its place, we shall not require the same effort to remove it as before. This phenomenon would form a very serious drawback to the working of many forms of electro-magnetic apparatus if there were no means of getting over it. Fortunately there are. It is sufficient if we break the iron magnetic circuit by a film of air, a layer of paper, or, more conveniently, a thin plate of brass, to get rid of what would otherwise be the troublesome effects of residual magnetism.

We shall also find another phenomenon arise from our having broken our ring by taking out a sixteenth part as described. It has been explained that the magnetic influence always passes, no matter what may be the medium; the effect of the insertion of a resisting medium being merely *the reduction of the strength* of the magnetism; and it was also explained that though magnetism passed invisibly, it could be rendered evident by the presence of iron. This may be shown in a very striking manner. If we take our ring minus its sixteenth, place a sheet of paper or glass over it, and sprinkle iron filings over the aperture, we shall find these filings, when free to move under the influence of the exciting power, arranging themselves in regular order from one end of our ring to the other, across the break; and if we investigate the matter further, we shall find that the reason these iron filings arrange themselves in this way is because each has become a small magnet under the influence of the exciting power of our ring, and each places itself in accordance with the two laws before stated, viz.:--

1. That, it being a magnet, having a N. pole, that should point to the S. pole of the large magnet, and the S. pole of the filing to the N. pole of the large magnet.

2. That the N. poles of the filings repel the N. poles of other filings, and the S. poles the S. poles; and the joint operation of these two laws produces the curves shown, which Faraday termed the lines of force, or the direction in which the magnetic force is manifested.

As a ring would not usually be a convenient form for a magnet that is to be used in electro-magnetic apparatus, the horse-shoe form is generally adopted. For permanent steel magnets, a strip of steel is bent into the form shown in Fig. 1, and its magnetic circuit is closed by another strip of steel or iron, or by some portion of the apparatus of which it is to form a part. For electro-magnets, the horse-shoe form is also generally adopted, but it is made in four pieces instead of two, viz., two limbs upon which the wire that is to carry the exciting current is wound; a yoke, or back piece to complete the magnetic circuit on that side; and the armature, facing the poles, and moving in accordance with the will of the operator who controls the electric current, to complete the magnetic circuit on the other side, as Fig. 2.

FIG. 2—HORSE-SHOE STEEL MAGNET.

Lines of Force.—Before going further, it will be as well to deal with Faraday's very beautiful, but somewhat puzzling, conception, the lines of force.

Lines of force bear the same relation to magnetism that current does to electricity. The production of lines of force is the result of the work done by a given magnetic exciting power, in opposition to the magnetic resistance opposed to it; just as an electric current is the result of a given E.M.F. acting in opposition to a given electrical resistance. Moreover, the number of lines of force passing at any point is a measure of the strength of the magnetism at that point, just as the number of amperes passing in any electric circuit, or part of a circuit, is the measure of the strength of the electric current passing. As in an electric circuit also, the current strength is the same in every part of the circuit, so too in the magnetic circuit, the number of lines of force passing is the same in every part; with the proviso, as with the electric circuit, that if two or more paths are open to the lines of force, they will divide between those paths or branch circuits in the inverse ratio of the resistance of the several paths. Thus, if there be two paths open to the lines of force, one through *the air and the other through iron, the* dimensions being the same, they will divide in the ratio, according to Mr. Kapp's figures, of 1440 . 1. One part passing through the air and 1440 through the iron. It can easily be seen, however, that if the air path should be short and of large cross sections, while the iron path was the reverse, an appreciable portion of the lines would pass through the air. This point comes out very strongly in the matter of designing dynamo machines; what is known as the leakage path being in some cases of comparatively low resistance, owing to the form of the machine.

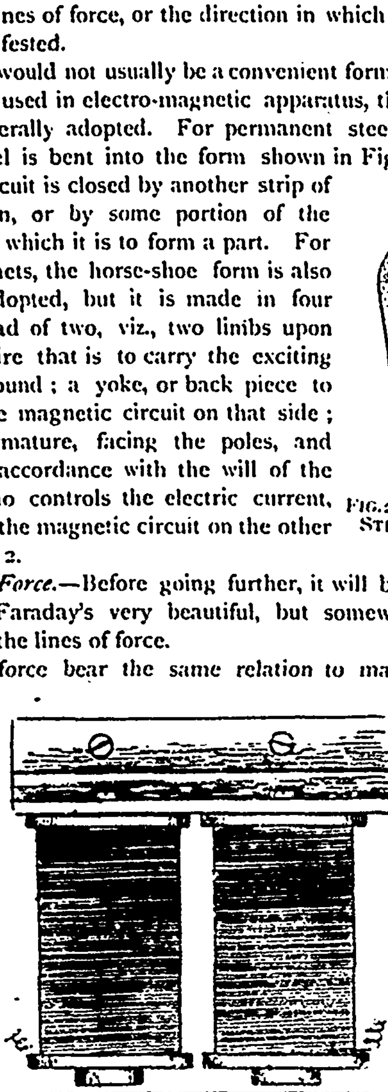

FIG. 2.—FOUR-PIECE ELECTRO-MAGNET WITH ARMATURE.

As with amperes also, lines of force are definite measurable quantities. Dynamo manufacturers calculate how many lines of force they have passing into an armature, and what the section of the iron should be to accommodate them, just as they calculate the number of amperes required in a given case, and the section of conductor required to accommodate them. But we have no convenient *quantities as yet, like the volt and the* ohm and the ampere, that we can refer to as analogous to the foot-pound in mechanics. We have no familiar name representing so many lines, though probably it may not be long before we have one. In order to render the subject clear, therefore, we can only refer back to the foundations of all these units, those of force, mass, and time. The unit line is that force which will move the unit body, the gramme, over unit distance, the centimetre, in unit time, the second. Therefore, when we say that there are so many lines of force passing into the armature of a given dynamo, we mean that we have the power present within the armature to do that number of centimetre-grammes of work in unit time, under the influence of the magnetism created in the machine; and, as engineers well know, these quantities are directly convertible into the more familiar foot-pounds, and H.P.

Lines of force, then, show the direction in which the magnetism present will cause any free magnetizable body to move; and the number of them at any point, referred to unit quantities as detailed above, show the force of magnetism available there, or, as it is termed, the strength of the magnetic field.

It must not be imagined that magnetism and lines of force represent continuous motion of the molecules of the body through which the magnetism passes; or that we should be justified in calling what we now know as lines of force, a magnetic current. They are nothing of the kind, nor are they analogous to an electric current, except in so far as has been described, and for two reasons. First, because magnetism is an *influencing* or inducing force, like gravity, and not a moving force like heat or electricity; and secondly, we *have* a magnetic current, viz., the motion that takes place in the magnetic circuit, among the molecules of the bodies through which the magnetic influence passes, at the moment the exciting power is applied, and at the moment when it ceases.

It will be easily understood from what has passed, that as the lines of force passing through air, say from pole to pole of a magnet, can radiate in all directions, unless their path is shaped for them by the introduction of some piece of iron, such as the armature, the force exerted varies, as in all similar cases, inversely as the square of the distance from the poles. It is doubtful, however, if this law holds good in a sufficient number of cases to be of any value, as it is evident that it must be subject to modification by every change in the conditions present.

FIG. 3.

It has been mentioned that the existence of an electric current passing through a conductor, implies a magnetic field around