III. *Experimental Researches in Electricity.—Twenty-sixth 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, &c. &c.*

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§ 32. *Magnetic conducting power.* § 33. *Atmospheric magnetism.*

¶ i. *Magnetic conduction.* ¶ ii. *Conduction polarity.* ¶ iii. *Magnecrystallic conduction.* § 33. *Atmospheric magnetism.* ¶ i. *General Principles..*

¶ i. *Magnetic conduction.*

2797. THE remarkable results given in a former series of these researches (2757. &c.) respecting the powerful tendency of certain gaseous substances to proceed either to or from the central line of magnetic force, according to their relation to other substances present at the same time, and yet the absence of all condensation or expansion of these bodies (2756.) which might be supposed to be consequent on such an amount of attractive or repulsive force as would be thought needful to produce this tendency and determination to particular places, have, upon consideration, led me to the idea, that if bodies possess different degrees of *conducting power* for magnetism, that difference may account for all the phenomena; and, further, that if such an idea be considered, it may assist in developing the nature of magnetic force. I shall therefore venture to think and speak freely on this matter for a while, for the purpose of drawing others into a consideration of the subject; though I run the risk, in doing so, of falling into error through imperfect experiments and reasoning. As yet, however, I only state the case hypothetically, and use the phrase *conducting power* as a general expression of the capability which bodies may possess of affecting the transmission of magnetic force; implying nothing as to how the process of conduction is carried on. Thus limited in sense, the phrase may be very useful, enabling us to take, for a time, a connected, consistent and general view of a large class of phenomena; may serve as a standard of meaning amongst them, and yet need not necessarily involve any error, inasmuch as whatever may be the principles and condition of conduction, the phenomena dependent on it must consist among themselves.

2798. If a medium having a certain conducting power occupy the magnetic field, and then a portion of another medium or substance be placed in the field having

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a greater conducting power, the latter will tend to draw up towards the place of greatest force, displacing the former. Such at least is the case with bodies that are freely magnetic, as iron, nickel, cobalt and their combinations (2357. 2363. 2367. &c.), and such a result is in analogy with the phenomena produced by electric induction. If a portion of still higher conducting power be brought into play, it will approach the axial line and displace that which had just gone there; so that a body having a certain amount of conducting power, will appear as if attracted in a medium of weaker power, and as if repelled in a medium of stronger power by this differential kind of action (2367. 2414.).

2799. At the same time that this idea of conduction will thus account for the place which a given substance would take up, as of oxygen in the axial line if in nitrogen, or of nitrogen at a distance if in oxygen, it also harmonizes with the fact, that there are no currents induced in a single gas occupying the magnetic field (2754.), for any one particle can then conduct as well as any other, and therefore will keep its place; and it also agrees, I think, with the unchangeability of volume (2750.).

2800. In reference to the latter point, we have to consider that the force which urges such a body as oxygen towards the middle of the field, is not a central force like gravitation, or the mutual attraction of a set of particles for each other; but an axial force, which, being very different in character in the direction of the axis and of the radii, may, and must produce its effect in a very different manner to a purely central force. That these differences exist, is manifest by the action of transparent bodies, when in the magnetic field, upon a ray of light; and also by the ordinary action of magnetic bodies: and hence, perhaps, the reason, that when oxygen is drawn into the middle of the field, in consequence of its conducting power, still its particles are not compressed together (2721.) by a force that otherwise would seem equal to that effect (2766.).

2801. So when two separate portions of oxygen or nitrogen are in the magnetic field, the one passes inwards and the other outwards, without any contraction or expansion of their relative volumes; and the result is differential, the two bodies being in *relation to and dependence on* each other, by being simultaneously related to the lines of magnetic force which pass conjointly through them both, or through them, and the medium in which they are conjointly immersed.

2802. I have already said, in reference to the transference onwards of magnetic force (2787.), that pure space or a vacuum permits that transference, independent of any function that can be considered as of the same nature as the conducting power of matter; and in a manner more analogous to that in which the lines of gravitating force, or of static electric force, pass across mere space. Then as respects those bodies which, like oxygen, facilitate the transmission of this power more or less, they class together as magnetic or paramagnetic substances (2790.); and those bodies, which, like olefiant gas or phosphorus, give more or less obstruction, may be arranged together as the diamagnetic class. Perhaps it is not correct to express both these qualities by the term *conduction*; but in the present state of the subject, and under the reservation already made (2797.), the phrase may I think be employed conveniently without introducing confusion.

2803. If such be a correct general view of the nature and differences of paramagnetic and diamagnetic substances, then the internal processes by which they perform their functions can hardly be the same, though they might be similar. Thus they *may* have circular electric currents in opposite directions, but their distinction can scarcely be supposed to depend upon the difference of force of currents in the *same* direction. If the view be correct also, though the results obtained when two bodies are simultaneously present in the magnetic field may be considered as differential (2770. 2768.) even though one of them be the general medium, yet the consequence of the presence of conducting power in matter renders a *single* body, when in space, subject to the magnetic force; and the result is, that when a paramagnetic substance is in a magnetic field of unequal force, it tends to proceed from weaker to stronger places of action, or is *attracted*; and when a diamagnetic body is similarly circumstanced, it tends to go from stronger to weaker places of action, or is *repelled* (2756.).

2804. Matter, when its powers are under consideration, may, as to its quantity, be considered either by weight or by volume. In the present case, where the effects produced have an immediate reference to mere space (2787. 2802.), it seems proper that the volume should be considered as the representation, and that in comparing one substance with another, equal volumes should be employed to give correct results. No other method could be used with the differential system of observation (2772. 2780.).

2805. Some experimental evidence, other than those of change of situation, of the existence of this conducting power, by differences in which, I am endeavouring to account for the peculiar characteristics of paramagnetic and diamagnetic bodies, may well be expected. This evidence exists; but as certain considerations connected with polarity preclude me from calling too freely upon iron, cobalt, or nickel (2832.) for illustrations, and as in other bodies which are paramagnetic, as well as in those that are diamagnetic, the effects are very weak, they will be better comprehended after some further general consideration of the subject (2843.).

2806. I will now endeavour to consider what the influence is which paramagnetic and diamagnetic bodies, viewed as conductors (2797.), exert upon the lines of force in a magnetic field. Any portion of space traversed by lines of magnetic power, may be taken as such a field, and there is probably no space without them. The condition of the field may vary in intensity of power, from place to place, either along the lines or across them; but it will be better to assume for the present consideration a field of equal force throughout, and I have formerly described how this may, for a certain limited space, be produced (2465.). In such a field the power does not vary either along or across the lines, but the distinction of direction is as great and important as ever, and has been already marked and expressed by the term axial and equatorial, according as it is either parallel or transverse to the magnetic axis.

2807. When a paramagnetic conductor, as for instance, a sphere of oxygen, is introduced into such a magnetic field, considered previously as free from matter, it will cause a concentration of the lines of force on and through it, so that the space occupied by it transmits more magnetic power than before (fig. 1). If, on the other hand, a sphere of diamagnetic matter be placed in a similar field, it will cause a divergence or opening out of the lines in the equatorial direction (fig. 2); and less magnetic power will be transmitted through the space it occupies than if it were away.

Fig. 1.

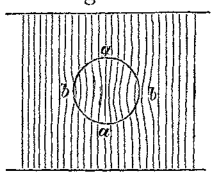
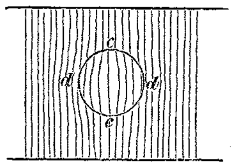


Fig. 2.



2808. In this manner these two bodies will be found to affect, *first* the *direction* of the lines of force, not only within the space occupied by themselves, but also in the neighbouring space, into which the lines passing through them are prolonged; and this change in the course of the lines will be in the contrary direction for the two cases.

2809. *Secondly*, they will affect the *amount* of force in any particular part of the space within or near them; for as every section across the line of such a magnetic field must be definite in amount of force, and be in that respect the same as every other section, so it is impossible to cause a concentration within the sphere of oxygen (fig. 1) without causing also a simultaneous concentration in the parts axially situated as *a a* outside of it, and a corresponding diminution in the parts equatorially placed, *b b*. On the other hand, the diamagnetic body (fig. 2) will cause diminution of the magnetic force in the parts of space axially placed in respect of it, *c c*, and concentration in the near equatorial parts, *d d*. If the magnetic field be considered as limited in its extent by the walls of iron forming the faces of opposed poles (2465.), then even the distribution of the magnetism within the iron itself will be affected by the presence of the paramagnetic or diamagnetic bodies; and this will happen to a very large extent indeed, when, from among the paramagnetic class, such substances as iron, nickel or cobalt are selected.

2810. The influence of this disturbance of the forces upon the place and position of either a paramagnetic or a diamagnetic body placed within the magnetic field, is readily deduced upon consideration and easily made manifest by experiment. A small sphere of iron placed within a field of equal magnetic power, bounded by the iron poles, has a position of unstable equilibrium, equidistant from the iron surfaces, and at such time a great concentration of force takes place through it, and at the iron faces opposite to it, and through the intervening axial spaces. If the sphere be on either side of the middle distance, it flies to the nearest iron surface, and then can determine the greatest amount of magnetic force to or upon the axial lines which pass through it.

2811. If the iron be a spheroid, then its greatest diameter points axially, whether it be in the position of unstable equilibrium, nearer to or in contact with the iron walls of the field. As the circumstances are now more favourable for the concentration of force in the axial line passing through the body than before, so this result can be produced by much weaker paramagnetics than iron, and I have no doubt could easily be produced by a vessel of oxygen or nitric oxide gas (2782. 2792.). It now becomes indeed a form, though not the best, of that experiment by which the magnetic condition of bodies is considered as most sensitively tested.

2812. The relative deficiency of power in diamagnetic bodies renders any attempt to obtain the converse phenomena to those of iron somewhat difficult; in order therefore to exalt the conditions, I used a saturated solution of protosulphate of iron in the magnetic field; by this means I strengthened the lines of power passing across it, without disturbing its equality in the parts employed, or introducing any error into the principle of the experiment, and then used bismuth as the diamagnetic body. A cylinder of this substance, suspended vertically, tended well towards the middle distance, finding its place of stable equilibrium in the spot where the paramagnetic body had unstable equilibrium. When the cylinder was suspended horizontally, then the direction it took was equatorial; and this effect also was very clear and distinct.

2813. These relative and reverse positions of paramagnetic and diamagnetic bodies, in a field of equal magnetic force, accord well with their known relations to each other, and with the kind of action already laid down in principle (2807.) as that which they exert on the magnetic power to which they are subjected. One may retain them in the mind by conceiving that if a liquid sphere of a paramagnetic conductor were in the place of action, and then the magnetic force developed, it would change in form and be prolonged axially, becoming an oblong spheroid; whereas if such a sphere of diamagnetic matter were placed there, it would be extended in the equatorial direction and become an oblate spheroid.

2814. The *mutual action* of two portions of paramagnetic matter, when they are both in such a field of equal magnetic force, may be anticipated from the principles (2807. 2830.), or from the corresponding facts, which are generally known. Two spheres of iron, if retained in the same equatorial plane, repel each other strongly; but as they are allowed to depart out of that plane, they first lose their mutual repulsive force and then attract each other, and that they do most powerfully when in an axial direction.

2815. With diamagnetic bodies the mutual action is more difficult to determine, because of the comparative lowness of their condition. I therefore resorted to the expedient, before described, of using a saturated solution of protosulphate of iron as the medium occupying the field of equal magnetic force, and employing two cylinders of phosphorus, about an inch long and half an inch in diameter, as the diamagnetic bodies. One of these was suspended at the end of a lever, which was itself suspended by cocoon-silk, so as to have extremely free motion, and the adjustments were such, that when the phosphorus cylinder was in the middle of the magnetic field, it was free to move equatorially or across the lines of magnetic force; it however had *no tendency* to do so under the influence of the magnetic force. The other cylinder was attached to a copper wire handle, and could be placed in a fixed position on either side of the former cylinder; it was therefore adjusted close by the side of it, and the two retained together until all disturbance from motion of the fluid or of the air had ceased; then the retaining body was removed, the two phosphorus cylinders still keeping their places; finally, the magnetic power was brought into action, and immediately the moveable cylinder separated slowly from the fixed one and passed to a distance. If brought back again whilst the magnet was active, when left at liberty it receded; but if restored to close vicinity, when the magnetic force was away, it retained that situation. The effect took place either in the one direction or the other, according as the fixed cylinder was on this or that side of the moving one; but the motion was in both cases across the lines of magnetic force, and was indeed mechanically and purposely limited to that direction by the mode of suspension. When two bismuth balls were placed, in respect of each other, in the direction of the magnetic axis, so that one might move, but only in the direction of that axis, its place was not sensibly affected by the other; the tendency of the free one to go to the middle of the field (2812.) overpowered any other tendency that might really exist.

2816. Thus two diamagnetic bodies, when in the magnetic field, do truly affect each other; but the result is not opposed in its direction to that of paramagnetic bodies, being in both cases a separation of the substances from each other.

2817. The comparison of the action of para- and diamagnetic bodies on each other, was completed by using water as the medium in a field of equal magnetic force, and suspending a piece of phosphorus from the torsion balance. When the magnetic power was on, this phosphorus was repelled equatorially, as before, by another piece of phosphorus, but it was attracted by a tube filled with a saturated solution of protosulphate of iron; so paramagnetic and diamagnetic bodies attract each other equatorially in a mean medium, but each repels bodies of its own kind (2831.).

¶ ii. *Conduction polarity.*

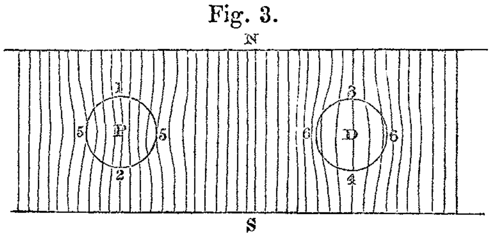
2818. Having thus considered briefly the effects which the disturbance of the lines of force, by the presence of paramagnetic and diamagnetic bodies, is competent to produce (2807. &c.), I will ask attention to that which may be considered as their polarity: not wishing by the term to indicate any internal condition of the substances or their particles, but the condition of the mass as a whole, in respect of the state into which it is brought by its own disturbance of the lines of magnetic force; and that, both in regard to its condition with respect to other bodies similarly affected; and also in regard to differences existing in different parts of its own mass. Such a condition concerns what may be called conduction polarity. Bodies in free space, when under magnetic action, will possess it in its simplest condition; but bodies immersed in other media will also possess it under more complicated forms, and its amount may then be varied, being reversed or increased, or diminished to a very large extent.

2819. Taking the simplest case of paramagnetic polarity, or that presented in fig. 1 (2807.), it consists in a convergence of the lines of magnetic force on to two opposed parts of the body, which are to each other in the direction of the magnetic axis. The difference in character of the two poles at these parts is very great, being that which is due to the known difference of quality in the two opposite directions of the line of magnetic force. Whether polar attraction or repulsion exists amongst paramagnetic bodies, when they present mere cases of conduction (as oxygen, for instance), is not yet certain (2827.), but it probably does; and if so, will doubtless be consistent with the attraction and repulsion of *magnets* having correspondent poles.

2820. When we consider the conduction polarity of a diamagnetic body, matters appear altogether different. It has not a polarity like that of a paramagnetic substance, or one the mere reverse (in name or direction of the lines of force) of such a substance, as I, WEBER and others have at times assumed (2640.), but a state of its own altogether special. Its polarity consists of a divergence of the lines of power on to, or a convergence from the parts, which being opposite, are in the direction of the magnetic axis; so that these poles, having the *same* general and opposite relations to each other, which correspond to the differences in the poles of paramagnetic bodies, have still, under the circumstances, that striking contrast and difference from the polarity of the latter bodies which is given by convergence and divergence of the lines of force.

2821. Let fig. 3 represent a limited magnetic field with a paramagnetic body P, and a diamagnetic body, D, in it, and let N and S represent the two walls of iron associated with the magnet (2465.) which form its boundary, we shall then be able to obtain a clear idea of the direction of the lines of magnetic force in the field. Now the two bodies, P and D, cannot be represented by supposing merely that they have the same polarities in opposite directions. The 1 polarity of P is importantly unlike the 3 polarity of D; but if D be considered as having the reverse polarities of P, then the 1 polarity of P should be like the 4 polarity of D, whereas it is more unlike to that than to the 3 polarity of D, or even to its own 2 polarity.

Fig. 3.



2822. There are therefore two essential differences in the nature of the polarities dependent on conduction, the difference in the direction of the lines of force abutting on the polar surfaces, when the comparison is with a magnet reversed, and the difference of convergence and divergence of these lines, when compared with a magnet not reversed; and hence a diamagnetic body is not in that condition of polarity which may be represented by turning a paramagnetic body end for end, while it retains its magnetic state.

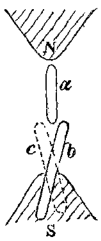
2823. Diamagnetic bodies in media more diamagnetic than themselves, would have the polar condition of paramagnetic bodies (2819.); and in like manner paramagnetic conductors in media more paramagnetic than themselves, would have the polarity of diamagnetic bodies.

2824. Besides these differences the bodies must have an equatorial condition, which, in the two classes of conductors, would be able to produce corresponding effects. The whole of the equatorial part of P (fig. 3) is alike in relation to the body P, or to the lines of force in the surrounding space; and there is a like correspondence in the equatorial parts of D, either to itself or to space; but these parts in P or in D differ in intensity of power one from the other, and both from the general intensity of the space. Such equatorial conditions must, I think, exist as a consequence of the definite character of any given section of the magnetic field (2809.).

2825. Though the experimental results of these polarities are not absent, still they are not very evident or capable of being embodied in many striking forms; and that because of the extreme weakness of the forces brought into play, as compared with those larger forces exhibited in the mutual action of magnets. Hence it is, that the many attempts to show a polarity in bismuth have either failed, or other phenomena have been mistaken for those properly referable to such a cause. The highest, and therefore the most delicate, test of polarity we possess, is in the subjection of the polar body to the line of direction of magnetic forces of a very high degree, when developed around it; and hence it is, that the pointing of a substance between the poles of a powerful magnet is continually referred to for such a purpose. It would be, and is utterly in vain to look for any mutual action between the poles of two weak paramagnetic or diamagnetic conductors in many cases, when the action of these same poles is abundantly manifest in their relation to the almost infinitely stronger poles of a powerful horseshoe or electro-magnet.

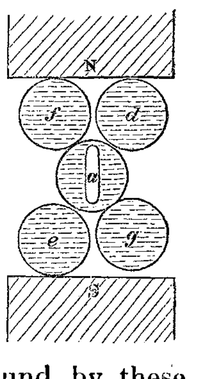
2826. I took a tube *a* (fig. 4), filled with a saturated solution of sulphate of cobalt, and suspended it between the poles of the great electro-magnet; it set readily and well. Another tube, *b*, was then filled with a saturated solution of sulphate of iron, and being associated with the S pole of the magnet, was brought near the cobalt tube in the manner shown, but not the slightest effect on the position of *a* was observable. The tube *b* was changed into the position *c*, to double any effect that might be present, but no trace of mutual action between the poles of *a* and *b* was visible (2819.).

Fig. 4.



2827. To increase the effect, the magnetic solution tube was suspended in water, as a good diamagnetic medium, between flat-faced poles (fig. 5). It pointed well. Two bottles of saturated solution of sulphate of iron were placed at *d* and *e*, but they did not alter the position of *a*; being removed into the positions *f* and *g*, neither was any sensible alteration of the position of *a* produced. I made the same kind of experiment with an air-tube in water, in which case it points axially (2406.), with the same negative result. I do not mean to assert that there was absolutely no effect produced in these cases (2819.); but if any, it must have been inappreciably small, and shows how unfit such means are to compare with those which are supplied by the pointing of a body when under the influence of powerful magnets. If polarity cannot be found by these

Fig. 5.



methods in paramagnetic bodies so strongly influential as saturated solution of iron, nickel or cobalt, it can hardly be expected to manifest itself by analogous actions in the much weaker cases of diamagnetic substances.

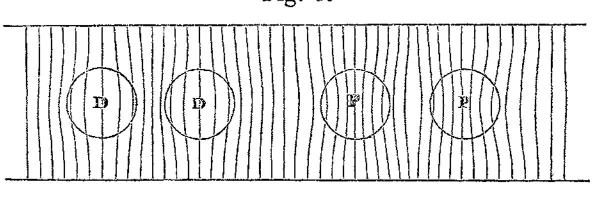
2828. When a spherical paramagnetic conductor is placed midway in a field of equal magnetic force, it occupies a place of unstable equilibrium, from which, if it be displaced ever so little, it will continue to move until it has gained the iron boundary walls of the field (2465. 2810.); this is a consequence of its particular polar condition. If the sphere were free to change its form, it would elongate in the direction of the magnetic axis; or if it were a solid of an elongated form, it would point axially, both consequences of its polar condition (2811.).

2829. So also in the case of diamagnetic bodies, their peculiar condition of polarity is shown by corresponding facts, namely, by a spherical portion having its place of stable equilibrium in the middle of the magnetic field (2812.), by a fluid portion tending to expand equatorially and become an oblate spheroid (2813.), and by the equatorial pointing of an elongated portion (2812.). If pointed magnetic poles are used, then the effects are very much stronger, but are exactly the same in kind, and dependent upon the same causes and polar conditions.

2830. There are another set of effects produced, which are either the results of the axial polarity just referred to, or else may be considered as consequences of the condition of the equatorial parts of the conductors (2824.). Two balls of iron, in a field of equal force, if retained in a plane at right angles to the line of force, *i. e.* with their equatorial parts in juxtaposition, separate from each other with considerable power (2814.), and the probability is that two infinitely weaker bodies of the paramagnetic class would separate in like manner. Two portions of phosphorus, being a diamagnetic substance, have been found also to separate under the same circumstances (2815.).

2831. The motions here are of the same kind, whereas they might have been expected to be the reverse (2816.) of each other; still they are perfectly consistent. The diamagnetics ought to separate, for the field is stronger in lines of magnetic force between them than on the outsides, as may easily be seen by considering the two spheres D D in fig. 6; and therefore this motion is consistent, and is in accordance generally with the opening or set equatorially, either of separate portions or of a continuous mass of such substances (2829.), in their tendency to go from stronger to weaker places of action. On the other hand, the two balls of iron, P P, have weaker lines of force between them than on the outside; and as their tendency is to pass from weaker to stronger places of action, they also sepa-

Fig. 6.



rate to fulfil the requisite condition of equilibrium of forces. Finally, a paramagnetic and a diamagnetic body attract each other (2817.); and they ought to do so, for the diamagnetic body finds a place of weaker action towards the paramagnetic body, and the paramagnetic substance finds a place of stronger action in the vicinity of the diamagnetic body, D P, fig. 6.

2832. I have frequently spoken of iron in illustration of the action of paramagnetic conductors, and considered the polarity which it acquires as the same with that of these conductors; but I must now make clear a distinction, which exists in my mind, with regard to the polarity of a magnet, and the polarity, as I have called it, due to mere conduction. This distinction has an important influence in the case of iron. A permanent magnet has a polarity in itself, which is possessed also by its particles; and this polarity is essentially dependent upon the power which the magnet inherently possesses. It, as well as the power which produces it, is of such a nature, that we cannot conceive a mere space void of matter to possess either the one or the other, whatever form that space may be supposed to have, or however strong the lines of magnetic force passing across it. The polarity of a conductor is not necessarily of this kind, is not due to a determinate arrangement of the cause or source of the magnetic action, which in its turn overrules and determines the special direction of the lines of force (2807.), but is simply a consequence of the condensation or expansion of these lines of force, as the substance under consideration is more or less fitted to convey their influence onwards. It is evidently a very different thing to originate such lines of power and *determine their direction* on the one hand, and only to assist or retard their progression without any reference to their direction on the other. Speaking figuratively, the difference may be compared to that of a voltaic battery and the conducting wires, or substances, which connect its extremities. The stream of force passes through both, but it is the battery which originates it, and also determines its direction; the wire is only a better or worse conductor, however by variation of form or quality it may diffuse, condense, or vary the stream of power.

2833. If this distinction be admitted, we have to consider whether iron, when under the influence of lines of magnetic power, becomes a magnet and has its proper polarity, or is a mere paramagnetic conductor with conducting powers of the highest possible degree. In the first place, it would have the real polarity of the magnet, in the second only that which I assign to oxygen and other conducting bodies. To my mind the iron is a magnet. It can be raised as a *source* of lines of magnetic power to an extreme degree of energy in the electro-magnet; and though, when very soft, it usually loses nearly all this power upon the cessation of the electric current, yet such is not the case if the mass of metal forms a continuous circuit or ring, for then it can retain the force for hours and weeks together, and is evidently for the time an original source of power independent of any voltaic current. Hence I think that the iron under the influence of lines of magnetic power becomes a magnet; and though it then has the same kind of polarity, as to direction, as a mere paramagnetic conductor, subject to the same lines of force, still with a great difference; for as the internal particles of iron become in a degree each a system producing magnetism, so their polarity is correlated and combined together into a polar whole, which, being infinitely more intense, may also be very different in the disposition of its force in different parts, to that equivalent to polarity, which a mere conductor possesses.

2834. It appears to me also as very probable, that when iron, nickel and cobalt, are heated up to the respective temperatures at which they lose their wonderful degree of power (2347.) and retain only so small a portion of it as to require the most sensible test to make it manifest (2343.), they then have passed into the condition of paramagnetic conductors, have lost all ability to acquire that state of internal polarity they could assume as magnets, and now have no other polarity than that which belongs to them as masses of paramagnetic matter (2819.). It is also probable that in many states of combination these metals may take up the mere conducting state; for instance, that whilst in the protoxide, iron may constitute a magnet, in the peroxide it is only a conductor; and in this respect it is not a little curious to find oxygen, which as a gas is a paramagnetic body (2782.), reducing iron down to, and indeed far below its own condition, weight for weight. In their various salts also and solutions, these metals may, in conjunction with the combined matter, be acting only as conductors.

2835. Perhaps I ought not to have called the condition of concentration or expansion of the lines of magnetic force in the bodies acting as conductors, a polarity; inasmuch as true magnetic polarity depends essentially and entirely on the *direction* of the line of force, and not on any mere compression or divergence of these lines. I have done so only that I might point with the more facility to facts and views that have heretofore been associated with some supposed polarity in the bodies which, whether paramagnetic or diamagnetic, I have been considering as mere conductors, and I hope that no mistake of my meaning will arise in consequence. I have already asked for such liberty in the use of phrases (lines of force, conducting power, &c.) (2149. 2797.) as may, for the time, set me free from the bondage of preconceived notions; these are, for that very reason, exceedingly useful, provided they are for the time sufficiently restricted in their meaning, and do not admit of any hurtful looseness or inaccuracy in the representation of facts.

¶ iii. *Magnecrystallic conduction**.

2836. The beautiful researches of Plücker in relation to magneoptic phenomena cannot have been forgotten, and I hope that my own experiments on magnecrystallic results (2454, &c.) are remembered in conjunction with his; the phenomena described by us are, as I believe, due to a common cause, and are the same in kind; and as far as they are presented by pure transparent bodies, are I think brought by Plücker into

* I must refer here to the important paper by MM. Tyndall and H. Knoblauch on this subject in the Philosophical Magazine, 1850, vol. xxxvii. p. 1. M. F.—January 6, 1851.

a proper relation to the positive and negative optic axis of such bodies*. In these cases a crystalline body sets powerfully, or takes up a particular position when placed in a field of magnetic force (2464. 2479. 2550.), without reference to its paramagnetic or diamagnetic character (2562.), and also without assuming any state which it can on its removal bring away with it (2504.).

2837. If the idea of conduction be applied to these magnecrystallic bodies, it would seem to satisfy all that requires explanation in their special results. A magnecrystallic substance would then be one which in the crystallized state could conduct onwards, or permit the exertion of the magnetic force with more facility in one direction than another; and that direction would be the magnecrystallic axis. Hence, when in the magnetic field, the magnecrystallic axis would be urged into a position coincident with the magnetic axis, by a force correspondent to that difference, just as if two different bodies were taken, when the one with the greater conducting power displaces that which is weaker.

2838. The effect of position would thus be accounted for (2586.); and also the greater aptness for magnetic conduction in one direction than in another (2588. 2591.): and, what appeared to me as an anomaly in the supposition, that a line of force could have reference indifferently to any part of a plane (2600.) disappears. That heat should take away this conducting power (2570.) seemed perfectly consistent with what we know of the effect of heat on the magnetic condition of iron, oxygen, &c., and also upon the conducting power for electricity in such cases as platina, sulphuret of silver, &c. Finally, the assumption did not appear inconsistent with the state which the body seems to assume for the time during which it is under the magnetic force (2609. &c.).

2839. But if such a view were correct, it would appear to follow that a diamagnetic body like bismuth ought to be less diamagnetic when its magnecrystallic axis is parallel (as nearly as may be) to the magnetic axis, than when it is perpendicular to it. In the two positions it should be equivalent to two substances having different conducting powers for magnetism, and therefore, if submitted to the differential balance, ought to present differential phenomena, corresponding in kind to those of oxygen and nitrogen (2774.), or phosphorus and bismuth, or any other two differing bodies. Though I have given certain results on a former occasion which seemed to bear on this point (2551. 2552. 2553.), they are not satisfactory in the present state of our knowledge, because the difference, if any, would be small (2552.), and quickly hidden by the employment of a single pointed pole. Other experiments, formerly described (2554–2561.), would not show a small difference in diamagnetic force (though quite fitted for their intended purpose), because they were made with flat-faced poles, and a field nearly equal in magnetic power.

2840. The differential torsion balance (2773.) enabled me to return to this matter with better hopes of success. A consistent group of bismuth crystals was selected

* Philosophical Magazine, 1849, vol. xxxiv. p. 450.

(2457.) and hung up on one side of the double cone core (2738.), whilst a cylinder of flint-glass was opposed to it on the other. The flint-glass was to be a standard of reference, and therefore neither its place on the balance nor condition was altered during the experiment. The bismuth group was placed with its magnecrystallic axis horizontal, and so that it could be turned in a horizontal plane, that the axis might be at one time parallel to the magnetic axis (or lines of force), and at other times perpendicular to it, but without any alteration of the distance of its centre of gravity from the opposed glass cylinder. Hence, having either one position or the other, it could still be compared with the cylinder.

2841. The magnecrystallic axis was first made parallel to the core or magnetic axis, the magnetic power developed, and when the diamagnetic bodies had taken their position of rest or stable equilibrium, the place of the balance lever was observed and recorded by means of a ray of light reflected from a mirror attached to it. Then the bismuth was turned through 90°, or until its magnecrystallic axis was perpendicular to the axis of the double cone core; and now, when the magnet was excited, the place of the bismuth was found to be further out from the core than before. On being turned through 90° more, so as to be in a position diametral to the first (2461.), its place was again a little nearer to the magnet; and when in the fourth position, which is diametral to the second, then it was further out. Thus the crystallized bismuth proved to be diamagnetic in different degrees, according with certain directions of its magnecrystallic axis, being more diamagnetic when this axis was perpendicular or transverse to the lines of magnetic force, than when it was parallel to them; and thus the expectation founded upon theoretical considerations (2839.) was confirmed.

2842. I tried to obtain similar results with a cube of calcareous spar (2597.); for it is evident that if its optic axis, being in a horizontal plane, is first placed parallel to the magnetic axis and then perpendicular to it, the body ought to be more diamagnetic in the first position than in the second, inasmuch as the latter is the position which it takes up under the influence of its magnecrystallic or magneoptic condition. I could not however obtain any distinct results, partly because its power is in all respects very inferior to the bismuth, partly because of the present imperfection of my torsion balance, and partly because of the size and shape of the calcareous spar. A sphere or a cylinder, having the optic axis perpendicular to the axis of the cylinder, would be more correct as forms of the substances to be tried.

2843. In concluding this part of the subject relating to the magnetic conducting power, I will now refer to some of the cases which I think experimentally establish its *existence* in the two subdivisions of magnetic bodies (2805.). The place and position of iron in a field of equal force (2810. 2811.) is no doubt a result of the extraordinary power which this body has of transmitting the magnetic force across the space which it occupies, whether the particles of the iron be considered as polar or not

(2832.), and therefore I accept the converse phenomena as to place and position of a diamagnetic body (2812. 2813.) as proof that it has less power of transmitting the magnetic force than the space it occupies, and from that conclude that it conducts diamagnetically (2802.).

2844. The separation of paramagnetic bodies in the equatorial direction is a proof of the manner in which, by their better conduction, they disturb the position of the lines of force in the medium around them (2831.). The separation of two diamagnetic bodies, under the same circumstances, is an equal proof of the manner in which, by difference of conducting power, they also disturb the disposition of the force (2831.). The equatorial attraction of a paramagnetic and a diamagnetic body for each other, when they are in a medium, which in conducting power is between the two (2831.), is a proof not only of conduction in both, but also of their reverse condition in respect of each other and the medium.

2845. The place of a crystal of bismuth, either nearer to or further from the magnetic axis (2841.), according as its magnecrystallic axis is parallel or perpendicular to the axial line, is also a case of the difference of conducting power, and therefore of the possession of that power by the diamagnetic body. Many other cases might be quoted in illustration of the existence of that power which I assumed as conducting power (2797.), and which probably nobody may be inclined to deny. I will suppose that the above are enough to explain my meaning.

2846. It is hardly necessary for me to say that magnetic conduction does not mean electro-conduction, or anything like it. The very best electro-conductors, as silver, gold and copper, are below mere space in their ability to favour the transmission of magnetic force, so deficient are they in what I have called magnetic conduction. There is a striking analogy between this conduction of magnetic force and what I formerly called specific inductive capacity (1252. &c.) in relation to static electricity, which I hope will lead to further development of the manner in which lines of power are affected in bodies, and in part transmitted by them.

¶ iv. *Atmospheric magnetism* * †.

2847. It is to me an impossible thing to perceive, that two-ninths of the atmosphere, by weight, is a highly magnetic body, subject to great changes in its magnetic

* A most important paper by Professor CHRISTIE "On the Theory of the Diurnal Variation of the Magnetic Needle," appears in the Philosophical Transactions for 1827, p. 308. Led by the discoveries of SEEBECK in thermo-magnetism and the experiments of CUMMING, he was induced to search how far the idea of thermo-currents or thermo-magnetic polarity would apply to the natural phenomena, and concludes (p. 327), that, admitting that the *earth and the atmosphere* are substances in which such action can under any circumstances take place, these experiments would indicate that *any portion of the earth bounded by parallel planes with the atmosphere surrounding it, would become similarly polarized if one part were more heated than another.* Thus considering alone *the equatorial regions of the earth,* we should have *two magnetic poles on the northern side, and on the southern side two poles similarly posited*; *the poles of different names being opposed to each other on the contrary sides of the equator.*

† I ought to refer the readers of my paper to a theory of the *cause* of the daily variations by M. A. DE LA

character, by variations in its physical conditions of temperature and condensation or rarefaction (2780.), and at the same time subject to these physical changes in a high degree, by annual and diurnal variations, in its relation to the sun, without being persuaded that it must have much to do with the disposition of the magnetic forces upon the surface of the earth (2796.), and may perhaps account for a large part of the annual, diurnal and irregular variations, for short periods, which are found to occur in relation to that power. I cannot pretend to discuss this great question with much understanding, seeing that I have very little of that special knowledge which has been accumulated by the exertions of the great and distinguished labourers, HUMBOLDT, HANSTEEN, ARAGO, GAUSS, SABINE, and many others, who have wrought so zealously at terrestrial magnetism over the surface of the whole earth. But as it has fallen to my lot to introduce certain fundamental physical facts, and as I have naturally thought much upon the general principles which tend to establish their relation to the magnetic actions of the atmosphere, I may be allowed to state these principles as well as I can, that others may be placed in possession of the subject. If the principles are right, they will soon find their special application to magnetic phenomena as they occur at various parts of the globe.

2848. The earth presents us with a spheroidal body, which, consisting of both paramagnetic and diamagnetic substances, disposed with much irregularity as regards its large divisions of earth and ocean, are also equally irregularly disposed and intermingled in its smaller portions. Nevertheless it is, on the whole, a magnet, and, as far as we at this moment are concerned, an original source of that power. And

RIVE, founded upon the idea of thermo-electric currents in the atmosphere and earth; it will be found in a memoir entitled 'On the Diurnal Variation of the Magnetic Needle.' Annales de Chimie, 1849, xxv. p. 310.

A friend has recently called my attention to an observation by M. E. BECQUEREL, which has reference to the present subject, and is in the following words. "If we reflect that the earth is encompassed by a mass of air, equivalent in weight to a layer of mercury of 30 inches, we may inquire whether such a mass of magnetic gas, continually agitated and submitted to the regular and irregular variations of pressure and temperature, does not intervene in some of the phenomena dependent on terrestrial magnetism. If we calculate in fact what is the magnetic force of this fluid mass, we find that it is equivalent to an immense plate of iron, of a thickness a little more than $\frac{1}{10}$th of a millimetre of diameter (?), and which covers the whole surface of the globe." This passage is at pp. 341, 342 of vol. xxviii. Annales de Chimie, 1850, being contained in an excellent memoir, in which the author has well worked out those differential actions of different media, which I developed generally *five* years ago. Experimental Researches, 2357. 2361. 2406. 2414. 2423. &c. By such means he has rediscovered the magnetic character of oxygen and taken measurements of its force, being evidently unacquainted with the account that I gave of this substance in relation to nitrogen and other gases *three* years ago, in a letter published in the Philosophical Magazine for 1847, vol. xxxi. p. 401, and also in POGGENDORFF's Annalen and elsewhere;—hence the observations above. I cannot wonder at this, for I myself was not aware of M. E. BECQUEREL's paper until very lately. In my letter of 1847, I speak of oxygen as being magnetic in common air, p. 410; in carbonic acid, p. 414; in coal-gas, p. 415; in hydrogen, p. 415, its power then being equal to its gravity. I say that air owes its place to the oxygen and nitrogen in it, p. 416, and tried to separate these constituents by attracting the oxygen and repelling the nitrogen. At the end of the paper I hesitate in deciding where the true zero between magnetic and diamagnetic bodies is to be placed, and refer to the atmosphere as being liable to affections under the magnetic influence of the earth. It was these old results which led me on to the present researches. M. F.—Nov. 28, 1850.

though we cannot conceive at present that all the particles of the earth contribute, as sources, to its magnetism, inasmuch as many of them are diamagnetic, and many non-conductors of electric currents, yet it is difficult to say that any large portion is not concerned in the production of the force; hereafter it may be necessary, perhaps, to consider certain parts as mere conductors, *i. e.* as parts merely permeated by the lines of force, originating elsewhere, but for the present the whole may be assumed, according to the theory of GAUSS, as a mighty compound magnet.

2849. The magnetic force of this great system is disposed with a certain degree of regularity. We have the opportunity of recognising it only as it is exhibited in one surface, which, being very irregular in form, is always the same to us, for we rarely, if ever, pass out of it; or if we do, as in a balloon, only to an insensible extent. This is the surface of the earth and water of our planet. The magnetic lines of force which pass in or across *this surface* are made known to us, as respects their direction and intensity, by their action on small standard magnets; but their average course or their temporary variations *below or above*, i. e. in the air above, or the earth beneath, are only dimly indicated by variations of the force at the surface of the earth, and these variations are so limited in their information, that they do not tell us whether the cause is above or below.

2850. The lines of force issue from the earth in the northern and southern parts with different but corresponding degrees of inclination, and incline to and coalesce with each other over the equatorial parts. Their general disposition is represented by the system, which emanates from a globe having within one or two short magnets adjusted in relation to the axis. There seems reason to believe, from the analogy of such globes to the earth, that the lines of magnetic force which proceed from the earth return to it; but in their circuitous course they may extend through space to a distance of many diameters of the earth, to tens of thousands of miles. Messrs. GAY-LUSSAC and BIOT, in their ascent in a balloon, perceived some indication of a diminution in the intensity of the magnetic force at a height of about four miles from the surface; but we shall shortly perceive that they might be at the time in the midst of influences sufficient to account for all the effect, so that none of it might be occasioned by removal from the earth as a magnet. The increase of the intensity of the magnetic force, as we proceed from the equator towards the poles, accords with the idea of the enormous extension of this power.

2851. These lines proceed through space with a certain degree of facility, of which a general idea may be gained from ordinary knowledge, or from experiments and observations formerly made (2787.). Whether there are any circumstances which can affect their passage through mere space, and so cause variations in their condition; whether variations in what has been called the temperature of space could, if they occurred, alter its power of transmitting the magnetic influence, are questions which cannot be answered at present, although the latter does not seem to be entirely beyond the reach of experiment.

2852. This space forms the great abyss into which such lines of force as we are able to take cognizance of by our observing instruments, which issue from the earth, proceed, at least at all parts of the globe where there is a sensible dip; but, as it were, between the earth and this space, there is interposed the atmosphere, which, however considerable we may estimate it in height, is so small when compared to the size of the earth, or to the extent of space beyond it into which the lines of force pass, that the idea of its being a changeable, active something interposed *between* two systems far more extensive and steady in their nature and condition, will not lead to any serious error. It is at the bottom of this atmosphere that we live and make all our inquiries, whether by observation or experiment.

2853. The atmosphere consists, as far as we are concerned at present, of four volumes of nitrogen and one volume of oxygen, or by weight, of three and a half parts of the former and one part of the latter. These substances are nearly uniformly mixed throughout, so that, as regards their manner of investing the earth, they act magnetically as a single medium; nor does there seem to be any tendency in the terrestrial magnetic forces to cause their separation*, though they differ very strikingly in their constitution as regards this power.

2854. *The nitrogen* of the air does not appear to be either paramagnetic or diamagnetic; if removed from zero, in either of these respects, it is only to a very small extent (2783. 2784.). Whether dense or rare, it has apparently the same relation to and equality with space, as far as the present means of observation have proceeded. As respects the other element of change, namely, temperature, I concluded, from former imperfect experiments†, that nitrogen became more diamagnetic when heated than before; but as it was then mixed with the oxygen of the air, and the results were mingled together, I have, for the purposes of the present research, repeated the experiments far more carefully.

2855. A small helix of platinum wire, fixed at the end of thicker copper wires, could be placed in any position beneath the poles of the great electro-magnet, and being ignited by a voltaic battery, served to raise the temperature of the gas around it. The magnetic poles were raised, were terminated by hemispheres of soft iron 0·76 of an inch in diameter and 0·2 of an inch apart, and were covered by a glass shade, resting upon a thick flat bed of vulcanized caoutchouc. A tube passed through the bed, rising up to the top of the shade, by which any required gas could be introduced. A very thin plate of mica, about 3 inches square, was covered with an attenuated coat of wax on the upper side, and fixed horizontally over the magnetic poles within the shade. The small platinum helix was so placed as to be beneath the space, between the poles, and a little on one side of the axial line, so that a current of hot air rising upwards from it, could pass to the mica plate, and by melting the wax show where it came against the mica.

2856. All acted exceedingly well, *air* being in the glass shade. When there was no magnetic power on, the hot air from the ignited helix rose perpendicularly, and

* Philosophical Magazine, 1847, vol. xxxi. p. 416.

† Ibid. p. 418.

melted a neat round portion of the wax, showing the place of the current under natural circumstances; but when the magnet was thrown into action, then the wax on the mica remained unchanged, the hot air being thrown so far away from the axial line, and so cooled by its forcible mixture with the neighbouring air, as to be unable to melt a spot of wax anywhere. The moment the magnetic power was suspended, the column of hot air rose vertically and regained its original position.

2857. *Carbonic acid gas* was then sent into the shade, until twice as much as the contents of the shade had passed through the pipe (2855.); but as it was heavy and the common air could make its way out only at the bottom of the shade, there was no doubt air mixed with the carbonic acid, which at last remained about the poles. The platinum coil being now heated, the column of hot gas rose vertically, as before. On putting on the magnetic force it was deflected from the axial line, passing equatorially, and melted the wax about half an inch off from the former place. Believing that even this effect might be due to the air mingled with the gas, other two volumes of carbonic acid gas were directed into and through the vessel. After this the magnetic force caused much less deflection of the rising column. Two volumes more of carbonic acid were sent through, and now the hot current of gas rose so nearly vertical that there was scarcely any sensible difference of its place when the magnetic power was in full action, or when it was entirely absent. Hence I conclude that carbonic acid gas is very little affected in its diamagnetic relations by a difference of temperature equal to that between natural temperatures and a full red heat.

2858. *Nitrogen.*—This gas was prepared by passing common air slowly over burning phosphorus, and after being washed for twelve or fourteen hours, was sent into the shade so as to displace the carbonic acid. As it was lighter than the latter, it performed that service very well, and the portion remaining in the vessel probably contained no other oxygen or air than that it carried in with it. This nitrogen being then heated by the platina coil, was almost as indifferent to the magnet as the carbonic acid. The heated column rose (nearly) to the same spot against the mica, whether the magnetic power was active or not. It went outwards or equatorially a very small degree when the magnet was active, but this I attributed to a little oxygen still left with the nitrogen; and indeed nitric oxide gas shows oxygen in nitrogen so prepared. The platina coil was raised to as high a temperature as it could well support without fusion, and yet there was only this small effect sensible; hence I conclude that hot nitrogen is not more diamagnetic than cold nitrogen, and that indeed its magnetic relation is noways affected by such change of temperature.

2859. I raised the French shade (2855.) an inch for a moment, and then instantly placed it down again; and now, on making the magnet active and the coil hot, there was so much effect of dispersion of the gas within, that the melted spot of wax appeared nearly an inch outside of the standard place, yet only a very small portion of air or of oxygen could have entered the vessel under these circumstances.

2860. The nitrogen of the air is therefore, as regards the magnetic force, a very indifferent body; it does not appear to be either paramagnetic or diamagnetic; neither does it present any difference in its relation, whether it be dense or rare, or at high or low temperatures. I formerly found that the diamagnetic metals, when heated, did not seem to change in their relation to the magnet (2397.), and this now appears to be the case with such neutral or diamagnetic bodies as nitrogen and carbonic acid gases.

2861. *The oxygen* of the air differs in a most extraordinary degree from the nitrogen. It is highly paramagnetic, being, bulk for bulk, equivalent to a solution of protosulphate of iron, containing, of the crystallized salt, seventeen times the weight of the oxygen (2794.). It becomes less paramagnetic, volume for volume (2780.), as it is rarefied, and apparently in the simple proportion of its rarefaction, the temperature remaining the same. When its temperature is *raised*, the expansion consequent thereon being permitted*, it loses very greatly of its paramagnetic force; and there is sufficient reason, from a former result with air†, to conclude, that when its temperature is lowered its paramagnetic condition is exalted. How much its paramagnetic intensity might be increased by lowering it to the temperature of freezing mercury, as at the north or south poles of the earth, we cannot at present tell. Though a gas, it is apparently like the solid metals, iron, nickel or cobalt, when they are within the range of temperature which affects their magnetic forces; and it may, perhaps, like them, rise by cooling to a very high state.

2862. These relations it preserves when mingled with nitrogen in the air, as long as its physical and chemical conditions remain unchanged; but it is not irrelevant to remark, that every operation by which this active part of the atmosphere changes in its nature and passes into combinations, takes away its paramagnetic powers, whether the result be solid, liquid or gaseous.

2863. Hence the atmosphere is, in common phrase, a highly magnetic medium. The air that stands upon every square foot of surface on the earth, is equivalent, in magnetic force, to 8160 lbs. of crystallized protosulphate of iron (2794. 2861.). This medium is, by every change in its density, whether of the kind indicated by the barometer, or caused by the presence or absence of the sun, changed in its magnetic relations. Further, every variation of temperature produces apparently its own change of force, in addition to that caused by the mere expansion or contraction in volume, and none of these alterations can happen without affecting the magnetic force emanating from the earth, and causing variations, both in its intensity and direction, at the earth's surface. Whether these changes are in the right direction and sufficient in quantity to supply a cause for the variations of the terrestrial magnetic power, is the point now to be considered, for the illustration of which I will endeavour to construct a type case, and then apply it, as well as I can, to the natural facts.

2864. Let us assume the existence of two globes of air distinct from the surrounding atmosphere, by a difference of temperature or by a difference of density: the

* Philosophical Magazine, 1847, vol. xxxi. p. 417.

† Ibid. p. 406.

assumption is not too extravagant for an illustration, since PROUT showed that there were masses of air, larger or smaller, floating about in the atmosphere, and singularly distinct from the surrounding parts, by temperature and other circumstances. Not to complicate the expression, we will leave out of view, at present, the attenuation upwards, and will consider one of these globes as *colder* or denser than the contiguous parts, and that it is in a portion of space which without it would present a field of equal magnetic force, *i. e.* having parallel lines of equal intensity of force passing across it.

2865. The air of such a globe will *facilitate* the transmission of the magnetic force through the space which it occupies (2807.), making it superior, in that respect, to the surrounding atmosphere or space, and therefore more lines of magnetic force will pass through it than elsewhere (2809.). The disposition of these lines, in respect of the line of the dip of the place, will be something like what is represented in fig. 7, (2874.), and consequently the globe will be polarized as a conductor (2821. 2822.) of the paramagnetic class. Hence the intensity of the magnetic force and its direction will vary, not only within but without the globe, and these will vary in opposite directions, in different places, under the influence of laws which are perfectly regular and well known.

2866. First, as regards the *intensity,* which before was uniform (2864.). If the intensity is to be considered as expressing the amount of force which passes through any given place, then, in consequence of the definite amount of power which belongs to any section, as *a a,* of a given amount of lines of magnetic force (2809.), a concentration of these lines towards the middle, P, will cause an increase of intensity at that part, and a diminution at some other parts, as *b b,* from whence the influence of the power has been partly removed. Hence, supposing the normal condition to exist at *a,* if a test of intensity were carried from *a* to P, it would gradually enter parts *b* and *c,* in which the intensity was less than the normal condition, and these might be either without or within the globe P, or both (according to its temperature relative to the surrounding air, its size and other circumstances); it would then arrive at parts having the normal intensity; and lastly, at parts, P, having an intensity greater than the surrounding space; as it went outwards, on the opposite side of P, corresponding variations would occur in the reverse order.

2867. On transporting the test upwards, in the direction of the dip from *e,* where the intensity may be considered as normal, it would gradually occupy positions at *f g,* &c., in which the intensity would increase until it arrived at P, after which it would pass through places of less and less intensity, until at *p* it would again find the force in the normal state. If the test, in being carried upwards, be not taken along *the line of the dip,* then it will of course pass through variations like those described on the line *a* P, growing more and more in extent until the direction coincides with the line *a* P, which is at right angles to the dip and where they are at a maximum. Hence, to pass upwards through such a globe of cold air in our latitude, where the dip is 70° nearly, and at the equator, where it is 0°, would be a very different matter, and the necessary natural results of such a difference ought to appear hereafter.

2868. But a magnetic needle or bar is not a test of such intensity, *i. e.* it will not tell these differences, or it may tell them in a contrary direction. To understand this point, we have to consider that a needle vibrates by gathering upon itself, because of its magnetic condition and polarity, a certain amount of the lines of force, which would otherwise traverse the space about it; and assuming that it underwent no change by change of temperature, it would be affected in proportion to any variations in the intensity of these lines, provided everything else remained the same. But being under natural circumstances surrounded by the atmosphere, which is a medium liable to variation in its magnetic condition, both by heat and rarefaction, and by these variations affects the intensity or quantity of the force, it will vary in its indications by variations in these conditions. Thus, for instance, if it were in a large sphere of oxygen, I expect that it would, by its number of vibrations or otherwise, indicate a certain intensity; if the oxygen were expanded, that it would indicate a higher intensity, although the same amount of lines of force and magnetic energy were passing through the oxygen as before. If the oxygen were made dense, then becoming a better conductor, I presume it would convey onwards *more* of the force and the magnet *less*, for the power would be partly transferred from the unchanging magnet to the improving conductor around it.

2869. These experiments can hardly be made with oxygen except by means of extremely delicate apparatus, but like effects are easily shown experimentally in selected analogous cases. Thus let a thin small tube of flint-glass, about 1 inch long and $\frac{1}{2}$ an inch in diameter, be filled with a saturated solution of protosulphate of iron, and suspended horizontally by cocoon-silk (2279.) between the poles of the electro-magnet, in a vessel which may either contain air or water, or other media (2406.). In air it will point axially, and will be analogous to a needle under the earth's influence, and it will point with a certain amount of force. Fill the vessel with water, and now it will point with more force than before, though the water is a worse magnetic conductor than the air which was previously there; and it is precisely because the water *is* a worse conductor that the liquid magnet or test indicates more power. Increase the conducting power of the surrounding medium by adding sulphate of iron to it, and the indication of strength by the tube goes on diminishing, first returning to the degree of power it had in air, and then descending to lower gradations, for it returns with less and less force to its axial position when disturbed from it. So the magnetic needle employed for measuring intensity or magnetic force (for the same meaning is at present understood by the two terms), indicates, in a certain manner, the power thrown upon itself, and, I conclude, accurately, provided the condition of the surrounding medium remains magnetically unchanged; but if it be placed in different media or in an altering medium, I expect that it will not measure accurately the intensity in them, *i. e.* it will not measure directly the amount of force passing relatively through them. The difference in air under different conditions would be very small, still it is that difference which concerns us in *atmospheric magnetism*; and it is very important to know, whether, when the magnet indicates an increased intensity of force, it is altogether due to a real increase of the amount of the power at its source as it comes to us from the earth, or in part to a change in the magnetic constitution of the space around the magnet hitherto unknown to us.

2870. If what is now often indifferently called magnetic force or intensity have its results distinguished as of two kinds, namely, those of *quantity* and those of *tension*, then we shall more readily comprehend this matter. At present a needle shows both these as magnetic force, making no distinction between them, yet they produce effects on it often in opposite directions; for as they increase or diminish they both affect the needle alike; but as it is assumed that the tension can change whilst the quantity remains the same, and the quantity can be altered, yet the tension remain unaffected, the result by the needle will then be uncertain. If the tension in a given region be increased by diminishing the conducting power, the needle will show *increased force*; if it be increased by an increase of magnetic power in the earth from some internal action, the needle will still show *increased force*, and will not distinguish the one effect from the other. If the quantity in a region be increased by increasing the conducting power, the needle will show no such increase; on the contrary, it will indicate *diminution* of force, because the tension is diminished; or if the quantity be diminished by diminishing the conducting power, it will show *increased* force. The force might even lose in quantity and gain in tension in such proportions that the needle should show no change; or it might gain in quantity and lose in tension, and the needle still be entirely indifferent to the whole result.

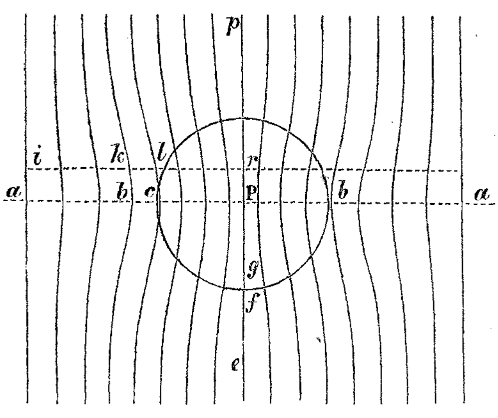
2871. If my view be correct, then the magnet is not, as at present applied, a perfect measure of the earth's magnetic force; for that may not change when the magnet by the influence of the different conditions of day and night, or of summer and winter, may show a difference. How *far* these uncertainties in its indication may affect the value of the observations made on the horizontal and vertical components of the earth's magnetic force as indications of that which they are expected to tell us, I do not know; but involving, as the effects do, two very different conditions, namely, variation of the conducting power and variation of the amount of force at its source, the one of which is chiefly in the atmosphere and the other in the earth, it seems to me to be of great consequence to the development of the theory of terrestrial magnetism, to have some method, if possible, of distinguishing these two points or effects from each other.

2872. Referring again to the model globe, fig. 7 (2874.), it appears to me, that if a magnet be used as the intensity test, it will indicate a less intensity at P rather than a greater one, for the very reason that the conducting power of the whole globe has been increased; and also, though the apparent diminution of intensity will probably be greater there than elsewhere, that the effect will occur in other parts, especially those on the right and left, and even at *b* and *b*, where the power transmitted, instead of being more, as at P, is really less than the portion transmitted in the normal or equable state of the magnetic field. With a diamagnetic globe of air, *i. e.* one warmer or more rarefied than the surrounding space (2877.), though it would convey less power as being a worse conductor, still it should cause the magnet to set with greater force, and so give an indication of increased intensity, and that also both within and equatorially without the globe.

2873. If it be true that the changes of the medium (2869.) can thus affect the magnet, and that such changes can rise up to a sensible degree in the gases, then a magnet might make a different number of vibrations in a given time in oxygen and nitrogen gases of the same density, for they are very different in their magnetic relations. It should make the greatest number in nitrogen; perhaps a delicate torsion balance would be a still more sensible test of such a result; but it is probable that the space around the needle should be large, and it would be requisite to ascertain that the two media opposed equal mechanical resistance to the vibrating needle.

2874. The variation of the *direction* caused by the typical globe (2864.) might be oblique to the horizontal and vertical planes, and consequently give results of declination and inclination, either separately or together. The direction would not vary in a central line parallel to the general dip of the surrounding space (fig. 7). Along another central line perpendicular to this (*i. e.* any line in the equatorial plane), *a* P, there would also be no variation of the direction, but in any other position there would be variations. Thus in the line *i r*, as the free needle passed from *i* to *k*, its lower end would be carried inwards towards the central line of dip P; this effect, after attaining a maximum, perhaps at *l*, would gradually diminish again, and by the time the needle had reached *r* the dip would be normal.

Fig. 7.



Corresponding effects would occur on the opposite side of the axial line *p e*; and if a needle be considered as in any place the dip of which is thus affected, and then be conceived as travelling in a circle round the axial line *p e*, it would always be in the surface of a cone, the apex of which is below.

2875. On the other hand, if the variations of the dip below the equatorial plane *a* P be considered, they will be equal in amount, but in the reverse direction, so that the magnetic needle, when deflected from its normal position, would have its upper end inclined inwards towards the axial line *p e*; or if moved round the axial line would always be in a conical surface, the apex of which is above.

2876. So the dip would vary in such a globe of air in every azimuth; and it would also vary in opposite directions in the upper and lower parts of the globe, and of the affected surrounding space.

2877. If we assume the existence of another typical globe of air (2864.), having a higher temperature than the surrounding atmosphere, then its condition will be that of a diamagnetic conductor, and will be represented by fig. 9 (2807.); and it will have power to affect both the intensity and the direction of the lines of force, in conformity with the action of the former globe, but in the contrary order. As regards the action of these globes, consequent upon the direction of the lines of force in and about them upon a needle coming within their influence, it may, in part, be represented by a magnet placed either in the direction of the needle for the cold globe, or in the reverse direction for the warm one; but as the lines of force of the combined system of the earth and such a magnet are very different in their arrangement to the lines of the earth affected by masses of warm or cold air having only conduction polarity (2820.), it would be too much to say that they correspond, or that the effects on the intensity or direction would be the same for similar distance from the centre of the globe of air and the representative magnet.

Fig. 8.

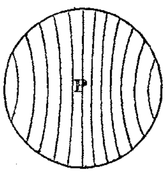
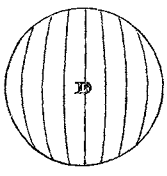


Fig. 9.



2878. In endeavouring to proceed, from these hypothetical and comparatively simple cases, which are given only to lead the mind on from the results of experiment to the supposed condition of matters as regards our atmosphere and the earth, we have to consider, that though there will be an effect, and though the intensity and direction of the magnetic force, upon the surface of the earth, must vary with changes of temperature and density of the atmosphere, still it will be in a manner very different from that represented by the typical globe of air, for the latter is a case which will never occur, though the variations of the natural case are almost infinite. Still the comparison holds in principle, and we may expect that as the sun leaves us on the west, some effect, correspondent to that of the approach of a body of cold air from the east, will be produced, which will increase and then diminish, and be followed by another series of effects as the sun rises again and brings warm air with him.

2879. The atmosphere diminishes in density upwards, and that diminution will affect the transmission of the magnetic force, but as far as it is constant, the effect produced by it will be constant too. The portion of the atmosphere which lies under the heating influence of the sun, as compared to its depth, will more resemble a slice of air wrapped round the earth than a globe. Still the inflection of the lines of force, both above and below this stratum, will occur, extending into space above and into the earth beneath (2848.), according to the known influence of magnetic power and its perfectly definite character (2809.). We are placed at the bottom of this layer of air, but as the atmosphere is denser there than higher up, and is also in many cases more affected there by changes of temperature, we are probably in a position where the inflections and variations due to the assumed causes exist in a considerable degree.

2880. There are innumerable circumstances that will break up, more or less, any general or average arrangement of the air temperature. For instance, the diversity of sea and land causes variations of temperature differently in different times of the year, and the extent to which this goes may be learned from the beautiful isothermal charts of Dove, now fortunately to be had in this country*. These variations may be expected to give, not merely differences in the regularity, direction and degree of magnetic variation; but because of vicinity differences so large as to be manifold greater than the mean difference for a given short period, and they may also cause irregularities in the times of their occurrence.

2881. On considering the probable results of the magnetic action of the atmosphere, it appears to me that if the terrestrial magnetic force could be freed from all periodical and small perturbations, and its disposition ascertained for any given time, it might still include certain effects constituting a part of atmospheric magnetism. For instance, there is more air, by weight, over a given portion of the surface of the earth at latitudes from 24° to 34°, than there is either at higher latitudes or at the equator; and that should cause a difference from the disposition of the lines of force which would exist if there were equality in that respect, or if the atmosphere were away. Again, the temperature of the air is greater at the equatorial parts than in latitudes north or south of it; and as elevation of temperature diminishes the conducting power for magnetism, so the proportion of force passing through these parts ought to be less, and that passing through the colder parts greater, than if the temperature of the air were at the same mean degree over the whole surface of the globe, or than if the air were away. Again, there is a greater difference in range of temperature of the air at the equator as we rise upwards than in other parts, and hence the lower part is not so good a conductor proportionately to the upper part, or to space, as elsewhere, where the difference is not so great; the magnetic power, therefore, should be in some degree weakened there, the lines of force being diverted, more or less, from the warm air and thrown into other parts, as the cooler atmosphere and space above, or the earth beneath, according to the principles before explained (2808. 2821. 2877.).

2882. The result of *annual variation* that may be expected from the magnetic constitution and condition of the atmosphere seems to me to be of the following kind. Assuming that the axis of rotation of the earth was perpendicular to the plane of its orbit round the sun, and dismissing for the present other causes of magnetic variation than those due to the atmosphere, the two hemispheres of the earth, and the portions of air covering them, would be affected and warmed alike by the sun, or at least would come into a constant relative state, dependent upon the arrangement of land and water; and the lines of magnetic force having taken up their position under the influence of the great dominant causes, whatever they may be, would not be altered by any annual change due to the atmosphere, since the daily mean of the

* Report of the British Association, 1848, Reports, p. 85.

atmospheric effect in a given place would at all parts of the year be alike. Under such circumstances the intensity and direction of the magnetic forces might be considered constant, presuming no sensible change to take place by the difference in distance from the sun which would occur in different parts of the orbit; and, as regards the two magnetic hemispheres, each would be the equivalent of and equal to the other, and they may for the time be considered in their mean or normal state.

2883. But as the axis of the earth's rotation is inclined 23° 28′ to the plane of the ecliptic, the two hemispheres will become alternately warmer and colder than each other, and then a variation in the magnetic condition may arise. The air of the cooled hemisphere will conduct magnetic influence more freely than if in the mean state, and the lines of force passing through it will increase in amount, whilst in the other hemisphere the warmed air will conduct with less readiness than before, and the intensity will diminish. In addition to this effect of temperature, there ought to be another due to the increase of the ponderable portion of the air in the cooled hemisphere, consequent upon its contraction and the coincident expansion of the air in the warmer half, both of which circumstances tend to increase the variation in power of the two hemispheres from the normal state. Then as the earth rolls on in its annual journey, that which at one time was the cooler becomes the warmer hemisphere, and consequently in its turn sinks as far below the average magnetic intensity as it before had stood above it, whilst the other hemisphere changes its magnetic condition from less to more intense.

2884. As the sum of the magnetic forces which crop out from the earth wherever there is dip on one side of the magnetic equator must correspond to the sum of like force on the other side (2809.), so they would not become more intense in one hemisphere, or more feeble in the other, without a corresponding contraction on the one hand, and enlargement on the other. The line of no dip round the globe may therefore be expected to move alternately north and south every year, or some effect equivalent to that take place. The condition of the two hemispheres under this view may be conceived by supposing an annual undulation of the force to and fro between them, during which, though neither the character nor the general disposition of the power be altered, there is in our winter a concentration and increase of intensity in the northern parts coincident with a diffused and diminished intensity in the south, and in summer the reverse.

2885. In respect of *direction*, alterations may also be anticipated. In the first place, and assuming that the magnetic poles and the poles of the earth coincide, the dip would increase in the cooling hemisphere towards the middle and polar parts; but it ought to diminish towards the magnetic equator, to accord with the concentration of the hemisphere of stronger power and enlargement of the weaker one; whilst on the other hand the dip ought to diminish at the polar and middle parts of the warming hemisphere and increase towards the magnetic equator. The magnetic equator would shift a little north and south of its mean place during each year, simultaneously with the whole system of magnetic lines. But as the magnetic poles do not coincide with those of the earth, or with what may be called the poles of the changing temperatures, so a cause of difference in direction will here arise.

2886. Again, it may be that as oxygen is cooled, its paramagnetic power may increase in a more rapid proportion than that of the change of temperature, so that the chief alteration of the disposition of the earth's force may be in the extreme northern and southern parts; and in combination with the holding power of the earth (2907.) may even cause a change the reverse of that expected above in lower latitudes. If in our winter the lines of force were to close together in the polar parts and to open out in lower latitudes, the balance of magnetic force would just as well be sustained as if *all* the lines in our hemisphere were to be compressed and strengthened, and be compensated for by a corresponding change in the south. In the former case, each hemisphere would balance its own forces, in the latter they would be balanced against each other. There can, I think, be no doubt, that as far as the mass of the earth and the space above our atmosphere are unchangeable in relation to annual and diurnal variation, so far they would tend to restrain any variation which might depend only on the varying temperature and state of the air; holding as it were the two sides of the variations, the increase and diminution of intensity, or the right and left hand in change of direction, nearer together than they otherwise would be.

2887. Further, if it be supposed that the whole of a hemisphere *is affected at once* in the same direction by change of temperature, it will *not be affected alike, but differently in different latitudes,* because of the difference in amount of that change.

2888. The difference of land and water (2880.) will still further break up any expected uniformity of the general result, and cause that certain parts of the cooling hemisphere shall increase in power more in proportion than other parts; and when these parts lie on opposite sides of the magnetic meridian of any given place, they would probably have power to cause an alteration in the declination of the needle at that place.

2889. As the annual changes of temperature are less at the equator than in parts more north or south, so there, probably, little or no annual variation would occur: none indeed as regards the varying temperature or expansion of the air, but only that portion which is consequent upon the alternate changes of the parts on its opposite sides (2884.).

2890. Another effect, which may be considered as an annual variation, but which is connected with the diurnal change, may be expected. As the daily changes in temperature of the atmosphere, influential upon a given place in north or south medium latitudes, are greater in extent in summer than in winter, so the corresponding magnetic variations may be expected to vary also, being larger in the northern hemisphere, when the sun is on the north side of the equator, and less when he is present in the southern hemisphere, and producing like correspondent change there.

2891. From a most important investigation by Colonel SABINE*, founded on the results of observations at Toronto and Hobarton, the facts appear to be that the magnetic intensity is greater in both hemispheres in those months which are winter in the northern hemisphere, and summer in the southern. Similar results are greatly wanted for other localities, and would show whether the different disposition of land and sea has anything to do with the question, or whether the results at Toronto and Hobarton are true exponents of hemispherical effects. Assuming Toronto and Hobarton as being such exponents, the dip in both hemispheres is greater (i. e. greater north dip at Toronto and south dip at Hobarton) in those months which are winter in the northern, and summer in the southern hemisphere. Whether there is any *annual* variation of the dip or total force in the equatorial parts of the globe is very important to determine. It would be well worth while to take up a station for the express purpose; the instruments are very simple, and the observations would require only a single observer. They are described in the paper referred to. Unfortunately such observations are not even made in Great Britain.

2892. The manner in which the diurnal variation may be produced or affected by the action of the sun on our atmosphere as the earth revolves in its beams, has been already generally referred to. The whole portion of atmosphere exposed to the sun receives power to refract the lines of magnetic force which traverse it, and the whole of that which covers the darker hemisphere assumes an equally altered, but contrary state, relative to the mean condition of the air. It is as if the earth were inclosed within two enormous magnetic lenses competent to affect the direction of the lines of force passing through them.

2893. I have already said that the action of the atmosphere thus affected might in some degree be compared at night time to that of an enormous, diffuse, and very feeble ordinary magnet, having the position that it would naturally take according to the line of dip, passing over us from east to west, and including us for the time within its influence: in the daytime the action would be like that of the similar journey, not of a corresponding magnet reversed in direction, but of a corresponding globe of diamagnetic matter (2821.). Assuming the maximum heat and cold to occur at midday and midnight, we might expect that the maximum effects would also occur near those periods as regards the variations of intensity (2824. 2866.); for, other things being the same, the central parts of the heated and cooled masses are those where the difference of intensity should be greatest.

2894. It might be expected that this variation in the *intensity* would be greatest at those parts of the globe over which the sun passes vertically, or nearly so; but that may depend upon two circumstances at least; first, whether the difference in the day

* On the means adopted for determining the Absolute Values, Secular Change, and Annual Variation of the Magnetic Force, Philosophical Transactions, 1850, p. 201.

and night temperature is greater there than at other places, because the extent of the variation may be dependent in part upon that difference; and next, whether the amount of effect to be expected is the same for the same difference in number of degrees of temperature at every part of the scale (2886.). If the conducting power of oxygen (2800.) should be found by future experimental measurements (2960.) to increase in a greater proportion for a fall of a given number of degrees at lower temperature than at high ones (including the effect of contraction for that fall (2861.)), then it may be that parts more distant from the sun will be more affected than those under it; or if the contrary be the case, less affected than otherwise would be expected.

2895. With regard to the daily variations, as respects the *direction* of the lines of terrestrial magnetic force, or the inclination and declination of the magnetic needle, the principles of the changes that may be expected to occur have been already referred to (2879.); and it remains for me to compare these expectations with a few simple cases of observation, in such a general manner as will tend to show whether the *direction* of action is, both in theory and fact, the same; and whether there is any probability that the effect has been assigned to its true cause; for this purpose I will confine myself entirely at present to a part of the daily variation, namely, the effect of the sun and air as the luminary arrives at and passes over the meridian.

2896. Profiting by the last volume which has issued from the powerful mind and careful hands of Colonel SABINE*, I will take the case of Hobarton. The observatory there is in latitude 42° 52′·5 south, and longitude 147° 27′·5 east of Greenwich. The absolute declination is 9° 60′·8 east, and the dip is 70° 39′ south. In order to have the place of the sun and the time of maximum and minimum temperatures at hand, I have transferred the mean temperature for January (summer) for seven years, 1841–48, and the mean temperature for June (winter) for the same period, corresponding to every hour in the day and night, from pp. lxxxiv. and cviii. to fig. 10, Plate I., where the middle series of numbers represents the hours, the line next below them a base line of temperature at 30° FAHR., and the two curves still lower down the mean hourly temperature for summer and winter. The short lines show generally the direction of the needle east or west of its mean position, the upper end being of course the north extremity. The positions about noon are distinguished by full lines, being those required for more immediate illustration.

2897. The north end of the magnetic needle at Hobarton is most east at 2 o'clock, and most west about 21 o'clock. Being at the extreme west at the latter hour, it passes through the full range of variation, or to the extreme east in five hours, or by 2 o'clock, and then requires the remaining nineteen hours to return to the utmost west. The maximum east and west declination is at 2 and 21 o'clock for summer, and at 3 and 22 o'clock for winter. The vertical positions show at what hours the declination was 0, and correspond with SABINE's zero. From 21 to 2 o'clock the needle

* Magnetical and Meteorological Observations, Hobarton, vol. i. 1850.

passes from one extremity of its variation to the other, the north or upper end traveling in the reverse direction to the sun, so that it and the sun cross the meridian together in opposite directions, nearly about or a little before noon. About 2 o'clock the needle is arrested, and after that time returns west, following the sun. It will be proper to state, that the north end of the needle, the motion of which has just been described, is the end towards the equator, and also, the upper end of a dipping-needle at Hobarton. This distinction will receive more significance presently.

2898. Hence the cause which affects the needle appears to be far more powerful, and more concentrated in time when the sun is present than when he is away. In this there is accordance between the time of the effect and the time when the sun could exert most influence on those magnetic conditions of the atmosphere, which are for the present supposed to govern that effect.

2899. It will be seen by examination of fig. 10, that the time of maximum temperature is not when the sun is on the meridian, but two hours after it, both in summer and winter. But in reference to temperature and its effect on the magnetic condition of the air, and through that on the needle, it is not the local temperature which is supposed to influence the needle, but that which affects enormous masses of air, above as well as below, and of which the temperature at the spot, however important it may become when we can properly interpret it, gives us as yet little or no knowledge. Still there are some points on which temperature has a more direct bearing. Thus the amount of variation of temperature is in summer double what it is in winter, and the amount of variation in the declination increases in the same proportion (2890.). The minimum temperature in winter is later than in summer, and the extreme western declination of the needle is also later at the same period.

2900. The varying *direction* of the magnetic lines of the earth is made known to us by observations in two planes, one the horizontal plane, to which the position east and west is referred, constituting declination, and the other a vertical plane passing through the line of mean declination, and supplying observations of inclination. The direction of the line of force referred to this plane might change so as either to increase or diminish the inclination, and it does increase at some places for the same hour of local time for which it diminishes at others; thus it increases at Greenwich whilst it diminishes at St. Helena, which is nearly in the same meridian. At Hobarton it changes rapidly at the east and west extremes of the variation, *i. e.* about 2 and 21 o'clock. From noon it diminishes until about 3 o'clock; it then continues nearly the same in summer, when the variation is greatest until 18 or 19 o'clock, from that time it increases until about 22 o'clock, and is nearly a maximum from thence till noon. Hence it will be understood, that the inclination is generally greatest during the rapid journey of the north end of the needle from west to east between 21 and 2 o'clock, and least in the other or prolonged half of the journey; and though this is partly broken up in the night effect, to be considered hereafter, still as a general result it always appears.

2901. All this may be roughly represented by fig. 11 (2909.), in which E.W. represents the path of the sun between the tropics as he comes up with the hours 21^h, 22^h, &c. in his daily journey, and *e* the path described by the north or upper end of the needle, freely suspended at Hobarton, and therefore showing both declination and inclination, *i. e.* the whole direction. Looking down upon such a needle, its upper end will take the course indicated by the arrow, and its position at any given hour is shown sufficiently by the leading lines.

2902. This relation of the motion of the needle to that of the sun has long been known; it has great significance in relation to my hypothesis of the physical cause of these variations. As regards the part of the action which I am considering, it is as if the pole of a magnet came on with the sun, of like nature to the upper end of the Hobarton needle, and at first drives that end west. Towards 19 o'clock the tendency westward diminishes, but the tendency south increases. At 21 o'clock, the increase in the sun's power, acting not directly from the sun but from a region in the atmosphere beneath it, is not sufficient to compensate for his more unfavourable position; the earth's force brings the needle back as regards declination, and then it passes eastwards, but the southerly motion or inclination still increases; about 24 o'clock, or noon, the sun is as to east or west declination indifferent, but powerful in southern action, making the inclination then, or soon after, a maximum. Then as the sun goes west of the needle, its power in driving the pole behind it eastward, will increase for a time, whilst the power producing inclination will diminish, until at 2 or 3 o'clock the earth's force will regain preponderance as the sun's power diminishes by distance, and the needle will return towards its least dip and mean inclination.

2903. All this may be represented experimentally by carrying a magnetic pole north of the dipping-needle, so as to represent the place of the sun-heated air to Hobarton, provided that pole be of the same kind as the north or upper pole of the needle. I have already stated (2877. 2863.), that when a portion of air is heated in a field of magnetic power, it loses in magnetic conduction power, and if in association with air less heated deflects the lines, assuming the state which I have distinguished as that of diamagnetic conduction polarity; then presenting the very polarity, or rather the very inflection of the lines of force, which would affect the needle, as it is affected. As the sun rises and passes north of such a place as Hobarton, the atmosphere under his coming influence becomes more and more heated and expanded; and referring to the model globes of air (2864. 2877.), it is as if such a warm mass passed with the sun through all the regions of the equator, extending also far north and south of it; and having Hobarton within its influence, produced the effects there observed.

2904. In such a view one sees a reason for the short time occupied in the return of the needle from west to east as the sun passes immediately over its meridian, and for the long time during which it is passing from east to west as the influence of the sun is slowly withdrawn, and then again slowly renewed during the remaining part of his journey, exception being made for the present of the paramagnetic effects due to cold.

2905. I will now consider the Toronto case of diurnal variation as it is presented to us in the volume of magnetical observations, issuing from the same authority and hands as the former volume*, and also in further observations down to 1848, sent to me by the kindness of Colonel SABINE. The position of the observatory is in lat. 43° 39′ 35″ N. and long. 79° 21′ 30″ W. The absolute declination is 1° 21′ 3″ W., and the mean or absolute dip is 75° 15′ N., so that as regards Hobarton it is on the other side of the equator, and nearly on the other side of the world. The result for the months of June and December are placed in a diagram corresponding to that for Hobarton (2896.), employing the Toronto time for the hours, Plate I. fig. 12.

2906. The north end of the needle is that universally referred to in speaking of the declination; its course at Toronto, during the immediate sun effect, is as follows:—Having gradually moved east from 16^h, it is at extreme east at 20 o'clock, and then returns from the east to extreme west in six hours, after which it moves eastward from the sun. But if we convert this into the motion of the equatorial extremity of the needle, for that is the *upper* end if the needle be free, and concerns us most in the comparison with Hobarton, then it will be seen that this end is most west at 19^h or 20^h; and leaving that position at that hour, it travels quickly eastward, passing through the full range of variation or to extreme east in six hours, or until 2^h, and then returns, following the sun.

2907. Looking at these results, I might repeat the words used in illustration of the Hobarton effects, but for the sake of brevity will simply refer to them. As before, the amount of variation in the declination is in summer double what it is in winter. The difference of temperature is three times greater. The extreme west and east declination is both in summer and winter at 20 and at 2 o'clock, so that the magnet holds to the time in both seasons; but the maxima and minima of cold, as shown before, vary in the two seasons, for the former is at 4 o'clock in summer and 2 in winter, whilst the latter is at 16 o'clock in summer, and 20 o'clock in winter. But this is a variation with consistency; for it will be seen by a moment's inspection, that in winter the maximum of heat has moved towards the time of most powerful action in the one direction, and the minimum has moved towards it in the other. The passage of the sun, therefore, over the meridian, and the period of rapid motion of the needle from west to east, still coincide.

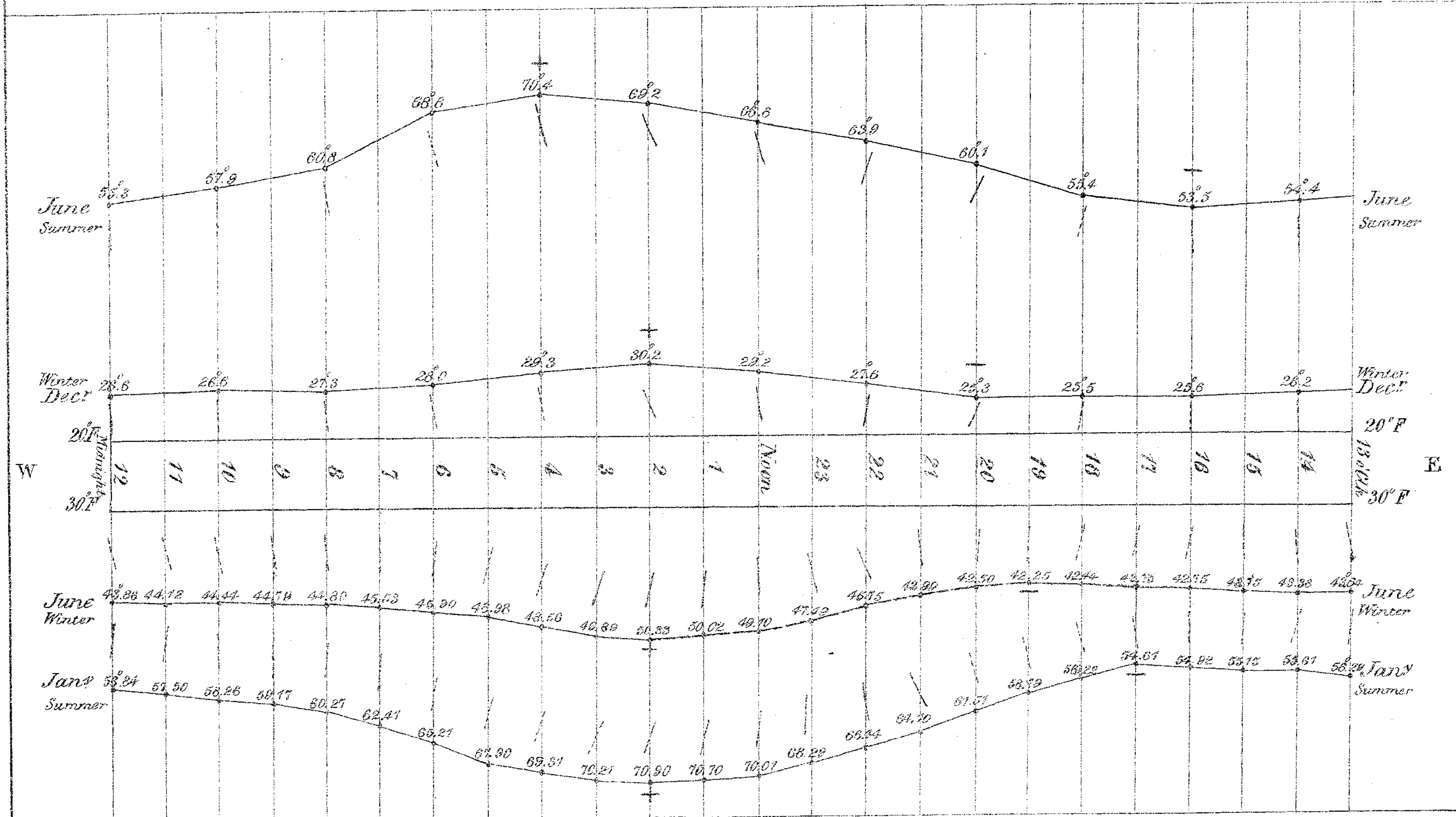
2908. The other element of direction is the inclination. Its variation is very small, but changes thus. A principal maximum dip occurs at 22 o'clock, and the extreme minimum dip at 4 o'clock.

2909. So all the effects may again be generally represented by an ellipse (fig. 13)

* Magnetical and Meteorological Observations. Toronto, 1840, 1841, 1842, SABINE.

Fig. 12.

Lat 43°. 39'. 35" N Toronto Long: 79°. 21'. 30" W



Lat 42°. 52'. 5. S Hobarton Long: 147°. 27'. 5 East

Fig. 10.

J. Basire, Lith.

as they were for Hobarton; and I may refer to the words then used, substituting

Fig. 13.

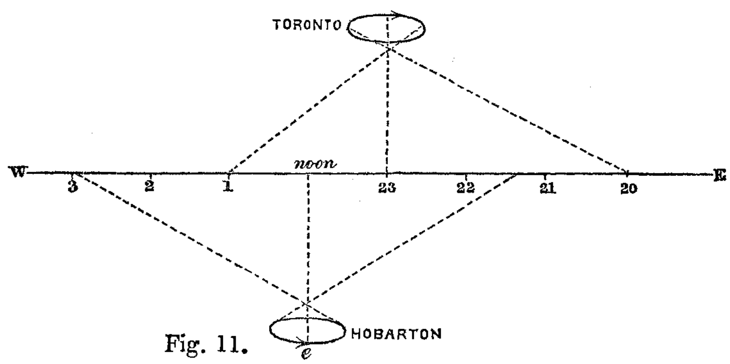


Fig. 11.

Toronto for Hobarton, and north for south (2901.). As the sun comes up from the east in his course between the two places, he drives, by the altered atmosphere beneath him, the upper ends of their needles before him, and outwards from the line of his path, as if he were a north pole to the Hobarton magnet, and a south pole to the Toronto magnet. By 22 o'clock, the earth's force, and the action of the air due to the sun's position, permit a return to the east, though the inclination for a time increases (2902.); both swing rapidly round from west to east as he passes over the meridian, and then having attained their maximum position eastward, soon follow after him under the influence of the earth's force, less and less counteracted by the retreating sun. So striking is the similarity between Hobarton and Toronto, that Colonel Sabine has already especially distinguished and described it*, and has shown, that, laying down the direction of motion in both cases by curves, and bringing the two curves together by their faces, they coincide almost exactly, with this single difference, that the Hobarton changes precede those at Toronto by an hour, or rather more, of local time.

2910. We cannot represent this day effect experimentally upon two such needles as those at Hobarton and Toronto by one pole of a magnet, though we can do it with each separately with different poles: but we see at once from the hypothesis, the reason why the sun acts in this manner (2877.), and how it is that the region of influential atmosphere that accompanies him in his journey round the globe, acts with one effect in the northern latitude and another in southern positions (2903.). The reasons also for the short time of the day journey and the lengthened period of the night return (2904.), are manifest. The occurrence of disturbances or secondary waves of power in the night time, and the condition both of the chief variation and the subordinate oscillations in summer and winter, will be considered hereafter.

2911. *Greenwich.*—The following results are taken from the volume of Greenwich Observations for 1847. The latitude is 51° 31′ N., and being removed nearly 80° in longitude from Toronto, the station is well contrasted with it and also with Hobarton.

* Hobarton Magnetical Observations, 1850, p. xxxv.

The mean declination is 22° 51′ 18″ W., and the mean inclination is 69° N. As it is the upper end of the dipping-needle which we have to consider for the purpose of a ready comparison with the sun's observed day action (2906.), I will describe that part of its course and place for Greenwich time which concerns us now. Moving westward before 19^h and 20^h, it then returns towards the east, and in six hours, or by 1^h or 2^h, has completed the great sun swing, after which it returns west, following the luminary. The vertical force is given as greatest between 3 and 4 o'clock, and least between 11 and 13 o'clock. The south end of the needle therefore is more upright at the former time and less at the latter; and as the latter occurs during the prolonged return part of the journey from east to west, including the night hours, so we perceive that the upper end of the needle performs its daily journey in an irregular closed curve, which the ellipse for Toronto, fig. 13 (2909.), may generally represent; it passes from east to west slowly during the night hours, approaching the equator at the same time, and then it returns from west to east with far greater rapidity, performing this part of its journey at a greater distance from the equator and nearer to the pole.

2912. *Washington, U.S.*—Latitude 38° 54′ N.; longitude 77° 2′ W.; the mean declination 1° 25′ W.; the mean dip 71° 20′ N. The south or upper end of the needle is in the morning at extreme west, about 20 to 22 o'clock, and at extreme east about 2 o'clock; it then returns slowly west, with the night action as in former cases, regaining extreme west at 20 to 22 o'clock. This is exactly the same movement for declination, in relation to the place of the sun, as for the former localities. I have not the variation of the dip, but theory would lead one to conclude that it is greatest between 22 and 2 o'clock, and least in the evening and night time. The total amount of declination variation is greatest in summer, as before, being 9′·87 in July and only 4′ in December. The greatest difference in the earth's temperature is also in July, being then nearly 20° FAHR., whereas in December and January it is only 10° FAHR. The shortest period between the extreme temperature, including therefore the quickest change of temperature, is from 16 or 18 to 2 o'clock, and consequently includes noon. All these conditions combine to produce the greatest magnetic action, and it is in the direction pointed out by the hypothesis.

2913. *Lake Athabasca.*—Latitude 58° 41′ N.; longitude 111° 18′ W. of Greenwich; mean declination 28° E. The observations are only for five months, but as the position is in a high latitude and may be important for future considerations, I give the results here. The extreme western position of the upper end of the needle is about 17 or 18 o'clock, and its extreme eastern position about 1 or 2 o'clock; so that, as far as declination is concerned, the action of the sun and atmosphere is as in former cases. The amount of declination variation is very great, being in October 21′·32; in November 10′·8; in December 9′·78; in January 16′·29, and in February 14′·87.

2914. *Fort Simpson.*—Latitude 61° 52′ N.; longitude 121° 30′ W. of Greenwich;

mean declination 38° E. These observations are only for two months, *i. e.* April and May 1844. The extreme western place of the upper or south end of the needle was at 19 o'clock, and its extreme eastern position at 2 o'clock. The result therefore is in perfect accordance with the preceding observations and conclusions. The amount of variation, as given in the horizontal plane, is very large, being 36′·26 in April and 32′ in May.

2915. *St. Petersburgh.*—Latitude 59° 57′ N.; longitude 30° 15′ E. of Greenwich; mean declination 6° 10′ W.; the dip 70° 30′ N. The observations are the mean of six years, and show that the upper end of the needle is extreme west in regard of noon, about 19^h and 20^h for the months of March to August, and that for the other months there is a western position about the same hours. The extreme east position is, for *all* the months, about half-past 1 o'clock, so that the sun's effect in passing over at the noon period is as in former cases. The greatest amount of variation is 11′·52 in June; in winter it dwindles away to as little as 1′·77. From theory, the dip may be expected to increase during the day hours and diminish at night.

2916. Thus these cases, which, including the chief feature of diurnal variation and sun action, were selected as a first and trial-test of the hypothesis, join their evidence together, as far as they go, in favour of that view which I am offering for their cause; nor have I yet found any instance of even an apparent contradiction in regard to the sun action. They assist the mind greatly in forming a precise notion of the manner in which the influence of the sun and air is supposed to act, not only in similar cases, but in respect of other consequences, *i. e.* in all that properly comes under the term of atmospheric magnetism; I will therefore now restate more particularly the principles which, according to the hypothesis, govern them, in hopes that I may be fortunate enough to assist in developing by degrees the *true physical cause* of the magnetic variations in question.

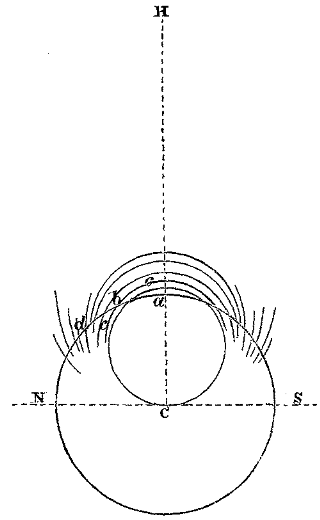
2917. Space, void of matter, admits of the transmission of the magnetic force through it (2787. 2851.). Paramagnetic and diamagnetic bodies either increase or diminish the degree in which the transmission takes place (2789.). This, their influence, I have expressed, for the time, by the phrase of magnetic conducting power, and I think have given sufficient first experimental evidence of the existence of the power and its effects in disturbing the lines of magnetic force (2843.). The atmosphere is, by the oxygen it contains (2861. 2863.), a paramagnetic medium, and has its conducting force greatly diminished by elevation of temperature (2856.) and by rarefaction (2782. 2783.), as has also been fully proved by experiment. The sun is an agent which both heats and rarefies the atmosphere, and in its diurnal course, the place of greatest heat and rarefaction must, speaking generally, be beneath it. The irregularities in the condition of the earth's surface and other causes do produce local departures from an exact relation of place, but they probably disappear partly, if not altogether, in the upper regions of the air.

2918. Assuming that *the air under the sun* is most changed magnetically, and confining the attention to a spot where the sun is vertical, for the purpose of considering the condition of the atmosphere there and at other parts in relation to it, the supposition of a globe of air over the spot will of course find no fit application (2877.). We are first to suppose the sun far away and the atmosphere in a mean state as to temperature, and then consider the sun as present in the meridian of a given place; and it is *the degree of alteration* in temperature and expansion of the air beneath and around the place of the sun, and the manner in which the change comes on and passes away, which concerns us. In relation to the surface of the earth, that alteration will be greatest somewhere beneath the sun, and will diminish in every direction around, becoming nearly nothing as to direct action at that part or circle of the earth where the sun's rays are tangent. In relation to elevation, it is a question yet whether the effect is greatest in amount at the surface, diminishing upwards. As regards the atmosphere, it must of course end with it, though as respects space itself (2851.), a reservation thought may arise. With regard to any alteration occasioned by the sun's influence in the opposite hemisphere, though there is none produced directly, yet indirectly there is that due to the falling of the temperature of the air, from the condition to which the sun, whilst above the horizon, had brought it. This change must be more tardy, irregular and disturbed, by local and other circumstances, than the opposite alterations produced by the direct influence of the luminary, and is that which occasions, by the hypothesis, the second maximum or minimum or other recurring night actions, made manifest by the needle in the hours when the sun is away.

2919. The lines of force which issue from a magnet are, as it were, located and fixed by their roots in a way well understood experimentally by those who have worked upon this subject. In the same manner the lines which issue from the earth more or less suddenly, according to the amount of inclination, are held beneath by a force of location; and because of the unchanging action of the earth in respect of atmospheric effect, are restrained more or less from alteration beneath during the changing action of the atmosphere. This fixation in the earth is a chief cause of certain peculiarities in the atmospheric phenomena as we observe them; and is productive of that rotation of the line of force about the mean position which we have already considered during the sun swing, and shall meet with again under the action of cold air. This condition of fixation at the lower parts of the lines of force occurs at every station where there is any dip at all, and gives for each the point of convergence round which the motion of the upper end of the needle takes place (2909. 2932.).

2920. So the atmosphere, under the influence of the sun, lies upon the earth altered most at the part beneath the luminary. It has received power to affect the lines of magnetic force differently to the manner in which it affected them in the sun's absence. It has become a great magnetic lens, able to refract the lines, and the manner in which it does so appears to be of the following nature. All the lines passing through this heated and expanded air, surrounded by other air not so much heated, will, because of its being a worse magnetic conductor than the latter (2861. 2862.), tend to open out (2807.); and the mass of heated air, as a whole, will assume the condition of diamagnetic polarity. If, therefore, for the sake of simplicity, the magnetic and astronomical poles of our earth be supposed as coincident, and fig. 14 represent a section taken through them and the place of the sun, then N and S will be the magnetic poles, and the different curves cutting the outline of the circle will sufficiently represent the course of the magnetic lines as they occur at or about the surface of the earth, H being the sun, and *a* the place immediately beneath it, which is also coincident with the magnetic equator. By this diagram we shall have an illustration of the hypothetical effect on the inclination of the needle.

Fig. 14.



2921. Considering the point *a* first, and assuming as yet that the maximum of change in the air is always at the surface of the earth, we shall find that there the lines of force will open out, preserving in some degree their parallel or concentric relation. Consequently a magnetic needle, free to move in every direction, and therefore taking up its position *in* the line of force, ought not, if placed at this spot, to be altered in its position. It ought to show perhaps a diminution of magnetic force transmitted through that spot; but, for the reason before given (2868.), I conclude it would indicate a greater intensity, the increased power thrown upon it through the diminution of the conducting power of the air in that place causing it to act as a more powerful needle.

2922. Proceeding to a point *b*, there the lines of force have dip. The same physical effect will be produced upon them here as before, *i. e.* the portions in the atmosphere will open out; but neither here nor in the former case will they continue to have the same curvature as before, for towards and in the earth, where they have their origin, they are restrained more or less from altering by the unchanging action of the earth (2919.); whilst at their more advanced parts, as at *c*, they enter into portions of the atmosphere which are nearer to the most intense lines of solar action, H C, probably also into the region of most intense action, and also into space, circumstances which cause more displacement of the lines, tending to separate by the tension of the parts altered in the air, than can happen *in* the earth (2848.). So the magnetic line of force at *b* will not move parallel to itself, but being inclined a certain degree to the horizon, when in the normal condition, will be more inclined, *i. e.* will have more dip given to it by the presence of the sun. This is the fact made manifest by the needle when indicating the position of the line as to inclination (2908.) at Hobarton, Toronto or elsewhere, by the motion of its upper end; for it is manifest that whatever happens on one side of the place of the sun and magnetic equator, when, as in our supposition (2920.), they coincide, will happen on the other.

2923. The case may be more simply stated, for the facility of recollection, by saying that the effect of the sun is to raise the magnetic curves, over the equatorial and neighbouring parts, from their normal position, in doing which the north and south dip are simultaneously affected and increased.

2924. At the place *d* like effects on the inclination must be produced, and theoretically it should be affected in the same direction even at N. and S. At the point *a* the inclination is supposed to be not at all altered, but going either north or south, the changes appear and increase. It is not probable that the maximum alteration will be at N. or S., but the latitude where it will occur must depend upon the many conjoined circumstances that belong to the case of a globe round which a magnetic lens, such as I have endeavoured to describe, is continually revolving.

2925. Instead of assuming that the sun is at H, let us suppose that we are looking at the diagram in a vertical position and towards the east; the sun coming up from the east and passing over our heads, and bringing with it that condition of our atmosphere which is the cause of the change. As it does so, all the magnetic curves would rise; the inclination would increase at *b*, *d*, and every place where there was any beforehand, in opposite directions on the two sides of *a*; this would go on until the sun was in the zenith, and then as it passed away and sank behind us, the lines would draw in again and the dip diminish to what it was at first. The maximum of dip would be when the sun was near the zenith, and the minimum when he was quite away.

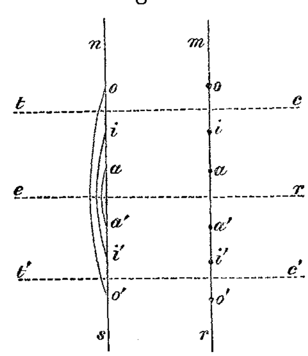
2926. But if the resultant of force be above in the atmosphere (2937.), which is by far the most probable, as it is the whole atmosphere which acts by heat diamagnetically, then the results would be modified; for if over *a* the lines of force might be *depressed*, and the inclination there would be diminished; at *b* it might not for the moment be affected; whilst in higher latitudes it would be increased, according as the line of force from the resultant in the atmosphere, wherever that might be, fell outside of the angle formed by the inclination with the horizon of a given place or within it. St. Helena, the Cape of Good Hope and Hobarton, furnish instances of the three cases.

2927. At the same time the total force would undergo a change in its amount; that transmitted through a given space would be least when the sun was in the zenith, and most when he was away (2863.). The total variation in the force should be greatest at *a*, and diminish from thence towards north and south. The daily variations of the inclination are so imperfectly known to us at present, that we cannot say how far the natural changes will accord with these expected variations, but as far as the observations go they agree with the theory.

2928. If the sun, instead of being over the equator, is at a tropic and so vertical, for instance over *b*, then the effects will be modified; and the resultant still being assumed as above, the lines of force which before were not affected, may be expected to descend and lessen the inclination, whilst other lines in higher latitudes, which before were increased in inclination, may now be but little affected, and other lines in still higher latitudes have, as before their inclination, increased. On the other side of the equator, the tendency of the lines would be to increase in inclination.

2929. Proceeding to that part of the expected change of position of the free needle which produces variations of *declination*, let *e r* in fig. 15 represent the sun's path in the equator, and *t c*, *t' c'* the same at the tropics; let *m r* be a magnetic meridian, and *a a'*, *i i'*, *o o'* places of equal north and south inclination on opposite sides of the equator. The curves of magnetic force seen in front in fig. 14, are now in the plane of the magnetic meridian, but may be considered as rising on opposite sides of the equator and coalescing over it. If the air on all sides were in its mean condition and the sun entirely away, these curves would be in the vertical plane *m r*; or if the sun near midday was so placed that the resultant of the heated and changed atmosphere was in the meridian *m r*, though effects of inclination would occur (2922.), still the curves would remain in the same vertical plane. But if the resultant were either to the east or the west of *m r*, variations of declination would be produced. For suppose the sun to be advancing from the east or *r*; because it gives the air a diamagnetic condition, the lines of force would tend to expand (2877.), and therefore move westward, as represented in the meridian *n s*; and the deflection caused thereby would be greatest upon the surface of the earth, because it is there that the curves as they enter the earth are held and restrained in respect of their normal position (2919.). As the warmed atmosphere came on, the western deflection would increase to a certain extent, and then diminish to nothing when the resultant was in the meridian; but as the latter passed on, the deflection would grow up on the eastern side of *n s*, and, after attaining a maximum, would diminish and cease as the warm air retreated.

Fig. 15.



2930. If the sun's path was in the northern tropic, *t c*, and the resultant in the atmosphere therefore to the north of the stations *a* or *i*, though that would make a difference in the amount of the declination variation, it would not alter its *direction*, for still the curves *a a'* and *i i'* would bear to the west as the sun came up, and would be on the meridian when the resultant was there also. There would be more effect produced at *i* than at *i'*, but the contrary character of the dip, in respect of the sun's place, would not alter the direction of the declination variation.

2931. A cold region of air acting, as at the coming on of night, upon the lines of magnetic force of the earth, would, by virtue of its paramagnetic character (2865.), produce corresponding effects both of inclination and declination, but in the contrary direction.

2932. Thus the lines of force which issue from the earth at all places upon its surface where there is any dip, will, by the hypothesis, under the daily influence of the sun, describe by their ascending parts a closed curve or irregular cone, the apex of which is below. As a fact this result is perfectly well known, but its accordance with the hypothesis is important for the latter. The mean position of the free needle will be in the axis of this curve or cone, and its return, either in declination or inclination, to the mean is an important indication of the amount and position of the variable forces which influence it at such times.

2933. My hypothesis does not at all assume that the heated or cooled air has become magnetic so as to act directly on the needle after the manner of a piece of iron, either magnetically polar or rendered so under induction. There is no assumed polarity of the oxygen of the air other than the conduction polarity (2822. 2835.) consequent upon a slight alteration of the direction of the lines of force. The change in the magnetic conducting power causes this deflection of the lines; just as a worse conductor of heat introduced into a medium of better conducting power disturbs the previous equable transfer of heat, and gives a new direction to that which is conducted; or as in static electricity, a body of more or less specific inductive capacity introduced into a uniform medium disturbs the equable lines of force which were previously passing across it.

2934. The sole action of the atmosphere is to bend the lines of force. The needle being held by these lines and, when free, being parallel to them, changes in position with the changes of the lines. It is not necessary even that the lines, which are immediately affected in direction by the altered air, should be those about the needle, but may be very distant. The whole of the magnetic lines about the earth are held by their mutual tension in one connected sensitive system, which has no sluggishness anywhere, but feels in every part a change in any one particular place. There may be, and is continually, a new distribution of force, but no suppression. So when any change in direction happens, near or distant, the needle in a given place will feel and indicate it, and that the more sensibly according to the vicinity of the place and the kind of change induced; but the disposition of the *whole* system has been affected at the same moment, and therefore all the other needles will be affected in obedience to the change in the lines of force which govern them individually.

2935. The needle is a balance on which all the magnetic power around a given locality fastens itself, even to the antipodes, and it shows for each place every variation in their amount or disposition, whether that occurs near or far off. Its mean position is the normal position; and as regards atmospheric changes, the fixation of the lines of force in the earth (2919.) is that which tends to give the lines a standard position (exclusive of secular changes), and so bring them and the needle back from their disturbed to their normal state. Hence, whilst considering the causes which disturb either the declination or the inclination, arises the importance of keeping in mind the mean position or place of the needle (2932.), and not merely the direction in which it is moving.

2936. So the well-known action of the sun on the needle is, by my hypothesis, very indirect; the sun at a given place affects the atmosphere; the atmosphere affects the direction of the lines of force; the lines of force there affect those at any distance, and these affect the needles which they respectively govern.

2937. I have, for the sake of convenience in considering a special action of the atmosphere, spoken of the resultant in the atmosphere dependent on the sun's presence; and will do so a little while longer without implying any direct action of this resultant, or that portion of air which yields it, upon the needle (2933.), for the sake of considering at what probable height it is situated in the air. That it cannot be on the surface of the earth, is shown by the depression of the lines and diminution of the dip at St. Helena and Singapore during the middle of the day; and that it is not even under the sun, is shown by the manner in which the greatest action precedes, in some degree, the sun, as at Hobarton and Toronto, and other places by different amounts of time; neither the time when the sun is on the meridian, nor the time when the observed temperature is highest (for that is after the sun), is the time of greatest action, but one before either of these periods. The changes in the temperature of the air produced by the sun, will not take place below and above at the same time. The upper regions of the atmosphere over a given spot are affected by the sun at his rising and afterwards, before the air below is heated; and therefore the effect from above would be expected to precede that below. The temperature observed on the earth does not show us, for the same time, the course of the changes above, and may be a very imperfect indication of them. The maximum temperature below is often two, three, or four hours after the sun, whereas, whatever heat the sun gives by his rays directly to the atmosphere, must be acquired far more rapidly than that. It is very probable, and almost certain, that at 4 or 5 o'clock A.M. in the summer months, the upper regions may be rising in temperature, whilst on the surface of the earth, through radiation and other causes, it is falling. The well-known effect of cold just before sunrise in some parts of India, and even in our country, is in favour of such a supposition. We must remember that it is not the absolute temperature of the air at any spot that renders it influential in producing magnetic variations, but the *differences* of temperature between it and surrounding regions. Though the upper regions be colder than the lower, their changes may be as great or greater; they happen at a range of temperature which is probably more influential than a higher range (2967.); and, what is of importance, they occur more quickly and directly upon the presence of the sun. The quantity of heat which the atmosphere can take directly from the sun's rays, is indicated by the different proportions we receive from him when he is either vertical or oblique to us, and so sending his beams through less or more air; and when he has departed, the upper parts of the air are far more favourably circumstanced for rapid cooling by radiation than the portions below. So that the final changes may be as great or greater than below, and we may learn little of them, or their order, or time, by observations of temperature at the earth's surface. In addition therefore to observations of magnetic effect, as depression of the lines of force at St. Helena, &c., there are apparently reasons deducible from physical causes, why the chief seat of action should be above in the atmosphere.

2938. In the midday effect the upper end of the needle passes the mean position

(2935.) on its return to the east generally before the sun passes the meridian going westward. At Toronto it is about an hour in advance; at St. Helena and Washington an hour and a half; at Greenwich and Petersburgh two hours; at Hobarton and the Cape of Good Hope the passage is about noon. Such results appear to indicate that the place of maximum action is in advance of the sun; and it probably is so in some degree, but not so much as at first may be supposed, as will appear I think from the following considerations.

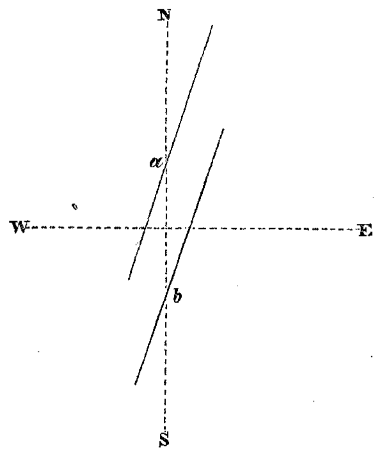
2939. The precession of the time of maximum action may depend in part upon some such condition as the following. As the sun advances towards and passes over a meridian, the air is first raised in temperature and then allowed to fall, and these actions produce the differences in different places on which the magnetic variations depend. But they depend also upon the *suddenness* with which or the vicinity at which these differences occur. Thus two masses of air, having equal differences of temperature, will affect the lines of force more if they be near together, and to the needle, than if they be far apart. And again, if a body of air were of a certain low temperature at one part, and, proceeding horizontally, were to increase rapidly to a certain high temperature and then diminish slowly to the first low temperature, such a body passing across a set of lines of magnetic force would affect them in opposite directions at the fore and after part; but it would affect them most on the rapidly altering side.

2940. Now the air as heated by the sun must be in this condition. According to analogy with solid and liquid bodies, being exposed to heat and then withdrawn, the changes of temperature that it would undergo would be more rapid in the elevation than in the falling, and so the changes in the preceding would be more rapid than in the following parts. To this would be added the effect of the atmosphere warmed by the earth; for as that is slower in attaining heat, as is shown by the time of maximum temperature, so its effects being gradually communicated to the air above, as the sun passed away, would tend to retard its fall and enlarge the difference already spoken of. Applying these considerations to the natural case, the strongest effect and the greatest variation should be towards the west, and the following or lesser action towards the east of the sun; and the mean condition of the needle for the whole change would be in advance of that body.

2941. Mr. Broun has made observations of the daily variation at different heights, namely, at Makerstoun and the top of the Cheviot Hills, where the height differs by nearly half a mile, and finds, I believe, no difference in the intensity, but that the progress is *first* at the higher station. It would be very interesting to have an observatory up above, but to give the results required it should have air and not solid matter beneath it.

2942. There is another circumstance which importantly influences the *times* of the passages of the declination variation. If two places north and south of the equator have equal dip and contrary declinations, *i. e.* if both their upper ends point east or west, then the effects ought to correspond and form a pair. But if both have east or west declination, according to the usual mode of marking this effect by the north end of the magnet, then the variations already described should come on as the sun passes midway between them, but there should be a difference in *time*. As the luminary appears and approaches, the needles *a* and *b* (fig. 16) will most probably be affected together; but, as he draws nigh, if the places have eastern declination, the one that is south will be soonest affected, and for the time most strongly, but will in a period more or less extended, be followed by the corresponding action at the other place. For as each needle will have returned from the first half of its series of changes to 0° by the time the sun is on its magnetic meridian, and as it will arrive at this meridian, as regards the south needle, before it does so for the north needle, so the south magnet should precede the other in its changes. If the declination of both were westerly, then the north needle would precede the south.

Fig. 16.



2943. The hypothesis advanced, besides agreeing with the facts regarding the direction of the needle's motions, as is the case generally, and if my hopes are well-founded, will be the case also in more careful comparisons; should also agree in the *amount* of force required for the observed declinations at given hours. I have endeavoured to obtain experimental evidence of the difference of action of oxygen and nitrogen on needles subjected to the earth's power, but have not yet succeeded. This however is not surprising, since a saturated solution of protosulphate of iron has failed under the same circumstances. More delicate apparatus may perhaps yield a positive result.

2944. That small masses of oxygen should not give an indication of that which is shown by the atmosphere as a whole is not surprising, if we consider that the mass of air is exceeding great, and includes a vast extent of the curves on which it, by the hypothesis, acts; and yet that the effect to be accounted for is exceeding small. The extreme declination at Greenwich is 12′, equal to about 4′ 24″ of east and west alteration on the free needle, so that that is the whole of what has to be accounted for. One could scarcely expect such an effect to be shown by small masses of oxygen and nitrogen acting on only a few inches in length of the magnetic curves passing through them, unless one could use an apparatus of extreme and almost infinite sensibility; but from what I have seen of oxygen when compared at different degrees of dilution (2780.), or at different temperatures (2861.), I am led to believe that the effects on it produced by the sun in the atmosphere will ultimately be found competent to produce these variations.

2945. Where the air is changed in temperature or volume, there it acts and there it alters the directions of the lines of force; and these by their tension carry on the effect to more distant lines (2934.), whose needles are accordingly affected. The transferred effect will be greater or less according as the distances are less or greater, and hence a change near at hand may overpower that at a distance, and a cloud close to a station may for the moment do more than the rising sun. These are the irregular variations; and the extent of their influence is well shown by the photographic records of Greenwich and Toronto. The volume of Greenwich Observations for 1847 contains a photographic record of the declination changes, February 18—19, 1849. Between 6 and 7 o'clock there is a variation of 16′ occurring in 18 minutes of time, or at the rate nearly of 1′ for each minute of time. The course of the mean variation for the same date and time is 1′·95 in two hours, or at the rate of 1 second for each minute of time, so that the irregular variation (which may be considered as a local variation in respect of the sun's power for the time) is sixty times that due to the effect of the great resultant; moreover it was in the reverse direction, for the temporary variation was from east to west, whilst the mean variation was from west to east.

2946. Another mode of showing how much the action of nearer portions of the atmosphere overpower and hide the effect of the whole mass, is to draw the line of mean variation for the twenty-four hours through such a photographic record as that just referred to, and then it will be seen in every part of the course how small the mean effect on the needle is, compared to the irregular or comparatively local effect for the same moment of time. The magnet with which these observations were made, is a bar of steel 2 feet long, $1\frac{1}{2}$ inch broad and a quarter of an inch thick, and therefore not obedient to sudden impulses; it is probable that a short, quick magnet would show numerous cases in which the irregular variation would be several hundred of times greater than the mean. Still all these irregularities and overpowering influences of near masses are eliminated by taking the mean of several years' observation, and thus a true result is obtained, to which the hypothesis advanced may be applied and so tested.

2947. Returning for a short time to the annual variation (2882.), I may observe, that it has been a good deal considered in discussing the daily variation. The arrangement of the magnetic effects by Colonel Sabine at Hobarton, Toronto, St. Helena and elsewhere, into monthly portions, proves exceedingly instructive and important, especially for places between and near the tropics. It supplies that kind of analysis of the annual variation which is given by the hours for the daily variation. Every month, by a comparison of its curve with those of other months, tells its own story, at the same time that it links its predecessor and successor together.

2948. I shall have occasion to trace these monthly means hereafter; but in the meantime refer to the effect of the sun's annual approach and recession indicated by these means, as according with the hypothesis in respect of near and distant actions (2945.). Hobarton and Toronto are in opposite hemispheres, so that the sun whilst approaching one recedes from the other, and the amount of variations therefore changes in opposite directions. Below is the average for each month, derived in the case of Hobarton from a mean of seven years, and in that of Toronto from a mean of two years.

	Hobarton. Lat 42° 52′·5 S.	Toronto. Lat. 43° 39′·35 N.
January	′ 11·66	′ 6·51
February	11·80	6·40
March	9·50	8·50
April	7·26	9·52
May	4·56	10·34
June	3·70 Winter.	11·99
July	4·61	12·70 Summer.
August	5·89	12·68
September	8·24	9·72
October	11·01	7·59
November	12·05 Summer	5·75
December	11·81	4·47 Winter.

The two stations are in latitudes differing only 47′ from each other; and the extreme difference of the atmospheric effect between summer and winter differs as little, being at one, Hobarton, which has the highest latitude, 8′·35, and at Toronto 8′·23.

2949. According to Dove, the northern hemisphere is warmer in July than the southern hemisphere by 17°·4 Fahr., and colder in winter by only 10°·7; the numbers being as follows:—

July.	Northern hemisphere 71°·0	62°·3	the whole globe.
	Southern hemisphere 53·6		
January.	Northern hemisphere 48·8	54°·15	the whole globe.
	Southern hemisphere 59·5		

The mean for the whole year is 59°·9 for the northern hemisphere, and 56°·5 for the southern. Therefore, as Dove further shows, the whole earth is in July, when the sun is shining over the terraqueous parts, 8° higher in temperature than in January, when it is over the watery regions: and from the influence of the same cause, the mean of the southern hemisphere is 3°·4 below the mean of the northern half of the globe. The difference between January and July is for the northern hemisphere 22°·2, and for the southern only 5°·9. These differences are so peculiar in their arrangement and so large in amount, that they must have an effect upon the distribution of the magnetic forces of the earth, but the data are not yet sufficient to enable one to trace the results. Sabine indicates a probability from his analysis of observations, that the sum of the earth's magnetic force is increased in intensity when the sun is in the southern signs, *i. e.* in our winter (2891.). I should have expected from theory that such results would have been the case, at least in those parts where the dip was not very great; because a colder atmosphere ought to conduct the lines of magnetic force better, and therefore the systems round the earth ought at such a time to condense, as it were, in the cooler parts. It would be doubtful, however, whether the needle would show this difference, because the lines of power would not be restrained above, as in the case formerly supposed (2922.), but could gather in from space freely. From what has been said, however, it will be evident that such a conclusion can only be drawn with any degree of confidence from observations made pretty equally over both hemispheres.

2950. If we should ever attain a good knowledge of the annual variation for several stations in different parts of both hemispheres, it would help to give data by which the depth at which the magnetic power is virtually situated might be estimated; for, as this power is expected to undergo undulations over very large portions of the earth's surface by the annual changes of temperature (2884.), so they would differ in character and extent according as the origin of the lines should prove to be more or less deeply situated.

2951. With regard to the many variations of magnetic force, not periodic or not so in relation to the sun, which yet produce the irregular and overruling changes already referred to (2945.), dependent, as I suppose, on local variations of the atmosphere, I may be allowed to notice briefly such points as have occurred to my mind.

2952. The *varying pressure* of the atmosphere, over a given part of the earth's surface, ought to cause a variation in the magnetic condition of that part of the earth. It is represented to us by a difference of three inches of mercury, or one-tenth of the weight of the atmosphere. Now the oxygen in a given space is paramagnetic in proportion to its quantity (2780.), and therefore it does not seem possible that that quantity over a given space of the earth's surface, whether it be recognised by volume as above, or by weight as in a given volume at the earth's surface, should be varied to the extent of one-tenth of the whole sum without producing a corresponding alteration in the distribution of the magnetic force; the lines being drawn together and the force made more intense by an increase of the quantity or of the barometric pressure, and the reverse effects produced at the occurrence of diminished pressure.

2953. At any spot which is towards the confines of that space where the air is increasing or diminishing in pressure, there will probably occur variations in the directions of the lines of force, and these will be more marked at such places as happen to be between two others, in one of which atmosphere is accumulating, whilst from the other it is retreating. Whether these changes (which I think must occur) produce by vicinity effects large enough to become sensible in our magnetic instruments, is a question to be resolved hereafter. To suggest the cause is useful, because to know of the existence, nature, and action of a cause, is important to the arrangement of the best means of observing and evolving its effects.

2954. *Winds and large currents of air above* may often be accompanied by magnetic changes if they endure for a time only. A constant stream like the trade-wind, may have a constant effect; but if, when the arrangement of the lines of magnetic force through the atmosphere is in a given state consequent upon the condition of the atmosphere at that time, a wind arises which mixes regions of cold and warm air together, or makes the air more dense in one region than another, or proceeding from one to another, balances regions which before were in different conditions, then every such change will be accompanied by a corresponding change in the disposition of the magnetic force, to which we may perhaps hereafter be able to refer by means of our instruments. Even tides in the air ought to produce an effect, though it may be far too small to be rendered sensible.

2955. The precipitation of *rain or snow* is a theoretical reason for the change of magnetic relations in the space where it takes place; because it alters the temperature where such precipitation occurs, and relieves it from a quantity of diluting diamagnetic or neutral matter. A *chilling hail-storm might* affect the needle in a summer's day. *Clouds* may have a sensible influence in several ways; acting at one time by their difference from neighbouring regions of clear air, and at other times by absorbing the sun's rays, and causing the evolution of sensible heat at different altitudes in the atmosphere at different places, or preventing its evolution more or less at the surface of the earth. Those masses of warmer or colder air of which meteorologists speak, which being transparent are not sensible to the eye, will produce their proportionate effect. And hypothetically speaking, it is not absolutely impossible that the hot and partially deoxygenated air of a large town like London, may affect instruments in its vicinity; and if so, it will affect them differently at different times, according to the direction of the wind.

2956. If one imagines on the surface of the earth a spot which shall represent the resultant there of the atmospheric actions above, and can conceive its course as it wanders to and fro, under the influence of the various causes of action which have been in part referred to, whilst it still travels onwards with the sun, one may have an idea of the manner in which it may affect the various observatories scattered over the earth. I believe that its course, as regards the east and west direction of its wanderings, is partly told in the photographic registerings of Greenwich and Toronto, being there mingled in effect with other causes of variation. This spot may be concentrated or diffuse; it may pass away and reappear elsewhere; there may even be two or more at once sufficiently strong to cause vibrations of the needle between them.

2957. The aurora borealis or australis can hardly be independent of the magnetic constitution of the atmosphere, occurring as it does within its regions, and perhaps in the space above. The place of the aurora is generally in those latitudes the air of which has a distinct magnetic relation, by difference of temperature and quantity, to that at the equator, and the magnetic character both of the aurora and of the medium in which it occurs ties them together; therefore, to be aware of and to understand in some degree the latter, will probably direct us to a better comprehension of the former. The aurora is already connected with magnetic disturbances and storms; it may in time connect them with changes in the atmosphere in a manner not at present anticipated, and as the suggestion is founded upon principle it seems deserving of consideration.

2958. Can the magnetic storms of HUMBOLDT be due to atmospheric changes? This is a question on which I would offer the following observations. Supposing a magnetic rest in the atmosphere, and that all local or irregular variations remained unchanged for the time, then if a change happened in one place it would be felt instantly everywhere else over the whole earth, and in proportion to the distance from the place of change. It would be felt instantly, because the impulse would not be conveyed chiefly or importantly through the matter of the earth or air, but through the space above, for the lines there are affected by changes in that part of them which passes through the atmosphere, and, as I conceive, would affect the other lines in space round our globe, which would in turn affect those parts of their lines, which, passing downwards to the earth, govern the needles below. In space, I conceive that the magnetic lines of force, not being dependent on or associated with matter (2787. 2917.), would have their changes transmitted with the velocity of light, or even with that higher velocity or instantaneity which we suppose to belong to the lines of gravitating force, and if so, then a magnetic disturbance at one place would be felt instantaneously over the whole globe.

2959. But the difficulty is to conceive an atmospheric change sufficiently extensive and sudden to make itself perceived everywhere at the same time amongst the comparatively local variations that are continually occurring. Still, if there were a lull in these disturbances by the opposition of contrary actions or otherwise for the same moment of time at two or more places, those places might show a simultaneous effect of disturbance, and that even when the cause might be very little or not at all sensible in the place where it occurred. A simultaneous change over an area of 600 or 800 miles in diameter, might produce less alteration in the middle of that area than at the extremities of radii of 1000 miles.

2960. It becomes a fair question of principle to inquire how far masses of the air may be *moved* by the power of the magnetic force which pervades them. When two bulbs of oxygen in different states of density are subjected to a powerful magnet with an intense field of force, the mechanical displacement of one by the other is most striking. Whether in nature the enormous volumes of air concerned, and the difference in intensity of the earth's magnetic force at the different latitudes where these may be supposed to be located, combined with the difference of temperature, are sufficient to compensate for the small portions of oxygen in the air and the smaller variations in density, is a matter that cannot at present be determined. The differential result of motion, as has been shown, is very great where the direct result, as of compression, is not merely very small but nothing (2774. 2750.), and the atmosphere is a region where the differential action of enormous masses is concerned.

2961. Now in the matter of difference of intensity, GAY-LUSSAC and BIOT conclude from their observations*, that the magnetic force is the same at a height of four miles as at the surface of the earth. M. KUPFFER, however, draws from GAY-LUSSAC'S

* Annales de Chimie, An. xiii. vol. lii. p. 86.

results the conclusion, that there was a little diminution, and Professor FORBES, from his experiments made in different parts of Europe*, concludes that there is a decrease of the force upwards. Such decrease may be a real consequence due to the difference of distance from the source of the terrestrial magnetic force; or, as is more likely, it may be due to the different proportions of oxygen there and at the surface of the earth. According to GAY-LUSSAC's account of the air brought from above, it was as 0·5 to 1·0, compared with the density below. Hence the paramagnetic power, added to space in the place above, from whence the air was taken, would not be more than one-half of that added by the presence of the denser atmosphere below. This I think ought to make a change in the distribution of the magnetic force; it would almost certainly do so at the equator, where the lines of force are parallel to the general direction of the atmosphere (2881.); and I think it would do so, as to the horizontal component, in the latitude where GAY-LUSSAC and BIOT made their aërial voyages. It is also just possible that the observers may have been in such relation to the heated or cooled air about them as to have had the difference observed produced, or rather affected, by some of the circumstances just described (2951.).

2962. Whether the result obtained by GAY-LUSSAC and BIOT indicate a change of power due to distance or not, this we know, that there *are* great changes from the magnetic equator toward the north and south; and that, as HUMBOLDT and BESSEL say, it is doubled in proceeding from the equator to the western limits of Baffin's Bay. And when so little as one-third of a cubic inch of oxygen can exert a force equal to the tenth of a grain, subject to the action of our powerful magnet, we may well conceive that the enormous sum of oxygen present, in only a few miles of heated or cooled atmosphere, can compensate for the great difference of magnetic force, and so, by a change of place, cause currents or winds having their origin in magnetic power. In such a case we should have a relation of magnets to storms; and the magnetic force of the earth would have to do with the mechanical adjustments and variations of the atmosphere, sometimes causing currents which without it might not exist, and at other times opposing those which might else arise, according as the great differential relations by which it would act (2757.) should combine with or oppose the other natural causes of motion in the air. Such movements would react upon the magnetic forces, so that these would readjust themselves, and so there would be magnetic storms, both material and potential, in the atmosphere, as there are supposed to be of the latter kind in the earth.

2963. In bringing this communication to a close, I have to express my obligations to two kind and able friends, Colonel SABINE and Professor CHRISTIE, for the interest they have taken in the subject, and on the part of the former for the extreme facilities afforded me in the use of observations and the data derived from them; but in doing so I must be careful not to convey any idea that they are at all responsible for the peculiar views I have ventured to put forth. I may well acknowledge that much

* Edin. Phil. Trans., 1836, vol. xiv. p. 25.

which I have written has been upon very insufficient consideration; but hoping that there might be some foundation of truth in the account of the physical cause of the variations which I have ventured to suggest, I have not hesitated to put it forth, trusting that it might be for the advantage of science. The magnetic properties and relations of oxygen are perfectly clear and distinct, and are established by experiment (2774. 2780.); and it is no assumption to carry these properties into the atmosphere, because the atmosphere, as a mere mixture of oxygen and nitrogen, is shown to possess them also (2862.)*. It varies in its magnetic powers, by causes which act upon it under natural circumstances, and make it able to produce some such effects as those I have endeavoured generally to describe.

2964. If it be a cause, in part only, of the observed magnetic variations, it is most important to identify and distinguish such a source of action, even though imperfectly, for the attention is then truly and intelligently directed in respect of the action and the phenomena it can produce. The assigned cause has the advantage of occurring periodically and for the same periods, as a large class of the effects supposed to be produced by it; and if the agreement should appear at first only general, still that agreement will greatly strengthen its claim to our attention. It has the advantage of offering explanations and even suggestions of many other magnetic events besides those which are periodical, and it presents itself at a time when we have no clear knowledge of any other physical cause for the variations, but are constrained vaguely to refer them to imaginary currents of electricity in the air or space above, or in the earth beneath.

2965. The causes, both of the original power and of its secular variations, are unknown to us. But if, accepting the earth as a magnet, we should be able to distinguish largely between internal and external action, and so separate a great class of phenomena from the rest, we should be enabled to define more exactly that which we require to know in both directions, should be competent to state distinctly the problems which need solution, and be far better able to appreciate any new hints from nature respecting the *source* of the power and the effects that it presents to us.

2966. The magnetic constitution of oxygen seems to me wonderful. It is in the air what iron is in the earth. The almost entire disappearance of this property also, when it enters into combination, is most impressive, as in the oxynitrogens and oxycarbons, and even with iron, which it reduces into a condition far below either the metal or the oxygen, weight for weight. Again, its striking contrast with the nitrogen, which dilutes it, impresses the mind, and by the difference recalls that which also exists between them in relation to static electricity (1464.) and the lightning flash. Chlorine, bromine, cyanogen and its congeners, chemically speaking, have no magnetic relation to oxygen. In nature it stands in this respect, as in all its chemical actions, alone.

2967. There is much to do with oxygen relative to atmospheric magnetism. Its

* Philosophical Magazine, 1847, vol. xxxi. pp. 409, 406.

proportion of paramagnetic force at different temperatures and different degrees of rarefaction, will require to be accurately ascertained, and this I hope to effect by a torsion balance, in course of construction (2783.). Indeed, I hope that this great subject may be largely touched and tried by experiment as well as by observation, and therefore gladly make it part of these experimental researches.

2968. One can scarcely think upon the subject of atmospheric magnetism without having another great question suggested to the mind (2442.), What is the final purpose in nature of this magnetic condition of the atmosphere, and its liability to annual and diurnal variations, and its entire loss by entering into combination either in combustion or respiration? No doubt there is one or more, for nothing is superfluous there. We find no remainders or surplusage of action in physical forces. The smallest provision is as essential as the greatest. None are deficient, none can be spared.

Royal Institution,
September 14, 1850.

APPENDIX.

Received November 12, 1850.

The following Tables of data obtained at Toronto, St. Petersburgh, Washington, Lake Athabasca and Fort Simpson, supplied to me by the kindness of Colonel Sabine, have not yet been published. The data for Hobarton and Greenwich are in the volumes of observations for those stations.

Toronto.—Longitude 77° 5′ West. Latitude 43° 40′ North. Approximate declination 1° 25′ West. Mean inclination 75° 15′ North.

Diurnal variation of the Declination in the several months, from July 1842 to June 1848 inclusive.

Increasing numbers denote a movement of the south or upper end of the magnet towards the West.

Toronto mean time.	0h. Noon.	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h. Midn.	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	Daily means.
January	′0·87	′0·00	′0·00	′0·53	′1·44	′2·28	′2·89	′3·47	′4·43	′4·53	′4·39	′4·06	′3·66	′3·42	′3·63	′3·87	′4·46	′3·84	′3·88	′4·44	′5·48	′5·80	′4·79	′3·03	3·30
February	0·78	0·00	0·06	0·94	1·58	1·91	2·73	3·13	4·02	4·44	4·69	4·45	4·31	3·81	3·54	4·07	3·97	4·86	4·95	5·20	5·97	5·70	4·64	2·53	3·43
March	1·44	0·01	0·00	0·59	1·74	2·90	3·82	4·77	5·63	6·60	6·47	6·86	6·04	6·42	6·55	6·34	6·69	6·59	7·10	8·30	9·38	9·40	7·15	4·22	5·21
April	1·25	0·00	0·16	1·02	2·76	4·12	5·14	6·31	7·05	7·14	7·60	7·66	7·39	7·32	7·65	7·82	8·08	8·33	9·46	10·09	10·20	9·10	6·87	3·74	6·09
May	1·16	0·00	0·29	1·56	3·24	5·11	6·08	6·27	6·18	6·75	7·36	7·49	7·40	7·26	6·72	7·10	7·80	9·70	11·02	12·16	12·03	10·28	6·90	3·52	6·39
June	1·37	0·00	0·02	0·94	2·53	4·35	5·45	6·11	6·10	6·66	6·66	6·87	6·77	6·50	6·37	6·36	7·29	9·03	11·34	12·34	12·09	10·54	7·67	4·04	6·12
July	1·53	0·09	0·00	0·84	2·18	3·98	5·20	5·77	6·31	6·34	7·31	7·38	7·67	7·06	6·42	6·37	6·86	8·53	10·54	12·01	12·22	10·69	7·65	4·27	6·13
August	1·11	0·00	0·73	2·61	4·52	6·12	7·60	7·52	8·05	8·97	8·51	8·40	8·14	7·69	7·65	7·83	8·24	9·50	12·09	13·89	13·79	11·51	7·31	3·73	7·31
September	0·03	0·00	0·76	2·92	4·62	6·04	6·78	6·83	7·62	7·84	7·83	7·08	7·50	7·66	7·53	7·77	8·45	8·38	9·79	11·16	10·24	8·60	5·34	2·25	6·37
October	0·48	0·00	0·31	1·38	2·38	3·06	3·84	4·33	4·92	5·76	5·68	5·48	5·00	5·21	4·89	5·16	5·82	5·74	5·50	6·39	7·32	7·02	5·17	2·63	3·89
November	0·75	0·00	0·34	1·37	2·21	2·91	3·96	4·89	5·16	5·70	5·54	5·26	4·51	3·79	3·80	4·51	4·44	4·99	4·95	5·70	6·31	6·08	4·57	2·35	3·92
December	1·20	0·18	0·00	0·61	1·67	2·56	3·30	3·89	4·39	4·62	4·95	4·48	4·09	3·49	3·04	3·56	3·92	4·02	3·81	4·18	4·50	5·22	4·67	2·83	3·30

Toronto.—Mean Diurnal variation of the Inclination in the several months, from July 1842 to June 1848.

Increasing numbers denote increasing inclination.

Toronto mean time.	0h.	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	Daily means.
January	′1·02	′0·77	′0·53	′0·22	′0·00	′0·09	′0·16	′0·21	′0·25	′0·33	′0·34	′0·38	′0·47	′0·54	′0·58	′0·45	′0·33	′0·28	′0·22	′0·21	′0·36	′0·54	′1·04	′1·06	0·43
February	0·86	0·61	0·36	0·12	0·01	0·00	0·09	0·12	0·19	0·26	0·27	0·31	0·37	0·45	0·49	0·44	0·41	0·30	0·27	0·44	0·69	0·70	0·79	0·86	0·39
March	1·02	0·77	0·47	0·14	0·00	0·00	0·12	0·22	0·24	0·35	0·40	0·44	0·45	0·53	0·50	0·50	0·46	0·46	0·47	0·62	0·81	0·95	1·00	1·05	0·50
April	0·99	0·77	0·54	0·17	0·05	0·00	0·14	0·35	0·49	0·53	0·49	0·61	0·56	0·59	0·64	0·61	0·60	0·66	0·74	0·80	0·90	1·03	1·16	1·16	0·61
May	0·83	0·52	0·22	0·06	0·00	0·11	0·27	0·33	0·47	0·62	0·64	0·66	0·76	0·86	0·87	0·89	0·92	1·04	1·00	1·01	1·11	1·29	1·30	1·12	0·70
June	0·89	0·60	0·26	0·05	0·00	0·00	0·16	0·34	0·53	0·68	0·73	0·83	0·84	0·90	0·91	0·98	1·03	1·05	1·08	1·12	1·17	1·27	1·37	1·19	0·75
July	0·67	0·55	0·17	0·07	0·00	0·06	0·17	0·24	0·39	0·40	0·51	0·56	0·62	0·56	0·66	0·78	0·83	0·87	0·81	0·80	0·88	1·03	1·14	0·93	0·57
August	0·85	0·51	0·21	0·00	0·02	0·04	0·25	0·40	0·42	0·44	0·48	0·55	0·53	0·64	0·65	0·73	0·74	0·84	0·89	1·00	1·09	1·25	1·26	1·13	0·62
September	1·35	0·82	0·35	0·10	0·00	0·10	0·29	0·49	0·53	0·55	0·57	0·63	0·68	0·70	0·70	0·75	0·57	0·65	0·68	0·95	1·28	1·64	1·85	1·71	0·75
October	0·93	0·67	0·39	0·14	0·00	0·06	0·21	0·30	0·37	0·39	0·40	0·49	0·62	0·45	0·40	0·33	0·22	0·22	0·32	0·55	0·85	1·04	1·15	1·11	0·48
November	0·94	0·75	0·45	0·22	0·11	0·18	0·12	0·18	0·20	0·20	0·23	0·33	0·33	0·31	0·21	0·22	0·12	0·07	0·00	0·08	0·42	0·14	0·89	1·00	0·32
December	0·91	0·88	0·51	0·27	0·05	0·01	0·02	0·16	0·21	0·27	0·33	0·30	0·38	0·34	0·28	0·22	0·14	0·08	0·09	0·00	0·17	0·34	0·66	0·81	0·31
Hourly means	0·94	0·69	0·37	0·13	0·02	0·05	0·17	0·28	0·36	0·42	0·45	0·51	0·55	0·57	0·57	0·58	0·53	0·54	0·55	0·63	0·81	0·93	1·13	1·10	0·54

Toronto.—Mean Diurnal variation of the Total Force in the several months, from July 1842 to June 1848.

Increasing numbers denote increasing Force. Mean Total Force at Toronto 13·9.

The figures express the changes in parts of the whole Force.

Toronto mean time.	0h.	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	Daily means.
	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00	·00
January ……	005	011	017	023	022	024	023	023	023	020	019	015	010	009	004	003	004	005	008	009	010	003	000	000	012
February……	006	012	019	022	024	026	026	027	025	023	019	017	009	005	003	004	003	006	009	010	016	004	000	001	013
March………	004	011	019	026	029	031	031	031	028	025	020	014	005	002	002	002	003	003	010	013	013	007	002	000	014
April ………	012	020	031	039	045	045	044	039	034	027	020	012	008	007	003	000	009	011	013	012	012	009	006	006	019
May…………	004	013	015	031	038	042	038	035	029	025	017	011	004	002	002	003	008	010	015	013	009	003	000	000	015
June ………	003	008	017	025	029	031	030	028	022	018	014	011	006	002	002	001	006	011	014	014	010	005	002	000	013
July…………	015	019	030	038	044	047	043	039	031	026	021	015	007	004	000	002	005	011	016	017	015	014	010	002	020
August ……	027	034	044	042	057	057	051	046	041	032	023	010	006	001	003	000	006	018	026	026	024	019	019	021	026
September …	029	043	053	060	060	056	052	050	044	038	034	029	019	007	000	001	004	009	018	022	028	015	016	021	030
October ……	013	021	027	032	032	033	033	034	031	026	023	018	007	003	005	002	000	005	011	014	018	011	008	006	017
November …	007	014	022	026	028	025	025	028	024	018	015	011	007	004	001	003	000	003	007	009	008	002	001	003	011
December …	004	010	019	020	023	021	021	021	019	018	017	012	010	008	006	007	003	003	007	006	006	006	001	000	011
Hourly means	011	018	026	032	036	037	035	033	029	025	020	015	008	005	003	002	004	008	013	014	014	008	005	006	017

Toronto.—Mean Temperature of the Air in the several months, from July 1842 to June 1848, in degrees of Fahrenheit's scale.

Toronto mean time.	0h.	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	Daily means.
January ……	27°·8	28°·3	28°·6	28°·5	28°·0	27°·1	26°·3	25°·8	25°·5	25°·3	26°·3	24°·6	25°·6	23°·5	23°·4	21°·6	23°·2	23°·0	23°·7	23°·6	23°·9	24°·8	26°·0	27°·1	25°·48
February……	27·4	28·2	28·5	28·5	28·0	26·9	25·6	24·6	23·8	23·2	22·7	22·2	22·0	21·7	21·3	20·9	20·5	20·2	20·0	19·9	20·9	22·9	24·9	26·3	23·80
March………	33·8	34·4	35·0	34·9	34·3	33·6	31·9	30·5	29·5	28·6	28·0	27·3	27·3	26·8	26·3	26·2	25·8	25·5	25·0	25·9	27·8	29·9	31·6	32·8	29·71
April ………	47·6	48·5	49·0	49·0	48·6	47·9	46·1	43·5	41·8	40·7	39·8	39·3	39·1	38·6	37·9	37·3	37·0	36·6	36·8	39·2	41·5	43·6	45·2	46·6	42·55
May…………	59·0	59·9	60·2	60·3	60·3	59·9	58·1	55·2	52·6	50·7	49·7	48·8	48·0	46·9	46·3	45·6	45·1	45·2	47·6	50·6	53·0	55·2	56·8	58·0	53·04
June ………	66·7	67·5	67·9	68·3	68·5	68·1	66·6	63·9	60·6	58·4	57·0	56·1	55·7	54·8	54·1	53·3	52·7	52·9	55·6	58·5	60·8	62·7	64·4	65·6	60·86
July ………	72·9	73·7	74·5	74·8	74·7	74·3	72·7	69·2	65·1	62·9	61·8	60·7	59·8	58·9	58·3	57·6	56·9	56·9	59·8	63·4	66·0	68·2	70·1	71·5	66·02
August ……	73·0	73·9	74·5	74·8	74·6	74·1	72·5	68·4	65·3	63·6	62·4	61·6	60·7	60·0	59·4	58·7	58·3	58·1	59·6	63·2	66·3	68·7	70·6	72·1	66·43
September …	63·9	64·5	64·9	64·9	64·7	63·7	61·1	58·3	57·1	56·0	54·9	54·2	53·8	53·3	52·7	52·2	51·6	51·1	51·7	54·2	57·0	59·5	61·5	62·9	57·90
October ……	49·7	50·3	50·5	50·3	49·6	47·8	45·8	44·7	43·9	43·1	42·3	41·6	41·0	40·4	40·1	39·9	39·5	39·4	39·6	40·4	42·8	45·6	47·5	48·9	44·35
November …	39·5	40·0	40·1	39·9	39·0	37·7	36·9	36·3	35·9	35·7	35·3	34·9	34·3	34·0	33·7	33·4	33·2	33·3	33·6	33·6	34·6	36·2	37·7	38·8	36·15
December …	29·9	30·4	30·7	30·5	29·8	28·9	28·2	27·9	27·5	27·3	27·0	26·9	26·6	26·0	25·7	25·5	25·5	25·5	25·1	25·0	25·4	26·6	27·9	29·1	27·44
Hourly means	49·27	49·97	50·37	50·39	50·01	49·17	47·65	45·69	44·05	42·96	42·27	41·52	41·16	40·41	39·93	39·35	39·11	38·97	39·84	41·46	43·33	45·32	47·02	48·31	44·48

St. Petersburgh.—Longitude 38° 18′ East. Latitude 59° 57′ North. Mean declination 6° 10′ West.

Mean Diurnal variation of the Declination in the several months, from 1841 to 1845 inclusive.

Increasing numbers denote a movement of the south or upper end of the magnet towards the West.

Mean time …	Noon. h m 0 21½	h m 1 21½	h m 2 21½	h m 3 21½	h m 4 21½	h m 5 21½	h m 6 21½	h m 7 21½	h m 8 21½	h m 9 21½	h m 10 21½	h m 11 21½	Midn. h m 12 21½	h m 13 21½	h m 14 21½	h m 15 21½	h m 16 21½	h m 17 21½	h m 18 21½	h m 19 21½	h m 20 21½	h m 21 21½	h m 22 21½	h m 23 21½	Means.
January ……	0·27	0·00	0·36	1·24	1·59	1·99	2·39	3·28	4·03	4·65	4·56	4·65	4·43	3·72	3·77	3·10	2·57	2·22	2·35	2·17	2·08	1·86	1·42	1·02	2·49
February ……	0·84	0·00	0·09	0·57	1·55	2·84	3·54	3·63	4·03	5·18	5·67	5·49	5·27	4·52	4·34	4·65	4·34	3·90	4·03	3·77	3·50	3·23	2·61	1·46	3·29
March ………	0·89	0·00	0·04	1·15	2·88	4·16	5·36	6·29	6·73	6·78	7·40	7·84	6·69	6·51	5·76	6·11	6·38	6·16	6·65	6·56	6·73	6·38	4·96	2·79	5·05
April ………	1·59	0·00	0·36	2·17	4·03	5·54	7·04	7·93	8·33	8·02	9·30	9·17	8·68	8·46	8·73	8·59	9·17	9·30	9·48	10·01	10·68	9·75	7·58	4·61	7·01
May…………	1·02	0·00	0·62	2·13	3·68	5·49	6·96	7·44	7·18	6·82	7·44	8·24	8·55	8·73	8·82	9·66	10·23	10·72	11·12	11·39	11·12	9·92	7·49	3·54	7·01
June ………	1·77	0·00	0·00	1·37	2·92	4·52	5·76	6·25	6·25	6·56	7·13	7·13	7·49	8·28	8·68	9·70	10·23	10·94	11·30	11·39	11·52	10·10	7·35	4·12	6·70
July…………	1·46	0·04	0·00	1·11	2·39	3·94	4·96	5·27	5·98	5·98	6·78	7·49	7·66	7·71	8·42	8·55	9·30	9·52	9·83	9·75	9·04	8·46	6·96	3·90	6·02
August ……	0·27	0·00	0·40	2·44	4·16	5·94	7·04	6·73	7·49	7·27	7·35	7·27	8·02	8·11	8·06	8·55	9·30	9·88	10·19	10·19	9·44	8·42	5·67	3·15	6·47
September …	0·57	0·00	0·84	2·57	4·30	6·33	6·78	7·49	7·97	8·06	8·33	7·49	7·04	7·31	7·40	6·78	7·04	6·91	7·27	7·31	7·13	6·25	4·12	1·95	5·72
October ……	0·31	0·00	0·48	1·77	3·59	4·08	4·87	5·76	6·02	6·56	6·91	6·20	5·71	5·18	4·78	4·39	4·16	3·99	4·21	4·83	5·09	4·65	3·32	1·59	4·10
November …	0·09	0·00	0·36	1·55	1·90	2·71	2·79	3·15	3·81	4·39	4·47	4·34	3·68	3·06	2·75	2·35	2·22	1·82	1·82	1·90	1·77	1·77	0·93	0·57	2·26
December …	0·53	0·00	0·36	1·24	1·82	2·39	2·79	2·97	4·03	4·56	4·56	4·52	3·68	3·10	2·88	2·53	2·04	1·82	1·77	1·77	1·82	1·68	1·28	0·93	2·29
Hourly means	0·80	0·00	0·33	1·61	2·90	4·16	5·02	5·52	5·99	6·24	6·66	6·65	6·41	6·22	6·20	6·25	6·42	6·43	6·67	6·75	6·66	6·04	4·47	2·47	4·87

St. Petersburgh.—Mean Temperature of the Air in the several months, from 1841 to 1845 inclusive. FAHRENHEIT's scale.

Mean time …	Noon. h m 0 21½	h m 1 21½	h m 2 21½	h m 3 21½	h m 4 21½	h m 5 21½	h m 6 21½	h m 7 21½	h m 8 21½	h m 9 21½	h m 10 21½	h m 11 21½	Midn. h m 12 21½	h m 13 21½	h m 14 21½	h m 15 21½	h m 16 21½	h m 17 21½	h m 18 21½	h m 19 21½	h m 20 21½	h m 21 21½	h m 22 21½	h m 23 21½
January ……	20·28	20·71	20·67	20·41	19·82	19·89	19·73	19·71	19·74	19·76	19·67	19·49	19·38	19·33	19·29	19·19	19·04	18·90	18·79	18·79	18·74	18·81	19·24	19·98
February ……	18·34	18·58	18·70	18·65	18·27	17·35	16·88	16·52	16·32	16·09	15·95	15·67	15·55	15·48	15·39	15·19	14·97	14·88	14·76	14·65	15·19	15·66	16·61	17·35
March ………	25·61	26·30	26·97	27·01	27·01	26·13	24·74	23·88	23·20	22·44	21·94	21·31	20·70	20·07	19·62	19·26	18·84	18·54	18·34	18·74	19·87	21·38	22·95	24·53
April ………	37·85	38·07	38·58	38·81	39·53	38·63	36·54	34·62	33·35	32·38	31·42	30·72	30·07	29·55	29·08	28·61	28·36	28·42	29·21	30·63	32·16	33·75	35·39	36·79
May ………	53·46	53·80	54·31	54·72	55·10	54·29	52·23	49·84	47·91	46·19	45·38	43·90	43·16	42·37	41·83	41·47	41·56	42·73	44·19	46·06	47·88	49·57	51·17	52·65
June ………	63·03	63·48	63·83	64·36	64·97	64·07	61·90	59·97	58·19	56·48	55·04	54·07	53·26	52·58	52·00	51·50	52·27	53·33	54·95	56·57	58·21	59·72	59·02	62·15
July…………	66·44	66·93	67·21	67·46	67·93	67·26	65·28	63·61	62·01	60·57	59·56	58·86	58·05	57·33	56·86	56·48	56·68	57·53	58·86	60·59	62·06	63·43	64·76	65·90
August ……	67·10	68·00	68·56	68·69	69·23	68·56	65·73	63·70	62·26	60·89	60·08	59·22	58·14	57·60	57·20	56·57	56·14	56·73	57·65	59·45	61·29	63·12	64·71	66·06
September …	54·50	55·66	55·91	55·78	55·83	54·56	52·62	51·16	50·15	49·43	48·89	48·31	47·75	47·25	46·85	46·44	46·26	46·06	46·17	47·21	48·76	50·56	52·20	53·37
October ……	41·92	44·80	42·76	41·98	41·78	40·92	40·30	39·89	39·56	39·31	38·86	38·52	38·32	38·14	38·00	37·85	37·73	37·67	37·53	37·71	38·28	39·11	40·12	41·04
November …	29·73	30·22	30·88	29·75	29·26	28·96	28·83	28·67	28·58	28·41	28·52	28·49	28·47	28·45	28·42	28·27	28·13	28·04	28·00	27·95	28·07	28·42	28·83	29·37
December …	26·04	26·45	26·40	26·27	26·13	25·91	25·70	26·02	25·52	25·48	25·48	25·32	25·21	25·12	24·96	24·85	24·85	24·92	25·03	25·03	25·14	25·25	25·39	25·79

Washington, U.S—Longitude 77° 2′ West. Latitude 38° 54′ North. Mean declination 1° 25′ West. Mean dip 71° 20′ North.

Mean Diurnal variation of the Declination in minutes, and temperature in Fahrenheit's scale, of the months of the years 1840, 1841, 1842, which are specified.

Increasing numbers denote a movement of the south or upper end towards the East.

Mean time	Noon. h m 0 12	h m 2 12	h m 4 12	h m 6 12	h m 8 12	h m 10 12	h m 12 12	h m 14 12	h m 16 12	h m 18 12	h m 20 12	h m 22 12	Mean.
January 1841–42	′ 4·10	′ 5·20	′ 3·96	′ 2·52	′ 0·87	′ 0·68	′ 1·01	′ 1·62	′ 1·66	′ 1·71	′ 0·91	′ 0·29	′ 2·04
February 1841–42	3·55	5·28	4·22	2·89	1·59	0·94	0·84	1·26	0·81	0·82	0·60	0·35	1·76
March 1841–42 ...	6·34	7·51	6·26	4·25	2·88	2·31	2·50	3·00	1·71	1·13	0·00	1·76	3·30
April 1841–42 ...	6·56	8·33	6·42	4·41	3·22	1·97	2·24	1·35	0·73	0·46	0·00	2·18	3·15
May 1841–42......	7·72	8·57	6·36	4·45	3·82	3·47	3·25	3·05	2·63	0·33	0·00	4·25	3·99
June 1841–42......	8·55	9·47	8·00	5·33	4·91	4·24	4·05	4·32	3·44	0·63	0·00	4·53	4·79
July 1840–41......	8·42	9·87	8·07	5·75	4·57	3·52	3·60	3·40	2·99	0·98	0·00	3·62	4·56
August 1840–41...	10·94	10·81	7·95	6·00	4·03	3·55	4·48	4·64	4·04	1·35	0·00	5·89	5·30
Sept. 1840–41......	8·76	8·44	5·43	4·45	2·62	3·31	2·83	2·86	2·44	0·87	0·00	4·22	3·85
October 1840–41	5·65	5·83	4·35	2·47	1·41	0·58	1·41	1·80	1·51	1·35	0·00	1·75	2·34
Nov. 1840–41......	4·69	4·79	3·33	1·60	0·51	0·74	1·14	1·41	0·82	0·71	0·00	1·83	1·79
Dec. 1840–41......	3·93	4·90	3·39	1·92	0·10	0·36	0·62	1·53	0·93	2·00	1·02	0·87	1·79

Temperature.

Mean time	Noon. h m 0 12	h m 2 12	h m 4 12	h m 6 12	h m 8 12	h m 10 12	h m 12 12	h m 14 12	h m 16 12	h m 18 12	h m 20 12	h m 22 12
January 1841–42	° 38·28	° 40·83	° 40·18	° 36·68	° 35·47	° 34·24	° 32·37	° 32·10	° 31·71	° 30·53	° 31·63	° 36·96
February 1841–42	40·03	42·51	42·28	38·22	35·38	33·86	32·58	31·22	30·51	30·18	31·44	36·72
March 1841–42 ...	51·39	53·61	53·28	49·96	46·20	44·37	42·48	41·26	40·06	39·87	42·28	48·06
April 1841–42 ...	57·68	59·81	60·20	57·21	52·18	49·12	47·91	46·91	46·12	46·49	49·93	54·02
May 1841–42......	66·37	68·48	68·69	65·93	59·83	56·70	55·19	53·34	52·42	55·50	59·72	63·23
June 1841–42......	79·32	81·85	82·75	76·89	72·29	68·70	66·83	66·04	65·07	68·26	73·63	77·37
July 1841	81·13	81·53	84·60	81·33	74·93	71·56	68·78	68·09	66·78	70·64	75·19	78·38
August 1840–41...	78·70	80·73	80·09	75·93	71·48	68·00	66·82	65·12	64·17	65·69	65·73	76·09
September 1841...	74·66	76·50	76·30	72·30	68·59	64·90	62·70	61·90	61·00	61·29	65·73	71·02
October 1841......	55·30	57·00	56·20	52·94	48·40	46·60	44·90	43·70	42·30	41·70	45·00	51·61
November 1841 ...	48·00	49·20	48·50	47·30	44·20	43·20	41·80	40·70	39·40	38·80	39·50	44·10
December 1841 ...	39·20	41·30	40·60	37·95	36·26	34·70	33·50	33·16	32·20	31·60	31·69	36·00

Lake Athabasca.—Longitude 111° 18′ West. Latitude 58° 41′ North. Mean declination 28° East.

Diurnal variation of the Declination in the months of October, November and December 1843, and January and February 1844.

Increasing readings denote a movement of the south or upper end of the magnet towards the West.

Mean time	h m 12 55	h m 13 55	h m 14 55	h m 15 55	h m 16 55	h m 17 55	h m 18 55	h m 19 55	h m 20 55	h m 21 55	h m 22 55	5 minutes to noon. h m 23 55	h m 0 55	h m 1 55	h m 2 55	h m 3 55	h m 4 55	h m 5 55	h m 6 55	h m 7 55	h m 8 55	h m 9 55	h m 10 55	5 minutes to mid-night. h m 11 55	Mean time.
1843. Oct....	1·13	7·49	6·23	18·95	21·32	8·55	13·35	9·90	10·72	7·03	2·29	2·70	0·00	0·29	0·02	0·98	0·49	2·88	1·88	3·75	3·47	3·30	8·42	0·49	13 days obs. in Oct. 1843.
Nov....	3·73	5·17	6·74	9·07	10·35	10·80	9·40	8·80	7·63	6·54	1·10	0·00	1·06	1·57	1·93	2·73	2·94	3·34	4·52	4·97	5·43	7·08	3·04	3·63	25 days obs. in Nov. 1843.
Dec....	3·04	6·16	5·57	5·65	9·23	7·61	9·78	6·73	6·58	5·33	1·94	0·55	0·03	0·00	0·83	2·37	2·63	3·81	4·18	3·57	4·35	7·19	4·05	6·05	25 days obs. in Dec. 1843.
1844. Jan....	5·69	8·48	6·97	12·57	16·29	10·05	9·97	10·02	9·96	7·95	4·99	2·10	0·39	0·00	2·75	1·67	2·47	3·63	4·72	5·15	5·44	3·97	6·71	2·18	25 days obs. in Jan. 1844.
Feb....	4·27	4·93	8·46	10·55	14·80	14·87	14·06	12·10	12·76	8·64	2·82	2·93	1·55	0·00	1·48	3·24	3·76	4·52	4·96	5·48	5·58	4·99	6·98	5·40	25 days obs. in Feb. 1844.

Fort Simpson.—Longitude 121° 30′ West. Latitude 61° 52′ North.

Diurnal variation of the Declination in the months of April and May 1844.

Increasing numbers denote a movement of the south or upper end of the magnet towards the West.

Mean time.	15 minutes past mid-night. h m 12 15	h m 13 15	h m 14 15	h m 15 15	h m 16 15	h m 17 15	h m 18 15	h m 19 15	h m 20 15	h m 21 15	h m 22 15	h m 23 15	15 minutes past noon. h m 0 15	h m 1 15	h m 2 15	h m 3 15	h m 4 15	h m 5 15	h m 6 15	h m 7 15	h m 8 15	h m 9 15	h m 10 15	h m 11 15	Mean time.
1844. April	5·82	6·03	17·45	25·16	22·90	36·80	36·26	37·60	30·14	25·27	18·77	8·27	5·72	2·16	0·00	1·37	1·23	0·43	0·30	4·04	4·62	1·26	2·86	5·55	20 days obs. in Apr. 1844.
May	1·56	7·77	11·71	15·63	17·19	23·73	28·22	32·69	29·80	20·29	15·51	9·49	4·74	3·75	0·70	0·75	0·80	0·00	0·19	1·90	6·72	3·51	2·29	1·67	18 days obs. in May 1844.