May 10, 1883.

Mr. JOHN BALL, M.A., Vice-President, in the Chair.

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

Dr. Dietrich Brandis (elected 1875) was admitted into the Society.

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

Aitchison, James Edward T., Surgeon-Major, M.D.
Browne, James Crichton, M.D., LL.D.
Dobson, George Edward, Surgeon-Major, M.A., M.B.
Duncan, James Matthews, A.M., M.D.
Fitzgerald, Prof. George Francis, M.A.
Flight, Walter, D.Sc.
Frost, Rev. Percival, M.A.
Gill, David, LL.D.
Groves, Charles Edward, F.C.S.
Grubb, Howard, F.R.A.S.
Langley, John Newport, M.A.
Reinold, Arnold William, M.A.
Trimen, Roland, F.L.S., F.Z.S.
Venn, John, M.A.
Walker, John James, M.A.

The following Papers were read:—

I. "Theory of Magnetism based upon New Experimental Researches." By Professor D. E. HUGHES, F.R.S. Received April 5, 1883.

In a preliminary note* I communicated to the Royal Society the formulated results of a lengthened series of experiments with the induction balance, and I now present the experimental evidences which led me to these conclusions.

From numerous researches previously made by means of the induction balance, the results of which I have already published, I felt convinced that in researches upon the cause of magnetism, I should have in it the aid of the most powerful instrument of research ever brought to bear upon the molecular construction of iron, as indeed of all metals. It neglects all forces which do not produce a change in the molecular structure, and enables us to penetrate at once to the interior of a magnet or piece of iron, observing only its peculiar structure and the change which takes place during magnetisation or apparent neutrality.

* "Proc. Roy. Soc.," vol. 34.

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The induction balance, while being one of the most simple instruments as regards its construction, and most powerful as to its powers of appreciating minute differences in the molecular construction of metals, requires a lengthened previous practical knowledge of its use and powers in order to obtain zero readings for each experiment. Thus with it we can very easily obtain an effect, such as a marked difference between two pieces of iron of similar size and chemical composition; but to reduce these differences, separate and measure them by the zero method, is of a peculiarly difficult nature. Not only does the electromotive force vary with each piece of iron, but also the time of its discharge, the time or duration of the effect being more variable and more indicative of the molecular structure than the electromotive force. Again, the form of the induction balance must vary according to the nature of the experiment. In some cases, where it is desirable not to pass an electric current through the metal, four coils should be used, as in the first instrument I presented to the Royal Society in 1879.* In others we should use three, two, or but one coil, as in the instrument which I shall describe in this paper. In order to avoid complication I will only mention results which can be easily obtained by this most simple form of apparatus, results which I believe can only be attributed to the molecular nature of magnetism.

This theory has long been foreseen, and predicted in almost complete perfection as regards the rotation of the molecules, by many authors, the earliest of whose notices, and the most clearly defined as being very near the results obtained by myself, will be found in the remarkable work by De La Rive,† 1853, who in chapter iii, page 317, under the title of "Influence of Molecular Actions upon Magnetism produced by Dynamic Electricity," says: "We have seen that heat, tension and mechanical actions generally facilitate magnetisation. M. Matteucci has found that torsion and percussion, and mechanical actions, not only facilitate the magnetisation produced upon soft iron by a helix that is traversed by a powerful current, but they also contribute, when the current has ceased to pass, to the destroying the magnetism in a very rapid manner; the same philosopher has likewise observed that torsion, when it does not pass beyond certain limits, augments the magnetisation produced upon steel needles by discharges of the Leyden jar.

"M. Marianini, who has made numerous and interesting researches upon magnetisation, arrived at curious results upon the aptitude that iron bars may acquire of becoming more easily magnetised in one direction than in another."

* "Proc. Roy. Soc.," vol. 29, p. 56.

† "A Treatise on Electricity, in Theory and Practice." By Aug. De La Rive. London, 1853.

M. De La Rive sums up a series of interesting experiments in these remarkable words: "The whole of the magneto-molecular phenomena that we have been studying lead us to believe that the magnetisation of a body is due to a particular arrangement of its molecules, originally endowed with magnetic virtue, but which in the natural state are so arranged that the magnetism of the body that they constitute is not apparent. Magnetism would therefore consist in disturbing this state of equilibrium, or in giving to the particles an arrangement that makes manifest the property with which they are endowed, and not in developing it in them. The coercitive force would be the resistance of the molecules to change their relative positions.

"There remains an important question to be resolved:

"Are mechanical or other actions, disturbers as they are of the electrical state, able of themselves to give rise to magnetism?"

Du Moncel, in his remarkable work on Magnetism, 1857, sustained and developed the views of De La Rive, and later, Wiedemann in "Poggendorff's Annalen," 1857—1859, as well as in his remarkable "Lehre von Galvanismus," 1861, sustained a similar theory. Wiedemann has lately given a *résumé* of his researches in the "Lumière Électrique," Paris, January 28, 1882, where he says—

"Nous admettons que les metaux magnétiques sont composés de molécules qui ont une polarité magnétique; nous ne voulons rien préciser quant à la cause même de cette polarité, qu'elle provienne de la séparation des fluids magnétiques, des vibrations d'un milieu entourant les molécules ou mieux encore de l'existance de courants élémentaires.

"Un corps ainsi constitué n'aura pas, en général, de magnétisme libre, parceque les axes magnétiques des molécules seront dirigés dans tous les sens et maintenus dans leurs positions respectives par les forces moléculaires. Mais une force magnétique extérieure, telle qu'une hélice où passe un courant, leur donnera une direction générale.

"En poursuivant cette hypothèse, M. Weber a réussi à expliquer théoriquement l'accroisement de la magnétisme d'une barre soumise à l'influence d'une hélice aimantée jusqu'à un maximum.

"Nous supposons, en outre, que les molécules dans leur mouvement éprouvent une certain résistance qui les empêche de suivre complètement l'influence des forces qui agissent sur elles."

In my preliminary note I gave the formulated results of a lengthened series of researches upon magnetism by the aid of the induction balance. As these agree in all important points with the theory of De la Rive, 1853, I do not wish it to be considered as a new theory or conception of molecular rotation, but as a theory based entirely upon researches into all the conditions of magnetism, and one which clearly defines the conditions of polarity and neutrality.

Gilbert, 1600, remarked the influence of torsion, stress, and vibra-

tions upon magnetism, since which time numerous researches have been made by means of torsion.

Matteucci* employed induction currents, by means of which he observed that mechanical strains increased or decreased the magnetism of a bar of iron.

Wertheim† published a long series of most remarkable experiments, in which he clearly proves the influence of torsion upon the increment or decrement of a magnetic wire.

Wiedemann‡ published his interesting experiments upon torsion-flexion in relation to magnetism, and in his remarkable work, "Galvanismus," 1861, relates his discovery of magnetism produced in an iron wire upon the passage or after of an electric current. He also gives a molecular theory of magnetism, similar to that of De La Rive, 1853, except that Wiedemann supposes that neutrality is the result of a heterogeneous arrangement, thus differing completely from the symmetrical neutrality that I have defined.

Villari§ showed increase or diminution of magnetism by longitudinal pull according as the magnetising force is less or greater than a certain value.

Gore,|| in numerous interesting experiments, shows the influence of electric torsion and the identity of molecular sounds.

Sir W. Thomson,¶ in a remarkable paper, shows the critical value of the magnetisation of iron, nickel, and cobalt under varying stress, and also the effects of longitudinal as well as transversal strain upon its electric conductivity.

Tomlinson** has recently shown completely the influence of strain upon the conductivity of all metals, and that strain produces a molecular change in their structure.

These employed each a somewhat different method, either by primary or secondary currents acting upon a galvanometer or the action of magnetism upon a magnetic needle.

This field of research has been so thoroughly examined that I should have hesitated before trying to reproduce the results by ordinary or similar means. The induction balance, however, seemed to me peculiarly adapted, from its extreme sensitiveness to molecular changes of structure, to analyse such changes as are produced by magnetism. I have put its powers to use in the following researches, and, as I have necessarily studied all the phases of magnetism, I have been

* "Compt. Rend.," t. xxiv, p. 301, 1847.

† "Ann. de Chim. et de Phys.," (3), t. l, p. 385, 1857.

‡ "Archives," t. xxxv, p. 39, et tome ii (nouv. période), p. 300.

§ "Poggendorff's Annalen," 1868.

|| "Phil. Trans.," 1874.

¶ "Phil. Trans.," p. 55, 1879.

** "Phil. Trans.," Part I, 1883.

obliged to use similar means, such as torsion, and also what would be a repetition of several experiments tried long since by others, if it was not for the fact that the induction balance enabled me to observe all the effects of stress on iron by means far more sensitive than any hitherto employed, and notice effects which, without its aid, would pass unperceived. Some idea of this extreme sensitiveness may be inferred from the fact that if we balance two pieces of iron to a complete zero, the addition or subtraction of the $\frac{1}{500000}$ part of iron, or the smallest filing to a large balanced mass of iron, will give out at once loud tones, which we can measure and appreciate.

In my previous experiments upon molecular magnetism I made use of an iron wire, but I have found that in all experiments upon magnetism it is far preferable to use thin flat strips, known as hoop-iron; as we can then have any desired amount of surface in the form of a thin flat bar.

Jamin had previously recognised the importance of using thin and wide steel pieces for his well-known magnets. We can easily magnetise them to saturation, and where torsion is applied the contour of the spiral becomes visible. Again, not only is the magnetism more equally distributed throughout their mass, but we are enabled to study the conditions of neutrality without the constant hindrance of superposed magnetism, as we constantly find in the case of a wire or bar of iron.

I cannot, within the limits of this paper, describe all the varied forms of coils and methods of obtaining perfectly defined zeros, which are necessary in any varied research with the induction balance; description of some of these will be found in my already published papers. I will now describe a simple form which will suffice for the experiments herein mentioned, and the following diagram shows its electrical communications.

A coil, having a large aperture, is fixed to a board; two small abutments or supports, A′A″, at a few inches distance on each side of the coil, allow us to suspend or fix an iron band or strip passing through the aperture, which then becomes the core of an electro-magnet. This forms the essential portion of the apparatus. The iron or copper strip rests upon the two supports A′A″, which are 20 centims. apart; at one of these it is firmly clamped by two binding screws, while the opposite end at A″ can turn freely. The strip of iron J′J″, upon which the researches are made, is 22 centims. long, and of any desired width and thickness; it is fastened by means of a binding screw B″ to the projecting end of an axle, which has a key or arm G, serving as a pointer moving upon a circle, and giving the degree of torsion which the wire may receive; a binding screw allows us to fasten the wire, after turning the pointer to any degree of torsion, and thus preserves the required stress as long as is necessary.

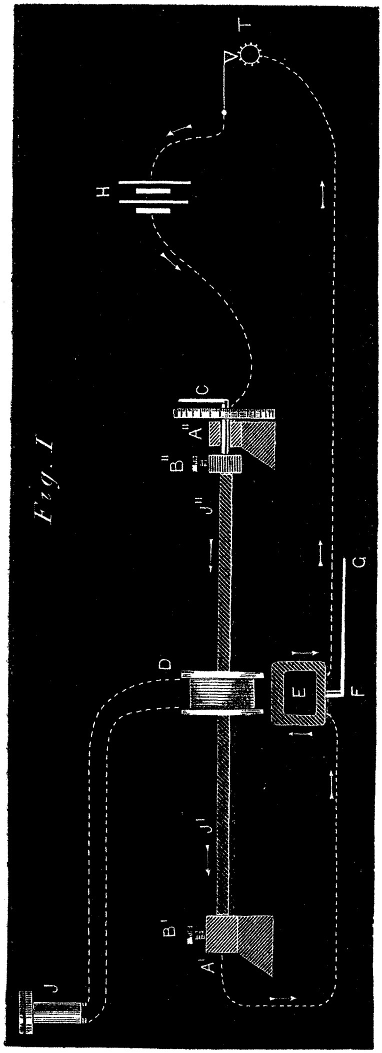


Fig. I

The exterior diameter of the coil D is $5\frac{1}{2}$ centims., and that of the interior vacant aperture $3\frac{1}{2}$ centims., the width is 2 centims. Upon this coil is wound 200 metres of No. 28 silk-covered copper wire. A compensating coil E, whose wires are (when at zero) perpendicular to the coil D, can be rotated upon its axle F by means of its index lever arm G, moving over a graduated circle not shown in the diagram The two coils D and E are affixed to the same piece of board, but independent of the board upon which rest the abutments A′A″, so

that they can, as desired, be moved to any portion of the strip of iron, in order that different portions of the same strip may be tested under a similar stress.

The coil D is joined to a telephone J or a sensitive galvanometer, whose terminals are reversed at each make and break of the current, and we may either pass the current in the manner described or may reverse all the communications, passing the current through the coil instead of the wire, and listening with the telephone to the induced current upon the iron wire alone.

The phenomenon of molecular movement upon the passage of an electric current through a wire or a coil surrounding a bar of iron was discovered by Page, 1837, and De La Rive published several memoirs on this subject in the "Comptes Rendus," 1846, wherein he not only clearly demonstrates the molecular cause of the sounds emitted at each change of the current, but also foreshadowed the theory which he published later in his "Treatise on Electricity," 1853. These movements have since been studied in a variety of ways, and by different methods, but they are all based upon the discovery of Page; as these sounds accompany all the rotations produced by torsion, in many cases too feeble to be heard, but becoming clearly audible by means of the microphone.

In my paper on "Molecular Magnetism," 1881, I proved by three different methods the identity of these sounds with all the phenomena of rotation. In the induction balance we observe only by the angular displacement of the molecules upon its wire or strip of iron, reacting both upon its own wire and the exterior coil; and the currents obtained from 1 centim. length of wire are sufficient to be clearly heard in the telephone held 10 centims. distant from the ear, and this with a feeble current of one Daniell element; under these conditions we hear no sounds in the wire itself, but they at once become audible by increasing the electric current or by the use of the microphone. We cannot, however, analyse sounds obtained in this way, nor can we perfectly analyse the induced currents which Matteucci was the first to obtain, unless we reduce them to a zero by an induction balance, a zero from which it is perfectly easy to perceive and measure the slightest change in the molecular structure.

Before relating a few of the representative experiments, and in order to avoid repetition, I will repeat the theory I gave in my preliminary note, based entirely upon researches on magnetism by the aid of the induction balance.

Theory of Magnetism.

1. That each molecule of a piece of iron, steel, or other magnetic metal is a separate and independent magnet, having its two poles

and distribution of magnetic polarity exactly the same as its total evident magnetism when noticed upon a steel bar magnet.

2. That each molecule can be rotated in either direction upon its axis by torsion, stress, or by physical forces, such as magnetism and electricity.

3. That the inherent polarity or magnetism of each molecule is a constant quantity like gravity; that it can neither be augmented nor destroyed.

4. That when we have external neutrality, or no apparent magnetism, the molecules and their polarities arrange themselves so as to satisfy their mutual attraction by the shortest path, and thus form a complete closed circuit of attraction.

5. That when magnetism becomes evident, the molecules and their polarities have all rotated symmetrically in a given direction, producing a north pole if rotated in this direction as regards the piece of steel, or a south pole if rotated in the opposite direction. Also, that in evident magnetism, we have still a symmetrical arrangement, but one whose circles of attraction are not completed except through an external armature joining both poles.

Experimental Evidences.

If in the induction balance already described we place an iron strip 1 or 2 centims. in width by $\frac{1}{2}$ millim. thickness, and pass rapid intermittent currents through it by means of the rheotome I, there is no induced current upon the coil D, as long as this strip, rod, or iron wire is entirely free from torsion, but the instant we apply the slightest torsion upon it by means of its key C, a very strong induced current in the coil gives loud tones in the telephone, which we can reduce to zero, and measure by the compensating coil E.

The phenomenon has this remarkable character: that a torsion of but $\frac{1}{360}$ part of a complete turn suffices to rotate the molecules to so great an extent as to be almost at the maximum of rotation that can be produced by torsion. I have demonstrated in previous papers* the phenomenon of molecular rotation, and that the induced currents so obtained are not direct from the central rod or wire to the coil, as the wires of the coil are perpendicular to the strip or rod of iron, and consequently at the zero of inductive effect; the induction from the central core upon the coil takes place through the medium of the rotated molecules whose angular displacement allows its reaction, both upon the coil and its central conducting strip, rod, or iron wire; a similar effect would take place if, instead of the rotated molecules, numerous oblong pieces of iron were rotated to a similar angle upon the conducting rod of iron. The induction or reaction of these could

* "Proc. Roy. Soc.," vol. 31, p. 525; vol. 32, pp. 25, 213, 1881.

take place at any degree which is not parallel or perpendicular to either the coil or its central conducting core, in direct proportion to its angular displacement.

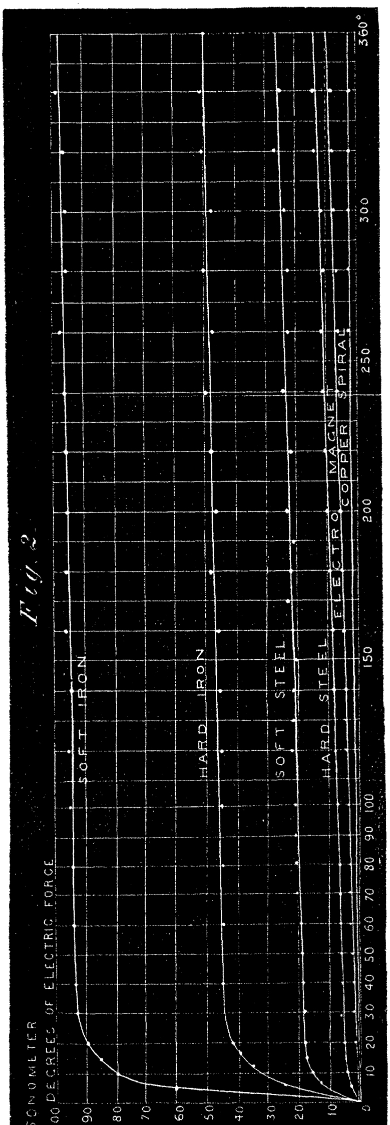


Fig. 2.

The induced currents from molecular rotation are extremely powerful in proportion to the length of wire or strip of iron acting

upon the coil; and they have the distinctive feature that the maximum effect is obtained with an extremely feeble torsion, differing entirely from induction obtained through the medium of the spirality or increased parallelism of the conducting wire in relation to the secondary coil, as the effect here is a gradually increasing force, and exceedingly feeble at the degree of torsion sufficient to produce the maximum of molecular rotation. Thus we have a distinct phenomenon of molecular induction, its law of rapid maximum separating it completely from that obtained from non-magnetic metals, or from spirality of electric currents. If we compare the force obtained by molecular rotation with mere spirality of the electric current, we find that $\frac{1}{20}$ of a single turn gives the maximum for iron, whilst for a conducting copper wire it would require a spiral of similar diameter of fifty whole turns to equal or balance the power obtained from molecular induction, thus the effect is 900 times greater for the same degree of spirality; and if we neglect its distinctive feature of rapid maximum and compare it with ordinary electro-magnetic force, we find that it requires upon an iron core fifteen whole turns of similar conducting insulated copper wires to produce the same force; or for the same degree of spirality of conducting wires, the electro-magnetic induction thus formed is 270 times weaker than that of molecular induction. Thus we have not only its distinctive feature of rapid maximum, but an induced current which cannot be imitated nor accounted for except on the hypothesis of molecular rotation.

It will be seen from the following diagram that the rotation takes place very rapidly with the first degree of torsion, and after 20° or $\frac{1}{18}$ of a complete turn shows only the increased effect due to continued spirality.

It is evident from the above diagram that the molecules are rotated to their maximum during the first 20°, or in reality during the portion within the limits of elasticity; from this point the molecules become rigid by the strain of torsion, and they are then only rotated directly as the spirality of the wire or rod. The diagram only shows the effect of a right-handed torsion, the opposite torsion giving equal though opposite electric currents.

If the wire is free from strain, no increase of electric current changes its zero; nor does it while under torsion, though we may then produce a confused zero, when a powerful current is used, as the electromagnetic effects from its centre free from strain superpose themselves upon those due to rotation. For this reason we should not employ more than one small bichromate cell, as its most powerful effects are obtained with a comparatively weak primary current.

Knowing this, we observe that, after the passage of an extremely strong current (which may be in the same or contrary direction), and return to our previous feeble current, we have exactly the same

induced force as before, and with the same clear zero. Thus the molecules are not only rotated by torsion as already shown, but they have an inherent polarity which cannot be augmented nor destroyed.

We may, however, increase the molecular rotation and consequent force obtained by the application of heat, thus allowing greater molecular freedom. Annealing increases the effect in iron in a marked degree, and alloying has a marked influence in rendering the molecules of iron more rigid. The induction balance allows us to appreciate this differential freedom in different varieties of iron and steel, and in a future paper I shall show how this phenomenon of rotation can be applied to important practical results by investigations into the chemical nature of different varieties of iron and steel, and show distinctly the separating line of iron and steel.

Molecular Inertia.

A phenomenon of inertia is observed in these experiments, which I regard as not only being a proof of rotation, but of possession by the molecules of true inertia. For when a slight torsion of 20° has been applied to the strip or rod of iron, and we return it slowly to its zero of torsion, we have a remaining rotation of the character of residual magnetism; this is generally about a quarter of the maximum effects and of the same polarity, the rod then requiring a momentary mechanical vibration in order to allow the molecules freedom to return, which they at once do to an absolute zero; we have here a lagging behind which is characteristic of inertia. We have, however, more evident proofs, for if instead of freeing the rod gradually from torsion, we allow it to spring back suddenly, then the molecules continue their rotation by their acquired velocity far beyond zero, producing in most cases (where the rod of iron is very soft) a contrary polarity of fully one-half of its previous value, and although the rod is perfectly free from torsion, we must apply a slight torsion in the previous direction before obtaining a zero; we have here a zero under torsion evidently due to molecular inertia, for the instant we give the slightest mechanical vibration to the rod, the molecules return to their true zero, and now the slightest torsion produces its true polarity as before.

This inertia is far greater in soft iron than in hard iron or steel, being directly proportional to its softness, the consequence of this being that the time of rotation or discharge of soft iron is very slow compared with that of steel, and requires a compensation for time of discharge for each species of iron. I have already mentioned this as a difficulty in obtaining true zero observations, and I now make use of this very troublesome inertia to determine at once the degree of softness of any wire or rod.

We can understand this phenomenon when we know that while the

molecules in steel are excessively rigid, they have the quality of elastic rigidity, consequently the elastic pressure which prevented free rotation serves to restore them quickly to their previous zero, and also prevents any springing past or rotating from beyond their true zero.

Effects of Magnetism.

If the molecules of iron have inherent polarity and rotate freely upon their axes, we should expect that we could rotate them by the influence of an exterior permanent magnet alone, and this proves to be the case, for if (when the rod is free from torsion and the molecules are at zero) we approach a powerful compound permanent magnet perpendicular to the rod, the molecules rotate under its influence as freely as we have seen previously under torsion. Supposing the magnet to be at 20 centims. distance, and that we gradually lessen this distance, we find the maximum rotation whilst the magnet is at 5 centims., passing this point it gradually diminishes to a complete zero when distant 3 centims. the molecules now being parallel with the rod or the inducing coil according to the direction of rotation, and consequently (as before explained) no induced currents are possible. If we now continue to approach the magnet, the molecules are still further rotated, and we have now strong induced currents of the opposite polarity to the previous, notwithstanding that the rod is evidently magnetised continually in the same sense.

The rotation here, with its zeros and change of polarity, whilst the rod is gradually magnetised by increasing degrees of magnetic force, is due to the magnetic influence being perpendicular to the rod, allowing full rotation, from the circular neutrality which I shall explain later; but if the magnet is approached in the line of the rod, instead of perpendicular to it, we have continued increased rotation until it touches the rod; in this case we do not cross a zero, because the molecules can only turn in the direction of saturation.

Symmetrical Arrangement.

When we have a rod of soft iron, free from torsion, it is perfectly homogeneous in its structure, and we have a complete zero at all portions of the wire, rod, or strip of iron, at the extremities as well as at the centre. In order to observe this we should employ a very narrow coil, the one employed by myself being a single insulated wire, wound spirally upon itself upon a cardboard, being a marvel of workmanship, given me by Mr. A. Stroh; by means of this coil, whose thickness does not exceed $\frac{1}{10}$ millim., we can explore rods of any length, and if any portion is under strain we at once hear loud tones. Thus I find in all rods that have not been annealed, spots or places showing strains which have been caused by their mechanical treatment, such as hammering, rolling, or drawing into wire. We can by this

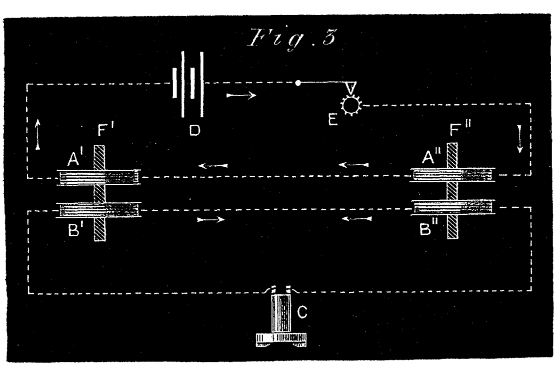
means not only perceive the strain but determine its direction by the polarity obtained. I have no doubt but that some day this will be practically applied to the appreciation of strains in iron shafts or cannons.

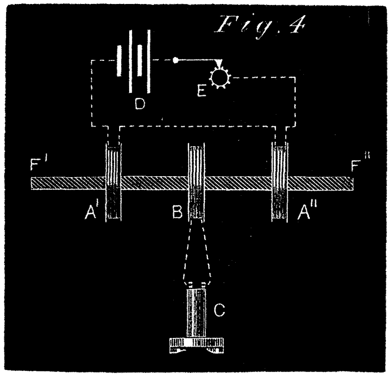
If we apply torsion to a soft iron rod, we find the degree of rotation equal at each section observed, quite independent of its length, consequently we find perfect symmetry of rotation throughout. If we magnetise the rod in such a manner as to leave its residual magnetism with several consequent poles, the portions into which the rod is thus divided are similar in their symmetry to several distinct magnets with their similar poles placed opposing each other, producing reversed induced currents at each consequent pole.

When we take observations by the induction balance, either upon electric conductivity or magnetism, we do not observe the effects as generally observed by other methods, viz., after the current has had time to reach its stable condition; we really observe the effects produced during the first instant of time, known as the variable period, observing from the first instant of electrical contact to a certain maximum, which can never be greater than the length of time of these contacts. These results are obtained by the rapid contacts of the rheotome, producing 500 vibrations per second, which the extremely rapid action of the telephone allows us to appreciate. Thus, the actual duration of the electrical contact is but $\frac{1}{1000}$ part of a second; and this proves the extremely rapid action of molecular rotation, as the effects which we have noticed are all produced in this fraction of a second.

Magnetic Conduction.

The following experiments were made by means of an induction balance of four and three coils, described fully in my paper, "Proc. Roy. Soc.," vol. 29, p. 56, 1879. The following diagram shows its electrical communications.





In fig. 3, two flat primary coils A′, A″ are near two similar secondary coils B′, B″, the distance between these coils being regulated by means of adjusting screws. The coils of B′, B″ are wound in contrary direction to each other, consequently the induced currents in each coil, if of equal strength, neutralise each other; as shown by the arrow, the induced currents act upon the telephone C. The primary coil A′ is joined through the battery D to the rheotome E and coil A″.

If we introduce a wire or bar of iron F′ in the coils A′, B′, the induced currents are increased by the magnetic conductivity from the upper to the lower coil, and as the coils A′, B′ and A″, B″ can be at any desired distance, or from 1 millimetre to 1 metre apart, we can test the conductivity of iron through any desired length. If we introduce into the second pair of coils A″, B″ a piece of iron of the same form, size, and molecular structure as that already in A′, B′, its effect on induced currents equals those of the first pair of coils and we have a perfect zero, but in practice we find that there is always some slight difference, even when the pieces are cut off the same bar; we have to compensate for this difference, and thus measure the differential structure.

In fig. 4 we have three coils, being the form adopted in my sonometer; the secondary coil B being equidistant from the primary coils A′, A″, acts upon the secondary coil in reversed direction, consequently a perfect zero of effect is found whenever the action of A′ equals that of A″, and this can be easily found by displacing either coil. If we introduce a bar of iron between the coils A′ and B, the balance no longer exists, owing to the greater electromagnetic conductivity on that side, but if the bar of iron F′ F″ is passed through the centre or axis of all the coils, as shown in the diagram, we have no effect except that due to a differential conducting power on one of its sides, the direction and force of which can be found by the amount of dis-

placement of the coil B necessary to find a zero. Thus, we can at once find the slightest strain or fissure, such as partial rupture in iron rods of any size or form. The coils may be close together or widely separated, and would find a practical application if applied to shafts undergoing constant strain, such as the screw shaft of steamboats.

The balance shown in fig. 3 is the one I generally employ, and is preferable for the following experiments.

If we take a flat disk of iron similar in form to our usual current coins, we find that if it is placed flat on or parallel with the coils, we have a great reduction of induced currents upon the pair of coils in which it is placed, due to the energy expended in creating the "Arago" circular currents, and its action then is precisely similar to copper or all non-magnetic metals, but if this disk is revolved 90°, or placed perpendicular, it then acts simply as a magnetic body and similar to the bar of iron F; the induced currents on its pair of coils are strengthened by the reaction of its electro-magnetic conductivity.

That conduction itself is due to molecular rotation is proved by the fact that soft iron shows a far higher conductivity than hard iron or steel; we observe here the same results of freedom and rigidity, and all the previous effects of rotation are again repeated as conduction. Soft Swedish charcoal iron shows such a marked superiority over all other irons and steel, as regards its power or the force obtained, that I feel convinced that the same superiority would be shown by its use for the cores of all electro-magnets, particularly those of telegraph instruments, where rapid action and the maximum of force obtainable from a feeble current are required.

Faraday showed that iron loses its magnetic force at red-yellow heat, and the induction balance is peculiarly adapted for investigating this phenomenon. If we place an iron wire or rod, as at F, we find on heating it that its conductivity gradually rises, being at black heat, just before the visible red, double of that noticed at the ordinary temperature, being a similar result to that previously noticed with the single coil balance. But if we increase the heat until the rod becomes red-yellow, all conductivity instantly vanishes and the iron apparently has lost all its powers, being then similar to a piece of copper or other non-magnetic metal; what takes place is, however, not destruction, for, at red heat, its inherent polarity reappears instantly with its full previous force. There seems no gradual diminution or reappearance of its polarity, it is sudden and apparently instantaneous, its time of action being less than the $\frac{1}{1000}$ part of a second. The induction balance will, no doubt, in the future, enable me to investigate this phenomenon.

I find that the conducting power of soft iron is greatly reduced by magnetising, generally one-fourth of its total conductivity, the residual magnetism being in reality a partial rotation, thus reducing

the available total amount of rotation. This is so evident from a series of experiments I have made on this subject, that I can safely predict that if an iron wire could be held charged to magnetic saturation, we should obtain no conduction whatever, and its action as regards the production of induced currents would be similar to copper; or, if the rotation were already complete and rigid, we should have no magnetic conductivity. We can observe this partial rotation in an iron rod, whose conductivity has been reduced by magnetising, as we have only to vibrate the wire, its molecules being rendered free instantly return to zero, and we have its previous full conducting powers.

The slightest torsion also reduces its conductivity, the greatest effect being on the first few degrees of torsion; thus torsion not only rotates the molecules during its elastic stage, but holds them imprisoned or fixed as rigidly as in hard iron or steel.

This form of induction balance allows us to demonstrate that polarity apart from the molecules does not exist. For if we balance one pole of a long magnetised iron or steel bar, we find the same conductivity for either pole, and the induced currents obtained are all in one direction, no matter if the coils act upon either pole or the apparent neutral centre; thus it is impossible with this form of balance to perceive any difference between north or south polarity. All that we observe is the degree of rotation of the inherent polarised molecules, and that this is symmetrical throughout is shown by the equal conducting power of all parts of a magnetised rod.

This form of induction balance also shows that the conducting powers of a bundle of fine iron wires and thin flat strips are equal, the thin band or strip of iron being superior to the fine wires if they are closely pressed together, as the maximum of induced rotative effect in all magnetic bodies is at or near the surface, consequently, a tube of iron will give greater power for a feeble force than a solid bar.

The time of discharge during which the molecules rotate or return to zero is comparatively short in bundles of loose iron wires, flat strips, and thin tubes, but exceedingly slow in solid bars. This confirms the results obtained by other methods, and which have already received practical application.

Visible Effects of Magnetism.

I have been able to repeat the greater portion of my researches with the induction balance, by simply observing the effects produced by magnetising iron and steel upon a magnetic direction needle according to the indications already given by the balance; by this means we are enabled to render visible most of the effects, but cannot so well determine the cause; in fact, without the aid of the induction balance all researches upon magnetism must remain incomplete. We

can, however, perceive the result of a supposed cause, and, as De la Rive has done, base a theory upon molecular rotation; but if we have previously analysed these movements by the aid of the induction balance, the following experiments will render visible effects due to molecular rotation.

The apparatus needed is simply a good compound horseshoe permanent magnet, 15 centims. long, having six or more plates, giving it a total thickness of at least 3 centims. We need a sufficiently powerful magnet, as I find that I obtain a more equal distribution of magnetism upon a rod or strip of iron by drawing it lengthwise over a single pole, in a direction from that pole as shown in fig. 5, as we can then obtain saturation by repeated drawings, keeping the same molecular symmetry in each experiment. A few well suspended magnetic needles of different powers are required, and as the needle itself induces magnetism, all observations should be made as far as possible by means of repulsion, repulsion being the only certain test (whenever the magnetism is feeble) that the iron or steel possesses independent polarity from that induced by the needle.

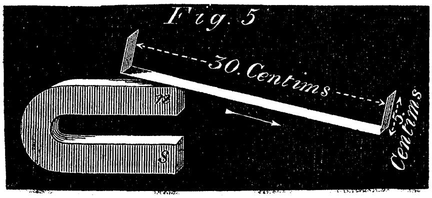
We should have also several flat strips of hoop-iron or thin band-iron, varying in width from 1 to 3 centims., and at least 30 centims. long, in order to observe one polarity free from the disturbance caused by the other. I find rods $\frac{1}{2}$ millim. in thickness are the most easily magnetised to saturation, and this is the size of ordinary common hoop or band iron sufficing for the following experiments.

If we magnetise one of these rods by drawing it over one of the poles of the permanent magnet, we find that it is strongly magnetic; but if we apply a few slight elastic torsions the magnetism rapidly disappears. This effect has been observed and numerous researches have been made on this subject since Gilbert, 1600. Wertheim, 1857, in the "Annales de Chimie," has given a detailed account of his experiments upon the diminution of magnetism by torsion.

The diminution depends entirely upon the freedom of its molecules, for if we take a pure Swedish charcoal iron well annealed, a single slight torsion completely renders the rod free from magnetism, the molecules at once rotate to neutrality. I have in my possession, and will demonstrate with it at the reading of this paper, a solid bar of iron, 2 centims. diameter, 40 centims. in length, which, when strongly magnetised, and acting strongly upon the magnetic direction needle, loses instantly all its apparent residual magnetism by the simple torsion produced by the fingers upon its surface. Hard tempered steel loses but 2 per cent. by continuous and violent torsion, its molecular rigidity is so great that we cannot rotate the molecules by any mechanical strains. We may thus roughly estimate the degree of molecular freedom by the number of torsions required to render it

neutral; ordinary hoop iron requiring generally eight double right and left elastic torsions before it is nearly neutral; there will be, however, still a slight residual magnetism, which can be instantly rendered neutral by a slight torsion given to the rod when held vertically; or we may reverse the residual magnetism by the same directive influence of the earth's magnetism.

I have found it convenient to attach two brass clamp keys to the extremities of the rods, or simply turn the ends at right angles, as shown in the following diagram.



Wertheim, 1857, remarked that if we magnetise a wire under torsion, there will be a diminution upon freeing it from torsion, a still greater upon giving it a contrary torsion; and that its original force is in a measure restored by returning to the torsion under which it was magnetised, designating this phenomenon as "La rotation du maximum de magnétisme," and it is difficult to explain this phenomenon except upon the hypothesis of molecular rotation.

Wiedemann discovered that a wire becomes magnetic on or after the passage of a current, and in his "Galvanismus" he points out its molecular character. Sir W. Thomson* expresses his opinion that the effects are due to the outside twist of the wire forcing the current to pass round a fixed centre, and, consequently, that the effects can be explained as ordinary electromagnetism. This view evidently takes notice of the spiral action of the current alone. I have repeated this experiment, and find that the magnetism increases directly as the electromotive force, so it would be difficult to infer that the action of the current is due to molecular rotation, if it was not for the fact that the wire is magnetic after the passage of the current, as can be rendered visible by torsion, consequently I believe Wiedemann was fully justified in regarding this effect as one of molecular rotation.

Dr. Hooke, 1684, remarked that steel or iron was magnetised when heated to redness and placed in the magnetic meridian. I have slightly varied this experiment by heating to redness three similar steel bars, two of which had been previously magnetised to saturation and placed separately with contrary polarity as regards each other, the third being neutral; upon cooling, these three bars were found to have identical and similar polarity. Thus the molecules of this

* "Phil. Trans.," 1879, p. 55.

most rigid material—cast steel—had become free at red heat, and rotated under the earth's magnetic influence, giving exactly the same force on each, consequently the previous magnetisation of two of these bars had neither augmented nor weakened the inherent polarity of their molecules. Soft iron gave under these conditions by far the greatest force, its inherent polarity being greater than that of steel.

The gradual rotation of the molecules may be observed by strongly magnetising a soft iron wire. If we then pass a feeble electric current we find a slight diminution of magnetism after its passage, and as we increase the force of the electric current the molecules almost entirely rotate to zero; and if we heat the wire to redness, or simply put it in mechanical vibration, we have at last perfect neutrality, the current having rotated the molecules as it does an exterior needle perpendicular to itself, being simply Oersted's discovery of external rotation of the needle applied to the molecule itself. The wire when thus rendered neutral can, as Wiedemann remarked, again show evidence of magnetism. The neutrality here is that known as chain or circular magnetism, each molecule forming a link of a chain whose circle of attractions is completed around the axis of the wire through which the current has passed.

In order to perceive the change of polarity which torsion produces when an electric current is passing through an iron wire, the wire, which may be 2 millims. diameter, and 40 centims. in length, should be placed horizontally east and west, the centre of the wire being 3 or more centims. above the axis of the needle, thus differing completely from the position of the wire in Oersted's discovery, as in the latter case the maximum rotation is obtained when the wire is parallel with the needle; but in the following experiments the maximum effect is obtained when the needle is at right angles to the conducting wires, and none whatever if parallel, its action being perpendicular to the exterior rotations of Oersted's discovery; and a similar phenomenon will be observed in all the rods mentioned later in the case of superposed magnetism.

An iron wire, under the conditions above mentioned, shows strong north or south polarity by a left or right handed elastic torsion; and if we leave the wire with a slight remaining permanent torsion, producing movement of the needle to the left, it diminishes upon breaking the electric circuit, and increases to its previous value on re-establishing the current; this is due to a slight mechanical molecular twist. If we now magnetise this rod slightly in a contrary direction (the needle then having a movement to the right) we find that upon re-establishing the current it now increases the right deflection. Thus the slight magnetism has completely reversed the influence of the previous mechanical torsion.

The question here arises, have we rotated the molecules from their previous position, or is it simply the reaction of magnetism considered

apart from molecular rotation, which has changed the spiral direction of the electric current? The answer to this is most clear—that it is entirely due to molecular rotation. If the wire is perfectly neutral, we obtain by the current of one half-pint bichromate cell 45° deflection of the needle to the left for a left-handed torsion, and a similar degree to the right for a right-handed torsion, depending altogether upon the softness of the iron for the degree of force obtained, but in all cases perfectly equal on each side. If we magnetise the wire so that it produces about 45° to the right, then a torsion to the right produces no effect whatever; the molecules have already rotated to the degree which mechanical torsion could produce, and torsion aided by the electric current can produce no further rotation. The left-hand torsion, however, preserves its full maximum effect, and restores the molecules to their previous position. If again we magnetise the wire to saturation, so that the needle is violently moved to the right, having 80° or more deflection, then the right-hand torsion, instead of augmenting it, instantly reduces the deflection to 45°, being the maximum allowed by a right-handed torsion. We have here, in the case of an electric spiral, decreased effects from an increased mechanical torsion in the same direction, and the experiment clearly shows the rotation of the molecules independent of mechanical directive action.

Being desirous of noticing the effects of powerful electric currents, Dr. Warren De La Rue, F.R.S., kindly aided me by passing a current from his well-known chloride of silver battery through iron and steel wires. A condenser, 42·8 microfarad capacity, charged by 3,360 cells, was used. We first passed this enormous electric charge longitudinally through the permanent magnet I have described, fig. 5, completely destroying its evident polarity by rotating the molecules to neutrality.

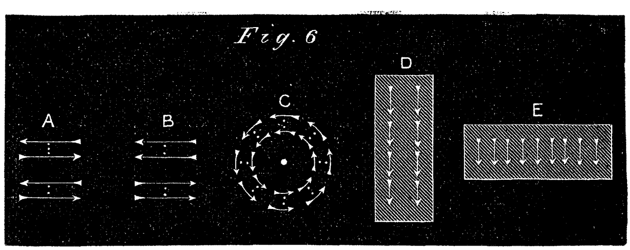
This experiment was followed by discharging the condenser through magnetised and neutral steel knitting needles with a similar result. Many authors have stated that a steel wire or needle became magnetised by the charge from a Leyden jar, and as this is contrary to the neutrality I have spoken of, we continued the experiments with a view to determine the conditions of such magnetic effects. We have found that the magnetisation supposed to be the result of the electric spark is in reality due to the direction in which the needle lies at the time of the passage of the spark. Thus wires, when held perpendicular to the magnetic meridian, or east and west, became perfectly neutral, even when previously strongly magnetised; but if they were held in the magnetic meridian, a feeble magnetism was always produced, the direction of which was due entirely to the earth's polarity, and had no relation whatever with the direction of the current. If, however, the wires were twisted, as in a rope, then we had electromagnetic effects, due to the direction of the twist and current.

Similar but stronger effects were observed on soft iron wires. A neutral iron wire, 3 millims. diameter and 40 centims. in length, was held vertically, to represent a lightning-rod, the enormous spark or charge from the condenser, charged by the 3,360 cells, striking its upper portion. This rod became invariably magnetised by the earth's directive influence, its upper portion being in all cases south and its lower north. The magnetism, however, was comparatively feeble, and only equal to that obtained on the same wire by mechanical vibrations caused by repeated blows on the upper portion of the wire with a wooden mallet. From these experiments we draw the conclusion that every lightning-conductor must be magnetised, but that if it is without spirality the magnetism can never be greater than that due to the directive influence of terrestrial magnetism.

If we could destroy or change the inherent polarity of iron, we should expect to find traces of it in wires which had been submitted to such an enormous electric current, but the wires thus acted upon remain similar in every respect to ordinary iron wires, their polarity for a given force and their neutrality being similar in nature and degree; consequently the inherent magnetic polarity has not been changed or destroyed.

Neutrality.

The induction balance is affected by three distinct arrangements of molecular structure in iron and steel, by means of which we have apparent external neutrality.



In fig. 6, at A, we have neutrality by the mutual attraction of each pair of molecules, being the shortest path in which they could satisfy their mutual attractions. At B we have the case of superposed magnetism of equal external value, rendering the wire or rod apparently neutral, although a lower series of molecules are rotated in the opposite direction from the upper series, giving to the rod opposite and equal polarities. At C we have the molecules arranged in a circular chain around the axis of a wire or rod through which an electric current has passed. At D we have the evident polarity induced by the earth's directive influence when a soft iron rod is held in the

magnetic meridian. At E we have a longitudinal neutrality produced in the same rod when placed magnetic west, the polarity in the latter case being transversal.

In all these cases we have a perfect symmetrical arrangement, and I have not yet found a single case in well-annealed soft iron in which I could detect a heterogeneous arrangement, as Wiedemann supposes, in the case of neutrality.

We may observe this symmetry without the aid of the induction balance; for, if we magnetise a rod under torsion (which we have already shown produces an ultimate rigidity), and observe the effects upon a directive needle, we find that every portion is equally magnetised, and in the same symmetrical arrangement of its molecules. We can also observe the probable existence of the double molecule, A, fig. 6, by magnetising a rod with feeble magnetic power. We then find a certain degree of magnetism, which is of exactly the same force as that produced when magnetised under a right-hand torsion, and if now we again magnetise it under a left-hand torsion, we have still the same force. This, without the existence of a double molecule, would have required a far greater inducing magnetic power to have rotated the molecules to the same degree under a contrary torsion. The limits of this paper do not allow me to bring further proofs of the existence of the double molecule, which the induction balance plainly indicates, as it requires a separate paper on this subject alone. If we consider the fire magnets of Dr. Hooke, we know that we cannot produce neutrality by heat, that we cannot melt or manufacture iron, except under the influence of the earth's directive influence, and that we can only produce apparent neutrality by vibrations or torsions, allowing, by the molecular freedom thus given, a complete closed circle of attractions, as at A or C, and that a similar apparent neutrality arises from the superposed magnetism of B, or the tranversal F, both of which in small wires or rods are apparently completely neutral.

We can produce a perfectly symmetrical closed circle of attractions of the nature of the neutrality of C, fig. 6, by forming a steel wire into a closed circle, 10 centims. diameter, if this wire is well joined at its extremities by twisting and soldering. We can then magnetise this ring by slowly revolving it at the extremity of one pole of a strong permanent magnet, and to avoid consequent poles at the part last touching the magnet, we should have a graduating wedge of wood so that whilst revolving it may be gradually removed to greater distance. This wire will then contain no consequent points or external magnetism, it will be found perfectly neutral in all parts of its closed circle; its neutrality is similar to C, fig. 6, for if we cut this wire at any point we find extremely strong magnetic polarity, the wire being magnetised by this method to saturation and having retained (which it will indefinitely) its circle of attractions complete.

My researches upon the molecular structure of neutrality required various kinds of iron and steel; my friend, Mr. W. H. Preece, F.R.S., kindly used his influence with the wire manufacturers supplying the Government telegraphs in procuring for me sixty different samples of iron and steel of a similar gauge, but of different qualities, as the induction balance has since proved, and the results obtained will be given in a future paper upon the "Molecular Structure of Iron and Steel."

Superposed Magnetism.

Knowing that we can rotate or diminish magnetism by torsion, I was anxious to obtain a complete rotation from north polarity to neutrality, and from neutrality to south polarity, or to completely reverse magnetic polarity by a slight right or left torsion.

I have succeeded in doing this and obtaining strong reversal of polarities, by superposing one polarity given whilst the rod is under a right torsion with another of the opposite polarity given under a left torsion, the neutral point then being when the rod is free from torsion. The rod should be very strongly magnetised under its first or right-hand torsion, so that its interior molecules are rotated, or, in other words, magnetised to saturation; the second magnetisation in the contrary sense and torsion should be feebler, so as only to magnetise the surface, or not more than one-half its depth; these can be easily adjusted to each other so as to form a complete polar balance of force, producing when the rod is free from torsion the neutrality as shown at B, fig. 6.

If we now hold one end of this rod at a few centimetres distance from a magnetic directive needle we find it perfectly neutral when free of torsion, but the slightest torsion right or left at once produces violent repulsion or attraction, according to the direction of the torsion given to the rod, the iron rod or strips of hoop-iron which I use for this experiment being able, when at the distance of 5 centims. from the needle, to turn it instantly 90° on either side of its zero.

The external neutrality that we can now produce at will is absolute, as it crosses the line of two contrary polarities, being similar to the zero of my electric sonometer, whose zero is obtained by the crossing of two opposing electric forces.

This rod of iron retains its peculiar powers of reversal in a remarkable degree, which distinguishes it completely from ordinary magnetisation, for the same rod when magnetised to saturation under a single ordinary magnetism loses its evident magnetism by a few elastic torsions, as I have already shown, but when it is magnetised under the double torsion with its superposed magnetism, it is but slightly reduced by vibrations or numerous torsions; and I have found it impossible to render this rod again free from its double polar

effects, except by strongly remagnetising it to saturation with a single polarity, the superposed magnetism then becomes a single directive force, and we can then by a few vibrations or torsions reduce the rod to complete neutrality.

The effects of superposed magnetism and its double polarity I have produced in a variety of ways, such as by the electromagnetic influence of coils, or in very soft iron simply by the directive influence of earth's magnetism, reversing the rod and torsions when held in the magnetic meridian, these rods when placed magnetic west showing distinctly the double polar effects.

It is remarkable also that we are enabled to superpose and obtain the maximum effects on thin strips of iron from $\frac{1}{4}$ to $\frac{1}{2}$ millim. in thickness, whilst in thicker rods the effect is far less, as it is masked by the comparatively neutral state of the interior, the exterior molecules then reacting upon those of the interior, allowing them to complete in the interior their circle of attractions.

I have already mentioned several different forms of induction balance which are applicable to—1. Testing the softness of iron and steel; 2. Researches upon the cause of tempering in steel; 3. Finding the dividing line of iron and steel; 4. Finding mechanical strains in shafts, cannons, or steamboat screw shafts; 5. Showing unmistakably the best quality of iron for electro-magnets; 6. Researches upon all the phenomena of magnetism, and upon all questions relative to the molecular structure of metals.

I was anxious to show upon the reading of this paper some mechanical movement produced by molecular rotation, consequently I have arranged two bells that are struck alternately by a polarised armature put in motion by the double polarised rod I have already described, but whose position at 3 centims. distant from the axis of the armature remains invariably the same. The magnetic armature consists of a horizontal light steel bar suspended by its central axle, carrying at its extremities two glass beads 5 millims. diameter serving as hammers; the bells are thin wine glasses, giving a clear musical tone loud enough by the force with which they are struck to be clearly heard at some distance. The armature does not strike these alternately by a pendulous movement, as we may easily strike only one continuously, the friction and inertia of the armature causing its movements to be perfectly dead beat when not driven by some external force.

The mechanical power obtained is extremely evident, and is sufficient to put the sluggish armature in rapid motion, striking the bells six times per second, and with a power sufficient to produce tones loud enough to be clearly heard in all parts of the hall of the Society. As this is the first direct transformation of molecular motion into mechanical movement I am happy to show it on this occasion.

On the reading of my preliminary note I demonstrated by visible experiments many of the points of the theory I have advocated, and which I believe explains all conditions of magnetism, and I propose on the reading of this paper to demonstrate experimentally the remaining evidences.

II. "Remarks on the Soundings and Temperatures obtained in the Faeroe Channel during the Summer of 1882." By Staff Commander T. H. TIZARD, R.N., H.M.S. "Triton." Communicated by SIR FREDERICK EVANS, K.C.B., F.R.S. Received April 16, 1883.

[PLATES 4–8.]

Introduction.—The exploration of the Faeroe Channel commenced by H.M.S. "Lightning," in 1868, under the direction of Dr. Carpenter, F.R.S., the late Sir Wyville Thomson, F.R.S., and Mr. Gwyn Jeffreys, F.R.S., at the instance of the Royal Society,* revealed a remarkable peculiarity, namely, the fact that over one portion of that channel the temperature of the water at the bottom differed 12° to 14° F. from that obtained at similar depths in the other portion, and further investigation by H.M.S. "Porcupine" in 1869 confirmed the observations previously obtained on board the "Lightning."

The cause of this phenomenon appears to have been unsuspected at the time, but during the voyage of H.M.S. "Challenger" several such peculiarities were observed, though not to such a marked extent, and a theory was formed that where differences of bottom temperature existed at equal depths in adjoining areas those areas would probably be found separated by submarine ridges.

Viewing the question on board the "Challenger" from our own observations, combined with those previously obtained in the "Lightning," "Porcupine," and "Shearwater," and with the advantage of Dr. Carpenter's conclusions on oceanic circulation published in the "Proceedings of the Royal Society" for 1869, it seemed to us reasonable to suppose that in those areas where the minimum temperature was found constant from a given depth to the bottom over an area contiguous to another where the temperature decreased as the depth increased, those areas must be separated by a submarine ridge, as then the phenomena might be readily explained. For instance, the condition might arise (*a*) if the minimum temperature was the mean winter temperature of the coldest portion of the separated area, in which case the water at the surface would be flowing in, whilst below it would be flowing out over the submarine ridge, as seems to be the

* See "Proc. Roy. Soc." for 1868.

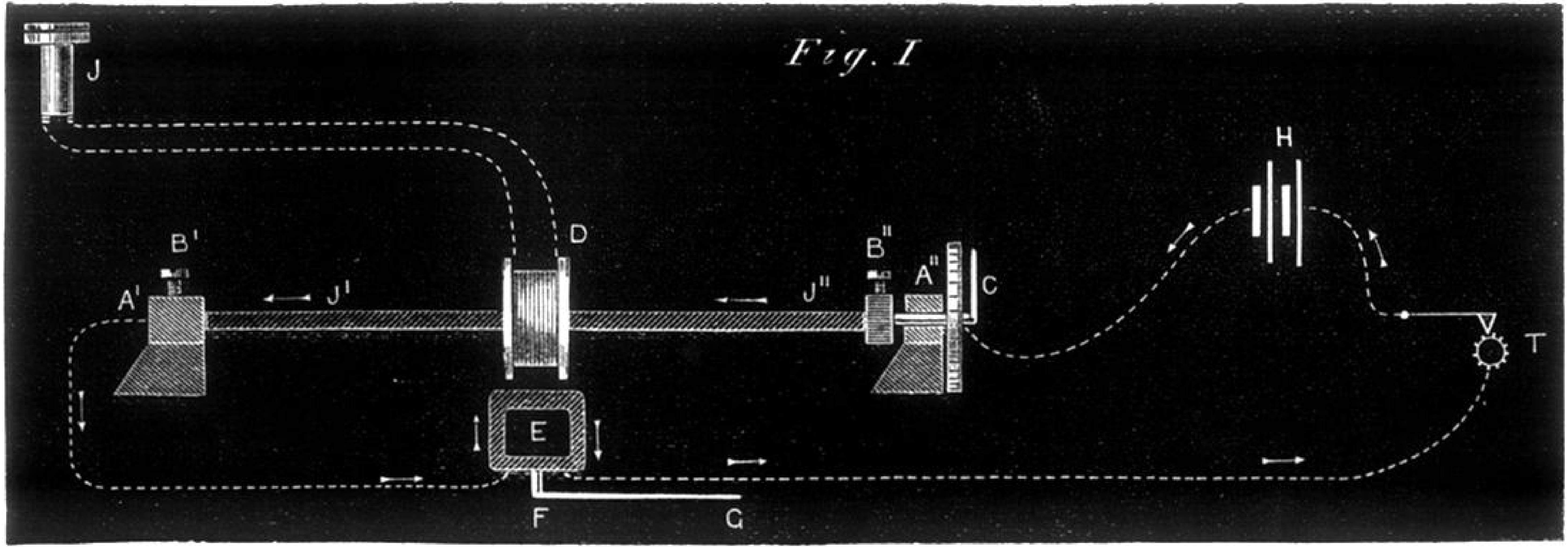


Fig. I
J
H
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C
T
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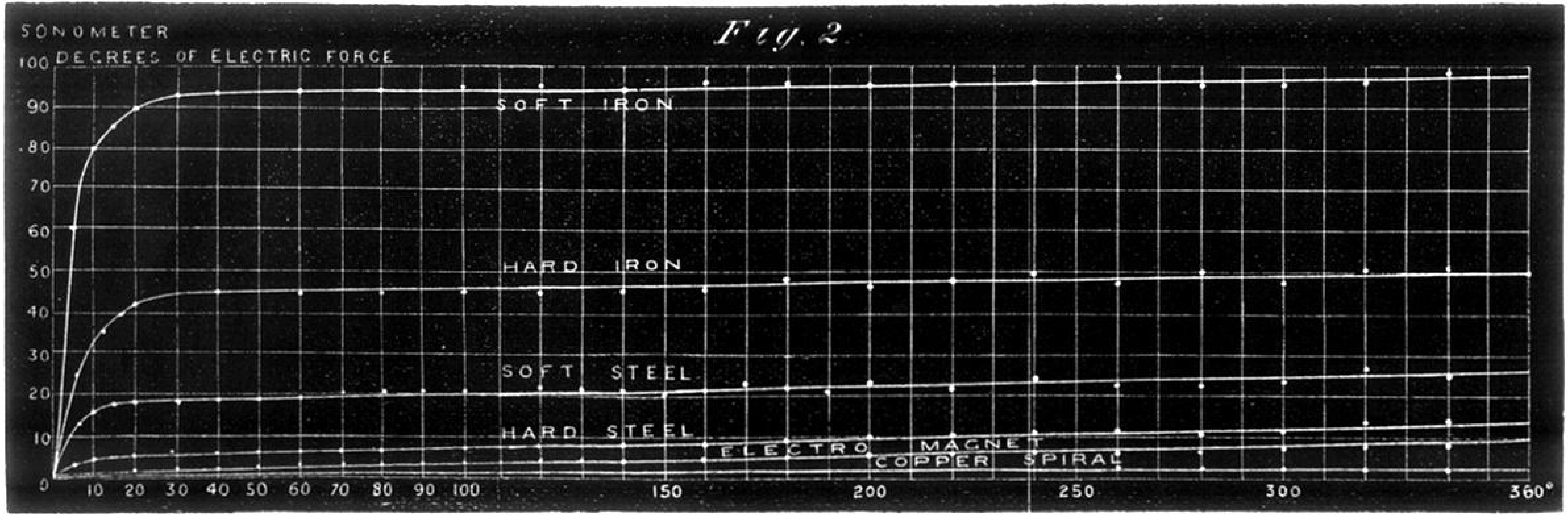
Fig. 2.


SONOMETER
DEGREES OF ELECTRIC FORCE
100
90
80
70
60
50
40
30
20
10
0
10 20 30 40 50 60 70 80 90 100 150 200 250 300 360°
SOFT IRON
HARD IRON
SOFT STEEL
HARD STEEL
ELECTRO MAGNET
COPPER SPIRAL

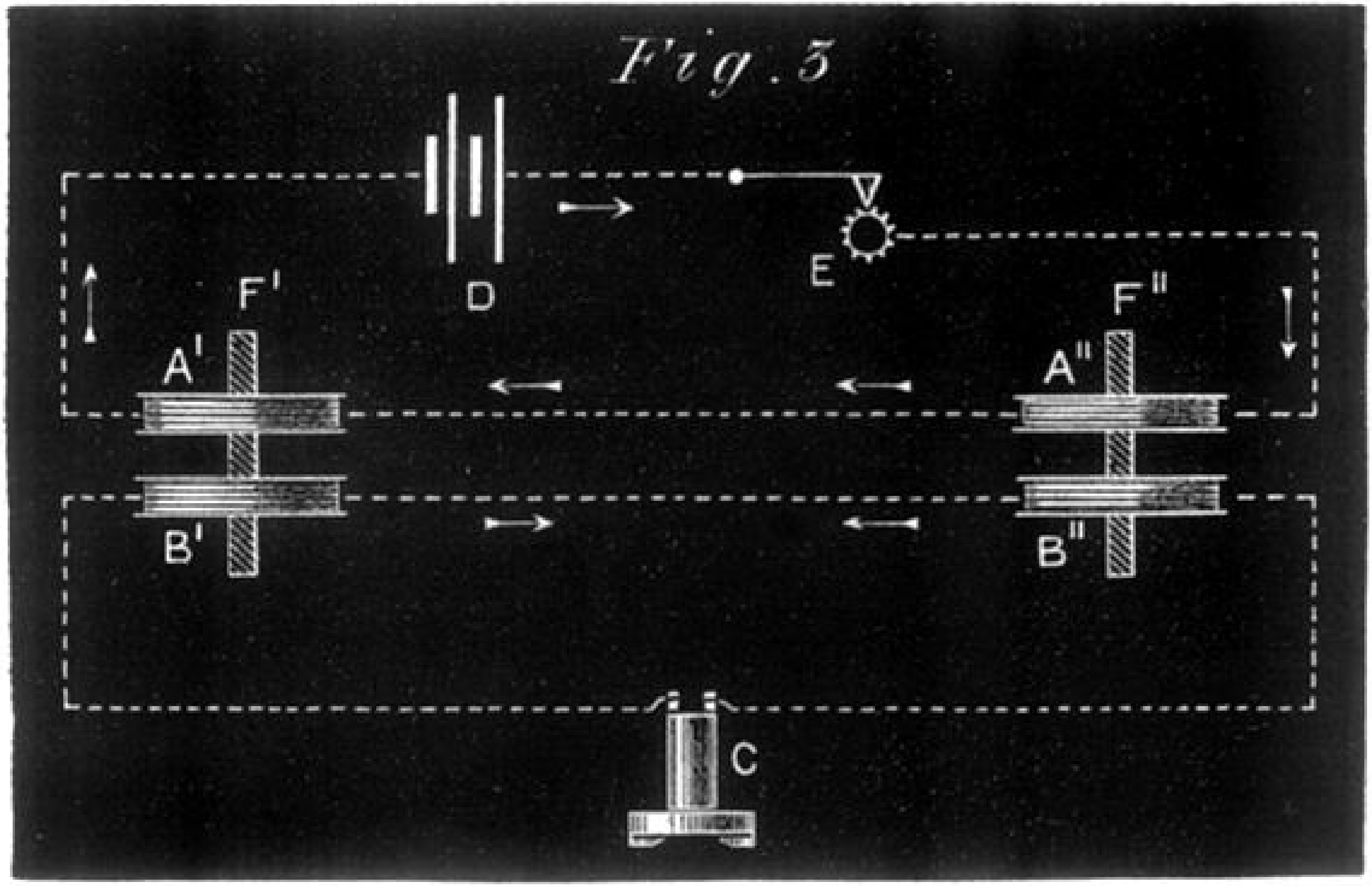


Fig. 5

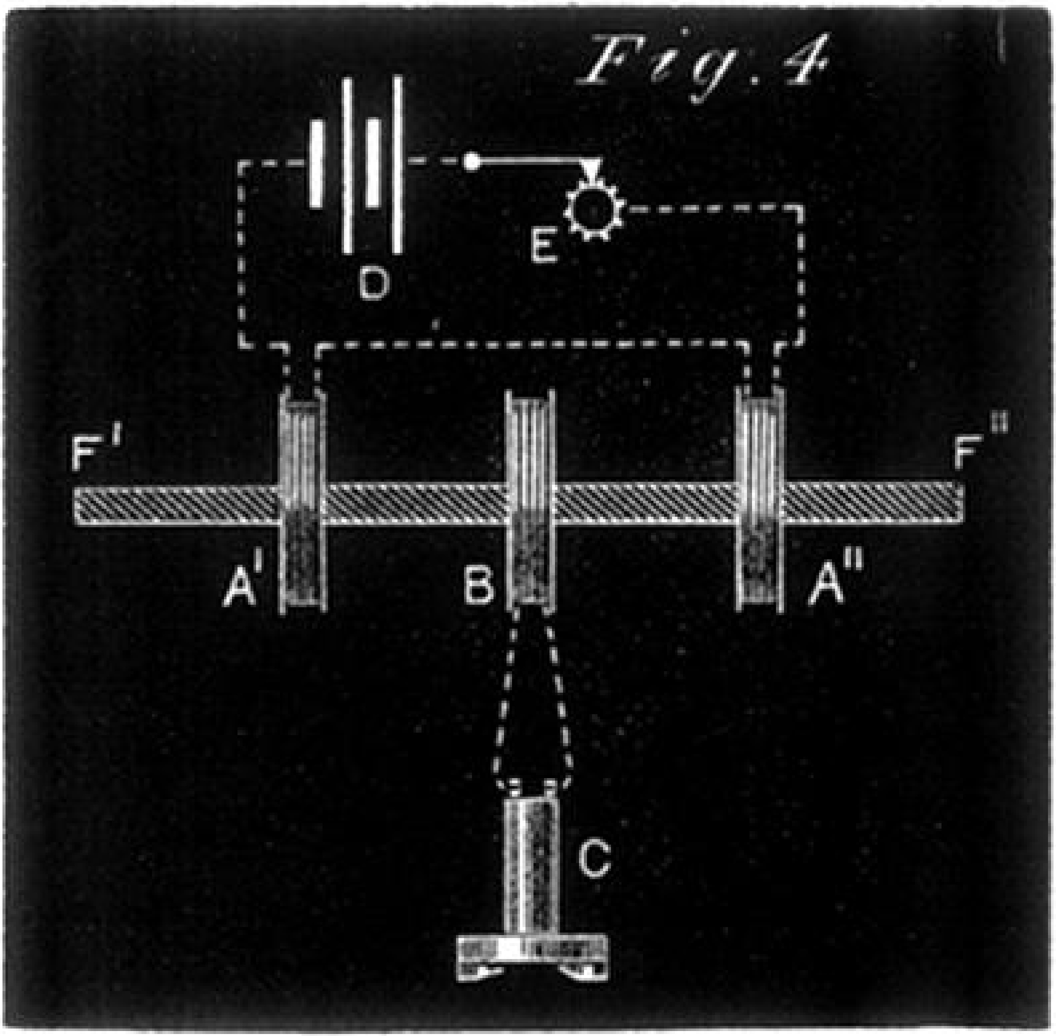


Fig. 4

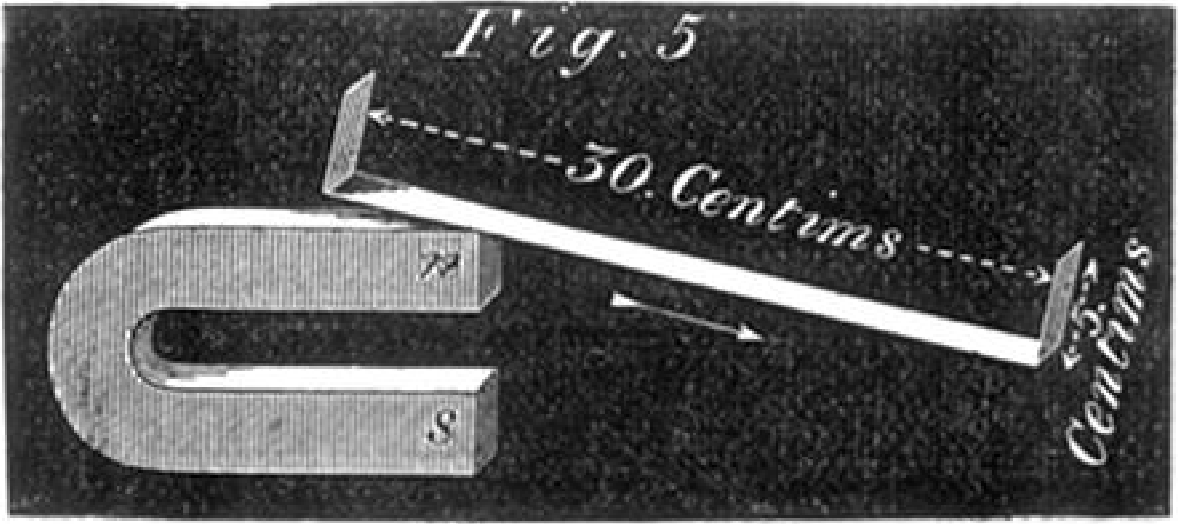


Fig. 5

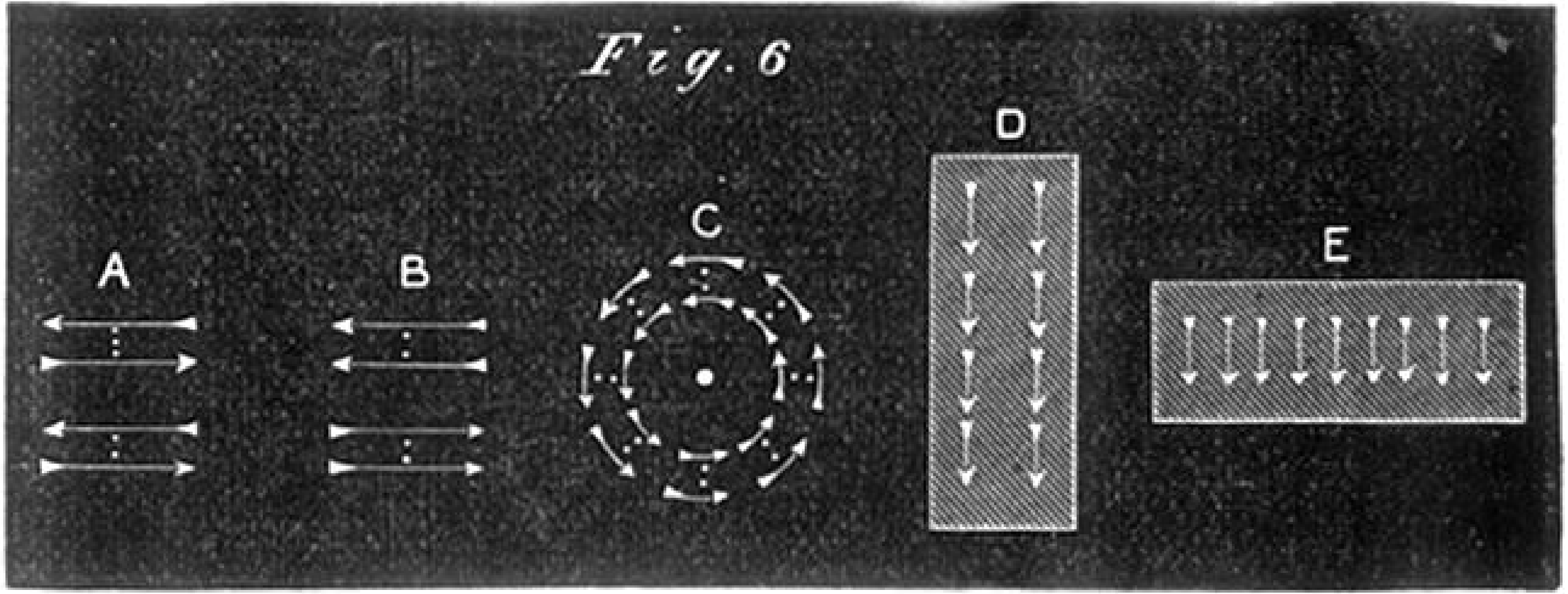


Fig. 6
A
B
C
D
E