What is light? What is ether? An overwiew of Einstein’s problem on the abolition of ether and on its inheliminable presence in General Relativity

Salvo D’Agostino - Sapienza Università di Roma - saldagostino21@gmail.com

Abstract: A study of the history of theories and experiments on Light is very extended, and covers many different aspects. I limit therefore my communication to the innovative views that ensued from Faraday’s and Maxwell’s field theory of Electricity and Magnetism. They discovered that light is an electromagnetic phenomenon, and that electromagnetic waves are propagated in ether with the velocity of light. Hertz’s great experiment was a relevant precedent to Albert Einstein’s revolutionary Relativity. I underline the problem of the abolition of ether in Einstein’s Special Relativity, and of its introduction in General Relativity.

Keywords: Maxwell, Hertz, Helmholtz, Einstein

1. Introduction

What is light? What is ether? Answers to these questions divided scientists and philosophers since an innumerable time. In analogy with a vibrating string as the causal source of music and sounds, Kepler, Huygens, and Newton argued that light was the invisible cause of our vision. Newton maintained that the spectral colors are Light’s fundamental components, and that Light is composed of particles. Fresnel made an experiment to convince his hard minded Laplace compatriot of the wavelike nature of light.

Maxwell’s field theory, and his electromagnetic theory of Light, fundamentally modified the scientists interests. Faraday’s view of independent existence of magnetic waves as free forces in space, differed from Maxwell’s conviction that ether had a role in his electromagnetic waves propagation. When Hertz in 1889 produced artificial electromagnetic waves, he was more favorable to Faraday’s view than to Maxwell’s conviction, and the transmission of forces through waves propagation represented for him the highest philosophical achievement in science. Maxwell’s theory was for him represented by Maxwell’s equation, a view on the nature of physics theories that had its relevance on Einstein’s revolutionary Relativity. As is known, Einstein thought that the abolition of ether was favorable to the success of his Special Relativity. Further on, however, he found that ether was a necessary background for General Relativity, and Unified Field Theories.

2. Maxwell's theory of light: a structural similarity betweem Maxwell's electromagnetic waves and the waves of light

James Clerk Maxwell brought into his Electromagnetic theory of light concepts and experimental data obtained from radically different atomistic and field theories. Theories of Mechanics and Electrostatic Potentials, and Wilhelm Weber's outstanding contributions to Electrodynamics were largely utilized. Green's and Stokes's elastic and hydrodynamic theories were also the underlying mathematics of Maxwell's equations. The identification of the velocity of electric and magnetic waves with the then known value for the velocity of light, a transition from a static to a dynamic field theory, represented an exclusive merit of the Scottish scientist. Maxwell's contributions to Electromagnetism and Field Theory have been frequently discussed in the history of science literature, with special attention to the discovery of his celebrated equations. However, the connection in Maxwell's research between Weber's velocity and velocity of his electromagnetic waves, has not been sufficiently analyzed, to my present knowledge, although this is one of the characteristic feature of Maxwell's approach to his theory of light (D'Agostino 1996). The quasi equality between Weber's velocity of motion of electric masses and Maxwell's velocity of electromagnetic waves has been misinterpreted as a logical consequence of premises that were foreign to Maxwell. Maxwell in fact duly underlined Weber's systematic definition of absolute units for electric and magnetic units, although he refused Weber's conception of a velocity of electric masses, and only accepted the experimental evidence of Weber's achievements. However, he considered the quasi-equality of Weber's velocity with his electromagnetic waves velocity one of the most important pieces of evidence in favor of his electromagnetic theory of light. And he added: "the best way to compare the properties of the electromagnetic medium to that of light is to compare the two velocity […] In the form which treats the phenomena of light as the motion of an elastic solid, the wavelike theory is still encumbered with several difficulties" (Maxwell 1954, p. 764).

Let us also notice after a few passage Maxwell's own comment a few years later: "the only ether which has survived is that which was invented by Huygens to explain the propagation of light" (Maxwell 1954, p. 771).

Writing in 1893, twenty years after Maxwell's Treatise, Oliver Heaviside quickly grasped the significance of Maxwell's innovations: "Elastic solid theories are a great deal too precise in saying what light consists of, and mechanical speculations in general should be received with much caution, and regarded rather as illustrations or analogies than expressions of facts. We do not know enough yet about the ether for dogmatizing".[1]

[1] The essence of Heaviside's statement concerns changes in "permittivity" and "electrical eolotropy". They can be *independently* observed, i.e., observed through electrical experiments which do not imply elastic-optical concepts or theories, whereas assertions concerning properties like density and elasticity of ether cannot be observed. The former are observable (factual) properties while the latter remain hypothetical assumptions.

3. Heinrich Hertz: ether polarization confirms Faraday's view of an independent existance of forces in space

In my analysis, I find enough evidence for Hertz's original conception of ether as a primitive polarized medium. He drastically refuted in fact Helmholtz's thesis that ether was secondarily connected to polarizations of the "Poisson type" (Hertz: "it is quite another question"). Hertz suddenly understood that the polarized medium was no less than ether itself, i.e., ether coincided with a polarized dielectrics. If this thesis is accepted, one has an explanation of the otherwise obscure passage in Hertz's Introduction: "I have rather been guided (in my experiments) by Helmholtz's work, as indeed may plainly be seen from the manner in which the experiments are set forth. But unfortunately, in the special limiting case of Helmholtz's theory which leads to Maxwell's equations, and to which the experiments pointed, the physical basis of Helmholtz's theory disappears, as indeed it always does [in Helmholtz] as soon as action-at-a-distance is disregarded. I therefore endeavored to form for myself in a consistent manner the necessary physical conceptions, starting from Maxwell's equations" (Hertz 1962). The different meaning attributed by Hertz to a polarization theory of ether can be better understood in the light of his conclusions on the nature of electric force, at the end of his work in electromagnetism. His basic tenet was in fact, that air and empty space could support electromagnetic wave not for the reason that they participate in the action of the supposed bound charges – according to a Poisson-Helmholtz conception – but, just on the reverse, air and material dielectrics behave like empty space for the reason that they participate in the nature of empty space, i.e. they embed "ether". For the electric force is, essentially, for Hertz a polarization of ether. One year later, following his experiments, he will attribute to Faraday's glory the new revolutionary concept of a dielectric action, and will express more clearly his ideas on this matter: "The most direct conclusion of the experiment on the finite velocity of propagation of electromagnetic forces, is the confirmation of Faraday's view, according to which the electric forces are polarizations existing independently in space" (Hertz 1962, p. 20).

A deeper consideration of the process which is at the origin of Hertz's contribution must take into account, in my opinion, Hertz's first approach to Maxwell's theory in his 1884 theoretical paper:[2] Maxwell's equations are therein deduced from old electrodynamics and from hypotheses that did not imply a dielectric action, in Helmholtz sense. Maxwell's equations result from a combination of Faraday's induction law, energy conservation, and his "principle of the unity of fields", a reiteration process, mathematically equivalent to a series expansion of the field. This fact might have counted in favor of his considering electric waves as dependent on something more essential than the behavior of material dielectrics. An important point in this paper is the so-called "principle of the unity of fields": the electric field has the same nature, irrespective of the mechanism through which it is generated, be it by standing or moving charges or by a static or changing magnetic field. The justification is found in the fact that "the electric field, according to Faraday's conceptions, is something existing in itself in space

[2] See the paper "On the relation between Maxwell's fundamental equations and the fundamental equations of the opposing electromagnetics" in (Hertz 1896, pp. 273-290).

independently of the way in which it is generated". It is this physical conception of a field as a self-sustaining entity that makes possible the conception of a self-sustaining wave of electric force as a physical entity (not a purely mathematical one).

A further example is given by Hertz in another passage: "Somewhat later on, I thought that I noticed a peculiar reinforcement of the action in front of such shadow forming masses, and of the walls of the room. At first it occurred to me that this reinforcement might arise from a kind of reflection of the electric force from the conducting masses; but although I was familiar with the conceptions of Maxwell's theory, this idea appeared to me to be almost inadmissible so utterly was it at variance with the conceptions then current as to the nature of an electric force" (Hertz 1962, p. 11).

Let us remark that Hertz admitted the irrelevance of the empirical role of observations in lack of the proper theoretical framework .

4. Einstein's Relativity: is ether a medium for the propagation of light?

The popular understanding of Einstein's decision to abolish ether in his celebrated 1905 essay on Special Relativity needs historical and philosophical analysis. Einstein's ideas on the ether problem are in fact strictly related to his technical and philosophical approaches to the whole context of his revolutionary theories. Einstein's original ideas on ether are condensed in one essay, in his 1920 book *Relativity, the Special and General Theory,* devoted to his early discussions on ether, and to his return to the same problem in his 1954 fifth Appendix added to the book, and titled *Ether and the Theory of Relativity and the Problem of Space* (Einstein 1954). Let us resume Einstein's most interesting remarks on ether in his 1920 essay.[3]

Einstein believes that "far-reaching similarity, which subsists between the properties of light and those of elastic waves in ponderable bodies", represented "a fresh support" for an elastic type of ether as a medium for light's waves. But the elastic approach to theory was also a source of great difficulties, because "neither Maxwell nor his followers succeeded in elaborating a mechanical model for the ether which might furnish a satisfactory mechanical interpretation of Maxwell's laws of the electro-magnetic field. *The laws were clear and simple, the mechanical interpretations clumsy and contradictory*" (my Italics). In Einstein's view, his special theory of relativity overcame the difficulties by a hard restriction. In his essay he assumed that ether consisted of particles whose motion was not observable in time:

> There may be supposed to be extended physical objects to which the idea of motion cannot be applied […] The special theory of relativity abstracted from ether the last mechanical characteristic. But, a non mechanical ether might appear as a superfluous requirement in place of electromagnetic fields as ultimate, irreducible realities […] If from the standpoint of ether this hypothesis appears at first to be an empty hypothesis, one should consider that in the electromagnetic processes in vacuo […] the electromagnetic fields appear as ultimate, irreducible realities, and at first it

[3] The following Einstein's original passages are quotations from Einstein 1920 essay.

> seems superfluous to postulate a homogeneous, isotropic ether-medium, and to envisage electromagnetic fields as states of this medium.

Let us remark that Einstein neglected that Herts stated that ether was a superfluous postulation, because he believed "the dualism still confronts us […] in the theory of Hertz, where matter appears not only as the bearer of velocities, kinetic energy, and mechanical pressures, but also as the bearer of electromagnetic fields".

Moreover, Einstein brought in another "argument" in favor of ether: "to deny the ether is ultimately to assume that empty space has no physical qualities whatever. The fundamental facts of mechanics do not harmonize with this view". A solution to the ether problem could be obtained by reducing the principles of mechanics to those of electricity, thus responding to the general tendency to give conceptual priority to electromagnetic concepts, especially when "a confidence in the strict validity of the equations of Newton's mechanics was shaken by the experiments with radioactive-rays and rapid cathode rays". One should not disregard however that the original Einstein's approach to ether couldn't neglect any attention to Lorentz, the authoritative supporter of an electrodynamic theory on the reality of ether. Let us notice how Einstein tends to conciliate the contrasting feature of the Lorentz's approach: "the space-time theory and the kinematics of the special theory of relativity were modeled on the Maxwell-Lorentz theory of the electromagnetic field". Moreover: "according to Lorentz's theory, electromagnetic radiation, like ponderable matter, brings impulse and energy with it, and as, according to the special theory of relativity, both matter and radiation are but special forms of distributed energy, ponderable mass losing its isolation and appearing as a special form of energy".

It is thus evident that Einstein regarded the role of a new ether as an intrinsic aspect of his recurrent hope of an unification of electromagnetism and gravitation:

> As to the part which the new ether is to play in the physics of the future we are not yet clear. We know that it determines the metrical relations in the space-time continuum, e.g., the configurative possibilities of solid bodies as well as the gravitational fields; but we do not know whether it has an essential share in the structure of the electrical elementary particles constituting matter. Nor do we know whether it is only in the proximity of ponderable masses that its structure differs essentially from that of the Lorentzian ether; whether the geometry of spaces of cosmic extent is approximately Euclidean.

In conclusion, we argue that Einstein accepted ether in his General Relativity as long as its physical nature could be conceived as something different from the centuries old concept of an uniform distributed special substance:

> What is fundamentally new in the ether of the general theory of relativity as opposed to the ether of Lorentz consists in this, that the state of the former is at every place determined by connections with the matter and the state of the ether in neighboring places, which are amenable to law in the form of differential equations; whereas the state of the Lorentzian ether in the absence of electromagnetic fields is conditioned by nothing outside itself, and is everywhere the same. The ether of the general the-

ory of relativity is transmuted conceptually into the ether of Lorentz if we substitute constants for the functions of space, which describe the former, disregarding the causes, which condition its state. Thus we may also say, I think, that *the ether of the general theory of relativity is the outcome of the Lorentzian ether, through relativation* [my italics].

5. Final considerations

The international success of Maxwell's and Hertz's local field theories, and the almost cotemporary triumph of Lorentz and Zeeman's antagonist theories of an atomistic microphysics, required a new type of analysis to scientists, historians, and philosophers of science.

It was Einstein's merit in 1905 to realize that excluding ether in his Special Relativity would advantage theoretical physics. However, he did not consider exclusion as an apodictic decision. At the end of his scientific life he was still fundamentally convinced that General Relativity could not renounce to ether: "according to the general theory of relativity space without ether is unthinkable: for in such a space there would not only be no propagation of light but also no possibility of existence for standards of space and time".

Since the theme of a theory that could succeed in associating gravitational and electromagnetic field as one unified theoretical context, interested Einstein's research on a Generalized Field Theory for the rest of his life. In this connection, Einstein's early neglect of ether declines in his mature reflections, and more comprehensive considerations are consistent with the fundamental tenets of his Relativity: "more careful reflection teaches us however, that the special theory of relativity does not compel us to deny ether. We may assume the existence of an ether; only we must give up ascribing a definite state of motion to it, i.e., we must by abstraction take from it the last mechanical characteristic which Lorentz had still left it. We shall see later that this point of view […] is justified by the results of the general theory of relativity".

The historian should concede that in Einstein's time conceptual relationship among ether, light, and electromagnetic waves, was far from presenting hopes for a rational approach. Very understandably, it was Einstein merit to settle the problem in his General Relativity by stating that in *line of principle* the velocity of light is a universal constant of nature.

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