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LVIII. *On the Physical Character of the Lines of Magnetic Force.* By MICHAEL FARADAY, *Esq., D.C.L., F.R.S. &c.**

[With a Plate.]

NOTE.—The following paper contains so much of a speculative and hypothetical nature, that I have thought it more fitted for the pages of the Philosophical Magazine than those of the Philosophical Transactions. Still it is so connected with, and dependent upon former researches, that I have continued the system and series of paragraph numbers from them to it. I beg, therefore, to inform the reader, that those in the body of the text refer chiefly to papers already published, or ordered for publication, in the Philosophical Transactions; and that they are not quite essential to him in the reading of the present paper, unless he is led to a serious consideration of its contents. The paper, as is evident, follows Series xxviii. and xxix., now printing in the Philosophical Transactions, and depends much for its experimental support upon the more strict results and conclusions contained in them.

3243. I have recently been engaged in describing and defining the lines of magnetic force (3070.), *i. e.* those lines which are indicated in a general manner by the disposition of iron filings or small magnetic needles, around or between magnets; and I have shown, I hope satisfactorily, how these lines may be taken as exact representants of the magnetic power, both as to disposition and amount; also how they may be recognised by a moving wire in a manner altogether different in principle from

* Communicated by the Author.

the indications given by a magnetic needle, and in numerous cases with great and peculiar advantages. The definition then given had no reference to the physical nature of the force at the place of action, and will apply with equal accuracy whatever that may be; and this being very thoroughly understood, I am now about to leave the strict line of reasoning for a time, and enter upon a few speculations respecting the physical character of the lines of force, and the manner in which they may be supposed to be continued through space. We are obliged to enter into such speculations with regard to numerous natural powers, and, indeed, that of gravity is the only instance where they are apparently shut out.

3244. It is not to be supposed for a moment that speculations of this kind are useless, or necessarily hurtful, in natural philosophy. They should ever be held as doubtful, and liable to error and to change; but they are wonderful aids in the hands of the experimentalist and mathematician; for not only are they useful in rendering the vague idea more clear for the time, giving it something like a definite shape, that it may be submitted to experiment and calculation; but they lead on, by deduction and correction, to the discovery of new phænomena, and so cause an increase and advance of real physical truth, which, unlike the hypothesis that led to it, becomes fundamental knowledge not subject to change. Who is not aware of the remarkable progress in the development of the nature of light and radiation in modern times, and the extent to which that progress has been aided by the hypotheses both of emission and undulation? Such considerations form my excuse for entering now and then upon speculations; but though I value them highly when cautiously advanced, I consider it as an essential character of a sound mind to hold them in doubt; scarcely giving them the character of opinions, but esteeming them merely as probabilities and possibilities, and making a very broad distinction between them and the facts and laws of nature.

3245. In the numerous cases of force acting at a distance, the philosopher has gradually learned that it is by no means sufficient to rest satisfied with the mere fact, and has therefore directed his attention to the manner in which the force is transmitted across the intervening space; and even when he can learn nothing sure of the manner, he is still able to make clear distinctions in different cases, by what may be called the affections of the lines of power; and thus, by these and other means, to make distinctions in nature between the lines of force of different kinds, or exertions, of power as compared with each other, and therefore between the powers to which they belong. In the action of gravity, for instance, the line of force is a straight line as far as we can test it by the resultant phænomena. It cannot be deflected, or even affected, in its course. Neither is the action in one line at all influenced, either in direction or amount, by a like action in another line; *i. e.* one particle gravitating toward another particle has exactly the same amount of force in the same direction, whether it gravitates to that one alone or towards myriads of other like particles, exerting in the latter case upon each one of them a force equal to that which it can exert upon the single one when alone: the results of course can combine, but the direction and amount of force between any two given particles remain unchanged. So gravity presents us with the simplest case of attraction; and appearing to have no relation to any physical process by which the power of the particles is carried on between them, seems to be a pure case of attraction or action at a distance, and offers therefore the simplest type of other cases which may be like it in that respect. My object is to consider how far magnetism is such an action at a distance; or how far it may partake of the nature of other powers, the lines of which depend, for the communication of force, upon intermediate physical agencies (3075.).

3246. There is one question in relation to gravity, which, if we could ascertain or touch it, would greatly enlighten us. It is, whether gravitation requires *time*. If it did, it would show undeniably that a physical agency existed in the course of the line of force. It seems equally impossible to prove or disprove this point; since there is no capability of suspending, changing, or annihilating the power (gravity), or annihilating the matter in which the power resides.

3247. When we turn to radiation phænomena, then we obtain the highest proof, that though nothing ponderable passes, yet the lines of force have a physical existence independent, in a manner, of the body radiating, or of the body receiving the rays. They may be turned aside in their course, and then deviate from a straight into a bent or a curved line. They may be affected in their nature so as to be turned on their axis, or else to have different properties impressed on different sides. Their sum of power is limited; so that if the force, as it issues from its source, is directed on to or determined upon a given set of particles, or in a given direction, it cannot be in any degree directed upon other particles, or into another direction, without being proportionately removed from the first. The lines have no dependence upon a second or reacting body, as in gravitation; and they require time for their propagation. In all these things they are in marked contrast with the lines of gravitating force.

3248. When we turn to the electric force, we are presented with a very remarkable general condition intermediate between the conditions of the two former cases. The power (and its lines) here requires the *presence* of two or more acting particles or masses, as in the case of gravity; and cannot exist with one only, as in the case of light. But though two particles are requisite, they must be in an *antithetical* condition in respect of each other, and not, as in the case of gravity, alike in relation to the force. The power is now dual; there it was simple. Requiring two or more particles like gravity, it is unlike gravity in that the power is limited. One electro-particle cannot affect a second, third and fourth, as much as it does the first; to act upon the latter its power must be proportionately removed from the former, and this limitation appears to exist as a necessity in the dual character of the force; for the two states, or places, or direction of force must be equal to each other.

3249. With the electric force we have both the static and dynamic state. I use these words merely as names, without pretending to have a clear notion of the physical condition which they seem meaningly to imply. Whether there are two fluids or one, or any fluid of electricity, or such a thing as may be rightly called a current, I do not know; still there are well established electric conditions and effects which the words *static*, *dynamic*, and *current* are generally employed to express; and with this reservation they express them as well as any other. The lines of force of the *static* condition of electricity are present in all cases of induction. They terminate at the surfaces of the conductors under induction, or at the particles of non-conductors, which, being electrified, are in that condition. They are subject to inflection in their course (1215. 1230.), and may be compressed or rarefied by bodies of different inductive capacities (1252. 1277.); but they are in those cases affected by the intervening matter; and it is not certain how the line of electric force would exist in relation to a perfect vacuum, *i. e.* whether it would be a straight line, as that of gravity is assumed to be, or curved in such a manner as to show something like physical existence separate from the mere distant actions of the surfaces or particles bounding or terminating the induction. No condition of *quality* or *polarity* has as yet been discovered in the line of static electric force; nor has any relation of *time* been established in respect of it.

3250. The lines of force of dynamic electricity are either limited in their extent, as in the lowering by discharge, or otherwise of the inductive condition of static electricity, or endless and continuous, as closed curves in the case of a voltaic circuit. Being definite in their amount for a given source, they can still be expanded, contracted, and deflected almost to any extent, according to the nature and size of the media through which they pass, and to which they have a direct relation. It is probable that matter is always essentially present; but the hypothetical æther may perhaps be admitted here as well as elsewhere. No condition of quality or polarity has as yet been recognised in them. In respect of *time*, it has been found, in the case of a Leyden discharge, that it is necessary even with the best conductors; indeed there is reason to think it is as necessary there as in the cases dependent on bad conducting media, as, for instance, in the lightning flash.

3251. Three great distinctions at least may be taken among these cases of the exertion of force at a distance; that of gravitation, where propagation of the force by physical lines through the intermediate space is not supposed to exist; that of radiation, where the propagation does exist, and where the propagating line or ray, once produced, has existence independent either of its source or termination; and that of electricity, where the propagating process has intermediate existence, like a ray, but at the same time depends upon both extremities of the line of force, or upon conditions (as in the connected voltaic pile) equivalent to such extremities. Magnetic action at a distance has to be compared with these. It may be unlike any of them; for who shall say we are aware of all the physical methods or forms under which force is communicated? It has been assumed, however, by some, to be a pure case of force at a distance, and so like that of gravity; whilst others have considered it as better represented by the idea of streams of power. The question at present appears to be, whether the lines of magnetic force have or have not a physical existence; and if they have, whether such physical existence has a static or dynamic form (3075. 3156. 3172. 3173.).

3252. The lines of magnetic force have not as yet been affected in their *qualities*, *i. e.* nothing analogous to the polarization of a ray of light or heat has been impressed on them. A relation between them and the rays of light when polarized has been discovered (2146.)*; but it is not of such a nature as to give proof as yet, either that the lines of magnetic force have a separate existence, or that they have not; though I think the facts are in favour of the former supposition. The investigation is an open one, and very important.

3253. No relation of *time* to the lines of magnetic force has as yet been discovered. That iron requires *time* for its magnetization is well known. Plücker says the same is the case for bismuth, but I have not been able to obtain the effect showing this result. If that were the case, then mere space with its æther ought to have a similar relation, for it comes between bismuth and iron (2787.); and such a result would go far to show that the lines of magnetic force had a separate physical existence.

* Philosophical Transactions, 1846, p. 1.

At present such results as we have cannot be accepted as in any degree proving the point of *time*; though if that point were proved, they would most probably come under it. It may be as well to state, that in the case also of the moving wire or conductor (125. 3076.), time is required*. There seems no hope of touching the investigation by any method like those we are able to apply to a ray of light, or to the current of the Leyden discharge; but the mere statement of the problem may help towards its solution.

3254. If an action in *curved* lines or directions could be proved to exist in the case of the lines of magnetic force, it would also prove their physical existence external to the magnet on which they might depend; just as the same proof applies in the case of static electric induction†. But the simple disposition of the lines, as they are shown by iron particles, cannot as yet be brought in proof of such a curvature, because they may be dependent upon the presence of these particles and their mutual action on each other and the magnets; and it is possible that attractions and repulsions in right lines might produce the same arrangement. The results therefore obtained by the moving wire (3076. 3176)‡, are more likely to supply data fitted to elucidate this point, when they are extended, and the true magnetic relation of the moving wire to the space which it occupies is fully ascertained.

3255. The *amount* of the lines of magnetic force, or the force which they represent, is clearly limited, and therefore quite unlike the force of gravity in that respect (3245.); and this is true, even though the force of a magnet in free space must be conceived of as extending to incalculable distances. This limitation in amount of force appears to be intimately dependent upon the dual nature of the power, and is accompanied by a displacement or removability of it from one object to another, utterly unlike anything which occurs in gravitation. The lines of force abutting on one end or pole of a magnet may be changed in their direction almost at pleasure (3238.), though the original seats of their further parts may otherwise remain the same. For, by bringing fresh terminals of power into presence, a new disposition of the force upon them may be occasioned; but though these may be made, either in part or entirely, to receive the external power, and thus alter its direction, no change in the amount of the force is thus produced. And this is the case in strict experiments, whether the new bodies introduced are soft iron or magnets (3218. 3223.)§. In this respect, therefore, the

* Experimental Researches, 8vo edition, vol. ii. pp. 191, 195.

† Philosophical Transactions, 1838, p. 16.

‡ Ibid. 1852.

§ Ibid. 1852.

lines of magnetic force and of electric force agree. Results of this kind are well shown in some recent experiments on the effect of iron, when passing by a copper wire in the magnetic field of a horseshoe magnet (3129. 3130.), and also by the action of iron and magnets on each other (3218. 3223.).

3256. It is evident, I think, that the experimental data are as yet insufficient for a full comparison of the various lines of power. They do not enable us to conclude, with much assurance, whether the magnetic lines of force are analogous to those of gravitation, or direct actions at a distance; or whether, having a physical existence, they are more like in their nature to those of electric induction or the electric current. I incline at present to the latter view more than to the former, and will proceed to certain considerations bearing on the question, with a view to the further and future elucidation of the subject.

3257. I think I have understood that the mathematical expression of the laws of magnetic action at a distance is the same as that of the laws of static electric actions; and it has been assumed at times that the supposition of north and south magnetisms, spread over the poles or respective ends of a magnet, would account for all its external actions on other magnets or bodies. In either the static or dynamic view, or in any other like them, the exertion of the magnetic forces outwards, at the poles or ends of the magnet, must be an essential condition. Then, with a given bar-magnet, can these forces exist without a mutual relation of the two, or else a relation to contrary magnetic forces of equal amount originating in other sources? I do not believe they can; because, as I have shown in recent researches, the sum of the lines of force are equal for any section across them taken anywhere externally between the poles (3109.). Besides that, there are many other experimental facts which show the relation and connexion of the forces at one pole to those at the other*; and there is also the analogy with static electrical induction, where the one electricity cannot exist without relation to, equality with, and dependence on the other. Every dual power appears subject to this law as a law of necessity. If the opposite magnetic forces could be independent of each other, then it is evident that *a charge* with one magnetism only is possible; but such a possibility is negatived by every known experiment and fact.

* The manner in which a large powerful magnet deranges, overpowers, and even inverts the magnetism of a smaller magnet, when it is brought near it in different directions without touching it, presents a number of such cases.

3258. But supposing this necessary relation, which constitutes polarity, to exist, then how is it sustained or permitted in the case of an independent bar-magnet situated in free space? It appears to me, that the outer forces at the poles can only have relation to each other by *curved* lines of force through the surrounding space; and I cannot conceive curved lines of force without the conditions of a physical existence in that intermediate space. If they exist, it is not by a succession of particles, as in the case of static electric induction (1215. 1231.), but by the condition of space free from such material particles. A magnet placed in the middle of the best vacuum we can produce, and whether that vacuum be formed in a space previously occupied by paramagnetic or diamagnetic bodies, acts as well upon a needle as if it were surrounded by air, water or glass; and therefore these lines exist in such a vacuum as well as where there is matter.

3259. It may perhaps be said that there is no proof of any outer lines of force, in the case of a magnet, except when the objects employed experimentally to show these lines, as a magnetic needle, soft iron, a moving wire, or a crystal of bismuth, are present; that these bodies, in fact, cause and develope the lines; just as in the case of gravity no idea of a line of gravitating force, in respect of a particle of matter by itself, can be formed: the idea exists only when a second particle is concerned. We are dealing, however, with a dual power; and we know that we cannot call into action, by magnetic induction upon soft iron or by electric currents, or otherwise, one magnetism without the other. Supposing, therefore, a bar of soft iron, or another bar-magnet, when brought end on and near to the first magnet, did by that approach develope the external force, the power which then only would become external should produce a corresponding external force of the contrary kind at the opposite extremity, or should not. If the first case occurs, it should be accompanied by the development of lines of force equivalent to it *within* the magnet. But I think we know, now, that in a very hard and perfect magnet there is no change of this kind (3223.). The outer and the inner lines of force remain the same in amount, whether the secondary magnet or the soft iron is present or away. It is the *disposition* only of the outer lines that is changed; their sum, and therefore their existence, remains the same. If the second case occurs, then the magnet, if broken in half under induction, should present in its fragments cases of absolute magnetic charge, or charge with one magnetism only (3257. 3261.).

3260. Or if it be imagined for a moment, that the two polarities of the bar-magnet are in relation to each other, but that whilst there is no external object to be acted upon they are related to each other through the magnet itself (an idea very difficult to conceive after the experimental demonstration of the course of the lines as closed curves (3117.3230.)), still it would follow, that upon the forces being determined externally, a change in the sum of force both within and without the magnet should be caused. We can now, however, take cognizance of both these portions of force; and it appears that, with a good magnet, whether alone or under the influence of soft iron or other magnets of fourfold strength, the sum of forces without (3223.), and therefore also within (3117. 3121.) the magnet, remains the same.

3261. If the northness and southness be considered so far independent of each other as to be compared to two fluids diffused over the two ends of the magnet (like the two electricities over a polarized conductor), then breaking the magnet in half ought to leave the two parts, one absolutely or differentially north in character, and the other south. Each should not be both north and south in equality of proportion, considering only the external force. But this never happens. If it be said that the new fracture renders manifest, externally, two new poles, opposite in kind but equal in force (which is the fact), because of the necessity of the case, then the same necessity exists also for the dependence and relation of the original poles of the original magnet, no matter what or where the first source of the power may be. But in that case the *curved lines* of force between the poles of the original magnet follow as a consequence; and the curvature of these lines appears to me to indicate their physical existence.

3262. If the magnetic poles in a bar-magnet be supposed to exert some kind of power internally, backward, as if they were centres of force, both within and without the magnet, by which they are able, upon the breaking of the magnet, to develope the contrary poles and their force, then that power cannot be the identical portion which is at the same time exerted externally; and if not the same, then when the magnet is broken, the two halves ought to have a degree of north or south charge. They ought not to be determinate magnets having equipotential poles. But they are so; and we may *break a hard magnet in half* whilst opposed to another powerful magnet which ought most to disturb the forces, and yet the broken halves are perfect magnets, equivalent in their polarities, just as if, when they were made by breaking, the dominant magnet was away. The power at the old poles is neither increased nor diminished, but remains in amount and in polar direction unchanged.

3263. Falling back, therefore, upon the case of a hard, well-made and well-charged straight bar-magnet, subject only to its own powers, it appears to me that we must either deny the joint external relation of the poles, and consider them as having no mutual tendency towards or action upon each other, or else admit that there is such an action exerted in or transmitted on through *curved* lines. To deny such an action, would be to set up a distinction between the action of the north end of a bar upon its south end, and its action upon the south end of other magnets, which, in the face of all the old experiments, and the new ones made with the moving wire (3076.), it appears to me impossible to admit. To acknowledge the action in curved lines, seems to me to imply at once that the lines have a physical existence. It may be a vibration of the hypothetical æther, or a state or tension of that æther equivalent to either a dynamic or a static condition; or it may be some *other state*, which though difficult to conceive, may be equally distinct from the supposed non-existence of the line of gravitating force, and the independent and separate existence of the line of radiant force (3251.)*. Still the existence of the state does not appear to me to be mere assumption or hypothesis, but to follow in some degree as a consequence of the known condition of the force concerned, and the facts dependent on it.

3264. I have not referred in the foregoing considerations to the view I have recently supported by experimental evidence, that the lines of force, considered simply as representants of the magnetic power (3117.), are closed curves, passing in one part of their course through the magnet, and in the other part through the space around it. These lines are identical in their nature, qualities and amount, both within the magnet and without. If to these lines, as formerly defined (3071.), we add the idea of physical existence, and then reconsider such of the cases which have just been mentioned as come under the new idea, it will be seen at once that the probability of curved external lines of force, and therefore of the physical existence of the lines, is as great, and even far greater, than before. For now no back action in the magnet could be supposed; and the external relation and dependence of the polarities (3257. 3263.) would, if it were possible, be even more necessary than before. Such a view would tend to give, but not necessarily, a dynamic form to the idea of magnetic force; and its close relation to dynamic electricity is well known (3265.). This I will proceed to examine; but before doing so, will again look for a moment at static electric induction, as an instance of the dual powers in mutual dependence by curved lines of force, but with these lines terminated, and not existing as closed circuits. An electric conductor polarized by induction, or an insulated, unconnected, rectilineal, voltaic bat-

* See Euler's views of the disposition of the magnetic force; also of the magnetic fluid, or æther and its streams. Letters, vol. ii. letters 62, 63.

tery presents such a case, and resembles a magnet in the disposition of the external lines of force. But the sustaining action (as regards the induction) being dependent upon the necessary relation of the opposite dual conditions of the force, is external to the conductor, or the battery; and in such a case, if the conductor or battery be separated in the middle, no charge appears there, nor any origin of new lines of inductive force. This is, no doubt, a consequence of the fact, that the lines of static inductive force are not continued internally; and, at the same time, a cause why the two divided portions remain in opposite states or absolutely charged. In the magnet such a division *does* develope new external lines of force; which being equal in amount to those dependent on the original poles, shows that the lines of force are continuous through the body of the magnet, and with that continuity gives the necessary reason why no absolute charge of northness or southness is found in the two halves.

3265. The well-known relation of the electric and magnetic forces may be thus stated. Let two rings, in planes at right angles to each other, represent them, as in Plate X. fig. 1. If a current of electricity be sent round the ring E in the direction marked, then lines of magnetic force will be produced, correspondent to the polarity indicated by a supposed magnetic needle placed at NS, or in any other part of the ring M to which such a needle may be supposed to be shifted. As these rings represent the lines of electro-dynamic force and of magnetic force respectively, they will serve for a standard of comparison. I have elsewhere called the electric current, or the line of electro-dynamic force, "an axis of power having contrary forces exactly equal in amount in contrary directions" (517.). The line of magnetic force may be described in *precisely the same terms*; and these two axes of power, considered as right lines, are perpendicular to each other; with this additional condition, which determines their mutual direction, that they are separated by a right line perpendicular to both. The meaning of the words above, when applied to the electric current, is precise, and does not imply that the forces are contrary because they are in reverse directions, but are *contrary in nature*; the turning one round, end for end, would not at all make it resemble the other; a consideration which may have influence with those who admit electric fluids, and endeavour to decide whether there are one or two electricities.

3266. When these two axes of power are compared, they have some remarkable correspondences, especially in relation to their position at right angles to each other. As a physical fact, Ampère* and Davy† have shown, that an electric current tends to

* *Ann. de Chim.*, 1822, vol. xxi. p. 47. † Phil. Trans. 1823, p. 153.

elongate itself; and, so far, that may be considered as marking a character of the *electric* axis of power. When a free magnetic needle near the end of a bar-magnet first points and then tends to approach it, I see in the action a character of the contrary kind in the *magnetic* axis of power; for the lines of magnetic force, which, according to my recent researches, are common to the magnet and the needle (3230.), are shortened, first by the motion of the needle when it points, and again by the action which causes the needle to approach the magnet. I think I may say, that all the other actions of a magnet upon magnets, or soft iron, or other paramagnetic and diamagnetic bodies, are in harmony with the same effect and conclusions.

3267. Again:— like electric currents, or lines of force, or axes of power, when placed side by side, attract each other. This is well known and well seen, when wires carrying such currents are placed parallel to each other. But like magnetic axes of power or lines of force repel each other: the parallel case to that of the electric currents is given, by placing two magnetic needles side by side with like poles in the same direction; and by the use of iron filings, numerous pictorial representations (3234.) of the same general result may be obtained.

3268. Now these effects are not merely *contrasts* continued through two or more different relations, but they are contrasts which *coincide* when the position of the two axes of power at right angles to each other are considered (1659. 3265.). The tendency to *elongate* in the electric current, and the tendency to *lateral* separation of the magnetic lines of force which surround that current, are both tendencies in the same direction, though they seem like contrasts, when the two axes are considered out of their relation of mutual position; and this, with other considerations to be immediately referred to, probably points to the intimate physical relation, and it may be, to the oneness of condition of that which is apparently two powers or forms of power, electric and magnetic. In that case many other relations, of which the following are some forms, will merge in the same result. Thus, unlike magnetic lines, when end on, repel each other, as when similar poles are face to face; and unlike electric currents, if placed in the same relation, stop each other; or if raised in intensity, when thus made static, repel each other. Like electric currents or lines of force, when end on to each other, coalesce; like magnetic lines of force similarly placed do so too (3266. 3295.). Like electric currents, end to end, do not add their sums; but whilst there is no change in quantity, the intensity is increased. Like magnetic lines of force similarly placed do not increase each other, for the power then also remains the same (3218.): perhaps some effect correspondent to the gain of intensity in the former case may be produced, but there is none as yet distinctly recognised. Like electric currents, side by side, add their quantities together; a case supplied either by uniting several batteries by their like ends, or comparing a large plate battery with a small one. Like magnetic lines of force do the same (3232.).

3269. The mutual relation of the magnetic lines of force and the electric axis of power has been known ever since the time of Œrsted and Ampère. This, with such considerations as I have endeavoured to advance, enables us to form a guess or judgement, with a certain degree of probability, respecting the nature of the lines of magnetic force. I incline to the opinion that they have a physical existence correspondent to that of their analogue, the electric lines; and having that notion, am further carried on to consider whether they have a probable dynamic condition, analogous to that of the electric axis to which they are so closely and, perhaps, inevitably related, in which case the idea of magnetic currents would arise; or whether they consist in a state of tension (of the æther?) round the electric axis, and may therefore be considered as static in their nature. Again and again the idea of an *electro-tonic* state (60. 1114. 1661. 1729. 1733.) has been forced on my mind; such a state would coincide and become identified with that which would then constitute the physical lines of magnetic force. Another consideration tends in the same direction. I formerly remarked that the magnetic equivalent to *static* electricity was not known; for if the undeveloped state of electric force correspond to the like undeveloped condition of magnetic force, and if the electric current or axis of electric power correspond to the lines of magnetic force or axis of magnetic power, then there is no known magnetic condition which corresponds to the static state of the electric power (1734.). Now assuming that the physical lines of magnetic force are currents, it is very unlikely that such a link should be naturally absent; more unlikely, I think, than that the magnetic condition should depend upon a state of tension; the more especially as, under the latter supposition, the lines of magnetic power would have a physical existence as positively as in the former case, and the curved condition of the lines, which seems to me such a necessary admission, according to the natural facts, would become a possibility.

3270. The considerations which arise during the contemplation of the phænomena and laws that are made manifest in the mutual action of magnets, currents of electricity, and *moving conductors* (3084. &c.), are, I think, altogether in favour of the physical existence of the lines of magnetic force. When only a single magnet is employed in such cases, and the use of iron or paramagnetic bodies is dismissed, then there is no effect of attraction or repulsion, or any ordinary magnetic result produced. The phænomena may all very fairly be looked upon as purely electrical, for they are such in character; and if they coincide with magnetic actions (which is no doubt the case), it is probably because the two actions are one. But being considered as electrical actions, they convey a different idea of the condition of the field where they occur, to that involved in the thought of magnetic action at a distance. When a copper wire is placed in the neighbourhood of a bar-magnet, it does not, as far as we are aware (by the evidence of a magnetic needle or other means), disturb in the least degree the disposition of the magnetic forces, either in itself or in surrounding space. When it is moved across the lines of force, a current of electricity is developed in it, or tends to be developed; and there is every reason to believe, that if we could employ a perfect conductor, and obtain a perfect result, it would be the full equivalent to the force, electric or magnetic, which is exerted in the place occupied by the conductor. But, as I have elsewhere observed (3172.), this current, having its full and equivalent relation to the magnetic force, can hardly be conceived of as having its entire foundation in the mere fact of motion. The motion of an external body, otherwise physically indifferent, and having no relation to the magnet, could not beget a physical relation such as that which the moving wire presents. There must, I think, be a previous state, a state of tension or a static state, as regards the wire, which, when motion is superadded, produces the dynamic state or current of electricity. This state would constitute and give a physical existence to the lines of magnetic force, and permit the occurrence of curvature or its equivalent external relation of poles, and also the various other conditions, which I conceive are incompatible with mere action at a distance, and which yet do exist amongst magnetic phænomena.

3271. All the phænomena of the moving wire seem to me to show the physical existence of an atmosphere of power about a magnet, which, as the power is antithetical, and marked in its direction by the lines of magnetic force, may be considered as disposed in sphondyloids, determined by the lines, or rather shells of force*. As the wire intersects the lines within a given

* The lines of magnetic force have been already defined (3071.). They have also been traced, as I think, and shown to be closed curves passing in one part of their course through the magnet to which they belong, and in the other part through space (3117.). If, in the case of a straight bar-magnet, any one of these lines, E, be considered as revolving round the axis of the magnet, it will describe a surface; and as the line itself is a closed curve, the surface will form a tube round the axis and inclose a solid form. Another line of force, F, will produce a similar result. The sphondyloid

sphondyloid external to the magnet, a current of electricity is generated, and that current is definite and the same for any or every intersection of the given sphondyloid. At the same time, whether the wire be quiescent or in motion, it does not cause derangement, or expansion, or contraction of the lines of force; the state of the power in the neighbouring or other parts of the sphondyloid remaining sensibly the same (3176.).

3272. The old experiment of a wire when carrying an electric current* moving round a magnetic pole, or of a current being produced in the same wire when it is carried per force round the same pole (114.), shows the electrical dependence of the magnet and the wire, both when the current is employed from the first, and when it is generated by the motion. It coincides in principle with the results already quoted, and it includes, experimentally, all currents of electricity, whatever the medium in which they occur, even up to the discharge of the Leyden jar and that between the electrodes of the voltaic battery. I think it also indicates the state of magnetic or electric tension in the surrounding space, not only when that space is occupied by metal or a wire, but also by air and other bodies; for whatever be the state in one case, it is probably general and therefore common to all (3173.).

3273. I will now venture for a time to assume the physical existence of the external lines of magnetic force, for the purpose of considering how the idea will accord with the general phænomena of magnetism. The magnet is evidently the sustaining power, and in respect of its internal condition or that of its particles, there is no idea put forth to represent it which at all approaches in probability and beauty to that of Ampère (1659.). Its analogy with the helix is wonderful; nevertheless there is, as yet, a striking experimental distinction between them; for whereas an unchangeable magnet can never raise up a piece of soft iron to a state more than equal to its own, as measured by the moving wire (3219.), a helix carrying a current can develope in an iron core magnetic lines of force, of a hundred or more times as much power as that possessed by itself, when measured by the same means. In every point of view, therefore, the magnet deserves the utmost exertions of the philosopher for

body may be either that contained by the surface of revolution of E, or that contained between the two surfaces of E and F, and which, for the sake of brevity, I have (by the advice of a kind friend) called simply the *sphondyloid*. The parts of the solid described, which are within and without the magnet, are in power equivalent to each other. When it is needful to speak of them separately, they are easily distinguished as the inner and outer sphondyloids; the surface of the magnet being then part of the bounding surface.

* Experimental Researches, 8vo edition, vol. ii. p. 127.

the development of its nature, both as a magnet and also as a source of electricity, that we may become acquainted with the great law under which the apparent anomaly may disappear, and by which all these various phænomena presented to us shall become *one*.

3274. The physical lines of force, in passing out of the magnet into space, present a great variety of conditions as to form (3238.). At times their refraction is very sudden, leaving the magnet at right, or obtuse, or acute angles, as in the case of a hard well-charged bar-magnet, fig. 2; in other cases the change of form of the line in passing from the magnet into space is more gradual, as in the circular plate or globe-magnet, figs. 3, 4, 5. Here the form of the magnet as the source of the lines, has much to do with the result; but I think the condition and relation of the surrounding medium has an essential and evident influence, in a manner I will endeavour to point out presently. Again, this refraction of the lines is affected by the relative difference of the nature of the magnet and the medium or space around it; as the difference is greater, and therefore the transition is more sudden, so the line of force is more instantaneously bent. In the case of the earth, both the nature of its substance and also its form, tend to make the refractions of the line of force at its surface very gradual; and accordingly the line of dip does not sensibly vary under ordinary circumstances at the same place, whether it be observed upon the surface or above or below it.

3275. Though the physical lines of force of a magnet may, and must be considered as extending to infinite distance around it as long as the magnet is absolutely alone (3110.), yet they may be condensed and compressed into a very small local space, by the influence of other systems of magnetic power. This is indicated by fig. 6. I have no doubt, after the experimental results given in Series xxviii., respecting definite magnetic action (3109.), that the sphondyloid representing the total power, which in the experiment that supplied the figure had a sectional area of not two square inches in surface, would have equal power upon the moving wire, with that infinite sphondyloid which would exist if the small magnet were in free space.

3276. The magnet, with its surrounding sphondyloid of power, may be considered as analogous in its condition to a voltaic battery immersed in water or any other electrolyte; or to a gymnotus (1773, 1784.) or torpedo, at the moment when these creatures, at their own will, fill the surrounding fluid with lines of electric force. I think the analogy with the voltaic battery so placed, is closer than with any case of *static* electric induction, because in the former instance the physical lines of electric force may be traced both through the battery and surrounding medium, for they form continuous curves like those I have imagined within and without the magnet. The direction of these lines of electric force may be traced, experimentally, many ways. A magnetic needle freely suspended in the fluid will show them in and near to the battery, by standing at right angles to the course of the lines. Two wires from a galvanometer will show them; for if the line joining the two ends in the fluid be at right angles to the lines of electric force (or the currents), there will be no action at the galvanometer; but if oblique or parallel to these lines, there will be deflection. A plate, or wire, or ball of metal in the fluid will show the direction, provided any electrolytic action can go on against it, as when a little acetate of lead is present in the medium, for then the electrolysis will be a maximum in the direction of the current or line of force, and nothing at all in the direction at right angles to it. The same ball will disturb and inflect the lines of electric force in the surrounding fluid, just as I have considered the case to be with paramagnetic bodies amongst magnetic lines of force (2806. 2821. 2874.). No one I think will doubt that as long as the battery is in the fluid, and has its extremities in communication by the fluid, lines of electric force having a physical existence occur in every part of it, and the fluid surrounding it.

3277. I conceive that when a magnet is in free space, there is such a medium (magnetically speaking) around it. That a vacuum has its own magnetic relations of attraction and repulsion is manifest from former experimental results (2787.); and these place the vacuum in relation to material bodies, not at either extremity of the list, but in the *midst* of them, as, for instance, between gold and platina (2399.), having other bodies on either side of it. What that outer magnetic medium, deprived of all material substance, may be, I cannot tell, perhaps the æther. I incline to consider this surrounding or outer medium as *essential* to the magnet; that it is that which relates the external polarities to each other by curved lines of power; and that these must be so related as a matter of necessity. Just as in the case of the battery above, there is no line of force, either in or out of the battery, if this relation be cut off by removing or intercepting the conducting medium, or in that of static electric induction, which is impossible until this related state be allowed (1169.)*; so in like manner I conceive, that without this external mutually related condition of the poles, or a related condition of them to other poles sustained and rendered possible in like manner, a magnet could not exist; an absolute northness or southness, or an unrelated northness or southness, being as impossible as an absolute or an unrelated state of positive or negative electricity (1178.).

* Philosophical Magazine, March 1843; or Experimental Researches, 8vo, vol. ii. p. 279.

3278. In this view of a magnet, the medium or space around it is as essential as the magnet itself, being a part of the true and complete magnetic system. There are numerous experimental results which show us that the relation of the surrounding space can be varied by occupying it with different substances; just as the relation of a ray of light to the space through which it passes can be varied by the presence of different bodies made to occupy that space, or as the lines of electric force are affected by the media through which either induction or conduction takes place. This variation in regard to the magnetic power may be considered as depending upon the aptitude which the surrounding space has to effect the mutual relation of the two external polarities, or to carry onwards the physical line of force; and I have on a former occasion in some degree considered it and its consequences, using the phrase *magnetic conduction* to represent the physical effect (2797.) produced by the presence either of paramagnetic or diamagnetic bodies.

3279. When, for instance, a piece of cold iron (3129.) or nickel (3240.) is introduced into the magnetic field, previously occupied by air or being even mere space, there is a concentration of lines of force on to it, and more power is transmitted through the space thus occupied than if the paramagnetic body were not there. The lines of force, therefore, converge on to or diverge from it, giving what I have called conduction polarity (2818.); and this is the whole effect produced as regards the amount of the power; for not the slightest addition to, or diminution of, that external to the magnet is made (3218. 3223.). A new disposition of the force arises; for some passes now where it did not pass before, being removed from places where it was previously transmitted. Supposing that the magnet was inclosed in a surrounding solid mass of iron, then the effect of its superior conducting power would be to cause a great contraction inwards of the sphere of external action, and of the various sphondyloids, which we may suppose to be identified in different parts of it. A magnetic needle, if it could be introduced into the iron medium, would indicate extreme diminution, if not apparent annihilation, of the external power of this magnet; but the moving wire would show that it was there present to its full extent (3152. 3162.) in a very concentrated condition, just as it shows it in the very body of a magnet (3116.); and the power within the magnet, it being a hard and perfect one, would remain the same.

3280. The reason why a magnetic needle would fail as a correct indicator of the amount of power present in a given space is, that when perfect, it, because of the necessary condition of hardness, cannot carry on through its mass more lines of force than it can excite (3223.). But because of the coalescence of like lines of force end on (3226.), such a needle, when surrounded by a bad magnetic conductor, determines on to itself many of the lines which would otherwise pass elsewhere, has a high magnetic polarity, and is affected in proportion; every experiment, as far as I can perceive, tending to show that the attractions and repulsions are merely consequences of the tendency which the lines of physical magnetic force have to shorten themselves (3266.). So when the magnetic needle is surrounded by a medium gradually increasing in conducting power, it seems to show less and less force in its locality, though in reality the force is increasing there more and more. We can easily conceive a very hard and feebly charged magnetic needle surrounded by a medium, as soft iron, better than itself in conducting power, *i. e.* carrying on by conduction more lines of force than the needle could determine or carry on by its state of charge (3298.). In that case I conceive it would, if free to move, point feebly in the iron, because of the coalescence of the lines of force, but would be repelled bodily from the chief magnet, in analogy with the action on a diamagnetic body. As I have before stated, the principle of the moving wire can be applied successfully in those cases where that of the magnetic needle fails (3155.).

3281. If other paramagnetic bodies than iron be considered in their relation to the surrounding space, then their effects may be assumed as proportionate to the conducting power. If the surrounding medium were hard steel, the contraction of the sphondyloid of power would be much less than with iron; and the effects, in respect of the magnetic needle, would occur in a limited degree. If a solution of protosulphate of iron were used, the effect would occur in a very much less degree. If a solution were prepared and adjusted so as to have no paramagnetic or diamagnetic relation (2422.), it would be the same to the lines of force as free space. If a diamagnetic body were employed, as water, glass, bismuth or phosphorus, the extent of action of the sphondyloids would expand (3279.); and a magnetic needle would appear to increase in intensity of action, though placed in a region having a smaller amount of magnetic force passing across it than before (3155.). Whether in any of these cases, even in that of iron, the body acting as a conductor has a state induced upon its particles for the time like that of a magnet in the corresponding state, is a question which I put upon a former occasion (2833.); but I leave its full investigation and decision for a future time.

3282. The circumstances dependent upon the shape and size of magnets appear to accord singularly well with the view I am putting forth of the action of the surrounding medium. If there be a function in that medium equivalent to conduction, involving differences of conduction in different cases, that of necessity implies also reaction or resistance. The differences could not exist without. The analogous case is presented to us in every part by the electric force. When, therefore, a magnet, in place of being a bar, is made into a horseshoe form, we see at once that the lines of force and the sphondyloids are greatly distorted or removed from their former regularity; that a line of maximum force from pole to pole grows up as the horseshoe form is more completely given; that the power gathers in, or accumulates about this line, just because the badly conducting medium, *i. e.* the space or air between the poles, is shortened. A bent voltaic battery in its surrounding medium (3276.), or a gymnotus curved at the moment of its peculiar action (1785.), present exactly the like result.

3283. The manner in which the keeper or sub-magnet, when in place, reduces the power of the magnet in the space or air around, is evident. It is the substitution of an excellent conductor for a poor one; far more of the power of the magnet is transmitted through it than through the same space before, and less, therefore, in other places. If a horseshoe magnet be charged to saturation with its keeper on, and its power be then ascertained, removing the keeper will cause the power to fall. This will be (according to the hypothesis) because the iron keeper could, by its conduction, sustain higher external conditions of the magnetic force, and therefore the *magnet* could take up and sustain a higher condition of charge. The case passes into that of a steel ring magnet, which being magnetized, shows no external signs of power, because the lines of force of one part are continued on by every other part of the ring; and yet when broken exhibits strong polarity and external action, because then the lines, which, being determined at a given point, were before carried on through the continuous magnet, have now to be carried on and continued through the surrounding space.

3284. These results, again, pass into the fact, easily verified partially, that if soft iron surround a magnet, being in contact with its poles, that magnet may receive a much higher charge than it can take, being surrounded with a lower paramagnetic substance, as air: also another fact, that when masses of soft iron are at the ends of a magnet, the latter can receive and keep a higher charge than without them; for these masses carry on the physical lines of force, and deliver them to a body of surrounding space; which is either widened, and therefore increased in the direction across the lines of force, or shortened in that direction parallel to them, or both; and both are circumstances which facilitate the conduction from pole to pole, and the relation of the external lines to the lines of force *within* the magnet. In the same way the armature of a natural loadstone is useful. All these effects and expedients accord with the view, that the space or medium external to the magnet is as important to its existence as the body of the magnet itself.

3285. Magnets, whether large or small, may be supersaturated, and then they fall in power when left to themselves; quickly at first if strongly supersaturated, and more slowly afterwards. This, upon the hypothesis, would be accounted for by considering the surrounding medium as unable, by its feeble magneto-conducting power, to sustain the higher state of charge. If the conducting power were increased sufficiently, then the magnet would not be supersaturated, and its power would not fall. Thus, if a magnet were surrounded by iron, it might easily be made to assume and retain a state of charge, which, if the iron were suddenly replaced by air, would instantly fall. Indeed, magnets can only be supersaturated by placing them for the time under the dominion of other sources of magnetic power, or of other more favourable surrounding media than that in which they manifest themselves as supersaturated.

3286. The well-known result, that small bar-magnets are far stronger in proportion to their size than larger similar magnets, harmonizes and *sustains* that view of the action of the external medium which has now been taken. A sewing-needle can be magnetized far more strongly than a bar twelve inches long and an inch in diameter; and the reason under the view taken is, that the excited system in the magnet (correspondent to the voltaic battery in the analogy quoted (3276.)) is better sustained by the necessary conjoint action of the surrounding medium in the case of the small magnet. For as the imperfect magneto-conducting power of that medium (or the consequent state of tension into which it is thrown) acts back upon the magnet (3282.), so the smaller the sum of exciting force in the centre of the magnetic sphondyloïds, the better able will the surround ing medium be to do its part in sustaining the resultant of force. It is very manifest, that if the twelve-inch bar be conceived of as subdivided into sewing-needles, and these be separated from each other, the whole amount of exciting force acts upon, and is carried onwards in closed magnetic curves, by a very much larger amount of external surrounding medium than when they are all accumulated in the single bar.

3287. The results which have been observed in the relation of *length* and *thickness* of a bar-magnet, harmonize with the view of the office of the external medium now urged. If we take a small, well-proportioned, saturated magnet, as a sewing-needle; alone, it has, as just stated, such relation to the surrounding space as to have its high condition sustained; if we place a second like magnetic needle by the side of the first, the surrounding space of the two is scarcely enlarged, it is not at all improved in conducting character, and yet it has to sustain double the internal exciting magnetic force exerted when there was one needle only (3232); this must react back upon the magnets, and cause a reduction of their power. The addition of a third needle repeats the effect; and if we conceive that successive needles are added until the bundle is an inch thick, we have a result which will illustrate the effect of a thickness too large, and disproportionate to the length.

3288. On the other hand, if we assume two such needles similarly placed in a right line at a distance from each other, each has its surrounding system of curves occupying a certain amount of space; if brought together by unlike poles, they form a magnet of double the length; the external lines of force coalesce (3226.), those at the faces of contact nearly disappear; those which proceed from the extreme poles coalesce externally, and form one large outer system of force, the lines of which have a greater length than the corresponding lines of either of the two original needles. Still, by the supposition that the magnets are perfectly hard and invariable, the exciting force within remains, or tends to remain the same (3227.) in quantity, there is nothing to increase it. The increase in length, therefore, of the external circuit, which acts as a resisting medium upon the internal action, will tend to diminish the force of the whole system. Such would be the case if a voltaic battery surrounded by distilled water, as the analogous illustration (3276.), could be elongated in the water, and so its poles be removed further apart; and though in the case of magnets previously charged, some effect equivalent to intensity of excitement may be produced by conjoining several together end on, yet the diminished sustentation of power externally appears to follow as a consequence of the increased distance of the extreme poles, or external, mutually dependent parts. Static electric induction also supplies a correspondent and illustrative case.

3289. The usual case in which the influence of length and thickness becomes evident, is not, however, always or often that of the juxtaposition of magnets already as highly charged as they can be, but rather that of a bar about to be charged. If two bars, alike in steel, hardness, &c., one an inch long and the tenth of an inch in diameter, and the other of the same length but five-tenths of an inch in diameter, be magnetized to supersaturation, the latter, though it contains twenty-five times the steel of the former, will not retain twenty-five times the power, for the reason already given (3287.); the surrounding medium not being able to sustain external lines of force to that amount. But if a third bar, two inches long and also five-tenths in diameter, be magnetized at the same time, it can receive much more power than the second one. A natural reason for this presents itself by the hypothesis; for the limitation of power in the two cases is not in the magnets themselves, but in the external medium. The shorter magnet has contact and connexion with that medium by a certain amount of surface; and just what power the medium outside that surface can support, the magnet will retain. Make the magnet as long again, and there is far more contact and relation with the surrounding medium than before; and therefore the power which the magnet can retain is greater. If there were such limited points of resulting action in the magnet as is often understood by the word *poles*, then such a result could hardly be the case, on my view of the physical actions. But such poles do not exist. Every part of the surface of the magnet, so to say, is pouring forth externally lines of magnetic force, as may be seen in figs. 2, 3, 4, 5 (3274.). The larger the magnet, to a certain extent, and the larger the amount of external conducting medium in contact with it, the more freely is this transmission made. If the second magnet, being an inch long, be conceived to be charged to its full amount, and then, whilst in free space, could have half an inch of iron added to its length at each end, we see and know that many of the lines of force originally issuing from that part of its surface still left in contact with the air at the equatorial part, would now move internally towards the ends, and issue at a part of the soft iron surface; indicating the manner in which the tension would be relieved by this better conducting medium at the ends, and by increased surface of contact with the surrounding bad conductor of air or space. The thick, short magnet could evidently excite and carry on physical lines of magnetic power far more numerous than those which the space about it can receive and convey from pole to pole; and the increase in the length of the magnet may go on advantageously, until the increasing sum of power, sustainable by the increasing medium in the circuit, is equal to that which the magnet can sustain or transmit internally; for all the lines of power, wherever they issue from the magnet, have to pass through its equator; and in this way the equator or thickness of the magnet becomes related to its length. So the advantageous increase in length of the bar is limited by the increasing resistance within, and especially at the equator of the bar; and the increase in breadth, by the increasing resistance (for increasing powers) of the external surrounding medium (3287.).

3290. It is very interesting to observe the results obtained when an attempt is made to magnetize, regularly, a thin steel wire, about 15 or 20 inches in length, and 0·05 of an inch in diameter. It can hardly be effected by bars; and when the wire is afterwards examined by filings (3234.), it is found to have irregular and consecutive poles, which vary as the magnetization is repeated with the same wire, as if they broke out suddenly by a rupture of something like unstable equilibrium; the effects apparently being chiefly referable to the cause now assigned. Again, when a magnet is made out of a thin, hard, steel plate, whose length is ten or twelve times its width, it is well known how the lines of force issue from it in greatest abundance at the extreme angles, and then at the edges; and how a spot on the face gives exit to a much smaller number of lines than a like spot on the edge, at the same distance from the magnetic equator. Iron filings show such results readily, and so also do the vibrations of a magnetic needle, and likewise the revolutions of a wire ring (3212.). Now this state of the plate-magnet is precisely that which would be expected from the hypotheses of the necessary and dependent state of the magnet on the medium surrounding it.

3291. The mutual dependence of a magnet and the external medium, assumed in the view now put forth, bears upon, and may probably explain, numerous observations of the apparently superficial character of the magnetism of iron and magnets in different cases. If a hard steel bar be magnetized by touch of other magnets, both the vicinity of the superficial parts of the bar to the exciting magnet in the first instance, and afterwards to the surrounding sustaining medium, will tend to cause the magnetism to be superficial in the bar. If a small magnet or a horseshoe bar be surrounded by a thick shell of iron as its external medium, the inner surface of the iron, or that nearest to the magnet, with its neighbouring parts, will convey on more power than the parts further away. If a thick iron core be placed in a helix carrying a feeble or moderate electric current, it is the part of the core nearest to the helix which becomes most highly charged. Probably many other like results may appear, or be hereafter devised, and may greatly help to assist the discussion of the question of physical lines of force now under consideration.

3292. When, in place of considering the medium external to a magnet as homogeneous or equal in magnetic power, we make it variable in different parts, then the effects in it appear to me still to be in perfect accordance with the notion of physical lines of magnetic force, which, being present externally, are definite in direction and amount. The series of substances at our command which affect the surrounding space in this respect, do not present a great choice of successive steps; but having iron, nickel and cobalt, very high as paramagnetic bodies, we then possess hard steel, as very far beneath them; next, perhaps, oxides of iron, and so on by solutions of the magnetic metals to oxygen, water, glass, bismuth and phosphorus, in the diamagnetic direction. Taking the magnetic force of the earth as supplying the source of power, and placing a globe of iron or nickel in the air, we see by the pointing of a small magnetic needle (or in another case, by the use of iron filings (3240.)), the deflected course of the lines of force as they enter into and pass out of the sphere, consequent upon the conducting power of the paramagnetic body. These have been described in their forms in another place (3238.). If we take a large bar-magnet, and place a piece of soft iron, about half the width of the magnet, and three or four times as long as it is wide, end on to, and about its own width from one pole, and covering that with paper, then observe the forms of the lines of force by iron-filings; it will be seen how beautifully those issuing from the magnet converge, by fine inflections, on to the iron, entering by a comparatively small surface, and how they pass out in far more diffuse streams by a much larger surface at the further part of the bar, fig. 7. If we take several pieces of iron, cubes for instance, then the lines of force, which are altogether outside of them, may be seen undergoing successive undulations in contrary directions, fig. 8. Yet in all these cases of the globe, bar and cubes, I at least am satisfied that a section across the same lines of force in any part of their course, however or whichever way deflected, would yield the same amount of effect (3109. 3218.); at the same time, this effect of deflection is not only consistent with, but absolutely suggests the idea of a physical line of force.

3293. Then the manner in which the power disappears in such cases to an ordinary magnetic needle is perfectly consistent. A little needle held by the side of the soft bar described above (3292.), indicates much less magnetic power than if the iron were away. If held in a hole made in the iron, it is almost indifferent to the magnet; yet what power remains shows that the lines through the air in the hole are in the same general direction as those through the neighbouring iron. These effects are perfectly well known, no doubt; and my object is only to show that they are consistent with, and support the idea of external media having magnetic conducting power. But these apparent destructions of power, and even far more anomalous cases (2868. 3155.), are fully accounted for by the hypothesis; and the force absolutely unaffected in amount is found, experimentally, by the moving wire. I have had occasion before to refer to the modification of the magnetic force (in relation to the magnetic needle), where, its absolute quantity being the same, it passes across better or worse conductors, and I have temporarily used the words *quantity* and *intensity* (2866. 2868. 2870.). I would, however, rather not attempt to limit or define these or such like terms now, however much they may be wanted, but wait until what is at present little more than suggestion, may have been canvassed, and if true in itself, may have received assurance from the opinions or testimony of others.

3294. The association of magnet with magnet, and all the effects then produced (3218.), are in harmony, as far as I can perceive, with the idea of a physical line of magnetic force. If the magnets are all free to move, they set to each other, and then tend to approach; the great result being, that the lines from all the sources tend to coalesce, to pass through the best conductors, and to contract in length. When there are several magnets in presence and in restrained conditions, the lines of force, which they present by filings, are most varied and beautiful (3238.); but all are easily read and understood by the principles I have set forth. As the power is definite in amount, its removability from place to place, according to the changing disposition of the magnets, or the introduction of better or worse conductors into the surrounding media, becomes a perfectly simple result.

3295. As magnets may be looked upon as the habitations of bundles of lines of force, they probably show us the tendencies of the physical lines of force as they also occur in the space around; just as electric currents, when conducted by solid wires, or when passing, as the Leyden or the voltaic spark, through air or a vacuum, are alike in these essential relations. In that case, the repulsion of magnets when placed side by side, indicates the lateral tendency of separation of lines of magnetic force (3267.). The effect, however, must be considered in relation to the simultaneous gathering up of the terrestrial lines of force in the surrounding space upon each magnet, and also the tendency of each magnet to secure its own independent external medium. The effect coincides with, and passes into that of the lateral repulsion of balls of iron in a previously equal magnetic field (2814.); which again, by a consideration of the action in two directions, *i. e.* parallel to and across the magnetic axis, links the phænomena of separation with those of attraction.

3296. When speaking of magnets, in illustration of the question under consideration, I mean magnets perfect in their kind, *i. e.* such as are very hard and hold their charge, so that there shall be neither internal reaction of discharge or development (3224.), nor any external change, except what may depend upon such absolute and permanent loss of exciting power as is consequent upon an over-ruling change of the external relations. Heterogeneous magnets, which might allow of irregular variations of power, are out of present consideration.

3297. With regard to the great point under consideration, it is simply, whether the lines of magnetic force have a *physical existence* or not? Such a point may be investigated, perhaps even satisfactorily, without our being able to go into the further questions of how they account for magnetic attraction and repulsion, or even by what condition of space, æther or matter, these lines consist. If the extremities of a straight bar-magnet, or if the polarities of a circular plate of steel (3274.), are in magnetic relation to each other externally (3257.), then I think the existence of *curved* lines of magnetic force must be conceded (3258. 3263.)*; and if that be granted, then I think that the physical nature of the lines must be granted also. If the external relation of the poles or polarity is denied, then, as it appears to me, the internal relation must be denied also; and with it a vast number of old and new facts (3070. &c.) will be left without either theory, hypothesis, or even a vague supposition to explain them.

3298. Perhaps both magnetic attraction and repulsion, in all forms and cases, resolve themselves into the differential action (2757.) of the magnets and substances which occupy space, and modify its magnetic power. A magnet first originates lines of magnetic force; and then, if present with another magnet, offers in one position a very free conduction of the new lines, like a paramagnetic body; or if restrained in the contrary position, resists their passage, and resembles a highly diamagnetic substance. So, then, a source of magnetic lines being present, and also magnets or other bodies affecting and varying the conducting power of space, those bodies which can convey onwards the most force, may tend, by differential actions, with the others present, to take up the position in which they can do so the most freely, whether it is by pointing or by approximation; the best conductor passing to the place of strongest action (2757.), whilst the worst retreats from it, and so the effects both of attraction and repulsion be produced. The tendency of the lines of magnetic force to shorten (3266. 3280.) would be consistent with such a notion. The result would occur whether the physical lines of force were supposed to consist in a dynamic or a static state (3269.).

3299. Having applied the term *line of magnetic force* to an abstract idea, which I believe represents accurately the nature, condition, direction, and comparative amount of the magnetic forces, without reference to any physical condition of the force, I have now applied the term *physical line of force* to include the further idea of their physical nature. The first set of lines I *affirm* upon the evidence of strict experiment (3071, &c.). The

* See for a case of curved lines the inclosed and compressed system of forces belonging to the central circular magnet, fig. 6 (3275.).

second set of lines I advocate, chiefly with a view of stating the question of their existence; and though I should not have raised the argument unless I had thought it both important, and likely to be answered ultimately in the affirmative, I still hold the opinion with some hesitation, with as much, indeed, as accompanies any conclusion I endeavour to draw respecting points in the very depths of science, as, for instance, regarding one, two, or no electric fluids; or the real nature of a ray of light, or the nature of attraction, even that of gravity itself, or the general nature of matter.

Royal Institution,
March 6, 1852.

LIX. *On the Ten-year Period which exhibits itself in the Diurnal Motion of the Magnetic Needle.* *By* Dr. Lamont *of Munich**.

THE remarkable experiments of Faraday relative to the diurnal motion of the magnetic needle, have induced me to submit the peculiarities of this motion to a closer examination, and thus to obtain a clearer view of the facts which accompany it.

Among these there exists at present one, which, so far as I am aware of, has hitherto remained unrecognised, but which seems of so important a nature that it cannot be omitted in any theory which undertakes to render an account of the diurnal variation; it is the following:—

The magnitude of the variations of declination have a period of ten years. For five years there is a uniform increase, and during the following five years a uniform decrease in the variations.

With us the magnetic declination is a minimum at about 8 o'clock in the morning, and is greatest at 1 o'clock in the afternoon. Subtracting the declination at 8 o'clock from that at 1 o'clock, we obtain *the magnitude of the diurnal motion.* From the hourly observations conducted in this observatory since the month of August 1840, we ascertain the following to be the magnitude of the diurnal motion for each month separately:—

1840.	Magnitude of the diurnal motion. ′	1841.	Magnitude of the diurnal motion. ′	1841.	Magnitude of the diurnal motion. ′
August	+10·63	January	+3·72	July	+10·07
September	10·97	February	5·13	August	9·86
October	7·72	March	8·43	September	8·78
November	4·40	April	11·49	October	6·82
December	3·51	May	11·47	November	3·71
		June	11·49	December	2·89

* From Poggendorff's *Annalen*, vol. lxxxiv. p. 572.

Fig. 1.

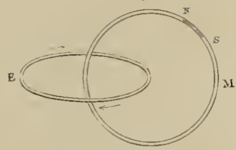

Fig. 3.

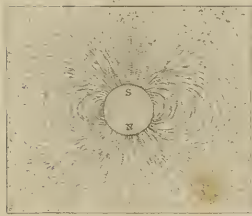

Fig. 2.

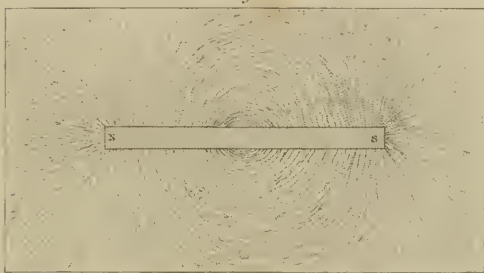

Fig. 4.

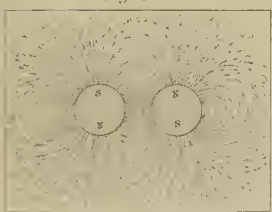

Fig. 5.

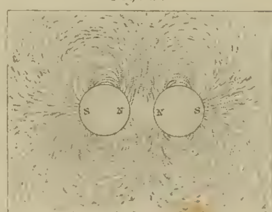

Fig. 6.

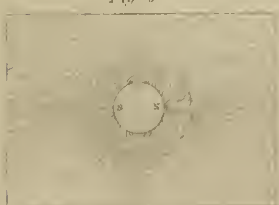

Fig. 7.

Fig. 8.