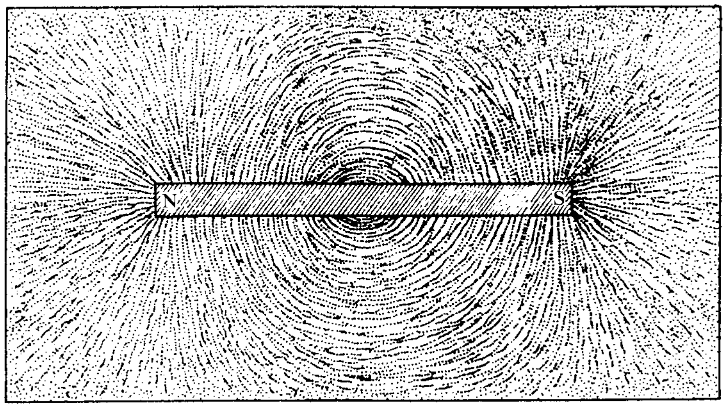
Fig. 2.



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 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;

3274. *At times their refraction is very sudden, leaving the magnet at right, or obtuse, or acute angles, as in … fig.2*: Faraday showed that lines of force within the bar run generally parallel to its axis (paragraphs 3116–3117), but lines emerging from the bar's sides must evidently have curved laterally, away from the axis. Within a long, narrow bar, however, a comparatively small departure from the axial direction suffices. Lines will therefore undergo most refraction outside, 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.

Fig. 3.

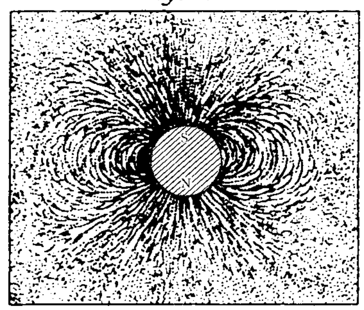


Fig. 4.

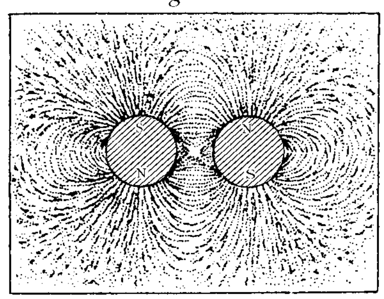
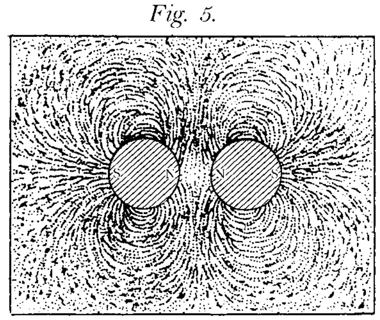


Fig. 5.



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

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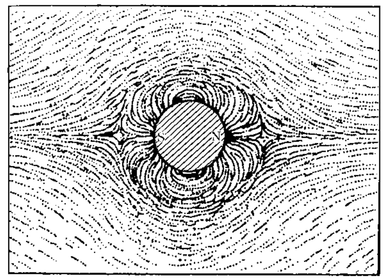
not inside, the bar. In Figure 2, then, lines exiting from the polar faces will have refracted very little, while those emerging laterally near the polar ends will have refracted through nearly right angles as they pass from the iron into the air. Lines closer to the central regions of the bar will have bent through larger, even obtuse, angles.

in other cases … more gradual, as in … figs. 3, 4, 5: Does Faraday think there is significant bending of lines *within* the circular magnets? He nowhere offers his reasons, if so. Yet if not, it is hard to see why he regards the refraction as "more gradual" in these cases, for the same range of exit angles, from zero to right and obtuse, can be seen in these figures too. Perhaps he means that in the circular magnet, *proportionally more* of the lines bend through acute angles, and fewer through right and obtuse angles, than in the long bar magnet.

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.

Fig. 6.



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 its 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

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3275. *would have equal power … with that infinite sphondyloid…*: Thus the organized magnetic pattern represents an integral power which can be spread out or confined, just as other physical entities can be expanded or compressed.

3276. *analogous in its condition to a … gymnotus*: Here is the comparison of *magnet to electric fish* discussed in the introduction. It complements Faraday's comparison of *fish to magnet* in the Fifteenth Series.

physical lines of electric force may be traced both through the battery and its surrounding medium: Faraday refers to *dynamic* lines of electric force, that is, lines of *current*.

A magnetic needle … will show them … by standing at right angles to the course of the lines: As discussed in the First Series' introduction, a magnetic needle endeavors to point perpendicularly to the direction of an adjacent electric current.

Two wires from a galvanometer will show them…: The galvanometer deflects when the wires are immersed in the conducting medium; but the deflection dwindles to zero when the line joining the wires is turned perpendicularly to 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 surrounding magnetic medium, deprived of all material substance, may be, I cannot tell, perhaps the æther. I incline to consider this 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.);[12] so I conceive,

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

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the line of current. Similarly, employing either their submerged hands or the disk collectors, Faraday and his colleagues were able to deduce the direction of electric lines of force in Gymnotus's tub (paragraphs 1775–1781).

3277. *I incline to consider this outer medium as essential to the magnet*: By contrast, the idea of action at a distance depreciates the regions surrounding an "active" center of force as mere passive territory having no role in determining or transmitting the action (paragraph 3270). In thus reinterpreting the magnet, Faraday implicitly reinterprets our general categories of agent and power—and begins to break down the distinction between them.

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.).

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 lines to 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

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3278. *In this view of a magnet, the medium or space around it is as essential as the magnet itself*: Thus it is a misleading figure of speech to identify the *iron* as "the" magnet. The iron is merely the tangible part of the magnetic system—its *body*, as Faraday will call it in the next paragraph and in paragraph 3284 below.

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 neighbourhood, though in reality the force is increasing there more and more. We can

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3279. *A magnetic needle, if it could be introduced into the iron medium, would indicate extreme diminution…*: A needle having greater conducting power than its surrounding medium will *point* axially (paragraphs 2811, 2828), since in gathering up lines of force it re-routes some of them from the medium through itself. But if the medium is iron, equal in conducting power to the needle, few or none of its lines would be transferred to the needle; and consequently the pointing tendency would decline or disappear. Note that by this account the number of lines passing through the needle *varies* as the surrounding medium is varied.

the power within the magnet … would remain the same: In the 29th Series, Faraday was able to effect only small changes in the strength of a hard bar-magnet, and then only through the influence of other, more powerful magnets. The presence of mere unmagnetized iron, therefore, should cause no significant increase or decrease.

3280. *it … cannot carry on through its mass more lines of force than it can excite*: Faraday showed in the 29th Series that a hard, well-charged magnet is essentially *constant* in power—that is, in the number of lines it supports.

the magnetic needle … seems to show less and less force in its neighbourhood, though in reality the force is increasing there more and more: A comment to the previous paragraph recounted how this would be true for a needle formed of soft iron. But here Faraday says he is talking about a "hard" needle—which sustains a constant number of lines, as we have already seen. How can its pointing tendency then vary, if the number of lines passing through it does not vary?

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 continuation 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.

3281. *If other paramagnetic bodies than iron be considered … their effects may be assumed as proportionate to the conducting power*: By "their effects" Faraday means the diminution of a magnetic needle's pointing tendency when surrounded by various paramagnetic media; the greater that decline, the greater we may assume the magnetic conducting power of the medium to be. But perhaps this remark should be restricted to soft iron needles; see the previous comment.

If the surrounding medium were hard steel… If a solution of protosulphate of iron were used…: The materials iron, hard steel, iron protosulphate solution, are named in order of decreasing magnetic conducting power. Thus an iron needle surrounded by each of these materials in succession would point with increasing vigor.

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.

3282. *The circumstances dependent upon the shape and size of magnets appear to accord singularly well with the view I am putting forth…*: In the following paragraphs Faraday will bring forth a parade of examples showing a close correlation between changes in form of the iron "body" with changes in the external disposition of a magnet's power. Note that before introducing these sometimes playful cases he is moved to recall the gymnotus "coiling incident" in the 15th Series.

3283. *the keeper … reduces the power of the magnet in the space or air around*: By concentrating the lines of force within itself, an iron keeper effectively withdraws them from neighboring regions (paragraph 3120, *comment*). But from another viewpoint, by substituting itself for the poorly conductive *air* the keeper raises the conductivity of the whole system and thereby enables it to receive a stronger initial magnetization.

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.

3283, continued. *The case passes into that of a steel ring magnet…*: A continuous steel ring might be thought of as a magnet and keeper so perfectly integrated, no part of the power passes into the air! Such rings when magnetized have been observed to "keep" their power for many years.

Faraday will choose this phrase, "passes into," several times again in succeeding paragraphs. Phenomena that "pass into" one another disclose a commonality, an affinity, among themselves. Experiments that disclose such passages can effect fundamental transformations in our experience and in our representative imagery. Perhaps the essential scientific activity, insofar as it is directed to *knowing* nature (not just tabulating facts and statistics about it), is the cultivation of such leading and metamorphosing strains within natural phenomena themselves. Recall Faraday's earlier anticipation in paragraph 3273, that "all these various phænomena presented to us shall become *one*."

3284. *masses of soft iron*: Affixed to the ends of a long, narrow magnet, they afford the lines of force a more gradual transition from their high concentration within the magnet body to their dispersion throughout the surrounding air.

the armature of a natural loadstone: A pair of iron caps covering the polar regions of an "armed" loadstone (paragraph 56). Their usefulness was long recognized; now Faraday identifies the principle of their operation.

the body of the magnet: That is, the *iron*—the palpable but by no means sole and exclusive constituent of the magnet.