The field concepts of Faraday and Maxwell

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We discuss how Faraday (1791-1867) and Maxwell (1831-1879) defined the field concept. According to them magnetic field was a region of the space close to magnetized bodies and electric field was a region of the space close to electrified bodies.

1. Introduction

In modern textbooks there is a great polisemy as regards the meaning of *electric field* and *magnetic field*, [1], [2], [3] and [4]. Field appears defined as a region of space, as a vectorial function, as something which propagates in space, as something which stores or contains energy and momentum, as a substance that mediates interactions between gross bodies etc.

Here we analyze how the field concept was presented by Faraday and Maxwell, as these two authors are normally considered the modern initiators of this concept. Although we restrict our analysis to these famous scientists, we agree with Heilbron when he mentioned that "the electricians of 1780 lacked the word but not the concept, which they called 'sphere of influence', *sphaera activitatis*, or *Wirkungkreis*", [5].

2. Faraday's Field Concept

Michael Faraday (1791-1867) utilized the word 'field' for the first time in November 7th, 1845, in his Diary, [6, Note 17]. But much before this time he had utilized expressions like 'magnetic curves' or 'lines of magnetic forces'. For instance, in the paper of 1831 in which he described his discovery of electromagnetic induction he presented this law in terms of a wire cutting the magnetic curves, which he defined as follows, [7, p. 281, §114]: "By magnetic curves, I mean the lines of magnetic forces, however modified by the juxtaposition of poles, which would be depicted by iron filings; or those to which a very small magnetic needle would form a tangent." In 1845 he gave this definition with the following words, [7, p. 595, §2149]: "But before I proceed to them, I will define the meaning I connect with certain terms which I shall have occasion to use: thus, by *line of magnetic force*, or *magnetic line of force*, or *magnetic curve*, I mean that exercise of magnetic force which is exerted in the lines usually called magnetic curves, and which equally exist as passing from or to magnetic poles, or forming concentric circles round an electric current. By *line of electric force*, I mean the force exerted in the lines joining two bodies, acting on each other according to the principles of static electric induction (1161, &c.), which may also be either in curved or straight lines." The most clear definition of these lines was presented by Faraday in a paper published in 1852, [7, p. 758, §3071]:

> A line of magnetic force may be defined as that line which is described by a very small magnetic needle, when it is so moved in either direction correspondent to its length, that the needle is constantly a tangent to the line of motion; or it is that line along which, if a transverse wire be moved in either direction, there is no tendency to the formation of any current in the wire, whilst if moved in any other direction there is such a tendency; or it is that line which coincides with the direction of the magnecrystallic axis of a crystal of bismuth, which is carried in either direction along it. The direction of these lines about and amongst magnets and electric currents, is easily represented and understood, in a general manner, by the ordinary use of iron filings.

Faraday began to mention the magnetic *field* in his publications presented to the Royal Society in 1845 and published in 1846, [7,p. 608,§2247, our emphasis]: "Another magnet which I have had made has the horseshoe form. [...] the poles are, of course, 6 inches apart, the ends are planed true, and against these move two short bars of soft iron [...] The ends of these bars form the opposite poles of contrary name; the *magnetic field* between them can be made of greater or smaller extent and the intensity of the lines of magnetic force be proportionately varied." The magnetic field is here related to the region between two magnetized bars. On §2252 he defined the axial and equatorial directions along or across the lines of magnetic force, [7, p. 608, §2252]: "I shall have such frequent occasion to refer to two chief directions of position across the magnetic field, that to avoid periphrasis, I will here ask leave to use a term or two, conditionally. One of these directions is that from pole to pole, or along the line of magnetic force; I will call it the *axial direction*: the other is the direction perpendicular to this, and across the line of magnetic force; and for the time, and as respects the space between the poles, I will call it the *equatorial direction*."

In many other places he utilized the expression 'magnetic field', [7]: pp. 634–6, §2463 to §2475; p. 690, §2806 to §2810; p. 694, §2831; p. 777, §3171 etc.

A clear definition of what he understood by a *magnetic field* appeared only in a paper read in 1850 at the Royal Society and published in 1851, [7, p. 690, §2806, our emphasis]:

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

That is, for Faraday a magnetic field may be taken as any portion of space traversed by lines of magnetic power. And these lines of magnetic power can be visualized by iron filings.

It is interesting to note that Faraday, mainly from 1851 onwards, considered the lines of magnetic power as representatives of local processes, perhaps states of the ether, as we can see of the passage that follows, [7, p. 759, §3075]:

> I desire to restrict the meaning of the term *line of force*, so that it shall imply no more than the condition of the force in any given place, as to strength and direction; and not to include (at present) any idea of the nature of the physical cause of the phenomena; or to be tied up with, or in any way dependent on, such an idea. Still, there is no impropriety in endeavouring to conceive the method in which the physical forces are either excited, or exist, or are transmitted; nor, when these by experiment and comparison are ascertained in any given degree, in representing them by any

method which we adopt to represent themere forces, provided no erroris thereby introduced. On the contrary, when the natural truth and the conventional representation of it most closely agree, then are we most advanced in our knowledge. The emission and the ether theories present such cases in relation to light. The idea of a fluid or of two fluids is the same for electricity; and there the further idea of a current has been raised, which indeed has such hold on the mind as occasionally to embarrass the science as respects the true character of the physical agencies, and may be doing so, even now, to a degree which we at present little suspect. The same is the case with the idea of a magnetic fluid or fluids, or with the assumption of magnetic centres of action of which the resultants are at the poles. How the magnetic force is transferred through bodies or through space we know not: — whether the result is merely action at a distance, as in the case of gravity; or by some intermediate agency, as in the cases of light, heat, the electric current, and (as I believe) static electric action. The idea of magnetic fluids, as applied by some, or of magnetic centres of action, does not include that of the latter kind of transmission, but the idea of lines of force does. Nevertheless, because a particular method of representing the forces does not include such a mode of transmission, the latter is not therefore disproved; and that method of representation which harmonizes with it may be the most true to nature. The general conclusion of philosophers seems to be that such cases are by far the most numerous, and for my own part, considering the relation of a vacuum to the magnetic force and the general character of magnetic phenomena external to the magnet, I am more inclined to the notion that in the transmission of the force there is such an action, external to the magnet, than that the effects are merely attraction and repulsion at a distance. Such an action may be function of the ether; for it is not all unlikely that, if there be an ether, it should have other uses than simply the conveyance of radiations (2591, 2787). [...]

Although Faraday does not seem to have utilized the expression electric field in his works, he would probably understand it as any portion of space traversed by lines of electric force (as we saw before, he defined these lines in §2149).

3. Maxwell's Field Concept

James Clerk Maxwell (1831-1879) followed closely Faraday's ideas and tried to express them mathematically. In a paper published in 1864 called "A dynamical theory of the electromagnetic field", he wrote, [8, p. 527]:

(3) The theory I propose may therefore be called a theory of the *Electromagnetic Field*, because it has to do with the space in the neighbourhood of the electric and magnetic bodies, and it may be called a *Dynamical* Theory, because it assumes that in that space there is matter in motion, by which the observed electromagnetic phenomena are produced.

(4) The electromagnetic field is that part of space which contains and surrounds bodies in electric or magnetic conditions.

In his *A Treatise on Electricity and Magnetism* originally published in 1873, we find the same definition of *field* as a region of space surrounding electrified or magnetized bodies. On §44 he wrote, [9, Vol. 1, p. 47]: "The electric field is the portion of space in the neighbourhood of electrified bodies, considered with reference to electric phenomena." A similar definition is given in §476 as regards the magnetic field generated by a wire carrying a steady current (Oersted's experiment), [9, Vol. 2, p. 139, our emphasis]: "It appears therefore that in the space surrounding a wire transmitting an electric current a magnet is acted on by forces dependent on the position of the wire and on the strength of the current. *The space in which these forces act may therefore be considered as a magnetic field*, and we may study it in the same way as we have already studied the field in the neighbourhood of ordinary magnets, by tracing the course of the lines of magnetic force, and measuring the intensity of the force at every point."

It is important to mention that in Maxwell's theory concept of space, as we can observe, for example, in the passage that follows [9, Vol. 2, p. 158, §502]:

The ideas which I have attempted to follow out are those of action through a medium from one portion to the contiguous portion. These ideas were much employed by Faraday, and the development of them in a mathematical form, and the comparison of the results with known facts, have been my aim in several published papers.

4. Conclusion

From these quotations we can see that Faraday and Maxwell defined the electric and magnetic fields as a region of space in the neighbourhood of electrified and magnetized bodies, respectively. Moreover, it appears as a reasonable hypothesis in the works of these two authors that this space was completely filled with something like an ether.

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