IX. *Experimental Researches in Electricity.—Thirtieth Series.* By Michael Faraday, *Esq., D.C.L., F.R.S., Fullerian Prof. Chem. Royal Institution, Foreign Associate of the Acad. Sciences, Paris, Ord. Boruss. Pour le Mérite, Eq., Memb. Royal and Imp. Acadd. of Sciences, Petersburgh, Florence, Copenhagen, Berlin, Göttingen, Modena, Stockholm, Munich, Bruxelles, Vienna, Bologna, Commander of the Legion of Honour, &c. &c.*

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3363. WHILST using lines of force as a true, searching, and as yet, never-failing representative of the one form of power possessed by paramagnets, diamagnets, and electric currents,—and whilst endeavouring simultaneously to make the principle of representation a key to new phenomena, and subjecting the principle itself to rigid cross examination,—I have had occasion to examine the action of certain magnetic bodies in different media and at different temperatures; and as the results are true, and must, therefore, be valuable in any view of the cause of magnetic action, I have thought them worthy of presentation to the Royal Society.

3364. When an unmagnetized but magnetic body, placed in a magnetic field, is affected by the forces thrown upon it, and under their action *sets*, or takes up a definite position, the effect may depend upon its peculiar molecular condition, or upon its relation to the surrounding medium, or upon both conjointly, or upon one or both combined with temperature. Some of each of these conditions have been the objects of my investigations.

§ 38. *Constancy of differential magnecrystallic force in different media.*

3365. When a sphere or cylinder formed from a crystal of calcareous spar or of bismuth is suspended in a particular direction in the magnetic field, it points with considerable power, whereas if formed out of amorphous or granular carbonate of lime or bismuth, it has no such tendency. In the latter case, it (by reason of its relation to the surrounding medium) is urged to move from stronger to weaker places of force; in the former case, also, it has the same tendency, but the power of pointing, which it possesses in addition, has no relation to the medium about it, but only to the difference in strength of the magnetic force, as developed in different directions within the sphere itself. Such effects constitute the branch of science known under

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the name of *magnecrystallic action.* Early experiments (2499–2501.) showed that, with respect to bismuth, the relation between the magnetic force in the axial and equatorial directions, was unchanged by varying the surrounding medium from water to a solution of sulphate of iron. This equality has, perhaps, been confirmed by other philosophers, and, it may be, with other substances; but not being aware of any strict investigation, I found it needful in relation to my own views, which required just now proofs more certain than those quoted, to enlarge and extend the experimental results.

3366. The method I have employed to compare the possible variations of force produced by different circumstances, has been to suspend the object, a magnecrystal for instance, by a torsion fibre or wire;—to place it in the magnetic field;—to adjust the torsion index so that it should be at zero when the crystal had taken its position of stable equilibrium;—then to put on right-handed torsion until the crystal had attained the point of unstable equilibrium, or the upsetting point, on that side; and after having noted the torsion required, to reverse the motion and put on left-handed force until the upsetting point on the opposite side was attained. Either of these forces, minus the deflection, is the measure of the upsetting force; and therefore the sum of these two observations, minus the number of degrees through which the crystal has moved in passing from one upsetting point to the other, may be considered as expressing the force which solicits the crystal to retain its stable position of rest. By thus making the observations on both sides of zero, the effect of set in the suspending torsion thread could be included in a regular and compensatory manner;—two definite starting-points (the upsetting positions) were ensured;—and also a large, *i. e.* a sensitive expression of the force to be measured was obtained.

3367. It is evident, that, when a magnecrystal is suspended in the magnetic field, and torsion force is gradually applied to deflect it from its position of rest, that force will grow up and carry the crystal round, until at last the latter will attain a position at which the setting forces of the crystal are equal to the torsion force, but beyond which the former will, by further motion of the crystal, fall more rapidly than the latter, so that the least additional torsion force will carry the crystal past that position and cause it to revolve through many degrees. This position (the upsetting point) being one of unstable equilibrium, is easily observed experimentally; and, by careful manipulation with the torsion index, it is also easily attained. When the two upsetting points are observed, the whole number of degrees of torsion required to proceed from one to the other, is an excellent measure of the setting force of the object. When the crystal is in the form of a cube or sphere and suspended between flat-faced poles, the two upsetting points are nearly at an angle of 45° with the axial line, and the angle between them is near upon 90°. I have found this angle to vary for the different objects employed; but, whilst the position of the poles, &c. remained the same, not for the same object, however the force might vary. It has therefore to be ascertained, experimentally, for each object, in any one series of observations where the force only varies; for being included in the motion of the torsion index it has to be subtracted, as a constant quantity, from the observed result, and then leaves the true expression of the torsion force exerted between the upsetting points.

3368. The magnet employed was that great one constructed by LOGEMAN, and sent to the Exhibition of 1851. It could sustain a weight of 430 lbs., and is, I believe, very constant in power. It, with the torsion balance now used, is described in the Proceedings of the Royal Institution*. The sliding pole-pieces were of square iron, and presented either pointed terminations towards each other, or two flat faces, 1·7 inch square, which could be brought up to the opposite sides of the troughs or vessels containing the different fluids and media required for the experiments. These vessels were of various sizes and kinds; but the outer ones were usually of copper, with flat sides, that the pole-pieces might bear against them, and be thus preserved in their position during the progress of a single experiment or a series of comparative results.

3369. The torsion suspender was about 24·5 inches in length; and was either a fine platinum wire, of which 28·5 inches weighed 1 grain, or a finer wire of silver; or a bundle of cocoon silk fibres. The last was useful for certain delicate experiments, but could not be employed except in limited cases; for its torsion force is liable to much variation under the influence of the vapour of water, camphine, &c. All these suspenders are liable to more or less of set, and that varies with the vibrations to which the apparatus is subject; but, by equalizing the time, by paying attention, and especially by alternating and combining right- and left-handed observations (3366.), the effect of this set may be obviated to a very great degree. The torsion wire terminated below by a hook, made out of a flat piece of copper foil, intended to receive on its edge a corresponding hook, attached to the object submitted to experiment.

3370. The crystal, or other object, was held by one turn of a fine copper wire, which was continued upwards for 5·7 inches, and terminated by a flat hook like that just described. In this way different objects could be attached to the torsion wire, yet without any possibility of loose or uncertain motion about the point of attachment. Each loop had a horizontal bristle fixed to it, and this, by its position, not only showed the place of the crystal or other object beneath, but being retained between moveable stops associated with a horizontal scale, it indicated when the crystal was approaching the upsetting points, and being held within, and governed by, the stops, allowed them, through it, to govern the crystal.

3371. The balance was enclosed by glass, to shut out currents of air as much as possible and prevent their production.

3372. Experiments on the differential magnecrystallic force of bodies surrounded by different media required the bodies to be immersed in those media; and, as the latter varied from one another in specific gravity, so they exerted different degrees of buoyancy upon the same crystal, and thereby caused different degrees of tension

* January 21, 1853, vol. i. p. 230.

upon the torsion wire:—thus, a crystal of tourmaline, which in air hung with the weight of 40·4 grains upon the wire, would in water hang with the weight of 27·3 grains, and in phosphorus with the weight of only 15·5 grains. As this variation would slightly change the value of the torsion degrees, compensating weights of pure copper were added at the lower end of the torsion wire (3369.), *i. e.* 5·7 inches above the place of the crystal and magnetic poles.

3373. *Bismuth crystal.*—A piece of uniformly crystallized bismuth was reduced to the form of an octagonal prism, the height of which was 0·45, and its average diameter about 0·28 of an inch; its weight was 77 grains. When suspended perpendicularly its magnecrystallic axis was horizontal, and therefore set in the magnetic field, which existed between the flat faces of the pole-pieces (3368.) fixed at the distance of 1 inch apart. The torsion suspender was, in this case, a bundle of ten cocoon silk fibres, only 5 inches in length. The temperature was 68° FAHR. The torsion between the upsetting points was as follows, for four different media, differing much in their magnetic relation:—

Air	2250°
Absolute alcohol	2269
Water	2230
Saturated solution of protosulphate of iron . .	2234

In another set of experiments, carbonic acid gas was compared with alcohol and water, and the result was the same in it as in them.

3374. Desiring to include a highly diamagnetic medium in the list, I employed phosphorus; but as the heat required to melt it is competent to change the magnetic force of the bismuth crystal (3399.), it was requisite to compare it with water at a like temperature:—this was done, the temperature of 160° FAHR. being chosen. The results came forth as follows:—torsion force in water 1945°; in melted phosphorus 1950°; and are therefore to be considered alike.

3375. The liquids employed as surrounding media were contained in wide thin glass tubes, placed within the copper trough against which the magnetic poles rested (3368). Much care was requisite in the use of phosphorus. This substance was covered with water, and when the bismuth was passed through the water into the phosphorus, although it did not wet with phosphorus, still the latter acted slightly upon it, producing a few minute bubbles of adhering gas. These were not found on after occasions, when the same crystal was employed. It was also necessary that the phosphorus should be perfectly clean and good. Films soon form in it, and more especially at the contact of the phosphorus and the covering water; and these, clinging to the suspending wire, embarrass the vibrations of the immersed crystal and render them uncertain; the least portion of burnt phosphorus makes these films abundant. Whenever they appeared, fresh clean phosphorus was employed.

3376. From these results and from many others not described, it follows that the differential magnecrystallic force, *i. e.* the relations of the magnetic force in different directions in a crystal of bismuth, is not altered by great changes in the magnetic character of the medium surrounding it; since they remain the same in phosphorus, alcohol, water, carbonic acid gas, air, and solution of protosulphate of iron;—a list which includes both diamagnetic and paramagnetic substances.

3377. *Tourmaline.*—As a paramagnecrystal, and therefore in contrast with bismuth, a black tourmaline was selected, regular in form, and nearly 0·37 of an inch in diameter. A piece, 0·36 in length, was cut off with flat ends; its weight was 40·4 grains, and its specific gravity 3·076. When suspended between the flat-faced poles with the axis of the prism horizontal, that axis set strongly in the equatorial direction, by virtue of the differential magnecrystallic force. On using a silk suspension (3369.) the necessary upsetting torsion force was as follows:—

	Temp.	Torsion force.
In air	57°	2534
In alcohol	56	2546
In water	56	2541
In solution of sulphate of iron saturated	57	2632

3378. These results sufficiently indicate that the torsion force, and therefore the differential magnecrystallic force, was alike for the same temperature, whatever the character of the surrounding medium. But to give more certainty, the fine silver torsion wire (3369.) was employed, and with the following results:—

	Temp.	Torsion force.
Water	65°	1082
Olive oil	65	1085
Alcohol	65	1081
Air	65	1079
Saturated solution of protosulphate of iron	65	1081

which sufficiently prove that the magnecrystallic force remained the same in degree, notwithstanding great variations in the character of the surrounding media. The angle between the upsetting points was 90°; but it has not been abstracted from the experimental results, inasmuch as that correction would make no difference in their character.

3379. The native *protocarbonate of iron* is very magnecrystallic, being also as a whole highly paramagnetic. A rhomboid was selected, and, being placed with its greatest length vertical and its shortest axis horizontal, was reduced, by grinding at the sides, to a rough octagonal prism, having an upright length of 0·6 of an inch, and an average horizontal breadth of 0·37;—the weight was 47·5 grains and the magnecrystallic axis horizontal. The magnetic force of this crystal was so great, that though the fine silver torsion wire (3369.) was employed with it, the pole-pieces had to be opened to the full extent of the magnet, *i. e.* to 4·7 inches, before the torsion force was sufficiently reduced to render the *set* of the crystal manageable. To lessen the power of the magnet by a cross bar of iron at the sides, I considered objection-able; inasmuch as that bar might take more or less of charge during the course of the experiments, and so render the magnetic power of the field in some degree variable. When the crystal was placed in succession in different media at the temperature of 66° Fahr., the results were as follows:—

In water	542 of torsion,
In air	543 of torsion,
In saturated solution of protosulphate of iron .	542 of torsion,

results which perfectly accord with those obtained in the former cases.

3380. The *red ferroprussiate of potassa* is a prismatic salt, which sets most strongly in the magnetic field, when the axis of the prism is horizontal and the plane passing through the obtuse linear angles is vertical. A crystal, reduced in length and width until these were nearly alike, and having therefore little or no mere paramagnetic or diamagnetic set (for the salt is very slightly paramagnetic in air), was placed in the magnetic field, surrounded first by air and then by camphine; the results were as follows:—in air the tension force was 314, and in camphine 316; the accordance being most close with the results before obtained.

3381. Thus the old conclusions (2499–2501.) are confirmed; there appears to be no experimental difference in the proportion of the force developed in different directions in a magnecrystal by the action of magnetic induction, whatever the nature of the medium surrounding it, and whatever the difference in paramagnetic and diamagnetic character of the crystals, or the media employed; crystals differing as much as bismuth and carbonate of iron, and media differing as greatly as phosphorus and saturated solution of sulphate of iron, having been employed.

3382. Theoretically, however, there ought to be small differences produced, and according to my view of the lines of force, as true representations of the magnetic power, they ought to be of the following nature. If a magnecrystal be subjected to the action of a constant magnet, whilst the magnetic field, and the whole space around the magnet, are occupied by a common medium, as air, and then a small part of the field around the crystal be occupied by another medium as in the experiments described, then, if the medium be a better conductor of the force, *i. e.* be more paramagnetic than the former medium, it ought to determine more force across that place; and that increase of force would be the same as if a stronger magnet had been employed, and so the magnecrystal should show a variation:—acting as if more highly affected than before, its differential power in two directions should appear greater. Or, if the part of the medium around the crystal were replaced by a medium more diamagnetic, *i. e.* a worse conductor, then less force would pass in that direction and the magnecrystal should appear weaker than before, and so point with less force. Even the very shape of these partial substitutions should have an influence, according as it might extend in the axial or the equatorial direction.

3383. But if *all* the medium reached by the powers of the magnet were changed at once, and not that part only about the magnecrystal in the magnetic field, then the use of a more paramagnetic or better conducting medium should have a contrary effect and make the magnecrystal appear less affected; for the transmission of power would be increased (proportionally) everywhere else, more than through it. On the contrary, the use of a more diamagnetic medium would have the reverse effect, and the transmission of force decreasing everywhere else more than through the crystal, would make the latter appear to increase in its peculiar condition of force. I am assuming that the magnet is unchangeable in power, and therefore *must* exert the like external force in every case; and after all, I conclude that these effects would be so small, as not to be observable except by the use of media differing far more from each other than those we at present possess. For my own part, I feel, even now, that the hypothesis of magnetic fluids cannot exist in the presence of conjoint paramagnetic and diamagnetic phenomena; but considerations such as those above, may be able to do good service in arranging hypotheses in their right places and giving them their true value.

3384. The aptitude of a magnecrystal, when in the magnetic field, to assume a maximum conductive state in a given direction, makes it similar in action to a permanently magnetized sphere; and therefore, however diamagnetic it may be, and however slight its magnecrystallic condition, still it will set in a definite direction, *i. e.* with its chief magnecrystallic axis* parallel to the magnetic axis of the field, even if it could be surrounded by a fluid medium having a paramagnetic condition equal to that of iron. And here I wish to correct an expression which has been allowed in a former series of these Researches (3158.), where it is said, that "an ordinary magnetic needle cannot show polarity in a field of equal force." It cannot of course exist in association with a field of equal force, for it would itself destroy the equality of the force, unless the medium around it were iron as high in paramagnetic power as itself; but even in such a case it would show polarity when deflected, for its magnetic axis would correspond in quality with a chief magnecrystallic axis, and it would always set or point in the accordant direction, *i. e.* axially in the magnetic field.

3385. Magnecrystals may be employed in experiments to measure magnetic force just as needles are, but in some points of view they are philosophically more accurate. A magnecrystal is equal in quality in all its parts; it appears to take up precisely the same state under the same inductive force and to have no coercitive or retentive faculty; whereas the force of a needle changes easily under inductive action, and when that action ceases the return towards its former condition is uncertain. It is also independent of the surrounding medium. Hence it may, in some cases, be found to supply a more true and certain standard of force, in the amount of tension required for its deflection.

3386. That magnecrystals are attracted or repelled with different degrees of force in different directions, has been long ago established by myself (2841.) and others.

* THOMSON on Magnecrystallic Axis, Philosophical Magazine, 1851, vol. i. p. 177.

As the difference of force remains constant when the surrounding medium is varied (3381.), it follows that the possibility exists of finding a magnecrystal and a medium so related, that the attraction and repulsion of the crystal, as a whole, should be convertible terms depending upon the position of the crystal in regard to the lines of force. I was desirous of verifying this result experimentally, and especially in relation to the case of mere space or a vacuum about the crystal, and therefore selected certain magnecrystals which promised favourable results, and yielded the following illustrations.

3387. The *tourmaline* crystal already employed (3377.) was found paramagnetic, not merely in water and air, but also in a saturated solution of protosulphate of iron; and though the difference in degree of attraction according to its position was very striking in all the media, the substance was for the present dismissed.

3388. *Red ferroprussiate of potassa*, being attracted in water or camphine, was repelled in the solution of iron, and therefore promised the desired result if it could be protected from the action of aqueous solutions*. Some good crystals were selected, and shortened by grinding until the length was little more than the breadth; then the angles were removed until each crystal became a rounded mass, after which they were made fast to suspending copper wires (3370.), 6 inches in length, so that the axis of the crystal prism should be in the horizontal plane, and, when in place in the magnetic field, either axial or equatorial at pleasure. Some wax was melted and kept at a temperature above the fusing-point, and the crystals being introduced and retained in the wax until they were above its fusing temperature, were then removed and carefully hung up. Afterwards a wax bath was prepared, of which part was fluid and part solid, and the cold crystals being suddenly dipped in and removed, brought away a congealed coat of wax which in the course of a few minutes became a compact envelope. Being left for a few hours, I found that they might afterwards be immersed and left in water, or in a solution of iron, for two or three days without any action between the crystal and the medium around it. No varnishing could thus protect them.

3389. A small torsion balance with a single cocoon thread was constructed. The end of the arm intended to sustain the crystal, was bent at an angle of 90°, so that the crystal could be suspended from it in either of two positions at right angles with each other. A counterpoise to the crystal was placed on the other arm, and the balance was covered with a jar to screen it from air currents. The crystal, when in place, hung down below the edge of the jar, descending into a vessel arranged at one pole of a great electro-magnet (2247.), so that it could be surrounded by any medium in which its actions were to be observed. The pole-piece terminated either in a cone, or an upright edge, or a face 1·5 inch square; the cone was the best, and the crystal

* Varnished crystals are not protected; when put into water the salt dissolves through every part of the coat; for, being soluble in alcohol, the coating matter is a mixture of resin and the salt. In solution of iron this substance dissolves in a very interesting manner whether unprotected or imperfectly coated.

was then able to approach the pole until separated only by the thickness of the glass of the vessel.

3390. A saturated solution of protosulphate of iron was prepared at a temperature of 65° FAHR., and a little sulphuric acid added to prevent the occurrence of turbidness upon the addition of water. This solution, more or less diluted, was put into the glass vessel, and when its motion had ceased, the crystal was placed on the balance and adjusted near the pole; then the magnet was excited by a voltaic battery and the effect observed. When the axis of the prism was in the magnetic axis, the crystal was repelled in all solutions stronger than one consisting of about eleven volumes of the saturated solution and six of water; in weaker solutions it was attracted, the force of attraction and repulsion varying, of course, as the medium varied. When the crystal axis was equatorial, *i. e.* when the chief magnecrystallic axis coincided with the magnetic axis of the field, then the crystal was repelled in all solutions stronger than one consisting of about eighteen volumes of the saturated solution and six of water. Hence there is a range of medium, varying in strength from that produced by adding either two or three volumes of the saturated solution to one volume of water, within which the crystal in one position is attracted and in the other repelled; and, as might be expected, a mixture of fourteen or fifteen volumes of solution with six of water, forms a medium in which the attraction and repulsion were nearly equal to each other. It was very easy in any of these media, to find a position for the crystal (by turning it on the vertical axis) in which it was neither attracted nor repelled. A second and a third crystal were, in succession, put upon the balance and gave exactly the same results.

3391. The *red ferroprussiate of potassa* is a crystal so paramagnetic as to be attracted in all positions in space. I therefore turned to *calcareous spar*, which, though it be diamagnetic in air, is not necessarily so in space, since air is, because of its oxygen, a magnetic body (2791.). Possessing a sphere of calcareous spar, given to me by Professor W. THOMSON, I tried it first in water, and found, that whether the optic axis was placed equatorial or axial in relation to the magnetic field, the sphere was attracted, though more in the former case than in the latter. Hence the body is less diamagnetic than water and so approaches to a vacuum. In order to compare it with a vacuum I employed carbonic acid as the medium*, but then found that in both positions it was repelled; hence its differential range as a magnecrystal cannot include the magnetic force exerted in space merely.

3392. This sphere is repelled in all positions in alcohol; therefore it would be easy, by the addition either of alcohol or a little solution of iron to water, to obtain a liquid intermediate in force between the forces of the sphere in its two positions.

3393. But though pure calcareous spar will not include space, yet it is probable that some crystals may be found by trial which will do so. I have various specimens of calcareous spar, which contain in combination minute portions of iron, and being

* Royal Institution Proceedings, Jan. 21, 1853, p. 233; or Experimental Researches, 8vo, vol. iii. p. 502.

magnecrystallic, set, in the magnetic field, with the optic axis axially, as TYNDALL and KNOBLAUCH describe*. As wholes they are attracted in every position, whether surrounded by air or carbonic acid (more strongly in the latter than in the former); and when free to revolve they set with the optic axis axially, even in solutions of iron. But there seems no reason why calcareous spars, intermediate between these and the sphere, should not be found by search; nor any reason to doubt that, being crystallized, they would be magnecrystallic. The further suggestions of hypothesis are, however, not very clear, inasmuch as we are not quite sure, without other experiments, whether such bodies may be accepted magnetically as simple bodies, or whether the optic axis would always point axially or equatorially as the body was paramagnetic or diamagnetic in relation to space; or whether the body would disappear from the list of magnecrystals altogether. For suppose such a body coincident in its general magnetic condition (as when pulverized or amorphous) with carbonic acid or space; and that being in its crystallized condition it should be magnecrystallic, and when formed into a sphere should, according to the results just given (3381.), point in the same direction and with the same degree of force, whether surrounded by water, or carbonic acid, or solution of iron;—what direction should the optic axis of such a sphere take? It cannot take that of the pure calcareous spar, and also that of the small rhomboids of ferrocarbonate of lime, for they are at right angles to each other in the magnetic field; neither does any reason appear why it should take one more than the other. I would willingly think that some valuable considerations and evidence regarding the true zero of magnetic force would arise in the investigation of this matter; but the former results with different media make me fear that the subject, when closely examined experimentally, will resolve itself into something of less importance. This matter is carried a little further in the relations of temperature (3416.); for if we consider a true zero as independent of temperature, then one temperature may be assigned for it as well as another; and it will be seen that, in the mixed substance presented by ferrocarbonate of lime, we have a body that can be placed as non-magnecrystallic in carbonic acid at a given temperature; whereas at higher temperatures it is magnecrystallic as carbonate of lime, and at lower temperatures as carbonate of iron.

§ 39. *Action of heat on magnecrystals.*

3394. Heat affects the degree and, perhaps, the disposition of the induced forces in magnecrystals (2569–2573.). There is as yet little or no experimental evidence bearing upon this subject, so that the following contribution for temperatures between 0° and 300° FAHR. may be acceptable. Some new arrangements of apparatus were required, the following brief description of which will probably be sufficient.

3395. Baths for the application of heat and cold were necessary. One, frequently

* Philosophical Magazine, 1850, vol. xxxvi. p. 178.

employed, was a copper vessel 1·15 inch broad in the direction of the magnetic axis, 3·5 long and 7 deep. When in its place between the magnetic poles, they could either bear against its sides or against blocks placed between it and them, so that the pole distances should be unchangeable for the time. The upper part was clothed in flannel and was within the balance box (3368.); the lower part passed through a hole in the magnet table, and could be heated by a spirit-lamp applied below. Oil was most frequently employed in this bath for high temperatures, but sometimes water; and then its surface was covered with oil to prevent evaporation and diminish the production of currents. A thermometer was inserted in this bath at one end to indicate its temperature.

3396. A copper cylinder, 1·1 inch in diameter, 3 inches in depth, closed at the bottom, and expanded at the upper edge, so as to rest on the side edges of the bath, was destined to hold the medium, either camphine, water, or oil, which was immediately around the crystal or other magnetic object. Currents were, of necessity, formed in the fluid, for it could neither be heated nor cooled without them; but the point was to reduce them as much as possible about the object to be observed, and the arrangement described was found very useful for this purpose. It was necessary that the fluid used in this cylinder should be very clean and clear from any filaments or other matters, that might obstruct the motion of the immersed object.

3397. Because of the relative positions of the thermometer and the object to be observed, it is evident, that, with rising temperatures, the former will at the same moment be hotter than the latter, whilst with falling temperatures it will be cooler. The influence of this circumstance was observed in many of the experiments (3408.); but as the cooling was much slower and far more regular than the heating, the chief observations were made as the temperature fell. The greatest source of errors existed in the currents, and could only be overcome, and then only in part, by slow and numerous observations. These currents were often found to have prevalent sets, but these were, to a large extent, remedied by the observations in two positions, *i. e.* at the upsetting points. For low temperatures a smaller trough was employed, well clothed in flannel and filled with an excellent frigorific mixture.

3398. *Bismuth crystal.*—The crystal before described (3373.) was placed on the torsion balance; its upsetting angle was then ascertained to be 105°; and being observed from time to time, it was found to remain the same both for low and high temperatures. The torsion force was measured, first at common temperatures, then as the temperature rose, and also as it fell; it was observed to be greater at the same upper temperature when rising than when falling; an effect referred by particular examination to the fact that the lower the temperature of the bismuth the greater the torsion force; and that, as before said, as the bismuth gained its temperature later than the oil and thermometer in the bath, so it was cooler in the first case than in the second, for the same thermometer indication. As the cooling was purposely rendered slow, that the temperature of the bismuth might be near to that indicated by the thermometer and the currents in the fluid weaker, so the observations were always considered best when made with a standing or a falling temperature.

3399. The following are the actual observations of one series made with the silver torsion wire as the temperature fell. The crystal was surrounded by oil. The upsetting angle is subtracted as before described (3367.):—

Temp.		Torsion force.	Temp.		Torsion force.	Temp.		Torsion force.	Temp.		Torsion force.
279° F.	...	82	225° F.	...	105	190° F.	...	118	152° F.	...	133
272	...	82	219	...	117	186	...	121	149	...	138
265	...	80	215	...	117	183	...	120	141	...	137
258	...	81	212	...	105	180	...	119	133	...	142
251	...	89	209	...	107	177	...	119	131	...	145
245	...	93	204	...	108	173	...	128	119	...	151
240	...	97	199	...	116	165	...	136	104	...	160
235	...	97	197	...	119	156	...	134	92	...	175
230	...	100	193	...	119						

It will be understood that each of the numbers under torsion force, increased by 105, will give the number of degrees of torsion experimentally observed. The observations at 219° and 215° are, I have no doubt, influenced by currents; but I kept myself purposely ignorant of what might be expected, and I give them as they were obtained. When these numbers are laid down on a scale (Plate III. See bismuth crystal C), having temperature in one direction and torsion force at right angles to it, and when a mean line is drawn through them, it appears to be a straight line; at least there is nothing in the results to justify the assertion, that the change of force at one temperature was different in degree from the change at another, within the range employed. The force, as expressed by such a line, was at 100° equal to 162, and at 280° it was 77; the whole loss within that range being 85, or above half the power it possessed at the lower temperature; in other words, an average alteration of 4·7 for every 10° Fahr.

3400. Another set of observations was made with the same bismuth crystal surrounded by water. Seventy-one observations were taken between 40° and 207°; and, by the substitution of a cold bath, some others were added on for temperatures between 5° and 70°, which were in perfect accordance with the former. These, when laid down (see Plate III., bismuth crystal A and B), also gave a straight mean line, even more close to the various observations than the former one. The force at 5° was 168; at 270° it was 90; at 100° it was 131. The whole change of force between 5° and 207° is 78, or nearly one-half of the force at 5°; it is at the rate of 3·86 for every 10° of temperature, which correspond very closely to the former result; for the rate becomes 4·8 if the force be converted into a scale of number corresponding with that of crystal C.

3401. It is not to be expected (without extreme care) that the numbers in the different series of observations with the same object should coincide. The variation of the medium, which in one case was oil and in the other water, should not, for the reasons given (3381.), produce any effect; neither, for the same reasons, should their possible variation by change of temperature produce any effect; but any change in the distance of the magnetic poles would produce an alteration, and I have no doubt that, in the first case, the poles were a little nearer to each other, and therefore the force at the same temperature greater. It was very satisfactory also to see that the two mean lines (selected only by the eye) converged towards each other with rising temperatures; thus at 100° the difference of torsion force is 31, whilst at 200° it is 21 nearly; as if they were indeed only the tangents of curves, and, at much higher temperatures, would coincide or become parallel nearly.

3402. These first observations are sufficient to show, that the differential magnecrystallic force of bismuth diminishes with elevation of temperature, and that to a large extent; that this occurs by a regular progression, which presents no appearance of any change of sign within the limits of temperature employed; that the progression appears within these limits to be represented by a straight line, or rather by a portion of a large curve, a supposition favoured by the approximation of the lines at higher temperatures; and that the return of the bismuth to its original degree of power is perfect upon the recurrence of the original temperature.

3403. It is of importance, not merely to examine the effect of temperature upon a crystal of bismuth, as one of different magnecrystals, but to compare the manifestation of magnetic force in bismuth when in this state with the corresponding manifestations when the metal is in other conditions, as in the compressed state; or in the amorphous or granular state, at which time it is affected merely as a diamagnetic body. I therefore proceeded to compress a piece of granular bismuth in one direction, and then cut out of it a short square prism, which, when suspended, was 0·5 of an inch in height and 0·36 in thickness, the line of pressure being horizontal and parallel to two of the sides; when in the magnetic field this line set, of course, equatorially, and the piece therefore, which weighed 128·5 grains, could be subjected to experiment in the same manner as the crystal before it (3398.).

3404. This compressed bismuth acted very well, the difference of torsion force being abundantly large enough for observation. The upsetting angle was 109° and not very definite, so that currents in the surrounding heated medium (oil) interfered more with its exact observance than in the case of the crystal. Such a result was, perhaps, to be expected; for it cannot be supposed that a piece of bismuth, so squeezed in a hydraulic press, should have the line of compressing force of equal intensity and like direction in all its parts, and therefore comparable, in that respect, to a crystal. The results corrected for the upsetting angle were at

70° F. torsion force was	. .	157
121° F. torsion force was	. .	140
157° F. torsion force was	. .	119
194° F. torsion force was	. .	116
211° F. torsion force was	. .	106

and are laid down upon the plate of lines (see bismuth compressed, D).

3405. It so happens, that the size of the bismuth and the force of the magnet place the observations between those of the crystal before obtained, and the results show how parallel the three are in their direction and nature. These seem, also, to be in a line, straight or nearly so. The force is at 70° equal to 159, and at 210° only to 105, being a loss of 54 for the 140° of difference between the two temperatures. If we take the loss of power for equal differences, at the same temperature, the results are very accordant.

	Torsion force. At 90°	Torsion force. At 207°		Loss of power.
Bismuth crystal, A . .	135	90	. .	45 or $\frac{1}{3}$ of the power at 90°
Bismuth crystal, C . .	167	112	. .	55 or $\frac{1}{3}$ of the power at 90
Bismuth compressed, D.	149	107	. .	42 or $\frac{1}{3\cdot5}$ of the power at 90

3406. The compressed bismuth data are few in number, and do not afford so good an indication as those obtained with the crystal; but the results are such as to give an additional reason to those advanced by Tyndall, that the magnetic force in compressed bismuth is of precisely the same nature in disposition, &c. as in crystallized bismuth. I have endeavoured to obtain some additional physical evidence, of another kind but in the same direction, by subjecting crystallized and compressed bismuth to the slow dissolving action of dilute nitric acid; but though signs of crystalline structure appear in both cases they are not clear or satisfactory.

3407. *Tourmaline.*—This substance, as a paramagnetic crystal, was then submitted to the action of heat, the crystal employed being that already described (3377.); its upsetting angle was 90°. A series of observations with the crystal in water was made, extending from 39° to 206°, which are entered in the plate of measurements as "Tourmaline crystal I." A second series was made with this crystal in oil, the temperatures reaching from 79° to 289°; they are entered as "Tourmaline crystal K." A third short series with the crystal in brine and extending from 7° to 69°, is entered as "Tourmaline crystal L." These results are recorded, not with the torsion numbers obtained, which, though occurring with the silver torsion wire, ranged from 640 to 1200 degrees of force, but in other numbers which conveniently entered within the range of the table adopted, and which were obtained by reducing the experimental results proportionately. It will be understood, of course, that the different entries in the diagram offer no absolute comparison between one body and another, *that* not being possible for equal bulks or weights of the substances, in a table like the present; but only a result for each particular body during change of temperature, the source of magnetic power and the measure of torsion force remaining invariable for the time.

3408. The precedence which the thermometer takes of the body (3397.), is here very manifest in the first observations of K. The progression of the numbers is generally good, either with rising or falling temperatures. The magnetic force in the crystal diminishes continually with increase of temperature; there is no change of sign. The loss of force between 7° and 289° is nearly half the force possessed by the crystal at the lower temperature; and, therefore, almost as much as that left at the higher temperature. The force returns perfectly upon the restoration of a lower temperature. There is no permanent disturbance of the specific magnetic capacity, nor anything like magnetic charge. The loss is not in arithmetical progression, but greater for an equal number of degrees at lower than at higher temperatures; and is best represented by a regular curve as the mean line. The two chief series agree very well together, and the third series, at low temperatures, is in near accordance with either. The loss of power at low temperatures, as 0°, is for the same number of degrees of elevation, three times as much as it is for temperatures about 270° or 280°.

3409. The return of this and other crystals to their first condition by return of temperature, combined with the observations made with iron, nickel, &c. (3424.), shows that the magnet, as a source of power, remained unchanged by the variation of temperature from 0° to 300° in the magnetic field.

3410. This tourmaline crystal (3377.) being hung between the poles of the great electro-magnet, was raised by a spirit-lamp to a full red heat, and then set well with its axis equatorially, though with diminished power; so that high temperature does not take away its magnecrystallic character: on cooling it returned to its first higher condition. On a former occasion I found that a like, short, thick, black crystal lost part of its power by the heat of a spirit-lamp flame, but on cooling, the tourmaline became very magnetic, pointed axially, and was strongly attracted. The latter effects were traced to a portion of peroxide of iron on one part of the crystal, which had been reduced to protoxide or even lower, by the vapour and heat of the spirit-lamp: digestion in hydrochloric acid removed this iron and restored the crystal to its first condition. The fact shows, that a temperature which takes away the high paramagnetic condition of iron or its protoxide could not destroy the peculiar condition of tourmaline as a magnecrystal.

3411. *Carbonate of iron.*—The crystal of this substance before described (3379.) was suspended in an oil bath, and carried through temperatures varying from 4° to 293°. Its upsetting angle was 96°. The results are in the diagram marked F. In another set of experiments, results were obtained about 0° and 60°, and are added, being marked G. The whole forms a very consistent series of observations, showing progressive loss of power with elevation of temperature, the diminution being much greater at low than at high degrees; and, on the whole, very great for the range of temperature employed. The loss of power about 0° and 32°, is four times as much as it is at 280° for an equal number of degrees. The whole power at 300° is 135; at 0° it is nearly tripled, being 380.

3412. When carbonate of iron crystallized, is heated, either in air or oil, up to or above a certain high temperature, it is almost sure to fly to pieces like a Rupert's drop. By perseverance, and by selecting the larger fragments when the breaking-up took place in oil, I obtained three pieces, which could be raised by the flame of a spirit-lamp to a red heat. Below a very dull red heat these crystals were *always* magnecrystallic; more at lower temperatures and less at higher:—regaining power as the heat fell and losing it when temperature increased, and that repeatedly. When the temperature was further raised and continued for a minute or more, the crystal ceased to be magnecrystallic, and lost nearly all magnetic power; but when lowered beneath a certain temperature, it became intensely magnetic, and was found to have lost its carbonic acid and become converted into magnetic oxide of iron.

3413. *Carbonate of lime.*—The sphere of calcareous spar was comparatively so weak in magnetic force, as to give no sufficient indication when a metallic torsion wire was employed with the LOGEMAN magnet; to employ a silk torsion thread would have been unsafe. A very high temperature, amounting to full ignition (being the highest that a spirit-lamp flame could communicate to a small rhomboid), did not take away the magnecrystallic condition of calcareous spar, or interfere with the pointing of the optic axis equatorially; for though the heat was sufficient to convert the exterior of the crystal (to which the aqueous vapour from the flame had access) into quick lime, still the internal crystalline part pointed magnecrystallically, and carried the altered part with it. This permanency, coupled with the low magnecrystallic state possessed by the crystal at common temperatures, shows that the power would decrease at a very low rate and in a very small degree, whilst rising from 0° of temperature to 300°.

3414. When a crystal of *red ferroprussiate of potassa* is heated, either in air or oil, it flies to pieces at a certain high temperature; beneath that degree, however, it retains its magnecrystallic character unaltered, except that the pointing is with less force at the higher temperatures than at the lower.

3415. The *ferrocalcareous spar* before described (3393.) suggested some very curious points of inquiry. It seemed probable that the iron within the crystal would retain its state of chemical combination under the action of heat, if the crystal as a whole should preserve its integrity at high temperatures: and if so, then, because of the slow alteration of calcareous spar by heat, and the much quicker alteration of carbonate of iron, as regarded magnetic force, it seemed further probable, that such a magnecrystal being heated sufficiently, would change its character; and that the axis of magnetic power, which at low temperatures was the maximum, would at high temperatures become the minimum axis, or line of minimum force: which indeed upon investigation proved to be the case.

3416. It was very difficult to raise these crystals above a certain temperature; near a given point, about 300° FAHR., they either broke up suddenly like a RUPERT's drop, or crumbled to pieces. No previous slow elevation of temperature appeared to prevent this disruption. Nevertheless some pieces were obtained, both in air and in oil, which, though much fissured, still adhered together, so as to represent the crystal. When these were properly suspended in the magnetic field, the short axis of the rhomboid (or optic axis) pointed axially at common temperatures, but when raised by a spirit-lamp to a point clearly below a red heat, the short axis pointed equatorially. When the crystal was allowed to cool, it again pointed axially, and when reheated its direction was equatorial; and this change could be repeated many times, without the crystal appearing to be at all altered, either by the production of caustic lime or of free oxide of iron:—its state and peculiar qualities were preserved. It was magnecrystallic at high and at low temperatures; but at the upper it was like pure calcareous spar and at the lower like carbonate of iron. At the lower temperature it was, as a whole, paramagnetic in air and therefore in carbonic acid gas. Whether at a given intermediate temperature it would cease altogether to be magnecrystallic, and would in carbonic acid gas be, as a whole, neither paramagnetic nor diamagnetic, and therefore in part, and for a given temperature, answer the inquiry before made (3393.), I cannot say.

3417. In the carbonate of lime and carbonate of iron, the short axis of the rhomboid is, emphatically, a *line* of direction, and points either equatorially or axially according to the nature of the crystal. A plane at right angles to it does not present sensible differences in particular parts, the force appears to be equal in all directions. So the whole change in the ferrocarbonate of lime appears to depend upon the circumstance, that, in the direction of the short axis, the aptness for magnetic induction decreases by heat more rapidly than in the *plane* at right angles to it; so as not merely to overtake the latter but to *pass by it*, and that in cooling it again returns towards, by, and beyond it:—the force in the equatorial plane or direction is probably varied, but nevertheless its whole range appears to be intermediate to that which the axial direction supplies.

3418. It would seem that such crystals as these could not have been formed at a high temperature and common pressures, inasmuch as they cannot sustain such a temperature now. They may even be considered, physically, as different substances at high and low temperatures; for a body which cannot expand and keep its integrity must have a very different arrangement of its molecular forces, when they are just about to burst the mass into particles, to that which exists when they are employed in giving permanency to the state into which they have brought them. The variations in magnetic relations are very striking for the two cases; perhaps some of the optical characters may be found to be affected also. The crystals are, I think, harder than those of calcareous spar, and always more fissured. Such calcareous spar as contains veins of minute crystals of pyrites is almost sure to prove of this peculiar nature.

3419. It would appear that magnecrystals (with the exception of the ferrocarbonate of iron), whether paramagnetic or diamagnetic, are all generally alike in their affections by heat; the differences of force in two given directions diminishing as the temperature is raised, increasing as temperature is lowered, and being constant for a given temperature. Such alterations might take place in various ways; a diminution by heat of the force of the stronger axis would account for it, so also would an increase of the force of the weaker axis; such doubtful points might be settled by combining with results like those I have given, others upon the *whole* paramagnetic or diamagnetic force of a crystal in a given position at different temperatures. I have little doubt, however, that, according to the general action of heat, the power of the crystal to suffer a certain amount of induction in a given direction through it, is lessened in every direction as the temperature rises, and that the effects I have measured are simply the differences between the whole changes in each of two directions. Experiment only can decide, whether a sphere of tourmaline, or carbonate of lime, would remain affected by the magnet at temperatures which would cause the magnecrystallic character of these bodies to disappear; but it seems almost certain that the diamagnetic force of a granular piece of bismuth must be equal to the sum of the forces of the variously arranged crystalline parts of which it is composed, and would disappear when their magnecrystallic character was taken from them by heat; and it is also certain that the magnecrystallic character of such crystals as can hold together, is retained at very high temperatures.

3420. If the absolute magnetic and the magnecrystallic character of bodies should be found to coincide, then the examination of magnecrystals by heat would acquire increased interest. In many cases we can examine the magnecrystallic disposition of force better than the whole sum of force, and an examination of a part of the rate of diminution might give us a considerable insight as to the nature of the whole. Further, if the magnecrystallic and the magnetic indications agree, so that the one set may be accepted as representing the other, then we have the advantage in magnecrystals, of dismissing the influence (changeable as it is by temperature) of the surrounding medium altogether (3376.). It is remarkable, that as no unmixed body has as yet altered in the character of its magnetism by heat, *i. e.* has not passed by heat from the paramagnetic to the diamagnetic class (assuming space, or its magnetic equivalent carbonic acid gas, to be at zero), or *vice versâ*, so no simple magnecrystal has shown any inversion of this kind; nor have any of the three chief axes of power changed their character or relation to each other. This has to be borne in mind when considering the possible case of a magnecrystal at zero, before referred to (3393.).

It does not appear, from the direction of the lines in the diagram, that much increase in the diamagnetic power of the bismuth is to be expected from the application of any low temperature within our reach. Being the chief diamagnetic substance, and a metal, one would have wished it to have given a curve rather like that of carbonate of iron or even tourmaline.

§ 40. *Effect of heat upon the absolute magnetic force of bodies.*

3421. The time is coming on when we shall require to know the effect of heat on the total magnetic force (under induction) of such bodies as, being paramagnetic or diamagnetic, are near to zero, *i. e.* as near as bismuth or oxygen; so that, amongst other points, we may examine the relation of the *whole* change of power to the change of the differential condition which occurs in magnecrystals. A difficulty, not met with before, is included in such investigations, by the dependence in a greater or smaller degree of the motions of the body upon the medium around it; for if the latter were to change by differences of temperature, the former would seem to have suffered a change though none might have occurred. The statement made on a former occasion (2359.), that paramagnetic solutions were not affected by heat, can hardly be accepted, without further confirmation, in the present state of the subject. If bodies at magnetic zero suffer no alteration by heat, then a fluid having that condition might be selected as a bath in which to try the changes of solid bodies not at zero; and a solid at zero might in like manner be employed to ascertain the variations by heat in the fluids surrounding it*: further, if paramagnetic solutions suffer no change, they may be employed to exalt the indications of diamagnetic bodies, such as bismuth or phosphorus. In the mean time the following results may be useful and acceptable.

3422. Being very desirous of knowing whether the variation of a piece of *amorphous*, i. e. *granular*, *bismuth* had the same progression for the same temperatures as a crystal of bismuth, I endeavoured to obtain some measures, but did not satisfy myself. I employed a bar of the metal about 0·55 of an inch long and 0·12 of an inch thick, between pointed poles; but the force of the bismuth under the influence of the LOGEMAN magnet was not sensible with a metallic torsion wire, and when a silk suspender was used (uncertain in itself), the indications were altogether overcome by currents in the surrounding fluid. A *tourmaline* crystal was just as unfavourable under the like circumstances; besides which, it must be understood that as tourmalines differ much from each other, specimens from the same crystal can only properly be compared.

3423. *Carbonate of iron.*—I found this substance sufficiently paramagnetic to supply indications with the LOGEMAN magnet, when the pointed poles were employed and placed 1·95 inch apart. The crystal formerly described (3379.) was therefore reduced by grinding to a plate, which being suspended with the optic axis or short diameter vertical, was then 0·6 of an inch in length, 0·17 in breadth, and 0·37 in height; a small copper cube was hung to it beneath, so as to give it weight in the oil-bath, and prevent its approach as a whole to either one or the other pole. The results obtained are entered in the diagram of curves (see carbonate of iron bar, E). They are not accordant with those given by the same substance as a magnecrystal. In the ascending part of the series the force at 126° is 157, and at 288° it is 133; the diminution 24 being only $\frac{1}{6\cdot54}$ of the force at 126°. In the descending part, the force at 96° is 182, and at 292° it is 125, the difference 57 being $\frac{1}{3\cdot2}$ of the force at 96°: both differences are much less than that with the crystal of carbonate of iron, for then the force at 96° was 255, and at 292° was 137, the difference 118 being almost half of the force at 96°. It is evident therefore that the forces of the bar do not diminish in the same ratio as the forces of the crystal; or else that the medium alters

* Royal Institution Proceedings, Jan. 1853, p. 232; or Experimental Researches, 8vo. vol. iii. p. 500.

importantly though in an unknown manner; or else that the bar as a whole exhibits some peculiar change connected perhaps with the crossing of the diagram lines indicating the ascending and descending results. If the oil of the bath had *lost* diamagnetic power by elevation of temperature (and gain is not to be expected), then the carbonate of iron should, on that account alone, have seemed to suffer a loss which would be added to its own loss; such an effect would have tended to give a result the reverse of that which in reality appears.

3424. Experiments were then made, as additions to former results*, upon the metals iron, nickel, cobalt, and with much facility, in the following manner. A copper cube 0·25 of an inch in the side, had a fine hole made through it, in a direction perpendicular to two of the faces, and a piece of clean soft *iron* wire 0·05 of an inch in length and 0·0166 in diameter, was placed in the middle of the hole. The cube, which weighed 46 grains, was then suspended as before between the magnetic poles, they being 4·86 inches apart. The power of the iron, thus subjected to the magnet, was such as to permit the employment of the platinum torsion wire (3369.), and so remove every objection as to any possible change of the torsion force. The upsetting points were very definite and were 108° apart. The results of the observations, at temperatures varying from 30° to 288°, are entered in the chart (see iron bar, P), and it will be seen that they present no sensible variation; as if the inductive force in the iron underwent no change during this alteration of temperature, but had obtained and kept its maximum degree. We know from other experiments, that at higher temperatures the force would decrease; that at a certain temperature the decrease, though progressive and not instantaneous (2345.), would be very rapid; and that at still higher temperatures it would again become slow and at last almost insensible: and we have reason to suppose that with tourmaline and carbonate of iron we should have a like inversion of the curvature if we could descend to very low temperatures.

3425. *Nickel.*—A small square bar of pure nickel was prepared; it was 0·09 of an inch in length, and 0·036 in thickness. A cube of copper like the former (3424.) had a cavity formed in its upper surface, in which the nickel was placed, and retained immoveable by the suspending wire, and the whole was submitted to changes of temperature. The upsetting angle was 112°. The results are given in the chart marked "Nickel bar M," beginning at the higher temperatures and descending to lower. It will be seen that there is a diminution of force at the upper temperature, which accords with the general effect of heat; and as we know that the temperature of boiling oil is enough to render even large masses of nickel insensible to the action of common magnets, we may believe that a very rapid and interesting series of changes would come on between 300° and 600°.

3426. *Cobalt.*—A small bar of pure cobalt, 0·08 of an inch in length and 0·027 square, was in like manner attached to a cube of copper, and subjected to the action of the magnet and heat. The upsetting angle was 118°. One reason for the differ-

* Experimental Researches, 2344–2347; also 8vo, vol. iii. p. 444.

ence of the upsetting angles of these metals, was the different proportions of length and thickness; another reason will appear further on (3427.). Two sets of results are entered in the chart of lines (marked N and O), both of which present an important indication. It may be observed, in the first place, of the results O, that ascending from 66° and then returning to nearly the same temperature, the cobalt seems to have gained a permanent increase of power of about 30 degrees of torsion force, the whole being about 380. This was ultimately referred to charge or coercitive power; for when, after the observations at 79°, the cube with the cobalt was turned round 180°, so as to reverse the ends as respects the magnetic poles, and then brought back into their first position and observed, the power of the whole seemed to have fallen, as is seen by the six results marked R on the scale; and this condition the cobalt retained though left in the last position for some time. I found, indeed, that small pieces of the iron, nickel, and cobalt, when ignited to remove charge, and then held for a moment in any position in the magnetic field, acquired a charge, which they retained when out of the field. It would seem, that, even when afterwards reversed in the magnetic field, this first charge, or the effect of it, is in part retained, but that at high temperatures the metal loses more or less of it; and hence the difference between the results at the beginning and end of the series of observations marked O. In those marked N the metal was, probably, either in such a condition as to have no permanent loss occasioned by heat, or not to have had the heat (of 290° only) continued long enough for the purpose.

3427. I think it very probable that iron and nickel would show like phenomena as the cobalt if they were sought for; and also that this quality of charge may affect the upsetting angle of pieces of metal differing in their proportions of length and thickness (3426.).

3428. Admitting all the effect of this charge, there is still another result evident in both the cobalt series, and in both parts of the series O; that is, the *increase* of power with elevation of temperature. This is, I believe, the first instance in which such a result has been recognized; and even though we might think for a moment that, whilst ascending from 66° to 300°, the higher temperatures had set the metal more free to give up adverse charge, as above supposed (3426.), still that would not account on descending for a *diminution* of force, without admitting that heat was also able to make the metal more favourable to receive charge; which is in fact to say that the power is greater at higher than at lower temperatures. This effect cannot depend upon any change in the surrounding medium, for, such is the enormous disproportion between it and the cobalt in equal volumes, that if its powers were either annihilated or doubled, the effect would be insensible amongst the results. If such be the truth with cobalt, then it is probable that a like result would occur with iron and nickel at some temperatures, and that in passing to lower temperatures than those employed we should arrive at one presenting the maximum magnetic induction for each, and below which their inductive force would diminish. Within the range employed, *i. e.* from 0° to 300°, the three metals seem to be in different parts of their course; nickel has passed the period of its maximum force, iron is in it, and cobalt has not yet attained to it; and this accords with the further change by temperature; for by greater elevation nickel first loses its distinctive power at about 635° FAHR.*; then iron at a moderate red heat†, and cobalt at a far higher temperature than either, near the melting-point of copper. Such a view as this increases very much the interest of the relation between heat and magnetism; especially as, if it be well founded, it will probably apply to substances in all states; to gases as oxygen as well as to metals like cobalt; in which case it may be that all bodies, whether paramagnetic or diamagnetic, have a certain temperature at which their induced magnetic condition being most favoured is a maximum, and above or below which their state diminishes.

3429. The effect of heat upon iron and steel, and therefore upon magnets generally, will have hereafter to be distinguished into that which it may produce in the case of iron considered as perfectly soft; and that which it may produce in the case of perfectly hard steel whether charged magnetically or not. It may be that its action upon a magnet, consisting of parts all equally hard and equally charged, may be very different from its action upon another magnet, having superficial or terminal parts harder and more charged than the rest; or as is usually the case, of which the parts are not, as steel, exactly alike, but give a resultant of many different actions

3430. In considering these remarkable effects of heat, the question still recurs, can substances be made to pass each other magnetically by any change of temperature? It does not appear as yet that any of them, being unmixed, can pass the zero presented by a vacuum or carbonic acid gas, *i. e.* none can be converted from the paramagnetic to the diamagnetic state, or *vice versâ*, these states being defined by that zero; and so far that would appear to be a true and natural zero. The further question may be asked, whether, if equal volumes of different bodies in the same shape were subjected to an equal magnetic force, at various temperatures, so that their forces might be expressed in their full and true relation, upon one diagram scale, would the lines expressing these forces ever cross each other? as far as I can see they would not; but the results are as yet far too few in number, and too imperfect in their nature, to justify any serious conclusion.

* Experimental Researches, 8vo, vol. ii. p. 219.

† Ibid. vol. iii. p. 444.

Royal Institution, October 9th, 1855.