

In: Proc. of the VI Taller Internacional “ENFIQUI 2008” – La Enseñanza de la Física y la Química (Universidad Pedagógica “Juan Marinello”, Matanzas, Cuba, 8 to 12 July 2008), pp. 1-4, M. G. P. Batista (editor).

## **“The multiple definitions of ‘field’ in the context of Electromagnetism”**

**J. E. A. Ribeiro, A. Vannucci and A. K. T. Assis<sup>†</sup>**

Instituto de Física - Universidade de São Paulo (USP)

C.P 66318, CEP 05315-970 – São Paulo, SP – Brasil

<sup>†</sup>Instituto de Física “Gleb Wataghin”, Universidade Estadual de Campinas – UNICAMP

CEP 13083-970 – Campinas, SP – Brasil

Michael Faraday (1791-1867) conceived the electromagnetic phenomena in terms of “lines of force” (“*power lines*”). To describe the electric/magnetic phenomena under analysis he denominated “field” as the spatial region around the objects under investigation. This conclusion can be drawn from the following part of his book *Experimental Researches in Electricity* [1]:

*‘I will now endeavour to consider what is the influence which paramagnetic and diamagnetic bodies, viewed as conductors, 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’* [1: §2806].

This same concept was adopted by James Clerk Maxwell as we can note from his definition of electric field:

*‘The Electric Field is the portion of space in the neighbourhood of electrified bodies, considered with reference to electric phenomena’* [2: §44].

This definition was also followed by Sir Joseph John Thomson (1856-1940), Nobel Prize in 1906:

*‘the region in which the [electric] attractions and repulsions are observed is called the electric field’* [3: 1]

The same definition was stated by Sir James Jeans (1877-1946):

*‘the space in the neighborhood of charges of electricity, considered with reference to the electric phenomena occurring in this space, is spoken of as the electric field’* [4: 24].

As we can observe, there was a strong agreement among the great scientists of the past in relation to what they understood about the field concept. However, as the time went by, the concept of field, in physics, ended up losing its original meaning. Instead of its original meaning, many others conceptions were adopted and are used in several text books. A list of the different meanings we find for *field* in the context of the Electromagnetism is now given:

- (1) Region in which charged particles or electric currents are under the influence of electromagnetic forces (original meaning of the concept, scarcely used nowadays).
- (2) Vectorial quantity, defined by a mathematical function ( $\mathbf{E}(\mathbf{r},t)$  - electric field and  $\mathbf{B}(\mathbf{r},t)$  - magnetic field).
- (3) Group of lines of force (electric or magnetic) in certain region.
- (4) State of the space. That is, as a condition of space.
- (5) Immaterial matter, susceptible to suffer the action of charged particles and electric currents.
- (6)  $\mathbf{E}(\mathbf{r},t)$  and/or  $\mathbf{B}(\mathbf{r},t)$  understood as real entities.

It is interesting to note that the concepts (2) and (3) are solely definitions that allow the manipulation of situations in which we are interested in, while the definitions (4) and (5) refer directly to the intrinsic reality.

We will now give examples where these different definitions are found in different physics text books.

(1) *Field as a region of the space around a charged body.*

*'Field in general signifies a region of space considered in respect to the potential behavior of test bodies moved about in it; the electricians of 1780 lacked the word but not the concept, which they called "sphere of influence", sphaera activitatis, or Wirkungskreis'*[5: 187].

(2) *Field as a vectorial quantity representing related processes.*

*'(...) these electric charges therefore generate an electric field vector at all points of space (in vacuo). (...) The electric field vector will be denoted by  $\mathbf{E}$  (...)'* [6: 1].

*'An electric point charge produces in its vicinity an electric field  $\mathbf{E}$ '* [7: 63].

*'We can write the force  $\mathbf{F}$  on a charge  $q$  moving with a velocity  $\mathbf{v}$  as  $\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$ . We call  $\mathbf{E}$  the electric field and  $\mathbf{B}$  the magnetic field at the location of the charge'* [8: 1-2].

*'The electric and magnetic fields  $\mathbf{E}$  and  $\mathbf{B}$  (...)' [9: 3].*

*(3) Field as lines of force.*

*'For the moment, all the lines of force, or briefly speaking, the field, indicate only how a test body would behave if brought into the vicinity of the sphere for which the field is constructed' [10: 131].*

*(4) Field as a state of space, as a distortion of the space.*

*'(...) because in the final analysis in a theory of fields the ponderable matter, or the elementary particles that constitute this matter, also have to be considered as 'fields' of a particular kind, or as particular 'states' of the space (...)' [11: 13].*

*'The natural interpretation of electrical interaction is that two objects simply attract each other: plus against minus. However, this was discovered to be an inadequate idea to represent it. A more adequate representation of the situation is to say that the existence of the positive charge, in some sense, distorts, or creates a "condition" in space, so that when we put the negative charge in it feels a force. This potenciality for producing a force is called an electric field' [12: 2-5].*

*(5) Field as an immaterial medium, which would be the responsible for the interacting charged particles.*

*'If the field is considered as the symbolic medium for the action between charges, equation (4.2) expresses the effect of the charges on the field, or, if one likes, they express the message given by the charges to the field. (...) We see that for the electromagnetic field the invariant diagonal sum of the tensor of the stresses and energy is zero. This agrees with the view that the field is a non-material symbolic medium for momentum and energy. In Chapter VII, 1, we called such media with zero mass telehapses. In quantum theory the telehapses related to the electromagnetic field are photons, which are immaterial, without mass (...)' [13: 127,129].*

*(6) Field as  $\mathbf{E}(\mathbf{r}, t)$  and  $\mathbf{B}(\mathbf{r}, t)$ , taken as real quantities.*

*'Ever since Faraday, the laws of electricity and magnetism have been expressed in terms of electric and magnetic fields,  $\mathbf{E}$  and  $\mathbf{B}$  (...)'*

*'What exactly is an electric field? I have deliberately begun with what you might call the "minimal" interpretation of  $\mathbf{E}$ , as an intermediate step in the calculation of electric forces. But I*

encourage you to think of the field as a “real” physical entity, filling the space in the neighborhood of any electric charge (...)’ [14: 52, 61].

This last statement deserves some comments. In the first place, Faraday never explicitly used the vector fields  $\mathbf{E}$  and  $\mathbf{B}$  to express the electromagnetic laws. In the second place, the question of what  $\mathbf{E}$  really is, does not make sense in the context under analysis. We do know *exactly what it is*. It is a vector field that satisfies the Maxwell’s equations. Maybe a better question would be: “What exactly represents an electric field?”. Furthermore, it does not seem reasonable to consider  $\mathbf{E}$  as a real entity, as the author suggests. It could be said that  $\mathbf{E}$  represents a real entity, but it is logically impossible to take it as the real entity itself.

From what we have discussed above we can conclude that the term field does not have a unique meaning. This can lead the physics students to misleading interpretations if the context of the word is not correctly analyzed.

## Bibliography

- [1] – FARADAY, M. *Experimental Researches in Electricity*, vol. III. New York: Dover Publications, 1965 (unabridged of the 1<sup>st</sup> edition, of 1855, published by Taylor and Francis).
- [2] – MAXWELL, J. C. *A Treatise on Electricity and Magnetism*, vol. I. New York: Dover, 1954 (unabridged of the 3<sup>rd</sup> edition, published by the Clarendon Press in 1891).
- [3] – THOMSON, Sir J. J. *Elements of the Mathematical Theory of Electricity and Magnetism*. Cambridge: Cambridge University Press, 1921 (5<sup>th</sup> ed.).
- [4] – JEANS, Sir J. *The Mathematical Theory of Electricity and Magnetism*. Cambridge: Cambridge University Press, 1941 (5<sup>th</sup> edition, 1925).
- [5] – HEILBRON, J. L. The Electrical Field before Faraday. In CANTOR, G. N. & HODGE, M. J. S.: *Conceptions of Ether*. Cambridge: Cambridge University Press, 1981.
- [6] – ATKIN, R. H. *Theoretical Electromagnetism*. New York: John Wiley & Sons Inc., 1962.
- [7] – BECKER, R. *Electromagnetic Fields and Interactions*. New York: Dover Publications, 1982 (unabridged 1964 transl).
- [8] – FEYNMAN, R. P., LEIGHTON, R. B., and SANDS, M. *The Feynman Lectures on Physics*, vol. II. Reading (Massachusetts): Addison-Wesley, 1964.
- [9] – JACKSON, J. D. *Classical Electrodynamics*. New York: John Wiley, 1998 (3<sup>rd</sup> edition).
- [10] – EINSTEIN, A. & INFELD, L. *The Evolution of Physics*. New York: Simon and Schuster, 1938.
- [11] – EINSTEIN, A. “On the Ether” (trad. from original German of 1924). In SAUNDERS, S. & BROWN, H. R. (eds): *The Philosophy of Vacuum*. Oxford: Clarendon Press, 1991.
- [12] – FEYNMAN, R. P., LEIGHTON, R. B., and SANDS, M. *The Feynman Lectures on Physics*, vol. I. Reading (Massachusetts): Addison-Wesley, 1963.
- [13] – FOKKER, A. D. *Time and Space, Weight and Inertia*. Oxford: Pergamon Press, 1965.
- [14] – GRIFFITHS, D. J. *Introduction to Electrodynamics*. Upper Saddle River (New Jersey): Prentice Hall, 1999 (3<sup>rd</sup> ed.).

Electricity and magnetism are 2 aspects of electromagnetism. (image will be uploaded soon). Electricity and magnetism were long considered to be separate forces. It was not until the 19th century that they were finally considered as interrelated phenomena. In 1905 Albert Einstein's special theory of relativity discovered beyond a doubt that both are aspects of one common phenomenon. Every charged body sets up an electric field in the surrounding space. A second charge can feel the presence of this field. The second charge is either attracted towards the initial charge or repelled from the charge, depending on the signs of these charges. Since the second charge also has an electric field, the first charge can feel its presence and is either attracted or repelled by the second charge also. Electromagnetic interaction is described by the means of Electromagnetic fields: field called electric field, field called magnetic field, field and field. Those fields are solution of Maxwell equations,  $\text{index}\{\text{Maxwell equations}\}$ , where  $\rho$  is the charge density and  $\mathbf{j}$  is the current density. This system of equations has to be completed by additional relations called constitutive relations that bind. "The Electric Field is the portion of space in the neighbourhood of electrified bodies, considered with reference to electric phenomena" [2: 44]. This definition was also followed by Sir Joseph John Thomson (1856-1940), Nobel Prize in 1906: "the region in which the [electric] attractions and repulsions are observed is called the electric field" [3: 1]. A list of the different meanings we find for field in the context of the Electromagnetism is now given: (1) Region in which charged particles or electric currents are under the influence of electromagnetic forces (original meaning of the concept, scarcely used nowadays). (2) Vectorial quantity, defined by a mathematical function ( $E(\mathbf{r},t)$  - electric field and  $B(\mathbf{r},t)$  - magnetic field). An electromagnetic field (also EMF or EM field) is a physical field produced by electrically charged objects. Checking what is electric charge it says "Definitions in physics are always somewhat circular, because they are not really definitions. Instead, they're descriptions of the world. The way to make sense of "circular definitions" is usually to think about the experiments that led to those definitions. " "Again, you have to understand things in the context of physics.  $q \ll 0$  means that the test charge doesn't disturb the charges that are creating the field you want to measure. Of course I don't literally mean that  $q$  is  $0$ ; it has to be sufficiently small, depending on the precision you would like to have. "

Javier Sep 6 '15 at 14:10.