Antecedents of the field's theory: Faraday's cosmovision against Newton's philosophy

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Abstract: - While teaching traditional electromagnetism at a basic level, in the early semesters of science and engineering careers, it is not mandatory or even convenient for teachers and students to invest much time from the curse in the revision of philosophical concepts of the physics theories discussed. This omission leads students to achieve an incomplete and generally confusing knowledge construction. In this article, the authors point out the specific case for constructing the "*Field*" concept, making a brief travel through Michael Faraday's conceptions, especially in those aspects where there is a counterview of his cosmovision against Isaac Newton's. The contrasting of both scientist's postulates, from which arise two paradigms that still coexist (Newton's mechanics and Maxwell's electrodynamics), provide the students with a solid base for understanding the motivations that lead the followers of one and other to defend the theories and perform developments intended to provide with internal and external consistency to each physical-philosophical theory.

Key-words: Electric field, physics teaching, electromagnetism, Newton, Faraday, Maxwell.

1. Introduction

The philosophy related to the physics theories, is generally not discussed in curses taught in undergraduate schools where scientific and technical careers are studied, e.g. schools, universities, institutes, etc. The reasons given for not including such aspects, generally are those referring to the fact that its inclusion would turn the curses dense and a higher number of hours would be required in order to cover the program's contents, occasionally it is also mentioned that there is a lack of interest from both; professors and students, due to this circumstance the individual scientist's conceptions, are only mentioned by some professors, generally in an anecdotic sense. Only in exceptional cases, professors or authors of commonly used as text ones, mention the philosophical origins of the physics theories they teach, with the intention of informing the student about this aspects, in order to contextualize the knowledge and attend the problems from which the scientific theories under study arise.

In the particular case of teaching Maxwell's electromagnetism, usually exposed in the earlier semesters of science or engineering careers, it can be confirmed that the students, with very few exceptions, do not realize that they are studying a physics theory which differs significantly from Newton's physical-philosophical theory. The origin of this situation, arises very likely from the fact that in most of the study programs the subjects related to the electromagnetism, establishes, with reasons supposedly didactical, a thematic order that starts with the treatment of electric phenomena, among which the first to be attended are those related to the charge and the electric current, arising naturally from the Coulomb law explaining the interaction among electric charges and from the Biot and Savart law explaining the interaction among electric currents. This procedure generally leads to the following effects:

In reference to the Coulomb's law, based on Newton's conceptions, it is natural for the students to consider that he is continuing with the study of the same theory he learnt in his courses about classic mechanics so when the study of Biot and Savart's law is started, if its origin is not clearly and deeply explained by the professor, it is unlikely that the student will question himself about the arising of the dependency of the forces among currents with the angle among the directions of the elements of the current, in fact, there is a clear tendency of the students to accept the apparition of the angles in calculating forces of interaction among currents, as a direct consequence of the mathematic formalism employed (cross product among vectors).

A particular and important case in which the omission to which the latest paragraphs refer to is evident, is precisely the introduction that most books (therefore professors) make on the concept of the electric field, to document this fact, it is enough to refer ourselves to some of the texts commonly used in electromagnetism education:

Tipler [1]. - *An electric charge creates an electric field E in all space and this field generates a force over another electric charge. The force is generated by the field in the position of the second electric charge, more than by the first electric charge, which is located at a certain distance.*

Resnick [2].- *The Coulomb law for the force between electric charges leads us to think in terms of action at a distance, represented as electric charge ←→ electric charge. Introducing again the field as an intermediary between electric charges, the interaction can be represented as electric charge ←→field←→electric charge. The first charge establishes an electric field, and the second interacts with the electric field of the first charge.*

In chapter 16 (Vol. 1) the author, first establishes the gravitational field and the argument is: "A basic fact of gravitation is that two particles are subject to mutual forces between them. This can be considered as a direct interaction between the two particles. This point of view is defined as distance action according to which the particles interact whether they are in contact or not. Another point of view is the concept of field; it considers that a particle modifies in someway the space that surrounds it generating a gravitational field. This field, whose intensity depends on the particle's mass, acts over any other particle, forcing a gravitationally attraction upon it".

Alonso & Finn [3]. - *We suggest the existence of an electric field on any region where an electric charge experiences a force.*

Hayt [4].- *If we consider a fixed charge into position, let's say Q_1 and a second charge slowly moves around it, it can be observed from any point that a force is acting upon this second charge; in other words, this second charge is exposing the existence of a field force.*

Fowles [5].- *Whenever an electrically charged particle is in the vicinity of other electric charges, a force is experienced. This force F is due to the electric field E originated by these other charges.*

Plonus [6].- *The Coulomb Law provides the force that will be generated over a punctual electric load Q_2, when this load is located nearby another punctual electric load Q_1. If we eliminate Q_2 but maintain Q_1 in a fixed position, it could be said that we are in the presence of an electric field all around the space of Q_1. The magnitude of the electric field at a certain point is the unit charge force upon a positive test force placed in that same spot, this has to be under the conditional that the test charge, called ΔQ_2, is small enough and does not disturbs the field in which it stands.*

It is clear that, without exception, the stated in these publications is correct from a physics point of view, nevertheless, could we consider it correct from a physics teaching point of view? The cause for which it is convenient (or necessary) to introduce the concept of field is never mentioned, nor are mentioned the causes that origined such conception and, it is possible that these aspects are the direct cause of the poor and vague knowledge that a percentage of the students achieve, according to Flores [7].

It would be ventured to say that, in general, there is a lack of interest on the side of the science and engineering professors, to cover the metaphysical aspects of the scientific theories that are taught to their students; nevertheless, given that the reality shows that such subjects are not touched in the regular courses, we have to accept that some of the main causes of this omission are caused by, amongst other things, the lack of time to deal with such subjects, the structure of the study programs, the content of the text books, the level of study, etc.

With the hope to help in the construction of the student's knowledge regarding the electromagnetic theory, this article presents a series of facts both historical and scientific, related to Michael Faraday's concepts, which allows us to conclude that they were the ones that in a decisive manner, led him to postulate the theory of the fields, which later Maxwell would dedicate to study and provide with the logical-mathematical formalism, gave it internal coherency and coherency with other related sciences; therefore led it to be considered as the paradigm according to Khun [8], that explains the electromagnetic phenomena at a macroscopic level.

For it, we will start with a description of the state science was in, in the early years of the XIX century, period in which the study of Faraday's field theory began.

The most extended conception of the universe was Newton's one, he had believers of high prestige, among which we can name Laplace, Ampère and Öersted, such conception coexisted with Leibniz's ideas [9], Descartes [10], and many others. Leibniz's like Descarte's ideas, referring to physics, were not formulated nor developed as strictly as Newton's ideas were exposed. According to Newton [11], the universe is constituted by three "entities":

1.- Solid and broad corpuscles.
2.- Empty space.
3.- Forces among the corpuscles, which act instantly at a distance or can act by contact among the corpuscles.

According to this fundamental model, Newton developed the mechanics (nowadays known as classic mechanics), which essentially describes the relationships among the forces and movements produced and, at the same time he developed the theory of gravitation, which establishes the existence of attractive forces, of central character, that always act instantaneously, from a distance, among the corpuscles, in the direction of the line which connects the centers of the corpuscles.

Newton's theory has the highlights of being "elegant" and "concrete" because from the point of view of the mathematical formalism, it can be expressed in four simple laws (three for the mechanics plus the expression of the law of gravitation).

If we analyze Newton's laws from its universe's conception, these result plausible: for example, the consideration that the gravitatory forces decrease their intensity according to the inverse square of the distance of separation among the corpuscles, has its origin in the geometry (the superficies of two concentric spheres are directly related to the squares of their radios). So, if one particle acts from a distance on another, through an empty and isotropic medium, it is reasonable that the intensity of the interaction decreases in the same proportion as the increase in the surface of a sphere whose radio equals the distance of separation among the particles.

In its gravitation's law, Newton affirms that the attractive forces among corpuscles are of a central character. This assumption can only make sense, if the space is conceived as homogeneous and isotropic. So, if we assume that a body acts directly on another, then there is no reason for it to pull or push the other to one side or another in any direction transversal to the line holding them together, instead of only bringing it near or moving it away from himself.

The validity of the Newton's first law rests on supposing that both, rest and rectilinear uniform motion are the same "state", this means, situations or configurations that keep their identity in time.

The authors do not intend to analyze deeply the concordance of these laws with the philosophic postulates supporting them, for the moment it is enough for us to affirm that Newton's theory has been of outmost success, that its followers achieved developments which without exaggeration, could be classified as impressive ones; two remarkable examples are the theories formulated by Laplace in the field of celestial mechanics and by Lagrange [12] in the analytical mechanics. Nonetheless, once the metaphysical scheme of Newton and his laws of mechanics were accepted as valid, some enigmas started to arise, under Khun's [13] definition. Newton's laws were not applicable when trying to solve some problems related to electricity, chemistry, light, cohesion and others. The attempts to solve these enigmas lead the research workers to go in pursue for another type of theories, therefore, other philosophical conceptions. Opposed to the physical-philosophical theory of Newton coexisted, as previously mentioned, several metaphysic systems and, for our purposes, are relevant the theories derived from the conceptions of Descartes, who postulated, according to Koyré [14] :

1.- Matter and extension are the same thing.
2.- The quantity of movement of the universe is constant.
3.- The forces do not exist.

With these affirmations, Descartes tried to establish physic laws, which will not be part of this document since they turned out to be false. Descartes laws were corrected after by Huygens, Wren, Wallis and Leibniz.

Leibniz modifies substantially the Descartes' theory by stating that:

1.- The force together with the extension, is an essential characteristic of the matter and must be assigned to every point of the matter (not only to those whose size is finite)
2.- For the matter to resist the penetration, the force must be repulsive.
3.- No sudden changes can happen in the nature (continuity principle).
4.- No vacuum can exist (for theological reasons).

However, the philosophical ideas, which, according to Berkson [15] influenced directly Michael Faraday while formulating his field's theory are Boscovich's ones [16]. Berkson bases his opinion on the fact that on Pearce's book [17], the following paragraph is stated, taken from Faraday's notes referring to the conferences from 1816:

"The idea of the solidity found an opposition and its existence is still under discussion. Implies a plain or full of matter; but a theory is arising which establishes that the matter is simply a collection of mathematic points, attractive and repulsive; and since these points do not have parts, it is said that they do not have extension nor solidity; and that if it was possible to overcome the attractive and repulsive forces, two portions of matter could coexist in the same place".

This paragraph prove that Faraday was aware of the theories formulated by Boscovich [18] or of those derived of them.

Faraday's conceptions in reference to the universe where the following:

1.- The unity of all the forces (all the forces are the same).
2.- The corpuscles do not exist (the prime matter of the universe is force only).

3.- The vacuum does not exist (the universe is full with forces).
4.- The action at a distance does not exist (the interaction happens only by the contact among adjacent elements).
5.- The interaction does not happen instantaneously (since it only occurs by the contact, it must happen progressively and for it must, necessarily, elapse in a certain period of time).

The publication of the field's theory of Faraday is preceded by two scientific events whose forthcoming was the following:

In his book Lenard [19] narrates the way in which in 1820, Hans Christian Öersted performs an experiment crucial to this analysis which consists of passing an electric current through a very thin conductor, which due to the pitch of the current, reaches a very high temperature. Demonstrates that the pitch of the electric current causes the diversion of a magnetized needle (compass) from its normal direction (pointing to the geographical north and practically horizontal). This experiment, which nowadays seems simple, demonstrated that the electric forces could be transformed in magnetic forces.

The explanation that Öersted gave to his experiment, based on his conceptions (which differed from Newton's), clarified that the electric forces could turn directly into magnetic forces and that the effects produced by the electric forces, did not occur in the direction of the line joining the current with the magnetic needle, but they were perpendicular. However, the explanations provided by Öersted were not clear enough.

While being aware of the experiment performed by Öersted, André Marie Ampère; follower of Newton's conceptions, reproduced the experiment and tried to explain the results with an approach based on Newton's philosophy.

In order to accomplish his explanation, Tricker [20] mentions that Ampère formulated the hypothesis of magnetism "not being a fluid different from the electric", it was simply a different aspect of the electricity; he postulated that the magnetic effects were produced by "circular electric currents inside the magnets" and these circular currents could interact with the inside currents of other magnets as well as with the "voltaic" currents.

It can be observed, that this hypothesis from Ampère, denies the existence of magnetic forces and this provides him with the possibility of explaining Öersted's experiment based on the fact that it is an interaction among effects of equal origin (electric forces). However, this hypothesis was also original since in that time the form of interaction among electric currents was not known. Ampère performed experiments in order to know the form in which two electric currents interact and he found the following:

1) Two electric currents which circulate through parallel wires, are attracted to each other if they circulate in the same sense and they repeal themselves if they circulate in opposite senses.

2) The pitch of both currents through both cables rolled in spiral, causes that they behave as magnets referring to attractions and repulsions. Based on the results obtained, Ampère developed a "Newtonian theory" from the law of interaction among electric currents establishing the following analogies:

a) He defined specific current sections infinitesimally small, which he named "current elements" (nowadays known as the differential elements of the current) and whose behavior was going to be analog to the "matter corpuscles" of Newton.

b) The interaction among the current elements was similar to the one of the corpuscles of Newton: it could be of attraction or of repulsion and occurred along the line of union of the current elements (this means, the forces were central).

c) The forces of interaction among the current elements were directly proportional to the intensity of the current in each element.

d) Although not explicitly told, Ampère considers that the forces of interaction among the current elements, act instantaneously at a distance.

e) The forces of interaction among the current elements were inversely proportional to the square of the distance of separation among these elements.

Ampère's interpretation of the results obtained under the hypotheses employed was brilliant. It has to be highlighted, the construction of the "current elements". From the mathematic point of view his theory being consistent and elegant, resides in it includyng the experimental results which supported and provided whit validity and coherency and, it is clear that from the point of view of the philosophical interpretation, his theory is based precisely in the physical-philosophical postulates of Newton.

We can highlight Ampère's conclusions after performing the same experiment as Öersted:

1) Elements of equal electric currents (in direction and sense) are attracted to each other and elements of different electric currents (same direction but with different sense) are rejected among themselves.

2) The interaction force between current elements is at its maximum whenever the current elements are parallel be-

tween themselves and perpendicular to the line that unites them.
3) When a current element (originally parallel to another) moves angularly going far from the parallel position, the force of interaction diminishes gradually up to disappearance.

2. Michael Faraday's analysis to the experiment performed by Öersted and Ampere's reproduction

Through the Faraday's notes, so called " Historical Sketch of Electromagnetism" analyzed by Tricker [21], it can be easily perceived him having a high respect for Ampere's work, nonetheless, he expressed his disagreement with Ampere's interpretation to the results obtained by Öersted in his experiment.
The following aspects can be pointed out:
1.- Ampère could not (based on Newton's theory), explain why the interaction forces among electric currents depended on the angle formed between the lines of direction from the currents. The analogy intended by Ampère between the Newton's corpuscles and the elements of the current was not fully accomplished (the forces of interaction among currents are not central forces)
2.- Faraday, as previously stated, considered the forces as the prime substance of the universe and therefore he did not accept the electric charge being "a fluid".
3.- Faraday expected that the law of interaction of the currents was similar to the law of interaction of the charges. This means, he expected equal currents to reject themselves and mutual attraction amongst different currents.
4.- The similarity expected by Faraday in reference to the interaction among charges and the interactions among currents, was not susceptible of being developed from Ampère's approach, since his theory did not include the static charges. This constituted a special point of disagreement of Faraday with the Ampère's theory.
5.- Ampère's theory could only be confronted for the case of closed currents since the open currents could not be achieved in those days, they lasted shortly since the only way of producing them was connecting a conductor among two metallic spheres with different electric charge.
Faraday, while referring to the experiment performed by Öersted and to the interpretation that he gave to the results obtained, in his text *Historical Sketch of Electromagnetism*, expressed his agreement with Öersted, in the fact that the phenomenon can be properly interpreted from a theory of fields and not through the theory of Newton like Ampère intended, nonetheless, such agreement is partial because while Öersted allocated the confined phenomenon in the current conductive cable, Faraday said:
"*The electric conflict is not confined in the conductor, but it extends in the space around the conductor because other way it would not act at a distance over the magnetized needle*."
It can be observed that in this paragraph Faraday establishes that the interaction takes place by adjacentness and not at a distance, that the "field" resides as much in the conductor as in the space around it.
When reproducing Öersted's experiment and analyzing the obtained results, Faraday explains that "the forces produces by the pitch of the electric current through the conductor, are circular". Whit this new vision, Faraday glances the possibility of constructing a device known as "electromagnetic rotations" which consisted in making a conductor rotate continuously around a magnet or vice versa and what now is know as the forerunner of the electric engine.
It is important to notice that when Faraday affirms that "the forces are circular", he is rejecting the idea of the forces acting at a distance and besides, his hypotheses about the forces being the only formers of the universe, denies the existence of the vacuum and the extense corpuscles. In conclusion, he is rejecting the base and fundamental of Newton's philosophy, then, providing the forces with a category of existence per se, this means, he considers them substantial, provided with reality and therefore, under his conception, any distinction between matter and force is nonsense. This conception of the world of Faraday in which force is the only prime substance of the universe, and fill it completely, allows him to postulate a field of forces in which each point of space has an intensity and a direction and therefore, each point of space (force) can interact with the adjacent points.

3. ¿What made Faraday's Theory attractive to other scientists?

The Faraday's ideas previously exposed, answered some questions in that age, for example:

a) Force conservation law.
b) The identicity of all forces (which means, all forces are the same).
c) Through the equalization of matter and force, the diversity source was annulated.
d) Its universe full of forces cancels the need for postulating the action at a distance.
e) While the forces acting (points) on adjacent forces, any action necessarily should be progressive (it cannot be instantaneous).

f) Considering the corpuscles as special configurations of forces, explains the hardness and elasticity of the corpuscles.

Of course, making a profound philosophical analysis of Faraday's theory is not the author's objective and its extension is not possible in this brief space. What is important to us is that with these ideas in mind, Faraday developed a very extense research program, whose results were published in a group of texts named Experimental Research on Electricity [23], they tell his experimental activity performed from 1830 to 1860 and which was the kick off for James Clerk Maxwell to establish the mathematical theory of electrodynamics [24], which currently explains the electromagnetic phenomena at a macroscopic level.

4. Conclusions

The importance of the "field" concept is fundamental especially in those physics basic courses; therefore it is convenient that such concept is clear for all students from both philosophical and operational point of view.

As mentioned before, the available books to the medium superior level students, include the concept of electric and magnetic field but only from an operational point of view and without further base than its own existence.

The authors of this work consider that it is important to acquire philosophical concepts regarding the physics subjects in order to enforce the understanding of the operational part as well as the historical context under which they have been developed.

The authors suggest keeping in mind these ideas, so that the studies of physics contain a complete formation both philosophical and operational of its fundamentals..

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