (NO_3H).

Corrected galvanometer deflection with air as dielectric = 3·90 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−201·7	9·05	2·36	Condenser charged with 94·2 volts.
−182·7	9·27	2·46	
−165·8	9·25	2·42	
−118·2	9·40	2·45	
−129·7	10·00	2·62	

Before carrying out these experiments with the concentrated nitric and sulphuric acids the condenser had been carefully re-gilt and a glass steady-pin substituted for the ebonite one.

IV. *Dielectric Constant of Sodium Fluoride* (NaF).

(10 per cent. solution.)

Corrected galvanometer deflection with air as dielectric = 4·04 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−199·3	9·3	2·33	Condenser charged with 94·2 volts.
−174·2	9·3	2·35	
−149·2	10·35	2·55	
−135·0	14·35	3·67	
−125·0	19·6	5·05	
−115·7	4·4	7·07	Condenser charged with 15·2 volts.

The electrical resistance of the condenser at −200 *pt.* with frozen sodic fluoride as dielectric was 2000 megohms.

V. *Dielectric Constant of Hydrosodic Fluoride* (NaFHF).

(10 per cent. solution.)

Corrected galvanometer deflection with air as dielectric = 3·42 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−201·8	8·87	2·28	
−186·0	8·87	2·25	
−169·0	8·95	2·30	
−178·8	9·0	2·31	
−148·8	9·7	2·49	
−142·2	10·9	2·79	
−131·5	15·4	4·02	

VI. *Dielectric Constant of Sodium Peroxide* (Na_2O_2).

(5 per cent. solution.)

Corrected galvanometer deflection with air as dielectric = 4·41 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−198·0	4·5	71	Condenser charged with 1·434 volts.
−184·5	5·5	87	

VII. *Dielectric Constant of Solution of Hydroxyl* (H_2O_2).

(20 per cent. solution by volume.)

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−203·5	10·8	2·38	Condenser charged with 99·2 volts.

Some experiments were then made by electrolysing freely certain electrolytes and freezing them with liquid air in the act of electrolysis. The dielectric constants were then subsequently determined in the frozen state.

VIII. *Dielectric Constants of Frozen Electrolytes, Electrolysed freely in the act of Freezing.*

Corrected galvanometer deflection with air as dielectric = 3·42 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
	(*a*) 5 per cent. aqueous solution of potassic hydrate electrolysed with 0·2 ampere and 8 volts. Evolved gas = 5·1 c.c.		
−200·0	3·85	71·4	Condenser charged with 1·434 volts. Electrical resistance of condenser 5000 megohms when frozen.
	(*b*) Water electrolysed with 1·0 ampere.		
−198·2	8·70	2·47	Condenser charged with 98 volts. Electrical resistance of condenser 5000 megohms when frozen.
	(*c*) Water electrolysed with 2·1 amperes.		
−198·0	8·65	2·42	Condenser charged with 98·9 volts.

It is evident that the action of electrolysis prior to, and during freezing has no sensible effect on the subsequently measured dielectric constant even though the surfaces of the cone condenser are strongly polarised in the act of freezing the liquid dielectric.

We have then paid some attention to the possible cause of the high dielectric values of some substances at very low temperatures. It is clear from the above described experiments with the Nernst bridge that for organic bodies such as ethylic alcohol, amyl alcohol, ethylic ether, and glycerine we obtain practically the same dielectric values at the low temperature, both when they are measured by the galvanometric method with a switch frequency of 120, and when measured by Nernst's method with a frequency of 350, or about three times as great.

On the other hand for certain other bodies such as the frozen dilute hydrates of potassium and rubidium, and the oxide of copper suspended in ice, the dielectric value at the low temperatures is much diminished by increasing the frequency.

Subsequently to the completion of the experiments described in this paper the suggestion has been made by R. Abegg* that the high dielectric values at low temperatures are due to polarization of the

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* 'Wied. Ann.,' vol. 62, p. 249.

electrodes of the condenser, and that the capacity measured is a polarisation capacity and not a true dielectric capacity, and he supports this contention by pointing out that whenever we have obtained a large dielectric value at the low temperature it has always been measured with an electromotive force of 1·434 volts, which is less than the ordinary full reverse electromotive force of polarization.

There are, however, reasons for considering that this contention is not a valid one. In the first place we have always in all the measurements begun operations by testing the dielectric capacity of our condenser with an electromotive force of one Clark cell (= 1·434 volts) in order to see roughly whether the dielectric value was large or small. If it was a small value we then gradually increased the electromotive force until a good readable galvanometer deflection was obtained. We never found that with an electromotive force of 1·434 volts, the dielectric constant of any substance was greater than with a much higher voltage.

In the next place, in many cases we changed from a working electromotive force of about 20 volts to one of 1·434 volts, and we never found any marked discontinuity in the calculated value of the dielectric constant at that point. If our previous papers on this subject are examined the following instances may be found.

Table VII.—Measurement of various Dielectric Constants with different Electromotive Forces.

Substance.	Temperature.	Dielectric constant.	Voltage with which constant was measured.	Reference.
Ice	− 89·4	27·6	19·8	'Roy. Soc. Proc.,' vol. 61, p. 318.
	− 87·2	29·0	1·4	
,, ...	−124·2	18·1	20·3	*Ibid.*, p. 321.
	−119·2	21·8	1·4	
Sodic chloride, 10 p. c. solution..	−118·5	21·2	20·2	*Ibid.*, p. 307.
	−114·0	22·3	1·4	
Potassic chromate, 30 p. c. solution..	−112·4	16·9	20·0	*Ibid.*, p. 387.
	−100·0	22·3	1·4	
Cupric carbonate, 10 p.c. suspension	−124·7	16·5	18·2	*Ibid.*, p. 390.
	−120·8	21·8	1·4	
Baric hydrate, 5 p. c. suspension	−178·0	23·9	19·5	*Ibid.*, p. 372.
	−174·2	25·5	1·4	
Bismuth oxide, 10 p.c. suspension	−129·2	19·9	17·8	*Ibid.*, p. 376.
	−127·3	24·5	1·4	

An examination of the above instances will show that if the electromotive force is changed from about 20 volts to 1·4 volts, it does not make a greater difference in dielectric constant than can be properly ascribed to the accompanying change in temperature.

[Again the following measurements were made at about the same voltage :—

Substance.	Temperature.	Dielectric constant.	Charging voltage.
Potassic Bicarbonate ...	−166·5	2·80	19·8
Sodic Bicarbonate	−166·7	48·70	19·8
Ferric Chloride........	−133·8	4·23	19·8
Sodic Chloride.........	−129·2	14·55	20·2
Cupric Carbonate	−132·7	3·42	18·2
Cupric Sulphate	−133·2	16·40	19·7
Lithic Hydrate	−198·0	3·23	19·8
Baric Hydrate	−196·8	20·10	19·5

It is unlikely that polarisation accounts for the differences between the dielectric constants of the above substances, taken pair and pair, when measured at nearly identical temperatures, and very nearly the same voltages.—*November* 8, 1897.]

In order to settle the matter finally we propose, however, to remeasure a number of those substances which have shown high dielectric values at the low temperature when measured by the galvanometric method at a frequency of 120 but using in all cases an electromotive force of 100 volts.

If under the larger electromotive force the dielectric values of some electrolytes still remain large, it will be difficult to ascribe this large value to polarization.

The facts, however, admit of another interpretation. It is clear that the dielectric constants of some substances at low temperatures are vastly more susceptible to change of electromotive force frequency than is the case with others, and that the electric strain produced by a given electric stress varies in some cases enormously with the time of imposition of the stress but very little in others.

Another argument against the view that these high dielectric values are due to polarisation, as ordinarily understood, is as follows: The results of most numerous experiments on water show that the dielectric constant at or near 0° C., is a number not far from 80. This value is obtained whether the electromotive force reversals are infinitely slow or whether they are very large. The results of the measurement of the electrical refractive index of water even with ether waves only 4 mm. in length, and, therefore, having a frequency of about $7·5 \times 10^{10}$, as given recently by Lampa,* indicate a number not far from 9·5 as the refractive index and hence give a dielectric value of 90. There can be no question of polarisation of electrodes in this last case. On the other hand an increase

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* 'Wien. Ber.,' Part 2*a*, p. 587, 1896; also p. 1049, 1897.

in frequency which hardly affects the value of the dielectric constant of water is sufficient to greatly decrease that of ethylic alcohol, and at the same frequency the dielectric constant of ethylic alcohol was found by Lampa to have fallen to a value of 5. Hence ethylic alcohol is more sensitive to change of frequency than water. There is, therefore, no *a priori* reason why we might not expect to find the same thing even in a much greater degree in certain other bodies at lower temperatures, viz., a true high dielectric value for a certain frequency, but great sensitiveness to increase of frequency in such fashion that increase of frequency greatly reduces the dielectric value. At the present stage of the enquiry it seems undesirable to endeavour to regard the facts wholly from the point of view of one hypothesis as to the nature of electrolysis.

We have again to mention with pleasure the assistance we continue to receive from Mr. J. E. Petavel in the observational part of these investigations.

Note added December 8, 1897. Received December 9, 1897.

Since the above paper was printed we have repeated some of our former experiments with the 5 per cent. solution of rubidic hydrate and the 5 per cent. solution of potassic hydrate, using the original method in which a condenser having the frozen electrolyte as dielectric is charged and discharged through a galvanometer, but employing much higher charging voltages. The object of these experiments was to apply a further test as to the validity of the contention put forward by R. Abegg, that we have obtained high dielectric values for certain of these frozen electrolytes in consequence of having invariably used an electromotive force of 1·434 volts in the experiments with these particular substances. In order to be able to work with larger electromotive forces we arranged three galvanometers of the Holden d'Arsonval type otherwise exactly similar, except in having different sensibilities and resistances. One was the 500-ohm galvanometer used in all our previous condenser experiments, another was a 100-ohm coil galvanometer, and a third was a 4-ohm coil galvanometer. These were used at the same distance (125 cm.) from the scale as formerly. An approximate test for the relative sensibility of these galvanometers was made by placing a Clark standard cell in series with each galvanometer through 100,000 ohms and noting the scale deflection produced. As the internal resistance of the galvanometers was at most only $\frac{1}{2}$ per cent. of the total resistance these scale deflections may be considered to be approximately produced by the same current. The scale deflections in centimetres were—

For the 500-ohm galvanometer....	37·3 cm.
„ 100-ohm „	6·7 „
„ 4-ohm „	0·55 „

Hence, the sensibilities are in the ratios of these deflections, and the deflections of the 100-ohm galvanometer must be multiplied by 5·5, and those of the 4-ohm galvanometer by 67·8, to reduce their scale readings to equivalent deflections in terms of the 500-ohm galvanometer.

The 500-ohm galvanometer was then used with the condenser and vibrator, as described in one of our previous papers.* The condenser having gaseous air as dielectric, the scale deflection for a frequency of 120 and an electromotive force of 97 volts was 3·2 cm. when corrected for capacity of leads.

The condenser then had its dielectric space filled with the 5 per cent. solution of rubidic hydrate, and was frozen in liquid air. The dielectric constant was next measured, using an electromotive force of 17·8 volts and the 500-ohm galvanometer. The value of the dielectric constant found, when corrected for the capacity of the leads, was 65·6. The mean corrected scale deflection was 38·5 cm. for 17·8 volts. This, reduced to its equivalent for 97 volts, is 210 cm. and 210/3·2 = 65·6.

In the next place the same experiment was repeated employing the 100-ohm galvanometer and an electromotive force of 79 volts. Applying the necessary corrections to the observed scale deflection of 23·5 cm., and reducing to the equivalent deflection on the 500-ohm galvanometer, gave 160 cm. as the value of the reduced deflection. Hence 160/3·2 = 50 is the dielectric constant. The rather considerable difference between these values (65·6 and 50) is not a matter for surprise, having regard to the extreme steepness of the dielectric curve of the rubidic hydrate solution at about the temperature of liquid air. As we were merely desirous of determining whether a considerable increase of electromotive force would greatly diminish the large dielectric value, we did not trouble to put in operation the rather elaborate platinum thermometer arrangements for determining the exact temperature of the dielectric. A reference to the dielectric-temperature curve of rubidium hydrate† will show that even one or two degrees of temperature change in the neighbourhood of −185° C., or −200° pt. makes a very considerable alteration in the dielectric value. The result, however, ascertained is that changing the electromotive force from 1·434 volts to 17·8 or 79 volts does not bring down the dielectric constant from a large value to a small one.

In the same way the 5 per cent. solution of potassic hydrate was tested.

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* 'Roy. Soc. Proc.,' vol. 61, p. 300, 1897.

† *Ibid.*, p. 378.

Using the 500-ohm galvanometer and an electromotive force of 9·88 volts we found 153 as the dielectric constant of the frozen electrolyte at the temperature of liquid air. Employing the 4-ohm galvanometer and 79·5 volts we found 175 as the dielectric constant.

All the above observations were taken at the temperature of liquid air and with an electromotive force frequency of 120. It is, therefore, quite clear that as far as these two frozen electrolytes are concerned, raising the charging voltage to a value far above that of the average electromotive force of polarisation does not bring down these abnormal values of the dielectric constant. On the other hand, a relatively small decrease in the temperature or *increase in the frequency at low temperatures* suffices to reduce the dielectric value of these frozen hydrates very considerably.* We may, therefore, say that the contention put forward by R. Abegg that the high dielectric values we have found for certain substances at the liquid air temperature are really polarisation capacities, does not seem to be borne out by the results of further experiment, and for the following reasons :—

(i) Because a very great increase in the charging electromotive force does not in any corresponding degree reduce the abnormally high dielectric values of certain frozen electrolytes to much smaller values.

(ii) Because when in the course of observations to construct a temperature dielectric curve, the working electromotive force has been changed from a value below the counter-electromotive force of polarisation to a value far above it, there is no break or discontinuity in the curve of dielectric value.

(iii) Because the great difference between quite similar electrolytes, such as the 10 per cent. solution of potassic and sodic carbonates, in respect of dielectric constant at equally low temperatures and under equal charging electromotive forces is left unexplained.

(iv) Because in the case of many substances, such as frozen ammonic hydrate, ice, and oxide of copper in suspension in ice, at very low temperatures, we find high dielectric values even though employing alternating currents of fairly high frequency (350 ∼).

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* The effect of increased frequency of electromotive force reversals in decreasing the dielectric constant is evidently dependent upon the temperature as well as on the physical state of the body. In the case of water an increase in the frequency from zero to 10^6 hardly affects the dielectric constant at all. In the case of ice at 0°C. the same increase in frequency reduces the dielectric constant from 80 to between 2 and 3. In the case of ice at −50°C., as we have shown above, an increase in frequency from 120 to 350 reduces the dielectric constant from about 60 to about 3·6. (December 21, 1897.)

(v) Because the high dielectric values of water and alcohol and other bodies at ordinary temperatures remain, even when the observations are taken with alternating electromotive forces of exceedingly high frequency and under conditions when there are no electrodes to polarise, as when the electric refractive index is measured with electromagnetic radiation.

We consider that the results of observations so far made are best expressed by merely considering the dielectric constant to be a function of the frequency and the temperature, and represented therefore by a *dielectric surface*, which surface has for some substances a region of abnormal dielectric ordinate.

In all cases so far examined by us, lowering the temperature sufficiently acts in the same manner in reducing the dielectric constant as sufficiently increasing the frequency, and both actions reduce the abnormally large dielectric values of some substances to values more approximately equal to the square of the optical refractive index of the body.

The question then to be considered is the physical reason for the high dielectric values for particular substances for certain ranges of electromotive force frequency and temperature. Whether this abnormal electric displacement is considered to be the result of a molecular strain superimposed on a true electric strain, or whether it is the beginnings of that molecular deformation which finally ends in chemical decomposition, remains to be seen. Having regard to the enormously high electrical resistivity which we have shown these frozen dielectrics to possess, it does not appear to us likely that polarisation in the sense of a deposition of ions on the electrodes can be invoked to explain the differences we have shown exist.

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nerve given in the third column, both the commencement and the culmination of the initial change are retarded, the propagation rate in this nerve at a temperature of 6° C. being slowed to 6 metres per second. A comparison of the fourth and fifth columns shows the retardation in the anodic as compared with the acceleration in the cathodic extrapolar region. Finally the time relations and the relative E.M.F. of the prolonged effect present in the instances given in the second and fourth columns may be compared with those of the initial change present in all the examples. It will be seen that the change producing the prolonged tail of the photographic record is one which differs from that producing the initial spike in the following important particulars: it develops slowly, taking from 0·006 to 0·01 second to culminate, its maximum E.M.F. is only one-tenth of that of the initial change, and it subsides slowly. It is not present in the instances given in columns I, III, and V.

In a more extended communication the authors hope to bring forward other features of the response of nerve, particularly the characters exhibited by the records of the changes produced by a series of stimuli and of those produced during reflex discharge of the central nervous system.

"On the Magnetic Susceptibility of Liquid Oxygen." By J. A. FLEMING, M.A., D.Sc., F.R.S., Professor of Electrical Engineering in University College, London, and JAMES DEWAR, M.A., LL.D., F.R.S., Fullerian Professor of Chemistry in the Royal Institution, London, &c. Received May 9,—Read May 12, 1898.

In a previous communication* we have described the initial investigations made by us to determine directly the numerical value of the magnetic permeability of liquid oxygen, and we there indicated that we hoped before long to present to the Royal Society the results of other experiments made by a different physical method which we anticipated would enable us to state whether liquid oxygen has a constant magnetic susceptibility, or whether, like a ferromagnetic substance, its magnetic susceptibility alters when subjected to different magnetic forces.

We have recently obtained results which, though limited to a certain range of force, we think afford fairly trustworthy values of the magnetic susceptibility of liquid oxygen under magnetising forces varying from 500 to 2500 C.G.S. units, and place them therefore on record.

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* 'Roy. Soc. Proc.,' 1896, vol. 60, p. 283, "On the Magnetic Permeability of Liquid Oxygen and Liquid Air."

The method used by us in these last experiments depends on the well-known fact that if a body, either paramagnetic or diamagnetic, is placed in a magnetic field of variable strength, it is subjected to a mechanical force tending to displace it in the direction in which the field varies most rapidly.

If the susceptibility of the body is so small that it does not sensibly disturb the distribution of the field, the measurement of this mechanical force may be made to furnish a knowledge of the absolute value of the magnetic susceptibility.

The necessary conditions are, however, that the volume (V) of the body must be of such small magnitude relatively to the form of the field that its magnetisation is not sensibly different from that which it would obtain if immersed in a uniform field, and also that the magnetic susceptibility (k) of the substance must be of small absolute value. Under these circumstances, if f is the mechanical force (reckoned in dynes) acting on the body, and H is the strength of the field at its centre, then the force in the direction x is given by the equation

$$f = k\mathrm{VH}\frac{d\mathrm{H}}{dx}.$$

The value k thus determined is a difference value, that is, it is equal to the difference between the susceptibility of the body and that of the medium in which it is immersed. Hence if one and the same body is placed in the same divergent field, but alternately surrounded by different media, the difference in the apparent susceptibilities of the body in the two cases will give us the difference of the true susceptibilities of the media. The experimental method employed by us consisted, therefore, in determining the forces acting on a small sphere of known susceptibility when suspended first in air, and next in liquid oxygen, and hence deducing the difference of the susceptibility of liquid oxygen and air, and therefore the absolute value of the susceptibility of liquid oxygen, knowing that of air.

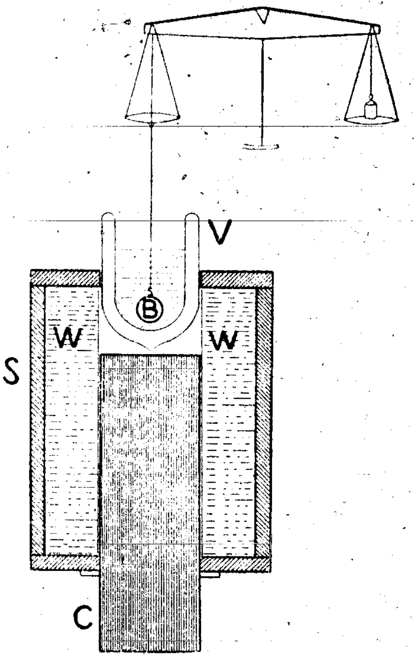
The first step was the construction of an electro-magnet capable of producing the required field. From the above-named conditions of success it will be seen that since the volume and susceptibility to be measured are both small, it is essential that the magnetic field shall not only be large but must vary very rapidly, or else the forces to be measured will be small.

An electro-magnet giving the required field was therefore designed as follows:—

The exciting bobbin consists of a single coil of double cotton-covered copper wire, No. 14 S.W.G. in size.

The coil is 30 cm. long, 18·5 cm. in outside diameter, and the aperture in the coil 9·5 cm. in diameter. The total weight of double cotton-covered copper wire on the bobbin is 71 lbs., and the total length of wire is roughly about 3300 feet. The total number of turns of wire on the bobbin is 2478. The wire is capable of carrying 12 or 14 amperes for considerable periods of time without dangerous heating. The total resistance of the wire is very nearly 5·5 ohms at 20° C.

This bobbin of wire is enclosed in a cylinder of mild steel of the same height as the bobbin, the walls of which are 2·5 cm. thick. This cylinder has movable circular end plates of steel 2·5 cm. in thickness fitting it, and in these plates are circular holes 9 cm. in diameter. A soft steel core was also provided, 37 cm. in length and 9 cm. in diameter, and having steel studs screwed into it so that the core could be held in he position shown in the diagram. The end surface of the inner core was 7·5 cm. below the upper surface of the wire coil. The steel used is high permeability magnet steel.



V, vacuum vessel; B, ball weighed; W, wire windings of magnet; S, C, steel shell and magnet core.

On passing a current through the magnet coils a magnetic field is created in the space just above the upper end of the inner steel core, which is very divergent, and which is not only strong, but varies very rapidly in an axial direction.

This magnet was placed underneath a shelf on which stood a very sensitive short-beam chemical balance capable of weighing to one-tenth of a milligram. From one pan depended a fine wire passing through a hole in the balance case and shelf, and served to suspend a ball just within the field of the magnet.

If the ball was counterpoised by weights and the magnet then excited, the ball was subjected to an upward or downward force which either decreased or increased its apparent weight, according as it was diamagnetic or paramagnetic. If W is the gain or loss in weight on exciting the magnet, V the volume of the ball, H the strength of the field at its centre, and dH/dx the rate of change of the field in a vertical direction, then the equation

$$.981W = k_1 VH \frac{dH}{dx}$$

gives us the value of the apparent magnetic susceptibility (k_1) in air of the body weighed.

In order to apply the method we require to know the value of the field H at different parts along the vertical axis of the magnet and also the value of the field for various exciting currents.

A careful preliminary investigation on this point was therefore made. Constant currents varying from 1 to 12 or 14 amperes were passed through the magnet coils and by means of a small secondary coil attached to a calibrated ballistic galvanometer the field strength at various points in the vertical central axis of the magnet was measured. These measurements extended from close contact with the magnet core to a point about 10 cm. above the end surface of the recessed polar end of the inner steel core.

The distance in centimetres of any point from the end polar surface of the inner steel core is denoted by x, this measurement being made as exactly as possible along the central vertical axis of the magnet. The strength of the field at this point in C.G.S. units is denoted by H, and the space rate of change in the x direction by dH/dx.

The following tables give the exciting currents (A) in amperes measured by a Weston ammeter, No. 3134, and the values of x and H.

The value of dH/dx at any point can be at once determined from the curve of H in terms of x.

Table I.—Magnetisation Curves of Tubular Electromagnet, the Induction Density or Field being measured at a point x centimetres from the Pole Face on the Axial Line.

Exciting current by Weston ammeter, No. 3134.	True current in amperes. A.	Induction density (H) at various distances x from the pole.		
		x = 0·15 cm.	x = 2·70 cm.	x = 5·25 cm.
15	15·15	4374	—	—
14	14·141	4200	—	—
13·9	14·040	—	3269	—
13	13·127	4054	3194	—
12	12·094	3848	3070	2002·5
11	11·124	3648	2888	1897
10	10·075	3407	2712	1782·5
9	9·082	3194	2543	1682
8	8·059	3014	2310	1557
7	7.059	2764	2153	1418·5
6	6·020	2504	1957	1273
5	5·015	2220	1740	1139
4	3·968	1884	1459	955·5
3	2·994	1481	1161	749
2	1·958	992	767	491·5

The induction density or field along the axial line was also measured for two constant excitations corresponding to currents of 12·094 and 6·020 amperes at various distances along the axial line, and the results are given in Table II.

The results in Tables I and II were then set out carefully in a curve, and from these curves an interpolation table constructed, showing the axial field at various points on the axis for different exciting currents, and these values are given in Table III.

Having calibrated the magnet, the following objects were provided to be used as bodies to weigh in the field, viz.:—

(1) A silver ball, (2) a rather smaller copper ball, (3) several hollow glass balls containing a little mercury, and (4) a bismuth ball.

In order to test the method and obtain confidence in the results, we made a number of preliminary measurements on the magnetic susceptibility of water, solutions of manganese sulphate, and ferrous sulphate of known densities.

These experiments were made by weighing the silver ball or hollow glass ball when immersed in these liquids contained in a beaker placed in the field cavity of the magnet.

Five weighings were always made—

(1) The weight of the ball in air, magnet not excited.

(2) The apparent weight of the ball in air, magnet excited.

(3) The apparent weight of the ball in water, magnet not excited.

(4) The apparent weight of the ball in the solution used, magnet not excited.

(5) The apparent weight of the ball in the liquid, the magnet being excited with a known current, and the position of the ball in the field accurately known.

From these weighings we obtain all the required information. For from (1) and (3) we obtain the volume of the ball, and from (1), (2), and (3) the magnetic susceptibility of the ball, and from (4) and (5) the magnetic susceptibility of the liquid.

The sphere used as a testing substance was suspended by a long fine platinum or gold wire from one pan of the balance. A small beaker filled with water or the salts solution under test was placed over the pole of this magnet and the sphere suspended in it.

In some cases when using strong exciting currents we found it

Table II.—Induction Densities (H) of Field of Tubular Electromagnet at various distances x along the Axial Line.

Distance from pole face $= x$ cm.	Field = H in C.G.S. units.	
	For 6·020 amperes.	For 12·004 amperes.
0·15	2485·5	3853
0·58	2475·5	3825
1·01	2404	3711
1·44	2307·5	3582
1·87	2196·5	3419
2·30	2068	3225
2·73	1935	3016
3·16	1794	2830
3·59	1666	2624
4·02	1557	2453
4·45	1455·5	2291
4·88	1346	2128
5·31	1253	1960
5·74	1151·5	1820
6·17	1052	1666
6·60	965·5	1521
7·03	867	1385
7·46	770	1260
7·89	680	1099
8·32	596	955
8·75	509·5	805
9·10	425	681
9·61	356·5	564
10·04	294·5	462
10·47	231·4	368
10·91	189·9	289
11·33	142·1	228
11·76	114·2	175

Table III.—Summary of Results of Field Measurements of Axial Field of Tubular Electromagnet.

Current by Weston ammeter, No. 3134.	Distance from pole face on axial line.			Ratios of induction density or field H to field corresponding to 6·0 or 12·0 true amperes.		
	0·15 cm.	2·70 cm.	5·25 cm.	0·15 cm.	2·70 cm.	5·25 cm.
0	0	0	0	0	0	0
2	994	762	492	0·3989	0·3908	0·3862
3	1476	1148	742	0·5923	0·5887	0·5825
4	1778	1460	952	0·7135	0·7487	0·7473
5	2220	1726	1128	0·8908	0·8852	0·8854
6	2492	1950	1274	1·0000	1·0000	1·0000
7	2760	2158	1422	1·1075	1·1066	1·1161
8	2996	2346	1556	1·2022	1·2031	1·2213
9	3226	2534	1678	1·2945	1·2995	1·3171
9	3226	2534	1678	0·8402	0·8363	0·8466
10	3438	2712	1782	0·8954	0·8950	0·8991
11	3650	2880	1890	0·9506	0·9504	0·9536
12	3840	3030	1952	1·0000	1·0000	1·0000
13	4028	3178	2080	1·0490	1·0488	1·0494
14	4208	3320	2168	1·0959	1·0957	1·0939
14·5	4292	3390	2210	1·1177	1·1188	1·1153
15	4374	3460	2254	1·1391	1·1420	1·1372

necessary to pack round the beaker of liquid with crushed ice in order to keep the temperature of the water or solution from being raised by radiation of heat from the magnet coils. Any rise of temperature in the liquid under test, by causing variation in density, introduces a difficulty in obtaining exact and comparable weighings of the ball.

The position of the ball in the magnetic field was very carefully adjusted, so that the centre of the ball was as nearly as possible on the axial line of the magnet. The distance of the centre of the ball from the end of the magnet core was also measured with as much accuracy as possible when the balance was lifted off its supports, and yet the balance index was in the zero position.

The distance from the pole face measured in centimetres is called the *distance from the pole* in the following tables. Corresponding to this distance (x) we know from the preliminary experiments and the results given in Tables I, II, and III the strength of the magnetic field (H) and its axial rate of variation dH/dx.

The dimensions and weights of the balls used were as follows:—

Ball made of	Weight in grams.	Diameter in cm.	Density.	Volume in c.c. at 15° C.	Volume in c.c. at −182° C.	Mean coefficient of cubical expansion between 0° C. and −182° C.
Silver	132·010	2·90	10·334	12·775	12·654	0·0000518
Copper	37·610	2·00	9·92	4·226	4·190	0·0000427
Bismuth	62·220	2·27	9·836	6·326	6·287	0·0000320
Glass ball containing mercury, No. 1 ..	18·663	2·32	—	6·539	6·513	0·0000200
Glass ball containing mercury, No. 2 ..	3·400	1·40	—	1·462	1·456	"
Glass ball containing mercury, No. 3 ..	32·500	2·68	—	10·343	10·340	"
Glass ball containing mercury, No. 4 ..	5·95	1·03	—	0·588	0·586	"

In each case a measurement was made of the magnetic susceptibility in air of the ball used, by weighing it in a known magnetic field and observing the loss or gain in weight.

In this manner the following determinations were made:—

The Magnetic Susceptibility of the Silver Ball.

Weight of silver ball in air at 15° C. = 132·010 grams.
Weight of silver ball in water at 2° C. = 119·235 grams.
Volume of silver ball at 15° C. = 12·775 c.c.

	I.	II.	III.	IV.
Loss in weight in grams of silver ball when weighed in field = W......................	0·0287	0·0284	0·0142	0·0132
Exciting currents of magnet in ampères	12	12	6	6
Magnetic field in C.G.S. units = H..........................	3320	2820	1798	2206
Field variation = $d\text{H}/dx$......	426	459	308	258
Distance of centre of ball from pole in cm....................	1·96	3·18	3·18	1·83
Calculated apparent susceptibility = $k^1 10^{-6}$	1·56	1·68	1·97	1·78

The absolute magnetic susceptibility of air is $0{\cdot}024 \times 10^{-6}$.

The mean apparent susceptibility of silver in air is therefore from the above figures equal to $-1{\cdot}75 \times 10^{-6}$, and the absolute value $k = -1{\cdot}73 \times 10^{-6}$.

E. Becquerel gives $-1{\cdot}74 \times 10^{-6}$ as his observed value for silver.

The Magnetic Susceptibility of the Bismuth Ball.

Weight of bismuth ball in air at 15° C. = 62·220 grams.
Volume of bismuth ball at 15° C. = 6·326 c.c.

	I.	II.	III.
Loss in weight in grams of bismuth ball when weighed in field = w ...	0·085	0·067	0·030
Exciting current of magnet in amperes ...	14·5	12	6
Magnetic field ...	2383	2135	1355
Field variation ...	415	372	236
Distance of centre of ball from pole = x in cm. ...	4·86	4·86	4·86
Calculated apparent susceptibility = $k'10^{-6}$ ...	−13·4	−13·3	−14·6

The absolute magnetic susceptibility of air is $0{\cdot}024 \times 10^{-6}$. The mean apparent susceptibility of bismuth in air is, therefore, from the above figures equal to $-13{\cdot}77 \times 10^{-6}$, and the absolute susceptibility $k = -13{\cdot}75 \times 10^{-6}$.

Recent values found by other observers are $-13{\cdot}4 \times 10^{-6}$ (P. Curie), and $-13{\cdot}3 \times 10^{-6}$ (L. Lombardi). Hence our own is in accordance with these.

The Magnetic Susceptibility of the Copper Ball.

Weight of copper ball in air at 15° C. = 37·610 grams.
Volume of copper ball ~~in air at~~ 15° C. = 4·226 c.c.

	I.	II.	III.	IV.
Gain in weight ~~in grams~~ of copper ball in field ...	0·009	0·005	0·0055	0·0035
Exciting currents of magnet in amperes ...	6	3	6	3
Magnetic field ...	1220	709	518	298
Field variation ...	227	132	193	111
Distance of centre of ball from pole in cm. ...	5·46	5·46	8·72	8·72
Calculated apparent susceptibility = $k'10^{-6}$ ...	+7·6	+12·5	+12·9	+28

The copper ball proved to be ferromagnetic, owing, no doubt, to traces of iron. We constructed a curve by which its susceptibility in various fields could be deduced from the above observations, but the only reason we employed it was because it seemed desirable to determine the absolute susceptibility of the liquid oxygen with bodies as far as possible different in susceptibility. Hence we selected silver, bismuth, and the above slightly ferromagnetic copper ball for the purpose.

The Magnetic Susceptibility of various Glass Balls partly filled with Mercury.

	No. 1 ball.	No. 2 ball.	No. 3 ball.	No. 4 ball (nearly full of mercury).
Gain or loss in weight in grams of ball when weighed in field	−0·001	This ball proved to be quite neutral in the strongest field we could produce	−0·0044	−0·0007
Exciting current of magnet in amperes	6	—	12	12
Magnetic field	1330	—	3180	2418
Field variation ...	231	—	474	391
Distance of centre of ball from pole of magnet in cm.	4·96	—	2·38	4·115
Calculated apparent susceptibility = $k^{1}10^{-6}$....	−0·5	zero	−0·277	−1·23

We have, then, the following data for the glass balls:—

	No. 1 ball.	No. 2 ball.	No. 3 ball.	No. 4 ball.
Weight in grams...	18·663	3·400	32·500	5·95
Volume in c.c. at 15° C.	6·539	1·462	10·3427	0·5882
Diameter in cm. ...	2·32	1·40	2·68	1·03
Absolute magnetic susceptibility in vacuum.........	$-0\cdot48 \times 10^{-6}$	$-0\cdot024 \times 10^{-6}$	$-0\cdot25 \times 10^{-6}$	$-1\cdot21 \times 10^{-6}$

As a further check on the method we employed the above determinations of the susceptibilities of the silver and glass ball, No. 3, to obtain the value of the susceptibility of distilled water. The measurements were as follows:—

Magnetic Susceptibility of Water.

I, with silver ball $\begin{cases}\text{susceptibility of ball} = -1{\cdot}73 \times 10^{-6}. \\ \text{volume of ball} = 12{\cdot}775 \text{ c.c.}\end{cases}$

II, with glass ball, No. 3 $\begin{cases}\text{susceptibility of ball} = -0{\cdot}25 \times 10^{-6}. \\ \text{volume of ball} = 10{\cdot}3427 \text{ c.c.}\end{cases}$

	I.	I.	II.
Gain or loss in weight of ball when weighed in field and in water	−0·0146 gram loss	−0·0163 loss	+0·0053 increase
Exciting currents of magnet in amperes...........................	12	14·5	12
Magnetic field	2802	2848	3180
Field variation....................	456	465	474
Distance of centre of ball from pole of magnet in cm..................	3·22	3·79	2·38
Apparent susceptibility of ball in water = $k'10^{-6}$................	−0·878	−0·945	+0·333

The absolute susceptibility of water is, therefore,

$$-(1{\cdot}73-0{\cdot}88)10^{-6} = -0{\cdot}85 \times 10^{-6}$$

and $-(1{\cdot}73-0{\cdot}94)10^{-6} = -0{\cdot}79 \times 10^{-6}$ from the experiments with the silver ball; and $-(0{\cdot}333 + 0{\cdot}253)10^{-6} = 0{\cdot}59 \times 10^{-6}$ from the experiments with the glass ball No. 3. The mean of these values gives $-0{\cdot}74 \times 10^{-6}$ as the absolute susceptibility of water. The following are some of the values obtained for the magnetic susceptibility of water by older and by more recent observers.

Observer.	Value of $k\,10^{-6}$ for water.
Faraday	0·72
E. Becquerel	0·67
P. Curie	0·79
Townsend..................	0·77
Quincke	0·81
Du Bois	0·84
Mean value =	0·77

Hence our value for water $0{\cdot}74 = k10^{-6}$ is not far from the mean of the above results.

Many other experiments were then made with various solutions of salts of iron and manganese, which satisfied us that we could place reliance upon the results of this method in measuring the magnetic susceptibility of a liquid, and we then proceeded to experiments with liquid oxygen.

The balls were accordingly all weighed in liquid oxygen contained in a vacuum vessel placed over the pole piece of the magnet. This vacuum vessel contained mercury in its vacuum space and was of an unusually excellent kind. In it liquid oxygen could be preserved for periods of many hours without a trace of ebullition, and no difficulty was experienced in making the weighings with great accuracy. These weighings of course served also to determine the density of the liquid oxygen used. The results are embodied in the following tables.

In each case the weighings give the apparent susceptibility of the liquid oxygen, and these figures have to be corrected by adding or subtracting a number representing the absolute susceptibility of the ball at the liquid oxygen temperature. Thus in the case of the silver ball the figure subtracted is two, as the nearest integer representing the susceptibility of silver at −182° C. In the case of the bismuth ball the figure subtracted is sixteen, in the case of the glass balls it is zero or at most unity, and in the case of the copper ball the correction is additive, depending on the value of the field.

Table V.—Determinations of the Magnetic Susceptibility of Liquid Oxygen.

1. *With the Silver Ball.*

Volume of ball = 12·684 c.c. at temperature of liquid oxygen.
Density of liquid oxygen = 1·1376.
Distance of centre of ball from pole of magnet = 5·37 cm.
Magnetic susceptibility of silver ball = $1{\cdot}73 \times 10^{-6}$.

Exciting current by Weston ammeter, No. 3134.	Field. H.	Field variation dH/dx.	Loss in weight of ball in grams., W.	Apparent susceptibility, $k_1 10^{-6}$.	Absolute susceptibility of liquid oxygen, $k 10^{-6}$.
15	2218	408	3·7585	322	320
14·5	2174	400	3·6242	323	321
12	1950	359	2·8845	319	317
9	1646	302·5	2·0365	317	315
6	1242	228	1·2303	337	335
4	928	170·4	0·6855	336	334
3	723	132·7	0·4213	343	341

Mean value of susceptibility of liquid oxygen as determined with the silver ball = 326×10^{-6}.

II. *With the Bismuth Ball.*

Volume of ball at temperature of liquid oxygen = 6·287 c.c.
Density of liquid oxygen = 1·1397.
Distance of centre of ball from pole = 4·865 cm.
Magnetic susceptibility of bismuth ball = $13·75 \times 10^{-6}$ at 15° C.
" " " = $15·9 \times 10^{-6}$ at −182° C.

Exciting current by Weston ammeter.	Field.	Field variation.	Loss in weight of ball in grams.	Susceptibility, $k_1 10^{-6}$.	Absolute susceptibility of liquid oxygen, $k 10^{-6}$.
12	2135	373	1·655	325	309
6	1356	236	0·705	344	328

Mean value of susceptibility of liquid oxygen as determined with the bismuth ball = 319×10^{-6}.

III. *With the Copper Ball.*

Volume of ball at temperature of liquid oxygen = 4·190 c.c.
Density of liquid oxygen = 1·140.
Distance of centre of ball from pole = 5·46 cm.
Magnetic susceptibility (varies from 8×10^{-6} to 15×10^{-6}).

Exciting current by Weston ammeter.	Field.	Field variation.	Loss in weight of ball in grams.	Apparent susceptibility, $k_1 10^{-6}$.	Absolute susceptibility of liquid oxygen, $k 10^{-6}$.
6	1220	227	0·3721	315	323
5	1080	201	0·2930	316	325
4	911	169·5	0·2696	318	329
3	709	131·9	0·1282	321	333
2	470	87·4	0·0546	311	326

Mean value of susceptibility of liquid oxygen as determined with the copper ball = 327×10^{-6}.

IV. *With the Glass Ball No.* 1.

Volume of ball at temperature of liquid oxygen = 6·513 c.c.
Density of liquid oxygen = 1·1391.
Distance of centre of ball from pole = 4·96 cm.
Magnetic susceptibility of glass ball = $0·48 \times 10^{-6}$.

Exciting current by Weston ammeter.	Field.	Field variation.	Loss in weight of ball in grams.	Apparent susceptibility. $k_1 10^{-6}$.	Absolute susceptibility of liquid oxygen, $k . 10^{-6}$.
7	1480	257	0·815	323	322·5
6	1330	231	0·671	329	328·5
3	777	134·9	0·229	329	328·5

Mean value of susceptibility of liquid oxygen as determined with the glass ball No. 1 = 326×10^{-6}.

V. *With the Glass Ball No.* 2.

Volume of ball at temperature of liquid oxygen = 1·456 c.c.
Magnetic susceptibility of ball = $0·024 \times 10^{-6}$.

Distance of ball from pole.	Exciting current of magnet.	Field.	Field variation.	Loss in weight of ball in grams.	Apparent susceptibility, $k_1 10^{-6}$.	Absolute susceptibility of liquid oxygen, $k . 10^{-6}$.
4·57	14·5	2500	427·5	0·4919	310·1	310
	14·5	2500	427·5	0·4916	309·9	310
	13	2350	402	0·4333	309·1	309
	12	2240	383	0·3936	309·1	309
	12	2240	383	0·3947	310·0	310
	6	1422	236·5	0·1721	344·8	345
	6	1422	236·5	0·1723	345·2	345
7·04	12	1379	317	0·2260	348·4	348
	12	1379	317	0·2252	347·1	347
	6	865	215	0·0894	323·9	324
	6	865	215	0·0894	623·9	324

Mean value of susceptibility of liquid oxygen as determined with the glass ball No. 2 = 325×10^{-6}.

VI. *With the Glass Ball No. 4.*

Volume of ball at temperature of liquid oxygen = 0·5858 c.c.
Magnetic susceptibility of ball = $-1·23 \times 10^{-6}$.

Distance of ball from pole.	Exciting current of magnet.	Field.	Field variation.	Loss in weight of ball in grams.	Apparent susceptibility, $k_1 10^{-6}$.	Absolute susceptibility of liquid oxygen, $k 10^{-6}$.
4·935	15	2392	437	0·1912	306	305
	15	2392	437	0·1902	305	304
	12	2102	384	0·1475	306	305
	6	1337	234	0·0628	336	335
	12	2102	384	0·1477	306·5	305
	6	1337	234	0·0620	332	331
4·115	12	2418	391	0·1795	318	317
	6	1532	238	0·0790	361	360

Mean value of susceptibility of liquid oxygen as determined with glass ball No. 4 ≑ 320×10^{-6}.

The absolute susceptibility is derived from the apparent susceptibility by adding or subtracting the susceptibility of the ball used according as it is paramagnetic or diamagnetic.

In the case of the copper ball, owing probably to traces of iron, the paramagnetic susceptibility is rather large and varies with the field. The proper additive correction was obtained by drawing a curve and setting off the observed values of the copper ball susceptibility as ordinates corresponding to the proper field strengths.

The mean value from all the six sets of observations comprising thirty-six determinations with the silver, copper, bismuth, and four glass balls is to give a value of 324×10^{-6} as the mean co-efficient of magnetic susceptibility of liquid oxygen. From the relation $\mu = 1 + 4\pi k$, the magnetic permeability can be deduced, and if $k = 324 \times 10^{-6}$ we have $\mu = 1·0041$, as the value of the permeability of liquid oxygen.

The value of μ we gave (see 'Proc. Roy. Soc.,' vol. 60, p. 292) as the result of our former experiments by a totally different method was $\mu = 1·00287$, or nearly, 1·003.

Hence these two methods agree in giving values of the magnetic permeability of liquid oxygen differing only by about one part in a thousand.

The results of the present work must, however, be taken as giving a much more probable value of the magnetic susceptibility.

On examining the above results it will be seen that there is a general tendency for the susceptibility with large fields of the order of 2500 to be less than the susceptibility for fields of the order of 500. The average susceptibility in fields of from 2500 to 1900 is more nearly 310×10^{-6}, and that in fields from 1100 to 500 more nearly 330×10^{-6}.

The difference only amounts to about 10 per cent. of the lower value, and it cannot be said that the observations are all of exactly equal weight.

The general result is to show that between the limits of $H = 500$ and $H = 2500$ the average magnetic susceptibility of liquid oxygen has a value which does not differ much from 324×10^{-6}, but with a small but decided tendency to decrease in strong fields.

The determination of the variation of susceptibility in much weaker fields is left undecided by these experiments, but by the employment of a torsion balance we hope to be able before long to give the ratios of the susceptibility in various fields much weaker than those employed in the foregoing experiments.

In connection with the determination of the absolute magnetic susceptibility of liquid oxygen, our attention has been much directed to the important matter of the determination of magnetic susceptibilities of substances in general at very low temperatures.

Having regard to the great loss in magnetic susceptibility experienced by the ferromagnetic metals in heating beyond a certain temperature, it has been frequently suggested that bodies of small susceptibility might become strongly magnetic if cooled to a sufficiently low temperature. Faraday made many experiments on this question, using solid carbonic acid as a refrigerating agent, but was not able to arrive at any conclusions.

A difficulty which presents itself in the use of liquid oxygen as a refrigerating agent for this purpose is the strongly magnetic quality of the liquid itself. All bodies except iron, nickel, and cobalt, and the strongly ferromagnetic bodies, become apparently diamagnetic when placed in liquid oxygen and in a non-uniform magnetic field.*

Moreover, for obvious reasons it is easy to weigh a diamagnetic or apparently diamagnetic body in a non-uniform field because the forces restoring the disturbed body to its original position increase with

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* An interesting experiment was made with a ball of ebonite which illustrates this fact. Ebonite is slightly magnetic in air, owing no doubt to iron impurity. Ebonite is denser than liquid oxygen. Accordingly, a small ball of ebonite dropped into the liquid oxygen contained in the vacuum vessel of the pole of the magnet sunk to the bottom of the vessel. On exciting the magnet the ebonite became apparently strongly diamagnetic and was repelled by the pole. It floated up in the liquid until it reached a level at which the diamagnetic repulsion just balanced the apparent weight of the ball in the liquid oxygen. Instructive lecture experiments can be made in this manner.

the displacement. If, however, an attempt is made to determine the force acting upon a paramagnetic body in a non-uniform field by a balance, the body weighed is in unstable equilibrium.

We have only recently overcome these difficulties. The method we have adopted for cooling the body under test, is to suspend it freely near the bottom of a test-tube, which is placed in a vacuum vessel, the interspace between the two being filled with liquid air. In this way the body is cooled by radiation to the temperature of liquid air, and yet it is suspended in, and surrounded by, gaseous air, the magnetic susceptibility of which is exceedingly small compared with that of liquid oxygen or liquid air.

By limiting the vibration of the balance within small limits by the stops, or by gradually varying the field of the magnet with a carbon rheostat, until the field is just able to move the object from a standard position against the fixed restraining force supplied by a constant counter-balancing weight, we have been able to effect the measurements of the apparent weight of the tested object at a given distance from the pole, and in a known field, even though the equilibrium is not stable. In this way we have made preliminary experiments on the variation in the diamagnetic susceptibility of bismuth, and of the paramagnetic susceptibility of manganous sulphate in the solid condition.

We made a preliminary experiment by weighing in and out of the magnetic field a small closed glass bulb, exhausted of its air both when in ordinary air, at the normal pressure and temperature, and then suspended on the dense gaseous air in the inner test-tube, which is at a temperature of −182° C. lying at the bottom of the inner test-tube, placed as above described in a vacuum vessel. We found the magnetic susceptibility of the dense air at −182° C. to be $+0{\cdot}28 \times 10^{-6}$, in other words about 10 times the susceptibility of air at the normal temperature and pressure. This number 0·28 is quite insignificant compared with numbers of the order of 100 or 300. Hence an object suspended in the above described manner, can be reduced to the temperature of liquid air without changing the susceptibility of the surrounding medium by an amount which is at all comparable either with that of liquid oxygen, or with the value of the susceptibility of bismuth, or of most paramagnetic bodies such as the salts of iron, nickel, cobalt, manganese, or of palladium, or any of the strongly paramagnetic bodies.

In this manner we have made a determination of the change in paramagnetic susceptibility of crystallised manganous sulphate in the form of powder.

We find that the susceptibility of the salt at 25° C. is to that at −182° C. in the ratio of 105 to 349 or 1 to 3·32.

These centigrade temperatures, 25° C. and −182° C., correspond to

298 and 91 on the absolute thermometric scale, and it is obvious therefore that the paramagnetic susceptibility of solid manganous sulphate is increased by cooling so that its value varies *inversely as the absolute temperature, and is increased threefold by cooling to the temperature of liquid oxygen.*

It has been shown by P. Curie, that the above law holds good for oxygen, palladium and other paramagnetic bodies at high temperatures; and E. Wiedemann (Pogg. Ann., vol. 126, p. 1, 1885) and Plessner (Wied. Ann., vol. 39, p. 336, 1890) have shown that for limited ranges of temperature, 16° to 60°, it is true for paramagnetic salts in the liquid and solid condition.

Our experiments show that this law may be valid over very wide limits, and to very low temperatures. We hope to fully examine this matter shortly, and to make a full examination of paramagnetic susceptibility at very low temperatures.

We have also made measurements of the magnetic susceptibility of bismuth at the liquid oxygen temperature.

From the mean of three experiments, we find that the diamagnetic susceptibility of bismuth is increased by cooling, and that it has the following values:—

Diamagnetic susceptibility of bismuth at 15° C. = 13·7,
" " " −182° C. = 15·9,

thus showing an increase of 16 per cent. on the lower value.

The diamagnetic susceptibility of bismuth is therefore not increased inversely as the absolute temperature on cooling.

The above considerations suggest that the very large paramagnetic susceptibility of liquid oxygen, which is five or six times greater than that of a saturated solution of ferric chloride, may in part be due to its low temperature.

Some experiments we have made on the susceptibility of manganous sulphate indicate that paramagnetic susceptibility varies directly as the density.

The density of liquid oxygen is 806 times that of gaseous oxygen at 0° C. and 760 mm., and its absolute temperature is just one-third.

Hence if the law that susceptibility varies as the density and inversely as the absolute temperature holds good down to the temperature of −182° C., and over the physical change of state, we should expect the susceptibility of the liquid oxygen to be 2418 (= 806 × 3) times that of the gas.

The magnetic susceptibility of gaseous oxygen as determined by Faraday, E. Becquerel, and others is $0·13 \times 10^{-6}$. Now $2418 \times 0·13 \times 10^{-6} = 314 \times 10^{-6}$.

The mean value we have found for the susceptibility of liquid oxygen is 324×10^{-6}, and many of our values for it are exactly 314×10^{-6}.

It seems therefore possible that for paramagnetic bodies over wide limits of density and temperature we may find that the magnetic susceptibility varies directly as the density and inversely as the absolute temperature.

We desire to add that our thanks are due to Mr. J. E. Petavel and Mr. J. T. Morris, for their assistance in carefully carrying out the tedious work of the ballistic observations, necessary to determine the field of the electro-magnet we have used.

"Aluminium as an Electrode in Cells for Direct and Alternate Currents." By E. WILSON. Communicated by Dr. J. HOPKINSON, F.R.S. Received ~~May 11,—Read~~ May 26, 1898.

This paper deals with the apparent great resistance which aluminium offers to the passage of an electric current when used as an anode in cells ~~containing, for instance, such an electrolyte~~ as alum in water. The following are references to papers which deal in whole or in part with this or other properties of aluminium when employed as an electrode in electric cells.

Wheatstone. 'Roy. Soc. Proc.' Read April 26, 1855. This is the earliest paper I have found dealing with the metal aluminium in voltaic cells, but Wheatstone does not appear to have noticed the apparent great resistance mentioned above.

Heeren. 'Mittheil. des Gewerbevereins für Hannover,' Jahrg. 1855, p. 342. Reference is made in this paper to Wheatstone's experiments.

Buff. 'Liebig's Annalen,' 1857, vol. 102, p. 269. The author of this paper points out that nine Bunsen elements were not able to pass a current through a cell having aluminium as an electrode. This is the first mention of this property I can find.

Ducretet. 'Comptes Rendus,' 1875, vol. 80, p. 280; also 'Journ. de Phys.,' 1875, vol. 4, p. 84. Observed great resistance in dilute sulphuric acid ~~due to aluminium~~ plate.

Beetz. 'Wied. Ann.,' 1877, vol. 2, p. 94. Supposes oxygen to be the cause of this apparent high resistance.

Winkelmann. 'Wied Ann.,' 1883, vol. 20, p. 91.

Wright and *C. Thompson.* 'Phil. Mag.,' 1885, Part 9, Series 5, vol. 19, pp. 27, 116, 203. Call attention to the non-compliance of aluminium with thermochemical data. Reference is made to the work of Julius Thomsen.

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"On the Conversion of Electric Oscillations into Continuous Currents by means of a Vacuum Valve."

By J. A. FLEMING, M.A., D.Sc., F.R.S., Professor of Electrical Engineering in University College, London.

Received January 24,—Read February 9, 1905.

An electric oscillation being an alternating current of very high frequency, cannot directly affect an ordinary movable coil or movable needle galvanometer.

Appliances generally used for detecting electric waves or electric oscillations are, therefore, in fact, alternating current instruments, and must depend for their action upon some property which is independent of the direction of the current, such as the heating effect or magnetizing force. The coherer used in Hertzian wave research is not metrical, since the action is merely catastrophic or accidental, and bears no very definite relation to the energy of the oscillation which starts it. Even the demagnetising action of electric oscillations, though more definite in operation than the contact action at loose joints, is far from being all that is required for quantitative research. It is obvious it would be an advantage if we could utilise the direct current mirror galvanometer for the detection and measurement of feeble electric oscillations. This can be done if we can discover a medium with perfect unilateral conductivity.

Some time ago, I considered the use of the aluminium-carbon electrolytic cell with this object. It is well known that a cell containing a plate of aluminium and carbon, immersed in some electrolyte which yields oxygen, such as dilute sulphuric acid or an aqueous solution of any caustic alkali, or salt yielding oxygen, has a unilateral conductivity within limits. An electric current under a certain electromotive force can pass through the cell from the carbon to the aluminium, but not in the reverse direction.

This action has been much studied and is the basis of many technical devices, such as the Nodon electric valve.

The electrochemical action by which this unilateral conductivity is produced involves, however, a time element, and after much experimenting I found that it did not operate with high frequency currents. My thoughts then turned to an old observation made by me in 1889, communicated to the Royal Society, amongst other facts, in a Paper in 1889, and also exhibited experimentally at the Royal Institution in 1890.[*] This was the discovery: that if a carbon filament electric

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[*] See 'Roy. Soc. Proc.,' vol. 47, p. 122, 1890, "On Electric Discharge between Electrodes at different Temperatures in Air and High Vacua," by J. A. Fleming, communicated December 16, 1889; see also 'Proceedings of the Royal Institution,'

glow lamp contains a pair of carbon filaments or a single filament and a metallic plate sealed into the bulb, the vacuous space between possesses a unilateral conductivity of a particular kind when the carbon filament, or one of the two filaments, is made incandescent. I have quite lately returned to this matter, and have found that this unilateral conductivity exists even with alternating currents of high frequency and is independent of the frequency. Hence, in a suitable form, it seemed possible that such a device would provide us with a means of rectifying electric oscillations and making them measurable on an ordinary galvanometer. The following experiments were, therefore, tried:—

Into a glass bulb, made like an incandescent lamp, are sealed in the ordinary way two carbon filaments, or there may be many filaments. On the other hand, one carbon filament may be used and a platinum wire may be sealed into the bulb terminating in a plate or cylinder of platinum, aluminium or other metal surrounding the filament. It is preferable to use a metal plate carried on a platinum wire sealed into the glass bulb, the plate being bent into a cylinder which surrounds both the legs of the carbon loop. The diagrams in fig. 1 show various forms of the arrangement. Diagram *a* shows a bulb with a single carbon filament surrounded by a metal cylinder, *b* shows one with two carbon filaments, and *c* a carbon filament and two insulated metal plates. The ends of the carbon filament which is rendered incandescent are marked + and − and the terminal of the other electrode of the valve is marked *t*. The bulb must be highly exhausted to about the pressure usual in the case of carbon filament incandescent lamps, and the metal cylinder or plate must be freed from occluded air.

Suppose that we employ such a bulb containing one carbon filament surrounded by a metal cylinder (see *a*, fig. 1). The filament may be of any voltage, but I find it most convenient to employ filaments of such a length and section that they are brought to bright incandescence by an E.M.F. of 12 volts. The voltage and section of the filament should be so arranged that the temperature of the filament corresponds with an "efficiency," as a lamp-maker would say, of 2·75 or 3 watts per candle.[*] The filament is conveniently brought to incandescence by a small insulated battery of secondary cells. A circuit is then completed through the vacuous space in the bulb between the cylinder and the filament by another wire which joins the external terminal *t* of the metal cylinder and that terminal of the carbon filament which is in connection with the negative pole of the heating battery. In this last circuit is placed a sensitive mirror galvanometer of the movable needle or movable coil type, and also a coil which may

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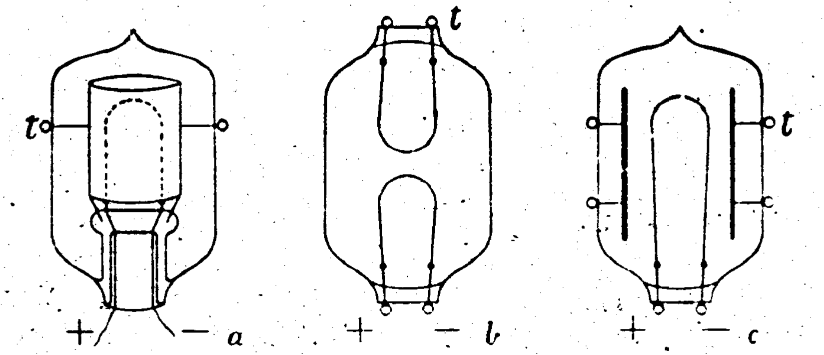
vol. 13, Part LXXXIV, p. 45, Friday evening discourse on February 14, 1890, "Problems on the Physics of an Electric Lamp," when this unilateral conductivity was experimentally shown.

be the secondary circuit of an air core transformer in which electric oscillations are set up. As is now well known, the vacuous space in the bulb permits negative electricity to move in it from the hot filament or cathode through the vacuous space to the cylinder or anode and back through the galvanometer and coil, but not in the reverse direction, as long as the cylinder is cool and the carbon filament not at a temperature much above the melting point of platinum. To illustrate the action of the bulb as an electrical valve, the following experiments can be shown:—

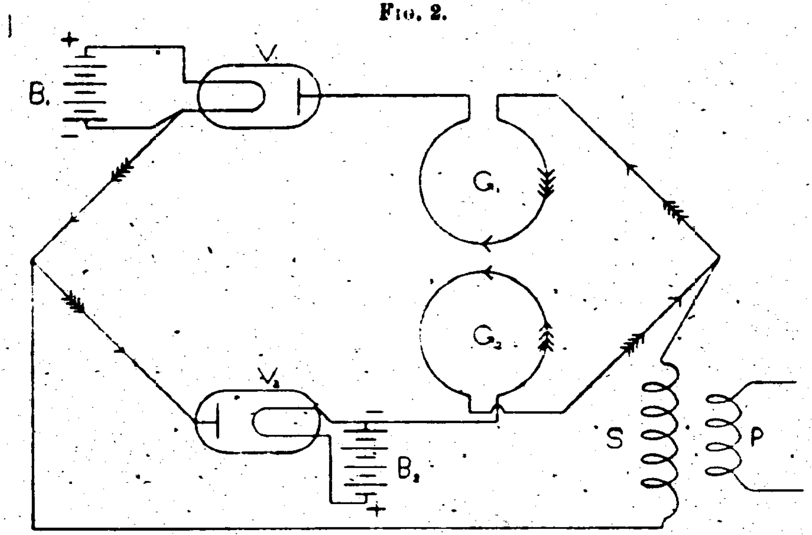
Electric oscillations are set up in a metal wire circuit by the discharge of a Leyden jar, as usual. This circuit takes the form of a thick wire of one or more turns, bent into the form of a circle or square. Some distance from this, we place another wire, of several, say eight

FIG. 1.



or ten turns, also bent into the form of a circle, and connect this last wire into the circuit of a galvanometer and vacuum bulb made as described, so that it is a circuit having unilateral conductivity. On exciting the oscillations in the primary circuit by an induction coil we have an alternating high frequency magnetic field produced, which affects the secondary circuit at a distance. The oscillations in this last are, however, able to flow only in one direction. Hence, the galvanometer is acted upon by a series of intermittent but unidirectional electromotive forces, and its needle or coil deflects. Since the field is a high frequency field, we can show the screening effect of a sheet of tin foil or silver paper in a very simple and effective manner by the effect it produces in cutting down the galvanometer deflection when the metal sheet is interposed between the primary secondary circuits. Also, if we move the secondary coil away from the primary coil or turn the two coils with their planes at right angles to one another, then the galvanometer deflection diminishes or falls to zero because the induction is decreased. Accordingly, we have in this vacuum valve and associated mirror galvanometer a means of detecting feeble alternating electric currents or oscillations. Another method is to employ a differential galvanometer and two vacuum valves. These must then be arranged, as shown in fig. 2, one circuit G_1 of the differential galvanometer is in series with one valve V_1 and the other circuit G_2 with the other valve V_2, but so joined up that currents flowing through the valves in opposite directions pass round the two galvanometer wires in the same direction as regards the needle and, therefore, their effects are added together on the galvanometer needle. Each valve must then have its own separate insulated battery to ignite the filament. Also, it is necessary that the connection with the oscillatory circuit must be made in both cases to the hot filament by that terminal which is in

Fig. 2.



connection with the negative pole of the local battery used to ignite the filament (see fig. 2).

This arrangement of a differential galvanometer and two valves transforms, of course, more of the alternating oscillation into direct current than when one valve alone is used. It provides us with a means of detecting electrical oscillations not merely in closed circuits but in open electrical circuits.

When so using it, it is necessary to associate with the oscillation valve and galvanometer an oscillation transformer for raising the voltage. The resistance of these valves, when in operation, may be anything from a few hundred ohms up to some megohms, depending on the state of incandescence of the filament and upon the electromotive force employed to drive the current through the vacuous space, as well as upon the size of the filament and the plate. This resistance does not obey Ohm's law, but the current increases to a maximum and then slightly decreases as the voltage progressively increases. The form of oscillation transformer employed with the device is as follows: A small air-core induction coil has a primary circuit, which consists of 52 turns of gutta-percha covered wire, wound in a helical groove cut on an ebonite rod 0·5 inch in diameter and 6 inches in length. The primary circuit is made of a No. 20 or No. 22 S.W.G. copper wire. The secondary circuit consists of 36,000 turns of fine silk-covered wire, No. 36, wound in six coils, each having about 6000 turns, and all joined in series. This secondary circuit has one terminal connected to one common terminal of the galvanometer and the other to the common terminal of the two oscillation valves (see fig. 4). The primary coil of this oscillation transformer has one terminal connected to earth and the other to a long insulated rod which acts as an aerial or electric wave collector. To prevent the direct action of the transmitter upon the secondary coil by simple electromagnetic induction, it is best to wind the secondary coil in two equal parts in opposite directions and to wind the primary in a corresponding manner.

If an electric wave sent out from a similarly earthed transmitter falls upon the rod, then an electrical oscillation is set up in the receiving circuit and therefore in the primary coil of the oscillation transformer inserted in series with it. This oscillation is raised in voltage by the secondary coil of the transformer, and by reason of the unilateral conductivity of a vacuum valve, placed in series with the coil, one part of the oscillation, viz., the positive or the negative current, passes round the galvanometer coils and affects it.

If we employ a sensitive dead beat galvanometer of the type called by cable engineers a "Speaking Galvanometer," then intelligible signals can be sent by making small and large deflections of the galvanometer corresponding to the dot and dash of the Morse alphabet; anyone who can "read mirror" can read off the signals as quickly as they can be sent on an ordinary short submarine cable with this arrangement.

The arrangement, although not as sensitive as a coherer or magnetic detector, is much more simple to use. Also it has one great advantage, viz., that it enables us to examine the behaviour of any particular form of oscillation producer. By means of it we can detect changes in the wave-making power or uniformity of operation of the transmitting arrangement, by the variation of the deflection of the galvanometer. Thus, for instance, if a spark-ball transmitter is being employed and the deflection of the galvanometer in association with the receiving aerial is steady, if we put the slightest touch of oil upon the spark-balls of the transmitter, their wave-making power is increased and the deflection of the galvanometer at once increases. Since the current through the galvanometer is the result of the groups of oscillations which are created in the receiving circuit, and since in the ordinary transmitter these oscillation groups are separated by wide intervals of silence, it is obvious that we can increase the sensitiveness of the above described arrangement by employing a very rapid break or interruptor with the induction coil. If, for instance, we employ a Wehnelt break with the induction coil or a high speed mercury break or alternating current transformer, we get a far better result as indicated by the deflection of the galvanometer than when employing the ordinary low frequency spring or hammer break.

The point of scientific interest in connection with the device, however, is the question how far such unilateral conductivity as is possessed by the vacuous space is complete. The electrical properties of these vacuum valves have accordingly been studied.

A bulb containing a 12-volt carbon filament rendered brightly incandescent by a current of about 2·7 to 3·7 ampères was employed. The filament was surrounded by an aluminium cylinder. The length of the carbon filament was 4·5 cm., its diameter 0·5 mm., and surface 70 square mm.

The aluminium cylinder had a diameter of 2 cms., a height of 2 cms., and a surface of 12·5 square cms. The filament was shaped like a horse-shoe, the distance between the legs being 5 mm. This filament was rendered incandescent to various degrees by applying to its terminals 8, 9, 10, and 11 volts respectively. Another insulated battery of secondary cells was employed to send a current through the vacuous space from the cylinder to the filament, connection being made with the negative terminal of the latter. The current through the vacuous space and the potential difference of the cylinder and negative end of the hot carbon filament were measured by a potentiometer. The effective resistance of the vacuous space is then taken to be the ratio of the so observed potential difference (valve P.D.) to the current (valve current) through the vacuum.

The following table records the observations. The column headed P.D. gives the potential difference between the hot filament and the cylinder, that headed A gives the current through the vacuous space in milliampères, that headed R the resistance of the space in ohms, and that headed $K10^5$ is 100,000 times the conductivity.

The result is to show that the vacuous space does not possess a constant resistance, but its conductivity increases rapidly up to a maximum and then decreases as the valve potential difference progressively increases. If we plot the current values as ordinates and potential difference of the valve electrodes as abscissæ, we find that the current curve quickly rises to a maximum value and then falls again slightly as the potential difference increases steadily. The conductivity curve also rises to a maximum and then decreases (see fig. 3).

The facts so exhibited are well-known characteristics of gaseous

Table I.—Variation of Current through, and Conductivity of, a Vacuum Valve with varying Electromotive Force, the Electrodes being an Incandescent Carbon Cathode and Cool Aluminium Anode.

Carbon filament at 11 volts, 3·77 amp., 41·47 watts.				Carbon filament at 10 volts, 3·44 amps., 34·43 watts.			
Vacuum Space.				*Vacuum Space.*			
P.D.	A.	R.	$K10^5$.	P.D.	A.	R.	$K10^5$.
0·6	0·024	25,000	4·0	0·7	0·014	50,000	2·0
5·4	0·261	20,550	4·86	2·8	0·073	38,360	2·6
8·8	0·480	18,330	5·45	8·2	0·392	20,920	4·76
18·2	3·880	4,691	21·4	12·8	0·824	15,530	6·56
22·9	26·790	855	118·1	16·2	1·789	9,816	10·70
29·1	28·02	1,038	96·1	20·1	5·352	3,756	26·6
37·1	28·426	1,305	76·6	23·3	9·68	2,407	41·4
49·0	26·50	1,719	58·0	35·9	10·037	3,577	28·0
70·2	26·87	2,613	38·3	49·7	9·794	5,075	20·0
100·0	24·36	4,105	25·0	71·6	8·920	8,027	12·5
				100·08	8·331	12,010	8·32

Carbon filament at 9 volts, 3·112 amps., 28·0 watts.							
Vacuum Space.							
P.D.	A.	R.	$K10^5$.	P.D.	A.	R.	$K10^5$.
0·5	0·005	100,000	1·0	24·2	2·389	10,130	10·0
2·5	0·049	50,020	2·0	28·2	2·437	11,650	8·6
5·2	0·128	40,625	2·46	36·6	2·508	14,590	6·86
8·3	0·324	25,620	4·0	48·6	2·535	19,170	5·0
8·8	0·361	24,380	4·1	58·5	2·374	24,640	4·0
12·6	0·70	17,970	5·5	72·5	2·253	32,180	3·0
16·4	1·735	9,452	10·5	102·0	2·067	49,350	2·0
20·4	2·351	8,677	11·2				

conduction in rarified gases.* It may be noted that there is in these current-voltage and voltage-conduction curves a general resemblance to the magnetisation and permeability curves of iron.

To examine further the nature of this conduction, the following experiments were made. If a vacuum bulb, as described, is joined up in series with a galvanometer and an electrodynamometer and an alternating electromotive force applied to the circuit, the two instruments will both be affected. The galvanometer is, however, affected only by

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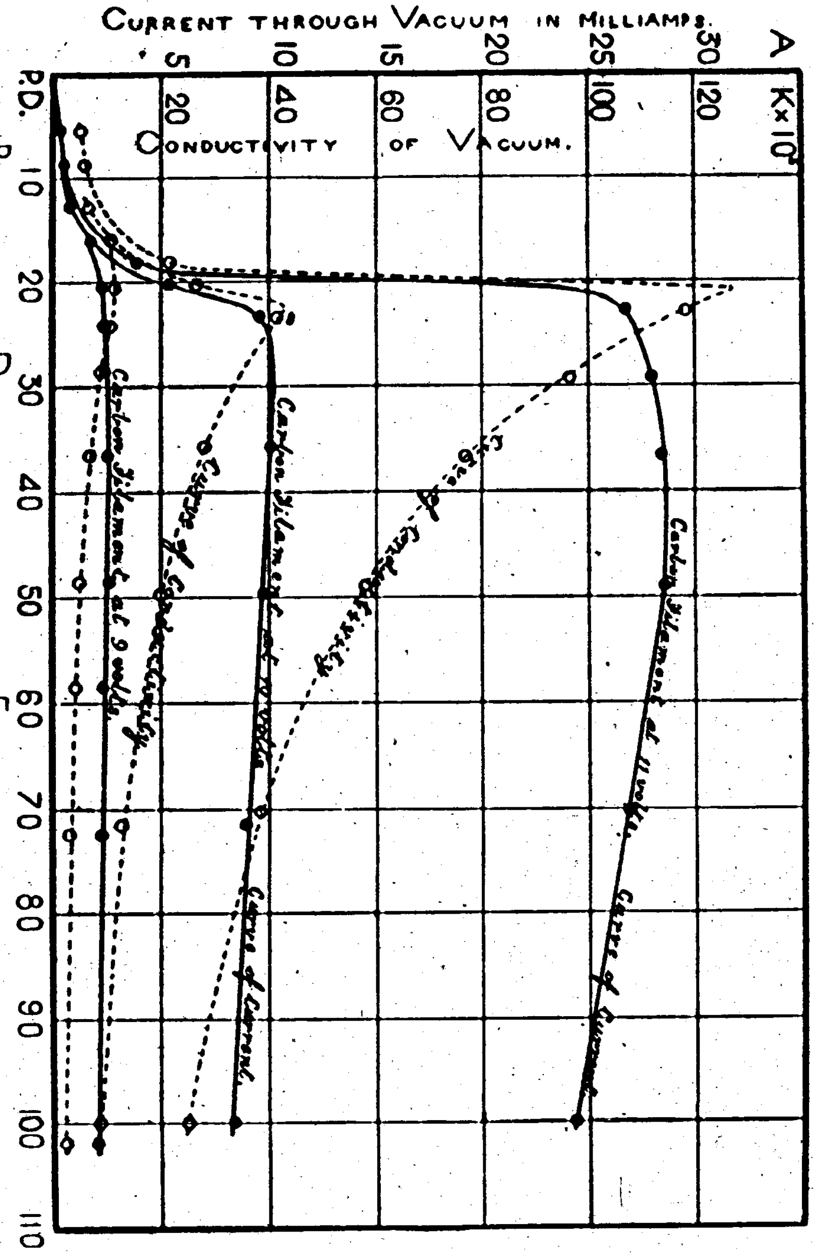
* See J. J. Thomson, 'Conduction of Electricity through Gases,' Chap. VIII.

FIG. 3.



the resultant flux of electricity in one direction. It measures the unidirectional current. The dynamometer is affected by the bilateral flux of electricity and it measures the total or alternating current. If, therefore, the vacuous space is totally non-conducting in one direction, one half of the alternating current will be cut out. The galvanometer will read the true mean (T.M.) value of the remanent unidirectional current, and the dynamometer will read the root-mean-square (R.M.S.) value. If the conductivity in one direction is not zero, then the galvanometer will read the T.M. value of the difference of the positive and negative currents, but the dynamometer will read the R.M.S. value of their sum.*

In the last case, the current through the valve may be considered to be a continuous current superimposed upon an alternating current.

If we call I the maximum value of the nearly sinoidal current in one direction, and I′ the maximum in the opposite direction, then we may say that the dynamometer reading (D) expressed in true current value is equal to $g\,(\mathrm{I}+\mathrm{I}')$ where g is the *amplitude factor*, and also that the galvanometer reading (G) in true current value is equal to $g/f\,(\mathrm{I}-\mathrm{I}')$ where f is the *form factor* of the current.† Hence—

$$\frac{\mathrm{D}}{\mathrm{G}} = f\frac{\mathrm{I}+\mathrm{I}'}{\mathrm{I}-\mathrm{I}'}, \quad \text{or} \quad \frac{\mathrm{D}/\mathrm{G}+f}{2f} = \frac{\mathrm{I}}{\mathrm{I}-\mathrm{I}'}.$$

The fraction $\dfrac{2f}{\mathrm{D}/\mathrm{G}+f}$, say β, expressed as a percentage may be called the *rectifying power* of the valve, for it expresses the percentage which the actual unilateral electric flow or continuous current through the valve is of that continuous current which would flow if the unilateral conductivity were perfect.

Perfect rectifying power, however, does not exist. There is not an infinite resistance to movement of negative electricity from the metal cylinder to the hot filament through the vacuum, although this resistance is immensely greater than that which opposes the movement of negative electricity in the opposite direction. This point was examined, as follows: A very sensitive electrodynamometer was skilfully constructed by my assistant, Mr. G. B. Dyke, the fixed coil having 2000 turns of No. 47 silk-covered copper wire and the movable coil 1000 turns. The suspension of the movable coil was by a fine flat phosphor-bronze wire at top and bottom. The deflection was observed by a mirror and scale.

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* If i is the instantaneous value of a periodically varying current with maximum value I and periodic time T, then the root-mean-square value (R.M.S. value) of i is defined to be $\left(\frac{1}{\mathrm{T}}\int_0^{\mathrm{T}} i^2dt\right)^{\frac{1}{2}}$ and the true mean value (T.M. value) of i is defined to be $\frac{2}{\mathrm{T}}\int_0^{\frac{1}{2}\mathrm{T}} idt$.

† The *form factor f* and *amplitude factor g* are the names given by the author (see 'Alternating Current Transformer,' J. A. Fleming, vol. 1, p. 585, 3rd edit.) to the ratio of the R.M.S. to the T.M. value of the ordinates of a single valued periodic curve, and to the ratio of the R.M.S. value of the ordinates to the maximum value during the period.

This dynamometer was placed in series with a shunted movable coil galvanometer of Holden-Pitkin pattern, and the two together placed in series with a variable section of an inductionless coil through which an alternating current was passing. A vacuum valve as above described was in series also with the galvanometer and dynamometer. The alternating current was derived from an alternator giving a nearly true sinoidal electromotive force. The form factor of the electromotive force curve of this alternator was determined and found to be 1·115, that for a true sine curve being 1·111.

The vacuum valve sifted out the alternating current flow and allowed the currents in one direction to pass, but nearly stopped those in the opposite direction. The indications of the electrodynamometer were proportional to the root-mean-square (R.M.S.) value of the sum of the two opposite currents, and that of the galvanometer to the true mean value (T.M.) of their difference. The galvanometer and dynamometer were both calibrated by a potentiometer by means of continuous current, and curves constructed to convert their scale readings to milliampères. Then with various alternating current electromotive forces, their readings were taken when in series with a vacuum valve and recorded in the following tables. The letter D denotes current in milliampères as read by the so calibrated dynamometer and G that read by the galvanometer. The ratio D/G is denoted by α, and the rectifying power, viz., $2f/\alpha + f$ by β.

The table shows that the value of α is not constant, but for each state of incandescence of the filament reaches a maximum which, however, does not greatly differ from the mean value for the range of currents used. If we set out the mean values of β in a curve (see fig. 4), in terms of the power expended in heating the carbon filament, we see that the rectification is less complete in proportion as the temperature of the carbon filament increases. This is probably due to the fact that as the filament gets hotter, it heats the enclosing cylinder to a higher temperature and enables negative electricity to escape from the latter.

Hence, I feel convinced that if the metal cylinder could be kept quite cool by water circulation the rectification would reach 100 per cent. or be complete.

An ideal and perfect rectifier for electric oscillations may, therefore, be found by enclosing a hot carbon filament and a perfectly cold metal anode in a very perfect vacuum. With a bulb such as that used for the above experiments all we can say is that the current passed through the vacuum is from 80 to 90 per cent. continuous, 100 per cent. implying that the vacuum is perfectly non-conducting in one direction and permits the flow of negative electricity only from the hot to the cold electrode. The necessity for keeping the cathode cold is shown by the following experiment:—An alternating-current arc was

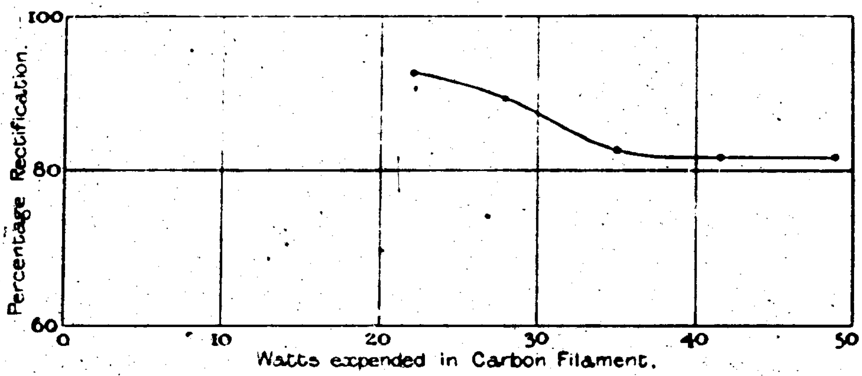
Table II.—Ratio of Electrodynamometer (D) to Galvanometer (G) Readings in Milliampères. Form Factor of E.M.F. Curve = 1·115 = f.

D.	G.	$D/G = \alpha$.	$2f/\alpha+f=\beta$.	
Carbon filament at 11 volts, 3·77 amps., 41·7 watts.				
0·85	0·57	1·49	0·86	Mean = 0·82..
1·33	0·85	1·56	0·83	
1·87	1·16	1·61	0·82	
2·30	1·40	1·64	0·81	
3·20	1·88	1·73	0·78	
3·52	2·10	1·68	0·80	
4·54	2·81	1·62	0·82	
Carbon filament at 10 volts, 3·44 amps., 34·43 watts.				
0·50	0·34	1·47	0·86	Mean = 0·83.
1·34	0·86	1·56	0·83	
2·28	1·48	1·54	0·84	
2·72	1·68	1·62	0·82	
2·78	1·71	1·63	0·81	
3·02	1·87	1·62	0·82	
3·53	2·17	1·63	0·81	
4·30	2·92	1·47	0·86	
4·25	2·88	1·48	0·86	
Carbon filament at 9 volts, 3·112 amps., 28·0 watts.				
0·40	0·31	1·29	0·93	Mean = 0·89.
0·73	0·50	1·46	0·87	
1·28	0·83	1·54	0·84	
1·65	1·15	1·43	0·88	
1·82	1·26	1·44	0·87	
1·78	1·26	1·41	0·88	
1·93	1·35	1·43	0·88	
1·94	1·41	1·38	0·89	
1·87	1·41	1·38	0·91	
1·83	1·39	1·32	0·92	
1·73	1·37	1·26	0·94	

formed between carbon rods, and an iron rod was placed so that its end dipped into the arc. An ammeter was connected in between either carbon and the iron rod, and indicated a continuous current of negative electricity flowing through the ammeter from the iron rod to the carbon pole. This current was, however, greatly increased by making the iron rod of a piece of iron pipe closed at the end and kept cool by a jet of water playing in the interior. In this manner I have been able to draw off a continuous current of 3 or 4 ampères from an alternating-current arc using 15 alternating-current ampères.

Returning, then, to the vacuum valve, we may note that the curves in fig. 3 show that the vacuous space possesses a maximum conductivity corresponding to a potential difference of about 20 volts between the electrodes, for the particular valve used. The interpretation of this fact may, perhaps, be as follows:—In the incandescent carbon there is a continual production of electrons or negative ions by atomic dissociation. Corresponding to every temperature there is a certain electronic tension or percentage of free electrons. If the carbon is made the negative electrode in a high vacuum these negative ions are expelled from it, but they cannot be expelled at a greater rate than they are produced. Therefore, there is a maximum value for the outgoing current and a maximum value for the ratio of current to electromotive force, that is for the conductivity.

FIG. 4.



This fact, therefore, fixes a limit to the utility of the device. The current through the vacuous space is, to a very large extent, independent of the electromotive force creating it, and is at no stage proportional to it, or at least only within a narrow range of electromotive force near to the maximum conductivity.

Whilst, therefore, the device is useful as a simple means of detecting electric oscillations, it has not that uniformity of conductivity which would make it useful as a strictly metrical device for measuring them. It can, however, perform the useful service of showing us how far any device for producing electric oscillations or electric waves produces a uniform or very irregular train of electric oscillations, and what changes conduce to an improvement or reduction in the efficiency of the transmitting device.

"On an Instrument for the Measurement of the Length of Long Electric Waves, and also Small Inductances and Capacities."

By J. A. Fleming, M.A., D.Sc., F.R.S., Professor of Electrical Engineering in University College, London.

Received January 26,—Read February 9, 1905.

The measurement of the length of the waves used in connection with Hertzian wave telegraphy is an important practical matter. Since the wave-length of the radiated wave is determined by the frequency of the electric oscillations in the radiator, the determination of this frequency is all that is required. The principle of resonance is generally called into assistance to effect this measurement. It may be done by the employment of either an open or a closed resonant circuit.

Instruments for this purpose have been devised in which some circuit having capacity (C) as well as inductance (L) in series with each other, has one or both these factors altered until the electrical time-period of the circuit agrees with that of the wave making circuit. Since this agreement depends upon the equality of the product $\sqrt{CL}$ for the two circuits, the author proposes to call this quantity $\sqrt{CL}$ the *oscillation constant* of the circuit and the number of oscillations in 2π seconds or $2\pi n$, where n is the frequency, the *oscillation number*. Then it is a property of simple oscillatory circuits that the product of the oscillation number and oscillation constant is unity. Some means has, therefore, to be employed to indicate when the adjustment of the two factors of the adjustable circuit has brought its oscillation constant into agreement with that of the transmitter circuit. In a wave-meter devised by J. Dönitz,[*] which is of the closed circuit form, a condenser of variable capacity has its terminals short-circuited by an inductance coil, and this coil is acted upon inductively by some part of the transmitter circuit so that oscillations are set up in it. A variation of the capacity is made until the root-mean-square value of the current in its circuit is a maximum. This is done by the employment of a sensitive form of hot wire ammeter.

There are, however, some objections to this form of wave-meter, and especially to the use of a hot wire ammeter. The root-mean-square value of the oscillation depends not only upon the maximum value and logarithmic decrement of the oscillations, but upon the number of groups of oscillations per second. Hence, if the discharger of the transmitter is an ordinary spark discharger, the variation of the oscillations due to variation in the break speed or spark-ball surfaces and, therefore of the root-mean-square value of the current set up in

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[*] See J. Dönitz, "On Wave Meters and their Uses," 'Elecktrotechnische Zeitschrift,' vol. 24, p. 920, 1903, Nov. 5; also 'The Electrician,' vol. 52, p. 407, Jan. 1, 1904.

the wave-meter circuit will be considerable. There is, therefore, some difficulty in finding the position of adjustment sharply.

Another point calls for attention. It is well known, from the theory of syntonised circuits, that if two circuits having capacity and inductance are brought into inductive relation to each other, the resulting complex circuit has two time-periods of oscillation. Even if the two circuits when separate and far removed have their time-periods adjusted to equality, the resulting time-period when they are brought into inductive relation to each other differs from the common value. There are, in fact, two frequencies in the coupled circuit, one greater and the other less than the common period. These, however, tend to equality and to indentity with the free independent period of each circuit separately in proportion as the mutual induction between the coupled circuits is reduced.* The object, therefore, held in view in designing the instrument here described was to construct one which, whilst having a fairly large inductance of its own, should be capable of being associated with the circuit to be tested, and set in action by it, by means of a mutual inductance as small as possible.

This has been achieved by making the part of the circuit of the instrument which is acted upon inductively by the circuit to be tested only a small part of the circuit on which its whole inductance depends. We are thus able to keep the self-inductance large and the mutual inductance small, and therefore prevent any great reaction of the secondary current upon the circuit which is being tested.

A closed circuit wave-meter has been devised on these lines by the author, employing a neon vacuum tube detector, which enables the measurement of the oscillation-constant of the transmitter circuit to be made with great accuracy and quickness, and is also useful for measuring small inductances and capacities.†

It is constructed in one form, as follows:—An ebonite tube, about 100 cms. long, has cut upon its outer surface a screw groove having 1·6 turns per centimetre and a length of 60 cms. is cut. In this groove is wound a bare copper wire, SS. No. 14 S.W.G. size (see fig. 1), one end of the wire is attached to a metal pin p_1 which forms a bearing supporting the tube, and the other end of the wire is insulated. To this latter end of the ebonite tube is attached a brass tube I 60 cms.

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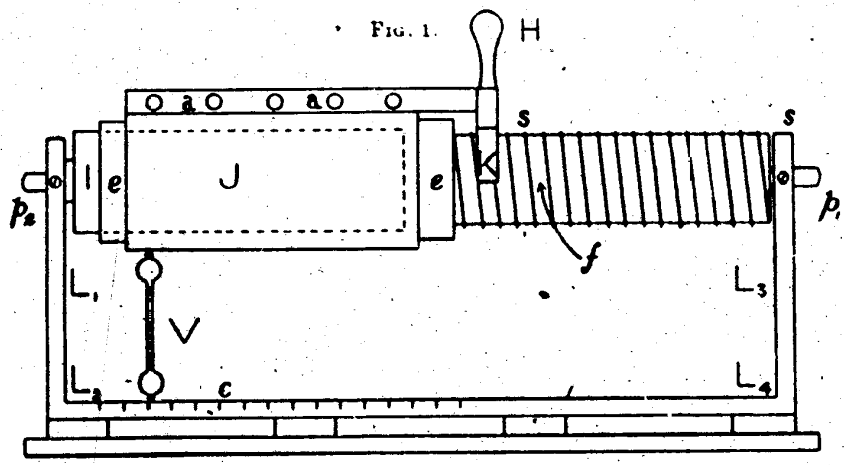
* See A. Oberbeck, "Ueber den Verlauf der Electrischen Schwingungen bei den Tesla'schen Versuchen," 'Wied. Annalen der Physik,' vol. 55, p. 627, 1895.

† The use of a neon vacuum tube as a sensitive indicator of a high-frequency electric field was mentioned first in a paper read by the author to the British Association at Cambridge, September, 1904. The author is indebted to Sir William Ramsay for two tubes of this gas. Sir James Dewar has shown that such neon vacuum tubes can be readily prepared from atmospheric air by the employment of absorbent charcoal at very low temperatures. It would be an advantage if the manufacture of these neon tubes could be placed on a commercial basis, in view of their utility for the purposes here described.

in length and 8 cms. outside diameter. Over this brass tube is placed an ebonite tube *ee* the sides of which are 5 mm. in thickness and its length 80 cms. This ebonite tube fits tightly on the brass tube. The brass tube is closed at the end remote from the inductance coil by a plate and a pin p_2 which forms a bearing for the whole apparatus. Over the larger ebonite tube is slipped a metal cylinder or outer jacket J which can slide easily on the ebonite tube. This jacket carries a rod

Fig. 1.



ending in a half-collar of metal K resting on the inductance spiral (see fig. 2). An ebonite handle H enables the jacket to be moved to and fro. It will be seen, therefore, that the arrangement constitutes a condenser formed of the inner and outer brass tubes separated by an ebonite dielectric, the capacity of which can be varied by moving the outer jacket away from the inner. Also this condenser is in series with an

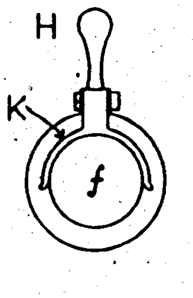


Fig. 2.

inductance coil, the inductance of which is reduced or increased by the same movement which reduces or increases the capacity. The oscillation constant of the arrangement is, therefore, variable between certain limits, and its variation with the displacement of the handle H follows a straight line law.

The pins p_1, p_2 (see fig. 1) which form, respectively, one of the terminations of the inductance and capacity, are connected together by a stout copper bar L_1, L_2, L_3, L_4, so completing the electric circuit, the capacity and inductance of which can be varied. In order to detect the condition in which the oscillations have a maximum value in this circuit, a vacuum tube V is employed (see fig. 1), which may preferably be a vacuum tube containing neon, or failing that, a tube containing rarified carbonic dioxide may be used, the glass being uranium. This vacuum tube should be constructed with two bulbs and with a narrow tubular portion like a spectroscope tube. It may be attached to the outer brass jacket as in fig. 1, or it may be attached to a bar connected with the inner brass tube, the vacuum tube being hung over the outer jacket. Also a scale is provided showing the position of the sliding jacket and which, therefore, can be graduated to show the oscillation constant of the arrangement for various positions of the jacket.

Supposing then that we desire to determine the frequency of the oscillations in any wire such as a Marconi aerial wire used in Hertzian-wave telegraphy, part of this wire is laid alongside the copper bar and the oscillations in it induce others in the circuit of the wave-meter. The oscillation constant is then varied by moving the outer jacket by means of the insulated handle H until the vacuum tube V glows most brightly. If proper adjustments are made of the position of the vacuum tube, it will be found that the tube does not shine at all until the outer jacket J is within a few millimetres of the position in which the oscillation constant of the instrument agrees with that of the circuit being tested. By taking two or three readings with the jacket, a little too far one way and a little too far the other way and approaching the right position from both sides and taking the mean scale reading, it is possible to obtain the oscillation constant with great accuracy. If the capacity is measured in microfarads and the inductance in centimetres, then it will be found that the oscillation constant required is generally some number lying between 1 and 20. The instrument already constructed by the author on this pattern is adapted for the determination of oscillation constants lying between 0·16 and 7·5.

In the case of Hertzian-wave telegraphy conducted on Marconi principles, the wave-length employed, reckoned in feet, is equal to 195·8 times the oscillation constant of the transmitter circuit, or reckoned in metres, to 59·73 times the oscillation constant. Hence, the above described instrument is capable of measuring wave-lengths from 30 to 1500 feet, and might easily be constructed to measure wave-lengths of any greater length.*

By a slight modification, the instrument can be constructed more simply as follows: A single ebonite tube is employed which may be

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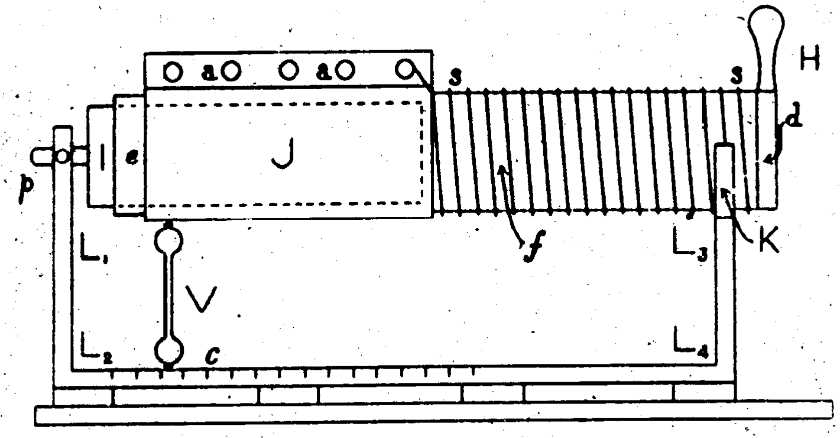
* *February* 11, 1905.—The author has since constructed one to measure electric waves up to 2400 feet in length.

a metre or a metre and a-half in length and 10 cms. outside diameter, the thickness of the walls being about 5 mm. On this tube is wound as before an inductance coil of 100 or 200 turns of No. 14 S.W.G. bare copper wire. Also the tube is provided with an outer jacket or brass outer tube J (see fig. 3). This is conveniently formed out of the sheet of thin brass bolted round the tube, and one end of the inductance coil SS is attached to this jacket, the other end of the coil being attached to a brass ring *d*, carrying an ebonite handle H. In the interior of this ebonite tube, at one end, there is an inner brass tube I which can slide easily in and out of the ebonite tube *e*. This brass

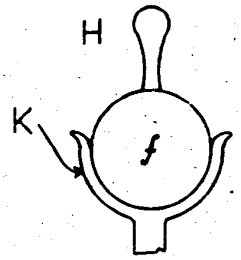
FIG. 3.



tube has a pin *p* fixed at one end, by which it is attached to a copper bar L_1, L_2, L_3, L_4, ending in a curved crutch or collar K on which the inductance spiral rests (see fig. 4). The other arrangements are as in the instrument already described.

The only differences between the forms shown in fig. 1 and fig. 4 are that in fig. 1 the outer metal jacket is movable and the inner one is fixed, whereas in the second form, the outer jacket is fixed with respect to the inductance coil, and the two together are drawn away from the inner brass tube, thus reducing the capacity and inductance at the same time. The instrument is very convenient for the measurement of small inductances. Thus, for instance, suppose it is desired to measure the inductance of a wire for high frequency currents, the wire having an inductance of not more than a few hundred centimetres, that is to say, something of the order of a microhenry, this inductance may be measured by the instrument in the following manner:—An insulated wire AB (see fig. 5) is laid alongside the copper bar L_2, L_4, and the circuit of the wire is completed by a condenser C of known capacity and a spark gap S. Oscillations are then set up in this condenser and wire by means of an induction coil as usual, and the handle H is shifted until the vacuum tube V glows or glows most brilliantly. We then know that the oscillation constant of the instrument in that position agrees with that of the circuit so formed. When that is the case, the oscillation constant of the wave-meter can be read off in the scale attached to it, and we, therefore, know the oscillation constant (call it O) of the circuit formed by the condenser and the wire. Hence, if C is the capacity of the condenser in that circuit and L is the inductance of the wire of the circuit, then $O = \sqrt{CL}$. If, then, we increase the inductance L by adding in series with it a wire of which the inductance is desired (call it L′), we can

FIG. 4.



then shift the handle H until we get a fresh agreement and find a second value O′ for the oscillation constant of the circuit. Then we have

$$O' = \sqrt{C(L + L')}.$$

Hence

$$L' = \frac{O'^2 - O^2}{C}.$$

As an illustration the following test measurement was made. A copper wire, the diameter (d) of which was 0·128 or 0·32 cm. was bent into a nearly complete circle 70 cms. in diameter. The inductance of this wire can be calculated from the formula

$$L' = 2\pi D\left(\log_e \frac{4\pi D}{d} - 2{\cdot}45\right) + \frac{R'}{2\pi n}.$$

In the above case $D = 70$ cms., and $d = 0{\cdot}32$ cm., and R′ is the resistance of the wire to oscillations having a frequency n. The value of L′ is then 2400 cms. This wire was joined in series with another wire laid alongside the bar L_2, L_4 of the measuring instrument and a condenser having a capacity of 0·00146 microfarad joined up in series with the circuit and a spark gap. The instrument was then used to determine the oscillation constant O′ of the circuit with the circular wire included, and the oscillation constant O when the circular wire was not included. It was found that O′ = 3·5 and O = 3·0. Whence

$$L' = \frac{12{\cdot}25 - 9}{0{\cdot}00146} = 2226 \text{ cms.},$$

a value in fairly close agreement with the calculated value, considering that the inductance is less than 2·5 microhenrys.

In this manner it is possible to determine the inductance of a foot or two of coiled copper wire for high frequency currents with fair accuracy. The oscillation constant of an instrument of the above form for various positions of the outer jacket or inner jacket, according to the form used, can best be determined directly by means of a standard wave-meter, such as that described by the Author in a paper to the British Association at Cambridge, September, 1904.*

In this last mentioned arrangement, a long ebonite tube is wound over uniformly with a fine silk-covered copper wire in closely adjacent turns and in one layer. The capacity and inductance per unit of length (c and l) of this long helix must then be determined by known methods, and from this measurement we can determine the velocity of propagation of an electric wave along the helix, for it is equal to the reciprocal of the square root of the product of the capacity and inductance per unit of length of the helix. If we form an oscillatory circuit (see fig. 5), consisting of a condenser, C, a variable inductance, L, and a spark gap, S, the variable inductance including a length of straight wire AB, which can be placed parallel with, and close to, the copper bar of the form of wave-meter described in this paper, then we can bring its oscillation constant into agreement with the oscillation constant of the circuit formed of the variable inductance and condenser. In order to determine the value of this oscillation constant we connect the long helix above described to one terminal of the condenser of the oscillating circuit above described, one spark ball being to earth. The arrangement must be as shown in fig. 5. The long helix of insulated wire HH is then provided with a sliding metal saddle D, which can be connected to the earth E, and this saddle is moved along the helix until a position is found such that by means of a neon or other sensitive vacuum tube V, we can detect a node of potential half-way between the saddle and the point of attachment of the helix to the oscillating circuit, the saddle itself being connected to the earth will also be a node of potential. Hence the distance between the saddle and the end of the helix attached to the oscillating circuit is equal to one wave-length of the wave travelling along the helix.

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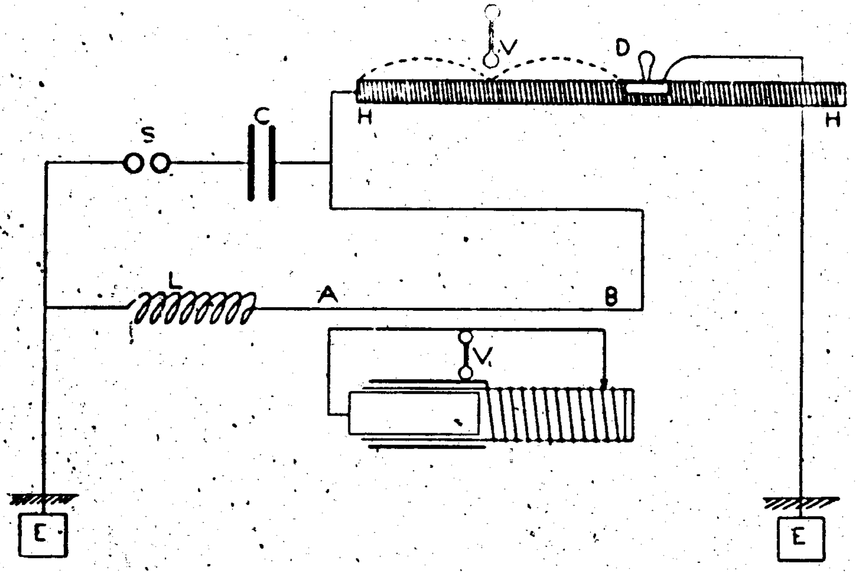
* See J. A. Fleming, "On the Propagation of Electric Waves along Spiral Wires, and on an Appliance for Measuring the Length of Waves used in Wireless Telegraphy," 'Phil. Mag.,' October, 1904.

If W is the velocity of the wave along the helix and λ is the wave-length of the stationary wave, as measured on the helix, and n the frequency of the oscillations, then $W = n\lambda$. If C is the capacity and L the inductance in the oscillatory circuit formed with the condenser of unknown capacity and variable inductance, then the frequency in this circuit is $n = 1/2\pi \sqrt{CL}$.

Also if c and l are the capacity and inductance per unit of length of the long helix, we have $W = 1/\sqrt{cl}$. Therefore

$$\frac{1}{\sqrt{cl}} = \frac{\lambda}{2\pi\sqrt{CL}}, \quad \text{or} \quad \sqrt{CL} = \frac{\lambda}{2\pi}\sqrt{cl}.$$

FIG. 5.



Hence, since λ can be measured, and the oscillation constant of the helix per unit of length $\sqrt{cl}$ is known, we have the oscillation constant of the exciting circuit, and therefore of the closed circuit wave-meter in any position when it is adjusted to agree with that circuit. Otherwise, if we have the means at hand, the oscillation constant of the instrument can be determined for various positions of the slider by simply measuring the capacity (C) of the condenser and inductance (L) of the helix which are effective in that position, and calculating the value of $\sqrt{CL}$ for various positions of the outer or inner jacket, according to the form of instrument used. The instrument can have its scale marked to show directly either oscillation constants (O) or frequencies (n), or aërial wave lengths (λ) in metres or feet. The instrument is not only useful for quantitative work in connection with Hertzian-wave telegraphy, but is very useful in the laboratory for the determination of the coefficients of coupling and mutual inductances of oscillation transformers.

If there be two circuits inductively connected, forming an air core transformer or oscillation transformer, and if these circuits have respectively coefficients of self-induction L and N, and a coefficient of mutual induction M, then we can determine L and N and M, if these are not too large, by the instrument, and also the "coefficient of coupling" of the transformer, viz., $M/\sqrt{LN}$.

For this purpose we connect the two circuits of the transformer in two ways. 1st, so that a current sent through the circuit flows round in the same direction in the two coils; and 2nd, so that it flows in the opposite direction in the two coils. In the first position, the effective inductance of the whole system is L_1, where $L_1 = L + 2M + N$, and in the second position it is L_2, where $L_2 = L - 2M + N$. Hence, $L_1 + L2 = 2(L + N)$, and $L_1 - L_2$, $= 4M$. Accordingly, we make four inductance measurements with the instrument. 1st, that of the primary coil alone, the secondary being open; 2nd, that of the secondary alone, the primary being open; 3rd, that of the primary and secondary together joined up to assist; and 4th, that of the primary and secondary together, joined up to oppose.

Twice the sum of the first two measurements should agree with the second, and one quarter of the difference of the last two gives the mutual inductance. Having therefore L, M, and N, we can calculate the coupling, $M/\sqrt{LN}$.

In making measurement of this kind with high frequency currents it is necessary to bear in mind that we cannot obtain the true separate inductance of the primary coil simply by measuring it with the secondary coil over it, even if that secondary coil has its terminals open. There is a quite sensible dielectric current which passes from turn to turn of the secondary coil when over the primary, even if that secondary coil is open, and this dielectric current has the effect, in accordance with well-known principles, of reducing the effective inductance of the primary circuit. Nevertheless, in the above measurement it is proper to take as L the inductance of the primary measured in contiguity to the open secondary, and as the value of N the inductance of the secondary measured in contiguity to the open primary.

As an example of such a measurement the following figures may be given. A certain air-core transformer had a primary consisting of one turn of thick stranded copper wire, and a secondary of eight turns of thinner stranded wire. Measuring as above described, the following values in centimetres were found by the appliance here described:—

$$L = 695 \text{ cms.}, \qquad N = 45{,}700 \text{ cms.}$$

$$L_1 = L + 2M + N = 53{,}000 \text{ cms.}$$

$$L_2 = L - 2M + N = 40{,}120 \text{ ,,}$$

Hence $M = \frac{1}{4}(L_1 - L_2) = 3{,}220$ cms.,

and $\frac{1}{2}(L_1 + L_2) = 46{,}560$ „

whilst from the independent measurements of L and N as above we have,

$$L + N = 46{,}385 \text{ cms.}$$

Hence, the agreement between the last two sums is fairly close. Also the coupling $M/\sqrt{LN}$ is found to be equal to 0·57.

It is usual to call the "coupling" of a primary and secondary coil "close" if it exceeds in value 0·5, and "loose" when it is less than 0·5.

The wave or frequency meter enables us to exhibit in the form of an attractive lecture experiment the well-known fact that the closing of the secondary circuit of an induction coil or transformer reduces the effective inductance of the primary coil. Also since it enables us to determine the frequency (n) of a high frequency current, and it enables us to determine also the value of the high frequency resistance R′ of a round sectioned copper wire of which the diameter d and steady or ordinary resistance R is known, since

$$R' = \frac{\pi d}{80}\sqrt{n}\,.\,R,$$

it becomes, therefore, a useful addition to laboratory appliances.

In Hertzian-wave telegraphy the varying power of waves of various lengths to travel over land or sea surfaces is well known, and it is, therefore, a practical necessity to be able to measure the wave-lengths of the wave sent out. The wave-meter enables us to conduct a kind of spectroscopy on a gigantic scale when we are operating with electric waves hundreds of feet in length instead of fractions of an inch.

We can by means of it discover, for instance, that a wave 300 feet in length travels well over a sea surface, but will not go across a city. On the other hand, the author has been able to communicate well across London by means of electric waves 1000 feet in wave-length.

[*Note added, February* 14, 1905.—The above-described instrument enables us to show that, in the case of an aërial wire or antenna, as used in wireless telegraphy, inductively coupled to a condenser exciting circuit, even if the two circuits, open and closed, have separately the same electrical time period, yet, when coupled, there are two waves radiated of different wave-lengths and frequencies, differing also in period from the free separate time period of each circuit. This result, predicted by theory, is confirmed by experiment.

A name is required by which to designate the instruments here

On the Properties of Magnetically Shielded Iron as Affected by Temperature.

By Ernest Wilson.

(Communicated by Dr. J. A. Fleming, F.R.S. Received March 20,—Read May 7, 1914.)

In a paper recently read before the Society,* it was shown that if a specimen of stalloy in ring form is placed within an iron shield and then subjected to a magnetic force of about 2 C.G.S. units, its permeability is increased. Moreover, careful demagnetisation was found to increase the permeability at the low forces at the expense of permeability at the higher forces. Further experiments have been made with the same material in ring form at high temperatures. It was thought that if the stalloy, when its temperature passes through the value at which the magnetic quality is regained on cooling, was simultaneously subjected to a magnetising force and shielded from the influence of the earth's magnetism, the permeability might be increased further. This has been found to be the case.

[*Note added May* 7, 1914.—My attention has been called to a paper by Messrs. H. Pender and R. L. Jones on "The Annealing of Steel in an Alternating Magnetic Field." These authors have obtained high values of the permeability (see the 'Physical Review,' 2nd Series, April, 1913, vol. 1, No. 4).]

In an earlier paper† experiments were described in connection with two small stalloy rings which have been used in the present experiments.

In Table I the present experiments are numbered in the order in which they were made, and the curves are numbered in correspondence with them.

Ring No. 1.

The specimen, which had been heated several times above the temperature at which magnetic quality is lost, was wound with an asbestos-covered wire and placed in a small iron box, the whole being heated in a gas furnace to the neighbourhood of 800° C. About two hours were required to heat the specimen. It was allowed to cool inside the magnetic shield previously used and described (*loc. cit.*), and at the same time it was subjected to a steady magnetising force of 3·12 C.G.S. units. About five hours were required to cool it to atmospheric temperature. When at atmospheric temperature the specimen was taken out and tested for magnetic permeability. The figures were obtained whilst gradually reducing the force and are given in Table I,

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* 'Roy. Soc. Proc.,' A, vol. 90, p. 179 (1914).

† 'Phys. Soc. Proc.,' vol. 23, Part 4, p. 253, June 15, 1911.

Table I.—Permeability.

Ring No. 1.

Expt.	1.		2.		3.		4.	
$H_{max.}$	Just after being taken out of furnace.		After being re-wound.		After demagnetisation from H = 4·17.		After being polarised at H = 6·16 and subjected to vibrations.	
	B.	μ.	B.	μ.	B.	μ.	B.	μ.
0·0105			2·67	254	4·81	457	3·29	312
0·0209			6·15	294	11·8	563	7·89	378
0·0522			23	441	42·8	820	34·2	655
0·105			63·6	606	116	1106	103	982
0·223			209	935	369	1655	365	1640
0·311	314	1060	397	1275	727	2340	748	2400
0·366	2072	5630			1150	3150	1210	3310
0·418					1870	4470	1920	4600
0·471	4030	8900			2710	5750	2750	5850
0·570	5910	10140	3892	7000	4280	7510	4360	7640
0·617			5140	8330	4840	7840	4920	7980
0·726					5900	8140	6040	8320
0·830	7530	9370	6860	8270	6665	8020	6780	8170
0·988			7590	7680	7540	7640		
1·16	8970	7190	8160	7030	8100	6980	8200	7070
1·39	10200	4720	8780	6500	8700	6280	9300	5920
2·41	10500	3430	10030	4300	9960	4130	9880	4870
3·81			10560	2930	10660	2800	10460	3780
6·16			11100	1950	11200	1820	11050	2480
12							11940	995
31·4							12800	408
45·6							13200	290

Ring No. 3.

Expt.	11.		12.	
$H_{max.}$	After polarisation to H = 174 in shield.		Demagnetised from H = 2 and resting all night.	
	B.	μ.	B.	μ.
0·00343	0·994	292	1·45	422
0·00687	2·01	293	2·98	435
0·0115	3·53	307	5·33	464
0·0228	7·96	349	12·1	531
0·0571	25·4	444	48·1	843
0·115	65·9	573	139·6	1214
0·243	218	898	482	1984
0·394	459	1170	964	2450
0·674	4280	6350	3250	5690
0·800	5430	6790	5440	6800
0·915	6320	6900	6320	6900
1·03	7060	6860	7010	6800
1·25			7600	6700
1·16	7920	6710		
1·34	8700	6350	8370	6410
1·76			9990	5660
3·12			12250	3030
4·66			13650	2930
5·54			14300	2580
9·79			15500	1580
10·45			15850	1520
17·42			16800	965
38·54			17970	466
50·4			18540	368
77·7			19300	248
119·5			20340	170

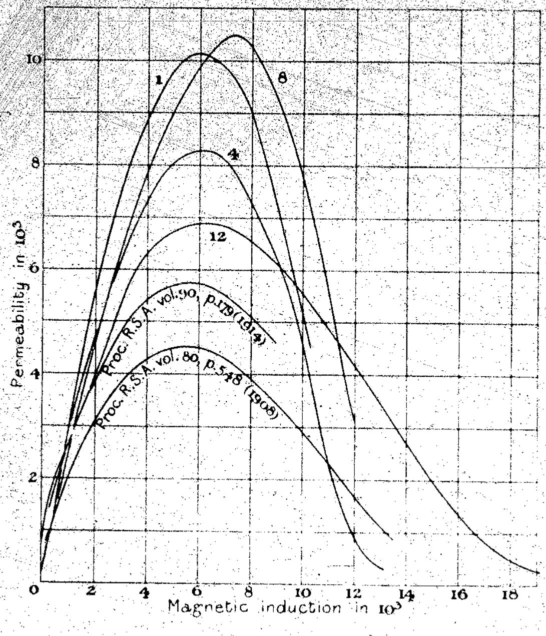
Table I.—*continued.*

Ring No. 2.

Expt. ……	5.		6.		7.		8.		9.		10.	
H_{max}.	Before heat treatment.		After annealing in shield without magnetising force.		After demagnetisation from H = 32 at 50 frequency.		Just after being taken out of furnace.		After re-winding but otherwise not treated.		After demagnetisation from H = 8·95.	
	B.	μ.	B.	μ.	B.	μ.	B.	μ.	B.	μ.	B.	μ.
0·00683	3·95	376	3·2	306	2·96	282			1·72	252	2·87	420
0·0139	9·8	471	6·91	332	6·66	321			3·39	283	5·75	414
0·0275	35·5	683	25·8	496	27·4	527	11·4	194	8·62	313	15·5	561
0·0689	93·3	905	71·1	690	82	796			34·5	501	58	842
0·129									88·6	688	151	1173
0·138	277	1250	218	1000	261	1200	45·8	281	98·6	715	160	1160
0·2935			364	1170	503	1610	158	501	366	1250	605	2060
0·345							*786	2490	817	2370	853	2470
0·414							2150	4910	1330	3210	1475	3560
0·483									2450	5070	2350	4870
0·552	2610	4250	1220	1980	2390	3890	4520	8510	3350	6060	3390	6140
0·621			3180	4400	3300	4570	6020	9540	4090	6580	4150	6610
0·759							7390	10180	5490	7230	5470	7210
0·814							8090	10200	5920	7270	5870	7210
			4010	4800	4080	4880						
0·966			5140	4940	5150	4850			6780	7020	6720	6960
1·10	5820	5020	5670	4850			9340	8810	7370	6700	7340	6670
	6070	5100	5950	4800	5650	4830	9660	8400				
1·31							10300	7620	8030	6130	8110	6190
1·54							10440	6910	8610	5590	8680	5640
											9430	5300
2·04							10880	5750	9790	4800	9660	4800
	8750	3420	8160	3780	8160	3670	11040	4990				
2·65			8720	3320					10360	3910	10330	3900
3·38	9850	2480			9900	2520	11800	3420	10850	3210	10700	3170
4·31											11200	2600
5·85	10900	1860										

* Obtained after the force had been put back from 0·438 to 0·315.

Experiment 1, and plotted in Curve 1. In all the other experiments the force has been increased gradually. It will be seen that the permeability rises



to about 10,000. The ring was then stripped and re-wound with cotton-covered primary and secondary windings, the secondary winding being next to the stampings, and this operation gave rise to considerable mechanical disturbance. Experiment 2 shows that the maximum permeability has dropped to 8330, and the initial permeability is small. On demagnetising the specimen (Experiment 3) the effect previously observed is produced, namely, the initial permeability is increased and the maximum reduced. On again polarising the specimen with a force of 6·16 and leaving it for four days the ring was subjected for about half an hour to a high alternating force having a maximum of 24 C.G.S. units at 80 complete periods per second. This caused the plates to vibrate and give the characteristic sound. After an interval of two days Experiment 4 was then made. It will be seen that the maximum permeability went up to 8320, and that the initial value was lower than in Experiment 3. Experiment 4 also includes the taking of a few hysteresis loops, the particulars of which are given in Table II. In the same table are also given figures taken from a normal specimen of stalloy which had been demagnetised most carefully.* The maximum values of the magnetic induction happen to be very nearly the same. It will be noticed that the coercive force H_0 in the present experiments is smaller for this value of the induction, whereas the residual magnetism B_0 is larger. The ergs per cycle per cubic centimetre are less in the ratio 705/1030.

Table II.—Hysteresis.

Expt.	$H_{max.}$	$B_{max.}$	Permeability, μ.	Ergs per cycle per cubic cm.	Coercive force, H_0.	Residual magnetism, B_0.
4	0·223	369	1655	5·53	0·0646	116
	0·471	2800	5940	215	0·306	2100
	0·726	6040	8320	705	0·404	5150
	2·77	10460	3780	1750	0·488	9020
'Roy. Soc. Proc.,' A, vol. 80, p. 548 (1908)	1·354	6050	4470	1030	0·60	4666

Ring No. 2.

This specimen had been cooled several times to the temperature of liquid air, and it was mentioned in the earlier paper† that such treatment had the effect of increasing permeability when in a demagnetised condition. It has behaved somewhat differently from Ring No. 1, that is to say, when the specimen has been polarised in the shield the maximum permeability has not suffered so marked a change as might have been expected from the earlier experiments. After a preliminary test (Experiment 5), as it was originally left after the cooling experiments, the ring was divested of its winding and raised to a temperature of about 800° C. It was then allowed to cool in the shield without any applied magnetic force. On re-winding it the permeability was found to be slightly smaller (Experiment 6). The ring was then wound with an asbestos-covered coil and allowed to cool from about 800° C. in the shield, with a steady force of 14 C.G.S. applied constantly. Experiment 8 was then made. As in the case of Ring No. 1,

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* 'Roy. Soc. Proc.,' A, vol. 80, p. 548 (1908).

† 'Phys. Soc. Proc.,' vol. 23, Part 4, p. 256, June 15, 1911.

a maximum permeability of over 10,000 was obtained, and it is larger than in the case of Ring No. 1, for the higher values of the magnetic induction. Curve 8 can be compared with Curve 1 in this connection. The specimen was then re-wound and Experiment 9 made. The effect of mechanical disturbance has again been to lower the maximum permeability, but in this case to 7230, as against 8330 in the case of Ring No. 1. After demagnetising the specimen from a force of 8·95 C.G.S. units Experiment 10 was made. It will be seen that, although the permeability at low forces is increased, the maximum value is not diminished, as might have been expected.

In each of the above cases no allowance has been made for slight possible burning away of magnetisable material.

Ring No. 3.

In order to compare the results above described with those obtained by treatment in the shield without heating, another specimen of stalloy was chosen and as the polarising forces used in the original paper were small, it was thought well to try the effect of a larger one. Ring No. 3 was polarised to a force of 174 C.G.S. units in the shield, and Experiment 11 was then made. The maximum permeability in this specimen has the value 6900 as against 5900 in the earlier experiments. Demagnetising the specimen from H = 2 C.G.S. units has increased the permeability at the lower forces but not seriously affected its maximum value. Curve 12 is interesting, as it shows that the moderate maximum permeability of 6900 gives rise to higher permeabilities at the larger values of the magnetic induction.

Electric Resistance.

An experiment has been made to discover whether the specific resistance of stalloy is affected when it has been subjected to cold treatment in the shield, and has yielded a negative result.

Conclusion.

The experiments show that the permeability of stalloy in ring form can be increased greatly by heat treatment; that is by allowing the material to cool through the temperature at which it becomes a magnetisable substance during the time that it is shielded from the influence of the earth's magnetism and subjected to a magnetising force. Values of the permeability higher than 10,000 have been obtained. A characteristic feature of the curve of permeability and magnetic induction is that the higher the maximum permeability the lower is the permeability at the higher values of the induction. The dissipation of energy due to magnetic hysteresis is lower than in the normal stalloy specimen for a given value of the magnetic induction.

The above experiments were made in the Sir William Siemens Electrical Engineering Laboratory, University of London, King's College. I wish to thank my laboratory attendant, Mr. George Jones, for the assistance which he rendered.

On Newcomb's Method of Investigating Periodicities and its Application to Brückner's Weather Cycle.

By Prof. ARTHUR SCHUSTER, Sec. R.S.

(Received April 21,—Read May 7, 1914.)

During the last few years of his life Prof. Simon Newcomb was keenly interested in the problem of periodicities, and devised a new method for their investigation. This method is explained, and to some extent applied, in a paper entitled "A Search for Fluctuations in the Sun's Thermal Radiation through their Influence on Terrestrial Temperature." The importance of the question justifies a critical examination of the relationship of the older methods to that of Newcomb, and though I do not agree with his contention that his process gives us more than can be obtained from Fourier's analysis, it has the advantage of great simplicity in its numerical work, and should prove useful in a certain, though I am afraid, very limited field.

Let $f(t)$ represent a function of a variable which we may take to be the time, and let the average value of the function be zero. Newcomb examines the sum of the series

$$f(t_1)f(t_1+\tau)+f(t_2)f(t_2+\tau)+f(t_3)f(t_3+\tau)+\ldots,$$

where t_1, t_2, etc., are definite values of the variable which are taken to lie at equal distances from each other. If the function be periodic so as to repeat itself after an interval τ, the products are all squares and each term is positive. If, on the other hand, the periodic time be 2τ, each product will be negative and the sum itself therefore negative. It is easy to see that if τ be varied continuously the sum of the series passes through maxima and minima, and the maxima will indicate the periodic time, or any of its multiples.

The large specific effects produced by traces of different gases seem to indicate that (*b*) may be an important factor.

4. The experiments cannot be held either to prove that the emission of electrons from hot carbon is an immediate consequence of chemical action between the carbon and the surrounding gases; or to invalidate those theories which regard this effect as a physical property of the hot solid.

* * *

The Magnetic Properties of Iron when Shielded from the Earth's Magnetism.

By Ernest Wilson.

(Communicated by Prof. J. A. Fleming, F.R.S. Received January 10,—
Read February 26, 1914.)

The primary object of the experiments described in this paper is to examine the magnetic properties of iron under small magnetic forces when shielded from the earth's magnetism. In a previous paper* experiments were described in which these magnetic properties were examined at low forces, and hysteresis loops obtained at maximum values of the magnetic induction as low as 0·937. The specimen, which was of the same material as used in the present experiments, was exposed to the influence of the earth's magnetism, and it is this influence which has now been removed as far as possible.

The specimen is of ring form and is built up to an axial length of 38·8 cm. of stampings of an alloy of iron known as "Stalloy," containing 3 per cent. of silicon. The internal and external diameters of each stamping are 7·6 and 12·75 cm. respectively, and the thickness varies from 0·34 to 0·14 cm. The secondary winding is next to the stampings and has 177 turns of copper wire 0·81 mm. diameter insulated by cotton impregnated with paraffin. The primary or magnetising winding has 10 turns of copper strip 19 mm. wide and 0·13 mm. thick covered with insulating tape.

The shield is built up to a length of 47 cm. of stampings of transformer iron 0·62 mm. thick. The internal and external diameters of each stamping are 30·5 and 40·6 cm. respectively. At each end are discs of soft iron 40·6 cm. diameter which together with two square end plates make up an overall length of 56 cm. The shield is firmly clamped by four bolts passing through

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* 'Roy. Soc. Proc.,' A, vol. 80, p. 548 (1908).

the end plates. For the insertion of the primary and secondary windings a few of the stampings nearest to the end discs have a small piece cut away so as to form a narrow opening into the shield.

The specimen is supported symmetrically within the shield and their common axis is placed at right angles to the magnetic meridian.

Throughout the experiments the ballistic galvanometer has been used. When it was desired to demagnetise the specimen, an alternator was used whose wave-form is a smooth curve having a maximum ordinate somewhat larger than that of an equivalent sine curve, and the current was gradually reduced by variation of resistance until it was of the order 4×10^{-4} ampère, the alternator being finally allowed to come to rest with its excitation left on.

In Table I will be found, for the respective experiments which are numbered, the magnetic induction B and in some cases the permeability μ corresponding to the given force H. In Table II will be found the figures obtained at the higher forces. In Table III will be found the results obtained from the hysteresis loops.

Preliminary experiments were made when the specimen was inside the shield in the virgin state, that is to say, as received from the makers and in a demagnetised state, the maximum magnetic force impressed upon the specimen being 0·59 C.G.S. unit. At this stage it was discovered that the insulation of the secondary winding was defective, and this threw a criticism upon the experiments. It is necessary to mention this because the previous magnetic history of the specimen is important, and the results will be alluded to later. The specimen was re-wound, and the experiments made thereafter may be placed in the following order.

Experiment 1: Specimen out of shield and exposed to the influence of the earth's magnetism. Hysteresis loops obtained.

Experiment 2: Specimen in shield. Hysteresis loops obtained after careful demagnetisation from a force of 0·59.

Experiments 3, 4, 5, 6: Specimen in shield and showing how high permeability was produced.

Experiments 6, 7, 8: Specimen in shield and showing the effect on permeability of allowing it to rest in a highly magnetised state.

Experiments 9, 10, 11, 12: Specimen in shield and showing the effect of allowing it to rest in a less highly magnetised state.

Experiments 13, 14, 15, 16, 17: Specimen in shield and showing the effect of allowing it to rest in a demagnetised condition.

Experiments 18, 19, 20: Specimen in shield. Hysteresis loops obtained after a moderate rest in demagnetised condition.

I. *Permeability.*

Experiments 1, 2: Before placing the specimen in the shield, Experiment 1 was made after demagnetisation from a force 0·3 at 52 complete periods per second. For each of the forces mentioned in Table I a hysteresis loop was obtained, the details of which are given in Table III. When in the shield the specimen was demagnetised from a force of 0·59, and Experiment 2 was made. Hysteresis loops were again obtained for the same forces as in Experiment 1. The permeability curves 1, 2, are plotted in fig. 1, and correspond to Experiments 1, 2, respectively. For comparison, the curve of permeability obtained in the previous paper (*loc. cit.*) is also plotted. This curve is somewhat higher than in Experiment 1, and in this connection it should be noted that the demagnetisation had been made from a much higher force than 0·59. Near the origin it differs in shape from those obtained in Experiments 1, 2.

Experiments 3, 4, 5, 6, on the production of high permeability: Up to this point it should be noted that the highest force ever applied to the specimen has been 0·59, and, at the close of Experiment 2, the specimen was left magnetised as the result of a force 0·0935, and eight days elapsed before further experiments were made. At the end of this time a magnetising force of 0·8, due to a continuous current, was applied, reversed a few times, and removed. Such a force as 0·8 applied to a demagnetised specimen has, in ordinary magnetic testing, a degrading or polarising effect, that is, the magnetic induction corresponding to a given smaller force is then lower than it would have been had the iron been in a demagnetised state originally.* In the shield, however, the reverse is the case, the specimen having been previously exposed to the earth's magnetism, and not subjected to so high a force as 0·8. A comparison of the figures obtained in Experiments 2 and 3, Table I, shows the increase in the permeability at the low forces. A comparison of curves 2, 5, in fig. 1 shows in the early stages how great is the increase in permeability caused by carefully demagnetising the polarised specimen.

Experiment 6 was next made to investigate the effect on permeability at higher forces than those given in Table I. It is practically a continuation of Experiment 5 and the figures are given in Table II. In fig. 2 the curve 6 shows the result obtained, and, for the purpose of comparison, the values of the permeability obtained in the earlier paper (*loc. cit.*). A maximum permeability of 5750 corresponding to a magnetic induction of 5500 is indicated, whereas the old experiments on the unshielded but

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* 'Roy. Soc. Proc.,' A, vol. 83, p. 1 (1909).

carefully demagnetised specimen show a maximum of 4600 for a magnetic induction of 5000. In the case of a specimen of almost pure iron a permeability of 5480, corresponding to a magnetic induction of 9100, was obtained,* and this is a high value.

Experiments 6, 7, 8, deal with the effect of resting the specimen when in a magnetised condition. Experiment 7 was made immediately after Experiment 6 was completed, that is without demagnetising the specimen and in Experiment 6 the force was taken up to 1·8. The result shows how greatly the permeability is affected in the earlier stages by the application of this previous force of 1·8. The specimen was again polarised by a force of 1·8 and left in this condition for about 18 hours. Experiment 8 was then made

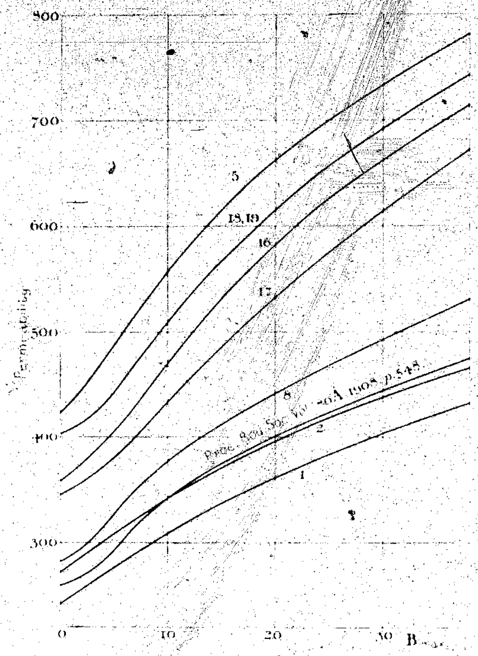

Fig. 1.

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* 'Roy. Soc. Proc.,' vol. 62, p. 369.

and continued to the higher forces as before, and the figures are given in Table II. Curve 8, fig. 1, shows how greatly the permeability is reduced in the early stages, and Curve 8, fig. 2, shows the later stages. It will be seen that for a magnetic induction of 5500 a permeability of 5900 is obtained, and this is even greater than that shown by Experiment 6. Curves 6, 8, cross one another at an induction of about 3500 and coincide when the induction is about 10,000. The similarity of Curve 8 in fig. 1 with that taken from the earlier paper is interesting. In the one case we have the specimen carefully demagnetised and exposed to the earth's magnetism, in the other the specimen is polarised and shielded. It is worthy of note that when in the polarised condition of Experiments 7, 8, careful

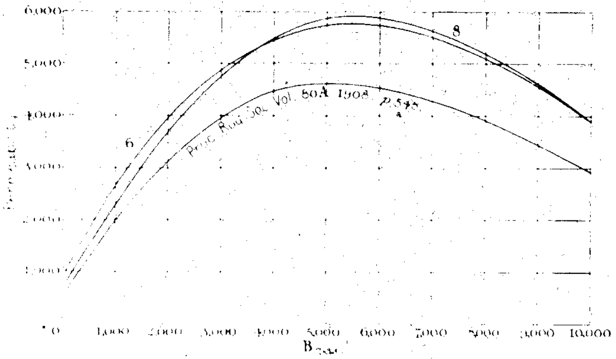

FIG. 2.

demagnetisation is required to restore maximum permeability at the lower forces.

Experiments 9, 10, 11, 12 show the effect of two periods of rest when the specimen is left polarised by the application of a force of 0·0935. It will be seen that when left the specimen tends to degrade itself or to experience a fall of permeability in the earlier stages but it gets into a fairly stable state after a long enough interval. This will be apparent if Experiment 12 be compared with Experiment 16 of the next section.

Experiments 13, 14, 15, 16, 17, show the effect of resting in a carefully demagnetised condition for periods of 3, 18½, 48 hours and 13 days respectively. The same (degrading) process is at work in the earlier stages, but after 48 hours' rest the specimen is more stable. The continuation of Experiment 17 is given in Table II. The points when plotted in fig. 2

Table I.—Permeability.

Expt.	1.	2.	3.	4.	5.		6.	7.		8.		9.	10.	11.	12.	13.	14.	15.	16.		17.	18.	19.
Maximum magnetic force H.	Out of shield after demagnetisation from H = 2·5.	In shield after demagnetisation from H = 0·59.	In shield after polarisation at H = 0·8.	In shield after demagnetisation from H = 1·2.	In shield immediately after demagnetisation from H = 2·5.		In shield 1½ hour after demagnetisation from H = 2·5.	In shield immediately after polarisation at H = 1·8.		In shield 18 hours after polarisation at H = 1·8.		In shield after demagnetisation from H = 2·5.	In shield 18 hours after polarisation at H = 0·0061.	In shield after demagnetisation from H = 1·5.	In shield 18 hours after polarisation at H = 0·0061.	In shield after demagnetisation from H = 1·8.	In shield 3 days after demagnetisation from H = 1·8.	In shield 18 hours after demagnetisation from H = 1·8.	In shield 18 hours after demagnetisation from H = 1·8.		In shield 13 days after demagnetisation from H = 2·5.	In shield 24 hours after demagnetisation from H = 1·8.	In shield 1½ hours after demagnetisation from H = 1·8.
	B.	B.	B.	B.	B.	μ.	B.	B.	μ.	B.	μ.	B.	B.	B.	B.	B.	B.	B.	B.	μ.	B.	B.	B.
0·000848	0·294	0·248	0·298	0·310	0·362	427	0·344	0·251	298	0·240	283	0·362	0·317	0·362	0·302	0·364	0·325	0·311	0·306	361	0·294	—	—
0·00168	0·412	0·462	[illegible]	0·686	0·721	429	0·695	0·502	299	0·476	283	0·722	0·662	0·717	0·622	0·718	0·675	0·651	0·612	364	0·586	[illegible]	0·68
0·00420	1·04	1·18	1·56	1·75	1·86	443	1·78	1·26	300	1·21	288	1·87	1·61	1·86	1·58	1·64	1·74	1·63	1·57	374	1·60	1·72	—
0·00843	2·15	2·44	3·28	3·74	3·98	472	3·74	2·66	316	2·48	293	3·94	3·10	3·90	3·26	3·31	3·62	3·40	3·26	387	3·30	3·50	—
0·0179	4·9	5·55	7·56	[illegible]	9·96	556	9·22	6·19	346	6·08	340	[illegible]	8·15	9·66	8·08	8·98	9·64	8·20	7·91	442	7·16	8·92	—
0·0496	17·2	19·6	28·8	36·3	39·2	791	37·7	22·2	447	22·7	458	36·2	35·1	37·7	34·9	37·8	36·5	34·8	34·4	694	31·1	—	36·4
0·0935	41·2	45·7	67·8	88·2	98·7	1060	96·8	56·2	587	52·5	562	91·0	86·8	89·6	85·4	89·7	88·3	86·2	95·0	1015	82·6	—	88·3

Table II.—Permeability.

Experiment 6 continued.			Experiment 8 continued.			Experiment 17 continued.		
Maximum H.	Maximum B.	Permeability, μ.	Maximum H.	Maximum B.	Permeability, μ.	Maximum H.	Maximum B.	Permeability, μ.
0·0996	110	1100	0·100	62·2	619	0·118	126	1070
0·138	172	1250	0·140	98·9	706	0·219	324	1480
0·206	311	1510	0·208	172	827	0·292	537	1840
0·279	521	1870	0·281	284	1010	0·435	1310	3010
0·329	767	2330		—	—	0·583	2600	4460
0·411	1190	2900	0·411	848	2060	0·829	4730	5710
0·465	1600	3450	0·468	1286	2750	1·13	6430	5690
0·584	2660	4560	0·588	2560	4350	1·47	7730	5260
0·780	4310	5530	0·782	4410	5640	1·74	8510	4890
1·03	5900	5730	1·03	6030	5850			
1·32	7220	5470	1·31	7210	5510			
1·52	7830	5150	1·52	7910	5200			
1·81	8680	4790	1·80	8660	4810			

Table III.—Hysteresis.

No. of Experiment.	Maximum H.	Maximum B.	Ergs per cycle per cubic centimetre.	Steinmetz index, β.	Steinmetz constant, α.	Permeability, μ.	Coercive force, H_c.	Residual magnetic induction, B_0.
1	0·000499	0·117				235		
	0·000849	0·204				240		
	0·00168	0·412				246		
	0·00420	1·04	0·0000190			248	0·000062	0·018
	0·00843	2·15	0·0000723	1·84	0·0000177	255	0·00018	0·038
	0·0179	4·9	0·000801	2·92	0·00000774	274	0·00071	0·18
	0·0496	17·2	0·0155	2·36	0·0000188	347	0·00417	1·47
	0·0935	41·2	0·0974	2·10	0·0000396	441	0·01	4·55
2	0·00168	0·462				275		
	0·00420	1·18	0·0000175			284	0·000047	0·016
	0·00843	2·44	0·0000569*	1·62	0·0000134	289		
	0·0179	5·55	0·000861	3·30	0·0000030	310	0·00050	0·18
	0·0496	19·6	0·0181	2·41	0·0000139	395	0·0040	1·47
	0·0935	45·7	0·102	2·04	0·0000419	489	0·010	4·45
8 and 19	0·00168	0·68	0·00000310			405	0·000016	0·0068
	0·00420	1·72	0·0000306	2·47	0·00000863	410	0·000058	0·028
	0·00843	3·59	0·000279	3·00	0·00000602	426	0·00031	0·13
	0·0179	8·92	0·00291	2·58	0·0000103	498	0·0014	0·65
	0·0496	36·4	0·0583	2·13	0·0000273	734	0·0063	4·9
	0·0935	88·3	0·305	1·87	0·0000702	944	0·0138	14·0
20	0·191	237·0	2·1			1240	0·037	47·4
	0·418	1016·0	39·5	2·01		2430	0·170	454·0
	0·783	4340·0	449·0	1·68		5540	0·393	3160·0
	1·62	8210·0	1300·0	1·67		5070	0·531	6130·0

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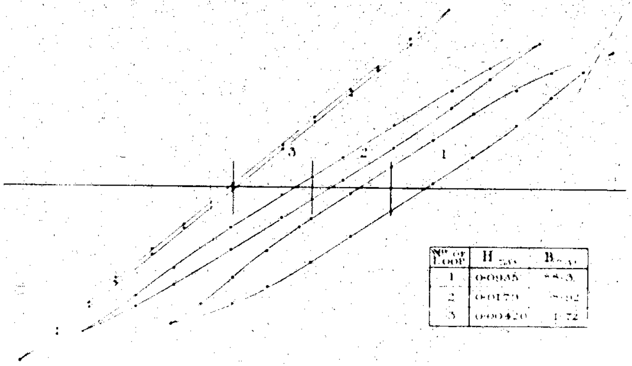
* It is possible that this value for the ergs is slightly too small. For some reason the curve is not so satisfactory as it should be, but it could not be repeated.

practically coincide with those of Curve 6. The rest of 13 days has produced the most noticeable effect at the lower forces.

[*Note added February* 26, 1914.—A rest of six weeks in a demagnetised condition shows no further diminution in permeability than does the rest of 13 days.]

II. *Hysteresis.*

In the previous paper (*loc. cit.*) when the stalloy specimen was exposed to the earth's magnetism, it appeared that the Steinmetz index increased from its ordinary value of 1·7 to 2·69, when the magnetic induction reached the value of 0·94. The present experiments show that after demagnetisation in or out of the shield the value of the index rises to a maximum in the neighbourhood of a magnetic induction of 3 and then diminishes. The preliminary experiments made when the specimen was in the virgin state bear out the same remark. The shape of the loops is well worthy of study. The loops in fig. 3 are selected from those taken in Experiments 18 and 19



No. of Loop	H_{max}	B_{max}
1	0·0345	88·3
2	0·0179	8·92
3	0·00420	1·72

Fig. 3.

and it will be seen that as the induction is reduced the shape is altered. The character of loop 1, for instance, when the maximum induction is 88·3, is more like that of the loop with which one is familiar in ordinary testing but it has sides which for a short distance are practically parallel straight lines. This is the beginning of a pronounced alteration in shape. Loop 2, fig. 3, shows this carried to a further stage. Loop 3 is remarkable in that its sides are practically two parallel straight lines, and the index has nearly passed its maximum value. Reference should be made to an interesting paper on this subject by Dr. W. M. Thornton.* The Steinmetz equation is that the ergs per cycle per cubic centimetre are equal to αB^{β}, where α and β are constants and B is the magnetic induction. The values of α and β are given in Table III. As to what would be the values of the index β if the experiments could be carried further cannot be said at present.

It should be mentioned that the coercive force has been taken from the point where the mean curve cuts the axis of H. It is well known that at this point on the curve the magnetic instability is such that tapping the specimen causes a change in the magnetic induction. When the force is varied from a positive or negative maximum to zero this instability in some cases asserts itself and would, if a mean curve were not drawn, indicate a somewhat smaller coercive force.

A few loops have been obtained as a continuation of Experiments 18 and 19 at the higher forces when the specimen was in a demagnetised condition and after a rest in that condition of one and a half days. The particulars are given in Table III, Experiment 20. By comparing them with the figures obtained in the earlier paper it will be seen, for instance, that for a magnetic induction of 8200, the ergs per cycle per cubic centimetre are less when in the shield in the ratio 1300/1688, and the permeability is greater in the ratio 5070/3850. The coercive force H_0 and the residual magnetic induction B_r are less.

The experiments throw light upon the early stages of the ordinary curve, which shows the relation between the coercive force and the intensity of magnetisation; it resembles the curve connecting the functions H and B of magnetic materials.

Conclusion.

The experiments show that the earth's magnetism may seriously affect the magnetisability of iron. Comparing the results obtained in these experiments when stalloy (in ring form) is magnetised and then carefully demagnetised whilst shielded from the earth's magnetism, with the results of similar experiments made on the same material in a carefully demagnetised condition but exposed to the earth's magnetism, the ratio of the permeabilities has a maximum of 1·79 when the magnetic induction has a value 172, and the ratio of the maximum permeabilities is 1·24. A maximum permeability of 5900 was obtained when the specimen was shielded and magnetised by a previous force of 1·8 C.G.S. units, and this is 1·28 times the maximum permeability obtained from the demagnetised and exposed specimen. The

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* 'The Electrician,' May 16, 1913, p. 211.

dissipation of energy by magnetic hysteresis for a given magnetic induction is less when the stalloy is in the shield and demagnetised than when it is first demagnetised and then exposed to the earth's magnetism. The Steinmetz index, after rising to a maximum of about 3 for a force of about 0·008 C.G.S. unit, begins to diminish as the force is reduced, and at about this point the hysteresis loops begin to experience a change in shape, becoming practically straight parallel lines.

[*Note added March* 10, 1914.—As was mentioned during the reading of the paper, the high permeability has persisted since the specimen was taken out of the shield on February 17, 1914. Experiments which are just completed show that it still exists.]

The above experiments were made in the Sir William Siemens Electrical Engineering Laboratory, University of London, King's College. I wish to acknowledge the assistance I have received from Mr. R. H. Smith and Mr. R. C. Burt. Mr. A. D. Keigwin very kindly re-wound the specimen for me, and Prof. Huntington very kindly lent me the shield. I have also to thank Messrs. Sankey and Sons, of Bilston, for presenting me with the stampings for the purpose of research.

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TOME VINGT-SEPTIÈME

1916

AVEC NOMBREUSES FIGURES ORIGINALES DANS LE TEXTE

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projet, là à l'état embryonnaire. Dans quelques centres seulement, où d'ailleurs elle existe déjà, l'organisation continuera, sans plus, à subsister. Donc, on n'aura en somme rien créé. Rappelons seulement que l'Allemagne a des Universités ou des Ecoles techniques dotées de ressources de plusieurs millions, qu'elle n'a jamais lésiné en matière de créations universitaires. A ce point de vue, le modèle est à imiter. J'ajoute que, avec un budget plus élastique, des ressources plus assurées, nos écoles techniques pourraient largement distribuer aux étudiants peu fortunés l'enseignement gratuit, alors qu'aujourd'hui on n'admet guère que des étudiants payants et les droits de laboratoire sont forcément très élevés, car ils constituent le plus clair des ressources. Rappelons encore que la démocratie américaine est entrée depuis longtemps dans cette voie : la moitié des Ecoles techniques supérieures américaines sont gratuites (Omer Buyse).

Je m'excuse d'avoir été si long. Je me résume; des élèves et de l'argent, c'est tout ce qu'il faut assurer à l'enseignement supérieur. Avec cela il ne faillira pas à sa mission et rendra au pays les services que celui-ci a le droit d'en attendre. Des mesures énergiques sont nécessaires pour cela. Mais nous sommes à l'époque des mesures énergiques. Et si on trouvait ces mesures révolutionnaires, je me bornerais à invoquer encore soit M. Liard, soit Cournot[1], soit M. Lavisse[2], qui ne sont pas des révolutionnaires, soit encore les dépositions Joseph Bertrand, Berthelot, Maneuvrier, Buquet (enquête Ribot.)

Quand on a signalé le mal, on ne peut se refuser à administrer le remède.

L. Zoretti,
Professeur à l'Université de Caen,
Directeur de l'Institut technique de Normandie.

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[1] *Des Institutions d'Instruction publique en France*, 1864, p. 185.

[2] *Questions d'enseignement national*, 1885, p. 240.

LES IDÉES DU PROFESSEUR FLEMING

SUR L'ORGANISATION DE LA RECHERCHE SCIENTIFIQUE

A la séance du 9 février de la *Royal Society of Arts*, à Londres, l'éminent professeur Fleming a lu une étude du plus haut intérêt sur l'organisation de la Recherche scientifique en Angleterre.

Ce sujet, toujours palpitant, est devenu de la plus brûlante actualité depuis que la guerre a démontré jusqu'à quel point nos ennemis avaient su mettre la science en coupe réglée à leur profit.

Hanté sans doute par le souvenir des beaux résultats obtenus en Allemagne par le système du *Massenarbeit*, le professeur Fleming propose l'institution d'un système du même genre en Angleterre, mais avec des modifications destinées à l'améliorer.

Ce *Massenarbeit* d'outre-Rhin ressemble un peu à l'exploitation des terrains aurifères du Klondyke ou du Transvaal. Un propriétaire achète un champ, puis il le divise en parcelles qu'il distribue à ses ouvriers ; chaque ouvrier fouille en tout sens son *claim* de façon à en sortir le plus possible. L'ensemble du rendement appartient au propriétaire; heureux celui qui récolte la pépite convoitée !

Or aujourd'hui nombreux sont les chercheurs infatigables, mais la plupart des recherches sont vaines, faute d'avoir été guidées, coordonnées. C'est vers ce but que tend l'organisation préconisée par M. Fleming.

I

L'auteur, après avoir rappelé l'importance de la science et son peu de place en Angleterre, montre la nécessité urgente, tant au point de vue de l'œuvre actuelle de la défense nationale que de l'avenir du pays, d'augmenter le bagage scientifique de l'Angleterre, et de le mettre sous la forme où les applications surgiront le plus facilement.

Il observe que la plupart du temps les découvertes du passé sont dues au travail et à l'initiative personnels ; elles ont été faites par des amateurs, dans le bon sens du mot, c'est-à-dire par des hommes travaillant seuls et selon leurs idées, et souvent sans rapports les uns avec les autres. Ce travail individuel est bien dans le caractère anglais; il a ses avantages, mais aussi ses inconvénients : il permet à des pionniers d'ouvrir de nouveaux champs de travail, mais il n'est pas favorable à leur exploitation complète et systématique.

Le progrès à réaliser doit consister dans l'organisation de la recherche, en faisant de la multitude des travailleurs scientifiques indépendants une armée où chacun aura sa place et son rôle déterminé. Il faut une coopération ordonnée et disciplinée. On évitera ainsi les travaux en double, les pertes de temps ; on utilisera complètement tous les génies, même ceux d'une valeur secondaire, qui sont précieux par leur persévérance au travail.

Pour décider les grandes lignes des recherches à entreprendre, des études préliminaires sont nécessaires; la *Royal Society*, de par sa situation et la largeur bien connue de ses vues, est toute indiquée pour prendre la tête de ce mouvement.

La plupart des Sociétés scientifiques ne sont plus guère, hélas, que les éditeurs de volumes composés de comptes rendus hétéroclites de travaux divers, dont certains sont déjà des lieux-communs et ne peuvent donner lieu qu'à des discussions oiseuses. Il y a toutefois d'heureuses exceptions, et la *British Association* a déjà souvent organisé des discussions sur des sujets préparés d'avance et du plus haut intérêt.

La *Société Faraday* a adopté depuis peu le même plan, en provoquant l'envoi des opinions d'un certain nombre de personnalités compétentes sur un sujet donné, pour servir de bases à la discussion de ce sujet en séance, discussion qui, préparée ainsi, ne peut manquer d'être féconde.

La fonction principale de ces différentes sociétés devrait être l'excitation à la recherche nouvelle, et l'étude des moyens les meilleurs pour y parvenir.

Au début de chaque session, le bureau devrait tracer un plan de travail et diviser les sujets d'étude selon le nombre de séances, demander à des chercheurs qualifiés des communications introductives, en distribuer largement des extraits, les faire suivre de courtes contributions dues à des spécialistes autorisés, de façon à concentrer l'attention et la discussion sur les points essentiels.

Mais il faut faire davantage: formuler jusque dans le détail des suggestions précises sur les travaux futurs à entreprendre, et les porter à la connaissance de tous ceux qui sont capables et désireux de s'y atteler.

Ce sujet est traité dans un *Livre Blanc*, publié en juillet dernier par le Ministère de l'Instruction publique anglais, et intitulé : « *Vues générales pour l'organisation et le développement des Recherches scientifiques et industrielles* ». Il semble préconiser l'établissement de deux comités : une Commission du *Conseil Privé*, qui assumerait le contrôle des dépenses votées par le Parlement pour la recherche scientifique et industrielle, et un *Conseil consultatif*, composé de savants et d'industriels compétents. Celui-ci s'occuperait : 1° de proposer l'institution de recherches spécifiques, 2° de l'établissement d'institutions spéciales, pour l'étude des problèmes concernant des industries particulières; 3° de l'établissement et de l'attribution de bourses d'études à des étudiants ou à des chercheurs en vue de ces recherches particulières.

Il est évident que ces *Conseils consultatifs* devront comprendre des hommes d'expérience au point de vue de la technique et des applications scientifiques, à côté des savants théoriciens.

Pour pouvoir traiter de toutes les questions, actuellement où chacun se spécialise, le *Livre Blanc* prévoit l'organisation d'un grand nombre de sous-commissions spéciales, renforcées d'experts dans la branche particulière de la science ou de l'industrie qui est visée.

Pour éviter de tomber dans la bureaucratie, et pour que la nouvelle organisation ne devienne pas un simple Département d'Etat, il serait bon que les *Bureaux consultatifs* soient élus par les Sociétés savantes et industrielles elles-mêmes, car parmi les membres de ces diverses associations, on trouvera les compétences diverses qui sont indispensables.

Dans chaque *Bureau*, on placerait un fonctionnaire du Ministère de l'Instruction Publique pour administrer les fonds publics provenant de subventions ou de dons divers, mais qui s'occuperait de cela seulement, ne s'immisçant en aucune façon dans les délibérations qui resteraient réservées aux savants.

Au reste, chacune des grandes Sociétés scientifiques de Grande Bretagne devrait déjà — si ce n'est pas fait — nommer un comité de recherches recruté parmi ses membres les plus connus ou les mieux doués. Il faudrait faire voter tous les membres, et rendre ce bureau renouvenable par fractions au bout d'un certain temps pour en rafraichir l'esprit. La Royal Society pourrait prendre la direction suprême de l'ensemble de ces bureaux destinés à l'organisation de la recherche scientifique, désignant les besoins généraux dans chaque domaine et les directions des recherches les plus nécessaire dans des comptes rendus succints. Le premier compte rendu ne contiendrait sans doute que des indications de lacunes, en laboratoires, appareils, chercheurs ; mais les suivants entreraient dans une discussion plus détaillée des problèmes attendant une solution et des recherches à entreprendre. Un archiviste ou secrétaire, nommé par chaque bureau parmi les savants sachant tenir une plume, condenserait les opinions importantes de façon à ne pas réunir des avis au hasard, mais à quintescencier l'avis général des experts dans une même branche. Ces comptes rendus, bien faits, auraient une valeur énorme comme documents pour les réformes à introduire en pratique.

Les *Bureaux consultatifs* devrait être subventionnés, afin que la recherche scientifique puisse devenir une profession libérale comme une autre. Il ne suffit pas de chercher partout des travailleurs, il faut leur permettre de gagner honnêtement leur vie... Un homme deviendra un « chercheur scientifique », comme il devient médecin ou avocat, et pourra donner ainsi tout son savoir, et non pas seulement pendant les vacances ou à temps perdu, comme le font actuellement certains savants qui professent dans les établissements d'éducation.

Des « bourses de recherches » de ce genre ont été fondées pendant l'Exposition de 1851 et ont donné de bons résultats ; leur subvention devrait être de 3.750 à 5.000 fr. par an.

Donc, pour les recherches scientifiques, création de bureaux consultatifs renouvelables sur vue du travail produit; division du travail distribué à des sous-commissions d'études et à des chercheurs professionnels.

On a coutume d'accuser les maisons anglaises dont la fabrication comporte des détails scientiques de ne pas s'être assuré, comme les maisons allemandes, les avis d'experts en la matière. Les savants, questionnés, ont répondu que cela tenait à l'imprévoyance ignorante des fabricants ; ceux-ci jettent à leur tour la pierre aux savants et les accusent de manquer d'esprit pratique. Il y a sans doute de l'un et de l'autre.

Les questions de prix de revient, de transports, de main-d'œuvre, d'approvisionnements, viennent compliquer singulièrement la recherche scientifique au moment de son d'application à l'industrie, et tel succès de science pure peut devenir un fiasco en science appliquée, de par ces causes secondaires, qui sont à considérer aussi avec attention.

Le secret professionnel aussi est de première importance, de même que la propriété d'une découverte. Si un savant au service provisoire d'un industriel fait une découverte d'un gros rapport, à qui appartiendra-t-elle ? A l'industriel qui prépare la voie, a fait venir le savant et lui a mis tous les atouts dans la main ? ou au savant dont l'intelligence a résolu le problème ? Et si le savant fait mine de ne rien trouver et emporte d'importants secrets qui peuvent lui être achetés à prix d'or par une maison rivale ?

M. T. Humberstone a traité de quelques-unes de ces difficultés dans une brochure éditée par le Ministère de l'Intruction publique anglais, où il rappelle la solution de la question préconisée aux Etats-Unis par feu le Professeur Robert Kennedy Duncan sous le nom d'*association de recherches industrielles*, où elle a donné de bons résultats. Les Universités choisissent parmi leurs élèves gradués des « *membres chercheurs* ». D'un autre côté, les fabricants sont invités à s'adresser aux universités pour la solution des problèmes qui les intéressent. De part et d'autre, on signe un contrat, un véritable contrat commercial, mentionnant la rémunération du *chercheur*, et sa gratification en cas de réussite. Celui-ci s'engage au secret, et à faire breveter la découverte possible par le fabricant. De la sorte tous les intérête sont sauvegardés : le fabricant a à sa portée les ressources du laboratoire universitaire; l'inventeur possède un stimulant et un salaire; l'université même bénéficie des découvertes de science pure qui peuvent être faites en chemin. Le *chercheur* acquiert progressivement de l'expérience et par conséquent de la valeur. C'est une variété nouvelle d'ingénieur-conseil, le savant-conseil.

On a souvent agité la question d'une récompense pécuniaire que l'Etat devrait accorder à ceux qui font progresser la science. Ceci est juste en théorie, mais inapplicable en pratique, car nul ne connaît la valeur d'une découverte scientifique, dont on ne se rend même compte que bien des années plus tard... trop souvent après que la tombe s'est refermée sur l'inventeur.

Pour illustrer cet aphorisme, M. Fleming cite le cas de Faraday, dont la découverte de l'induction magnéto-électrique en 1831 parut sans grande valeur alors et dont l'application a créé des richesses énormes. Il cite aussi le livre de Clerk Maxwell : « Théorie dynamique du Champ électromagnétique », considéré à son apparition comme une œuvre de science un peu exaltée, et qui provoqua vingt ans après les travaux de Hertz sur les ondes électriques, et nous donna trente cinq ans plus tard la télégraphie sans fil !

Comment payer des choses pareilles, les plus belles, celles qui dépassent l'entendement humain de leur époque ?

La seule possibilité consiste, non à payer les découvertes, mais à les faciliter en provoquant des collaborations, des associations d'études, des sociétés, des unions professionnelles de savants, assises sur les bases solides et bien comprises d'un système qui les renouvelle et les astreigne à une production intensive et régulière.

Le système des *Bureaux consultatifs* et celui des *Membres-chercheurs* peuvent être combinés profitablement pour en créer un troisième, meilleur encore, qui cumulerait l'encouragement et la récompense, la science pure et la science appliquée, la nouveauté et l'intérêt.

A la suite d'une démarche faite en mai 1915 par la *Royal Society* et la *Chemical Society* au Ministère de l'Instruction publique anglais, le Parlement a voté un crédit annuel de 625.000 fr. pour la recherche; c'est évidemment quelque chose, mais ce n'est pas encore assez.

II

M. Fleming étudie en second lieu les moyens nécessaires à la recherche scientifique, soit les matières et les appareils. Jadis, ils coûtaient peu de chose ; mais, actuellement, il n'en est plus de même : la recherche scientifique moderne nécessite, en général, un matériel coûteux.

Au commencement de la guerre, on eut la douloureuse surprise de constater que, pour toute la verrerie, la porcelaine, l'outillage de laboratoire, l'Angleterre était tributaire de l'Allemagne ou de l'Autriche. Même disette de produits pharmaceutiques, de colorants, de réactifs... Les sciences physiques n'étaient pas plus heureuses; l'électricité surtout manquait des éléments les plus indispensables : pas de fours électriques à résistance, pas de pompes pneumatiques pour vide élevé, pas de fils métalliques spéciaux pour bobines de résistances, pas de charbons pour lampes à arc, etc...

La prévoyance scientifique allemande éclate particulièrement au sujet du tungstène, indispensable à présent pour la fabrication des lampes à incandescence dans lesquelles il a détrôné le filament de carbone, et aussi pour les aimants et les machines-outils où l'acier au tungstène est nécessaire. Dès qu'ils se sont rendu compte de l'importance de ce nouveau métal, les Allemands ont voulu l'accaparer, achetant même toute la production des Indes anglaises, qui à elles seules fournissent un cinquième de la production mondiale. Ils achetaient le minerai brut et l'expédiaient en Allemagne pour être traité, et les Anglais se contentaient de racheter le tungstène métallique ou les instruments mêmes où il est employé. De la sorte, lorsque la guerre éclata, les Allemands, non producteurs, avaient un stock de métal, et les Anglais, producteurs, n'étaient pas capables d'en traiter une tonne!

Ceci n'est qu'un exemple entre mille, dit M. Fleming, « pour montrer l'imprévoyance anglaise opposée à la prévoyance allemande ». Il ne faudrait pas en conclure que les Anglais soient incapables; seulement ils trouvaient plus commode d'acheter que de fabriquer, à cause des difficultés du travail et des complications des lois fiscales.

M. Fleming note d'ailleurs avec plaisir les progrès faits depuis quelque temps, et qui dénotent en effet un grand effort accompli. Rien que pour l'industrie verrière, par exemple, ravivée par un *Comité de Recherches* fondé par l'*Institut de Chimie* sous la direction de feu le professeur Meldola, onze formules ont été établies et distribuées gratuitement aux verreries d'Angleterre, qui suppléent dès à présent aux besoins du pays, même en verres optiques ou pharmaceutiques inattaquables, tubes pour rayons cathodiques, ou autres spécialités. Certaines verreries de laboratoire, particulièrement compliquées, ne sont pas encore obtenues, mais cela viendra sans doute, comme on l'a réalisé pour la porcelaine chimique que l'on faisait aussi autrefois venir d'Allemagne.

Voilà pour le présent, mais il faut aussi envisager l'avenir. Après la guerre, l'Angleterre va-t-elle de nouveau s'engourdir et redevenir tributaire de l'Allemagne ?

Pour éviter de semblables errements, il faut créer pour l'Angleterre son indépendance scientifique absolue : c'est pourquoi il faut créer un *Bureau des Travaux scientifiques*.

Que les agences, les comités, les institutions, que tous ceux qui veulent contribuer à donner aux usines les informations scientifiques nécessaires se groupent, se fondent en une organisation unique, dont la fonction soit justement de distribuer les renseignements au sujet des modes de fabrication, des prix de revient, des brevets; en général, de tout ce qui touche aux recherches scientifiques.

Il faudrait subventionner, au début, ce *Bureau*, mais il ne tarderait pas à se suffire à lui-même, ne serait-ce que par le recouvrement des cotisations payées par les fabricants abonnés. De même que l'on s'abonne à une agence d'informations politiques ou financières, on s'abonnerait à cette agence d'informations scientifiques qui transmettrait les dernières nouvelles intéressant la fabrication, la science pure ou appliquée, l'outillage d'usine et de laboratoire, etc... Un atelier et un laboratoire d'essais seraient à la disposition des membres, pour permettre des expériences d'application, de matériel, et pour faciliter aux fabricants ou à d'autres abonnés les décisions à prendre, en leur montrant quel est l'objet, la matière ou l'instrument dont ils ont besoin.

On trouve un commencement d'exécution de ce programme dans les informations publiées par l'*Institute of Chemistry*, sur les réactifs d'analyse, préparées par un Comité spécial nommé par l'Institut et la Société des chimistes analystes. Une *Association anglaise de matériel de* *laboratoire* s'est fondée aussi par l'union de plusieurs firmes.

Il vaut mieux cependant réunir les intelligences que de les laisser travailler par groupements séparés; il y a là un effort national à faire pour sauvegarder l'indépendance scientifique de l'empire. L'éminent professeur supplie les législateurs d'étudier toutes les mesures à prendre pour non seulement aider à la création de cette indépendance, mais aussi pour éviter qu'elle ne soit tuée tôt après la cessation de la guerre, par la concurrence que ne manqueront pas de faire les Allemands.

Il faudra pour cela élaborer un système de lois commerciales destinées à protéger la recherche scientifique en Angleterre et chez ses alliés.

III

Le dernier point étudié par M. Fleming est la formation du contingent destiné à diriger les recherches scientifiques.

Le sommet de l'esprit inventif, le génie, est une chose qui ne se commande pas, qui ne s'achète pas. Cela est évident, mais on peut toujours le protéger, l'aider.

Il faut que le pays comprenne que les hommes si rares, doués d'une grande capacité scientifique et inventive, sont une richesse nationale incalculable ! Cette science, ce génie, ne doivent pas être dissipés dans la lutte pour le pain quotidien; on doit faciliter au contraire à leurs possesseurs la vie matérielle, afin d'utiliser toutes leurs facultés vers le but cherché. On doit pouvoir aussi développer chez de jeunes sujets les tendances au génie inventif, en s'y prenant d'une façon convenable.

Le système d'enseignement actuel est déplorable; les examens donnent des primes à la mémoire seule, et tuent l'originalité qui est d'une grande valeur; et, malgré toutes les critiques sur ce sujet, la routine reste la même. L'éducation parfaite a pourtant pour but :

1° De former le caractère et la volonté et de créer le jugement;

2° De donner les connaissances générales nécessaires pour accomplir certaines choses;

3° De développer l'initiative, et le pouvoir de comprendre les problèmes nouveaux.

Or, les méthodes actuelles d'enseignement se bornent le plus souvent à fournir des matières toutes digérées.

Une éducation complète doit d'ailleurs comprendre une part de science et de ses applications au bien-être général; et pourtant la plupart des maîtres ignorent tout de la science et ne cherchent même pas à en rien apprendre; ils s'en désintéressent. Dans les écoles, trop de place est accordée à la littérature et à la grammaire de deux langues mortes et peu ou pas du tout aux phénomènes physiques de la vie de chaque jour.

A cet état de choses doit être attribuée l'indifférence dont font montre les dirigeants de toutes les carrières libérales pour ce qui touche à la science.

Et pourtant, note M. Fleming, ce sont les découvertes scientifiques qui fondent les industries nationales ou les détruisent, précipitant dans la misère ou enrichissant de nombreuses populations. Il cite à l'appui de sa thèse la disparition bien connue de l'industrie de la garance en France et de l'indigo aux Indes, par la découverte de leur synthèse chimique en Allemagne et son application industrielle.

Voilà un exemple de la guerre économique, dont les armes sont les découvertes et les inventions scientifiques et qui n'est pas moins désastreuse que la guerre qui se fait par le fer et le feu.

La question primordiale est donc la suivante : quelles sont les mesures à prendre pour former les hommes qui porteront les couleurs de l'Angleterre dans cette bataille économique? Plus d'une application industrielle réalisée ailleurs a eu pour base les découvertes ou les suggestions de savants anglais. Ce qui a manqué dans ce pays, c'est la force de caractère nécessaire pour pousser les idées jusqu'au point où elles deviennent pratiquement productives. Il faut suivre l'exemple d'Edison qui, faisant les premiers essais de son phonographe, s'enferma, dit-on, à clef dans son laboratoire avec ses aides, et jura de ne laisser sortir personne avant que l'appareil n'eût parlé!

Il faut donc établir une union très étroite entre la science et l'industrie. Certains savants y voient un abaissement de la science. Certains industriels, par contre, ont tendance à mépriser la collaboration de la science. Et, pendant ce temps, l'industrie s'étiole et périclite.

Il faut que des liens solides soient formés entre les Universités, les grandes Ecoles et les usines, de façon à pouvoir utiliser immédiatement dans les fabriques et les ateliers les jeunes gens frais émoulus des Ecoles.

M. Fleming préconise, pour arriver à ces fins, le « sandwich system », qui consiste, pour des études devant durer quatre ans, à passer alternativement une année à l'usine et une année à l'école, la première et la troisième année à l'école, et la deuxième et la quatrième à l'usine. Il assure que les résultats sont meilleurs que ceux obtenus par deux années consécutives au même endroit.

Les professeurs devraient s'aboucher avec des hommes de la pratique pour échanger des idées sur les méthodes à suivre pour diriger le travail des étudiants-apprentis, afin d'en faire, non des théoriciens peu pratiques ou des praticiens non scientifiques, mais des hommes utiles et précieux.

La pression économique qui suivra la guerre aura peut-être, parmi ses résultats, celui de diminuer le nombre d'heures dépensées aux sports et aux jeux en Angleterre, et par conséquent d'augmenter le temps consacré aux choses de l'esprit. On pourra élever le niveau des classes et terminer déjà au collège certaines études que l'on faisait dans les Ecoles supérieures.

Il y aura aussi à agiter les questions économiques, que les jeunes gens devront connaître, apprécier, approfondir dès le début de leurs études spéciales. Ils devront apprendre, non seulement comment fonctionne une machine au point de vue mécanique, mais aussi comment elle fonctionne dans l'économie de l'usine, ce qu'elle coûte, ce qu'elle rapporte. De la sorte, ils tireront parti immédiatement de leur stage d'atelier, et acquerront plus vite ce « flair d'industriel » qui fait évaluer les choses immédiatement en possible et impossible, en profit et en perte.

Il faut, pour réparer les désastres de cette guerre affreuse, utiliser tout ce qui a été gaspillé, et abolir le coulage et l'insuffisance dans la vie quotidienne, industrielle, commerciale, domestique.

Il faut, dit en terminant l'éminent professeur, avoir recours à l'ordre le plus absolu, mettre de la méthode dans la recherche scientifique même.

Nul n'était mieux placé que M. Fleming pour mener à bien une étude complète sur les lacunes de la science industrielle en Angleterre, et les moyens d'y remédier. C'est par son influence et sa compétence reconnue qu'il obtint, il y a bien des années, l'établissement du *National Physical Laboratory* dont l'Angleterre est fière à juste titre, et qui a déjà rendu tant de signalés services.

Il faut espérer que sa voix sera de nouveau entendue, surtout à un moment où la France et l'Angleterre, comprenant l'importance absolue des recherches scientifiques, viennent de mettre en commun leurs nouvelles découvertes.

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