

# Epistemological and educational study of the electromagnetic wave propagation in the empty space (vacuum), and how students understand the vacuum's concept



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## Abstract

It is well known that, in teaching electromagnetism theory, university students learn that the electromagnetic wave can propagate in the **vacuum** (empty space) with a limited speed. This is it was a consequence of Michelson and Morley experiment, this experiment allowed to deny the idea of the **Ether** (which was supposed the medium of electromagnetic waves propagation). In this article we discuss the notion of the empty space (**vacuum**) and we try to see the difference between the **physical vacuum** and the **absolute vacuum**. How can we explain that empty space (**vacuum**) is characterized by physics properties? Is the notion of the empty space justified in other fields of physics, knowing that the general relativity appeals to the existence of the **Ether**? Is it possible to explain the experiment of Michelson and Morley with other hypotheses? Is there in physics science a crucial experiment? The idea of empty Space (**vacuum**) appeared in physics due to the carelessness (negligence) of major principles. "**All which exists shows itself**". Finally, from our experience in teaching at Algerian university, we noticed that students don't differentiate between the absolute **vacuum** and relative physical **vacuum**, and most of students whenever we use the word **vacuum** think about the absolute one. For this purpose, we wanted to clarify and focus on the problem with students, so, a questionnaire was presented, to homogenous sample of Algerian third year physics students related to the subject, in order to see how students understand the **vacuum**. But we concluded from the survey's results that indeed the **vacuum** concept in physics should have a profound educational revision.

**Keywords:** Space, ether, medium, experiment of Michelson and Morley, E. M. wave, mechanical wave, general relativity, quantum mechanics.

## Resumen

Es bien sabido que en la enseñanza de la teoría del electromagnetismo, los estudiantes universitarios aprenden que la onda electromagnética se puede propagar en el **vacío** (espacio vacío) con una velocidad limitada. Esta es una consecuencia del experimento de Michelson y Morley, el cual permitió negar la idea del **Éter** (que se suponía que era el medio de propagación de las ondas electromagnéticas). En este artículo se discute la noción de espacio vacío (**vacío**) y tratamos de ver la diferencia entre el **vacío físico** y el **vacío absoluto**. ¿Cómo podemos explicar que el espacio vacío (**vacío**) puede ser caracterizado con propiedades de la ciencia física? ¿La noción del espacio vacío está justificado en otros campos de la física, a sabiendas de que la relatividad general recurre a la existencia del **Éter**? ¿Es posible explicar el experimento de Michelson y Morley con otras hipótesis? ¿Existe en la ciencia física un experimento crucial? La idea del espacio vacío (**vacío**) apareció en la física debido al descuido (negligencia) de principios más importantes. "**Todo lo que existe se muestra por sí mismo**". Finalmente, a partir de nuestra experiencia en la enseñanza en la universidad argelina, nos dimos cuenta que los estudiantes no diferencian entre el vacío absoluto y vacío físico relativo. Cada vez que utilizamos la palabra vacío la mayoría de los estudiantes piensa en el vacío absoluto. Por ello, hemos querido aclarar y centrarnos en el problema con los estudiantes, por lo que, se presentó un cuestionario a una muestra homogénea de estudiantes argelinos de física tercer año, relacionados con la materia, con el fin de ver cómo los estudiantes comprenden el **vacío**. Por los resultados de la encuesta, hemos llegado a la conclusión de que efectivamente, el concepto de **vacío** en la física debe tener una profunda revisión de la educación.

**Palabras clave:** Espacio, El Éter, Medio, Experimento de Michelson y Morley, Ondas EM, Onda mecánica, Relatividad general, Mecánica cuántica.

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## I. EPISTEMOLOGICAL STUDY

As it is well known, it taught to the university students that; the electromagnetic wave propagation does not require a

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medium (environment) for its propagation, and this wave can propagate in the empty space (vacuum). In the time before appearance of special relativity, the ether was considered as medium of electromagnetic wave propagation.

But the special relativity and Michelson and Morley experiment have replaced the notion ether, by the vacuum notion. This was a consequence of the "negative" results of the Michelson and Morley experience [1]. On the other hand this space (vacuum) is characterized by physical constants, such as the electric permeability and magnetic permittivity, of the space. These constants intervene in the electric and magnetic fields expressions of the electromagnetic wave, we know that both the propagation speed of electromagnetic wave: and vacuum impedance are also determined with the previous constants. As we mentioned above before the adoption of the vacuum, the ether was the medium allowing the propagation of the electromagnetic waves. This medium was considered as elastic medium (mechanical property of the ether).

Because of the elasticity medium hypothesis of the ether, Michelson and Morley tempted their experience aiming to measure or study the motion of the Earth in the ether. Even the experience repeated several times with increasing precision in each time, it gave always a negative results, neither in their period time, nor later; the latest experience was the one of Stephan Schiller from the Institute of experimental physics of Düsseldorf in 2003 [2].

Our question is why they didn't conclude simply from this experiment that the ether is not equipped with this mechanical property. Also, why not, with this mechanical hypothesis and the high speed of these transverse waves, this ether would have an incompatible density with the existence of movements of bodies within it; it could be consequently extremely fluid and couldn't be detected easily. Other authors gave another hypothesis for explaining the Michelson and Morley experience by considering that the matter is made by waves and how it behaves during the movement, the arms of the interferometer are made by matter, thus by waves. If the ether exists, matter and light which are moving in the ether are subject to the same constraints on its part. The arms of the interferometer deform exactly in the same way as the light rays, which travels through them. The arm shortens in the direction of movement. So there is no difference path between the light rays. And then the experiment result is necessarily negative [3].

According to those authors, the thing which contracts is the matter formed by waves, the fact because these waves, tighten forward their movement (motion), like every wave train emitted by moving source; or as a receiver feels in relative motion to a wave [3]. These authors conclude that:

The experience of Michelson and Morley does not prove the modifications of the space and of the time and does not prove the non-existence of the ether, but indeed shows the (wave-matter) complementary between the light and the matter. So, those authors concluded the following: about the ether we can't say nothing, we can say only, it should have a needed medium, so that these waves vibrate and propagate [3]. In the beginning of 1893, Fitzgerald [4], and later, Lorentz presented such an explanation, but it was not retained [5], [6]. We notice that, this is only another authors reading of the experiment, but with other hypotheses. So,

the special relativity replaced the ether by a new conception of the space, which is the vacuum in which the light has limit speed. Ether which previously (before the special relativity) was considered the privileged frame, becomes irreconcilable with the principle of equivalence of frames, which retains no privileged frame. In our point of view, the physics constants ( $\epsilon_0$ ,  $\mu_0$ ), which are characterize what was called vacuum, are a definitive proof which shows this space is not an absolute vacuum because this last one does not exist physically.

On 1920, May the 05th, at Leyde University, Einstein who denied the existence of the ether in the special relativity theory, has returned about the idea? We present as argument an extract of his conference which was given about the ether and the theory of relativity: "But on the other hand there is a weighty argument to be adduced in favor of the ether hypothesis, 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. For the mechanical behavior of a corporeal system hovering freely in empty space depends not only on relative positions and relative velocities, but also on its state of rotation, which physically may be taken as a characteristic not appertaining to the system in itself. In order to be able to look upon the rotation of the system, at least formally, as something real, Newton objectifies space.

Since he classes his absolute space together with real things, for him rotation relative to an absolute space is also something real. Newton might no less well have called his absolute space "Ether"; what is essential is merely that besides observable objects, another thing, which is not perceptible, must be looked upon as real, to enable acceleration or rotation to be looked upon as something real (End of the first extract) [7]. In the End of the first extracts, Einstein ends this conference by the following passage " By summarizing, being able to us say: according to the general theory of relativity, the space is endowed with physical properties; in this sense consequently the ether exists.

According to the general theory of relativity a space without ether is inconceivable, because not only the propagation of the light would be impossible. The case of space without ether, means, there would be even no possibility of existence rules and clocks, and consequently also for the space-time in the sense of the physics" [7].

Even though Einstein returned about the idea of empty space (vacuum) used the first time, by adducing in favor of the ether, we always see the idea of the empty space persisting until present in physics. In other hand we notice, especially in the case of mechanical physics always taught that the movement (motion) can only take place in an environment (medium) characterized by physical properties where there will be an exchange of energy between the mobile and the environment. We would like to notice that, in the case of electromagnetic wave, some authors especially who didn't believe in the existence of ether, interpreted that the energy exchange is previously reported between fields: the electric field (characterizing the medium) and the magnetic field (characterizing the

movement) [3]. We think that this characterization using electric and magnetic fields is only just a space's mathematical approach given to circumvent the problem of the propagation medium which was the ether.

energy of the mobile and the potential energy of the medium.

For the third and the fourth questions, the students answered results were better compared to the 1st and 2nd answers, but were unsatisfactory for a third year physics students.

## II. DIDACTIC STUDY

### A. Introduction

Because of the understanding difficulties of the concepts of vacuum to the students, which we mentioned during our teaching physics as a general case and electromagnetic theory as special case, we wanted to clarify some points concern the subject. For this purpose, we wrote a questionnaire sheet related to the subject. The questionnaire was presented to a sample of 40 homogenous third year physics students (case of Algerian universities). Our aim was to study the problematic in order to know what and how the students understood the concepts of vacuum.

### B. Questionnaire description

Answer: (yes) - (or: no) - (or: no idea) for each of the following questions:

- Does the absolute empty space 'vacuum' exist?
- Is it possible that the object's motion take place in a space without a medium?
- Does the vacuum mean a space without only matter and waves?
- Does the physical vacuum mean a relative vacuum?

### C. Questionnaire results

Figure 1 represents the results of the answers of the students, and Figure 2, represents the right answers.

## III. DISCUSSIONS OF THE RESULTS

The results got from the questionnaire show that nearly most of students gave different wrong answers to the above questions. (See Figure 1). When we compare the student's results in Figure 1, with the right answers in Figure 2, we find that the average of right answers was only about 34%, and the average wrong answers was about 66%. We can easily notice that the concept of empty space (vacuum), is not clear to the students. Now we would like to discuss the students' answers of the questions. In the first question, most of students believed the existence of a space without any thing inside, means without a matter or waves, or particles, or even virtual particles, like they believe in the existence of the nil, (space full with nothing in).. In the second question also, most of students believed that a motion can be occurred or take place in a space without medium, it seems that students ignore or they didn't understand the basic principle of movement (motion), which is: the movement arise by an exchange between the kinetic

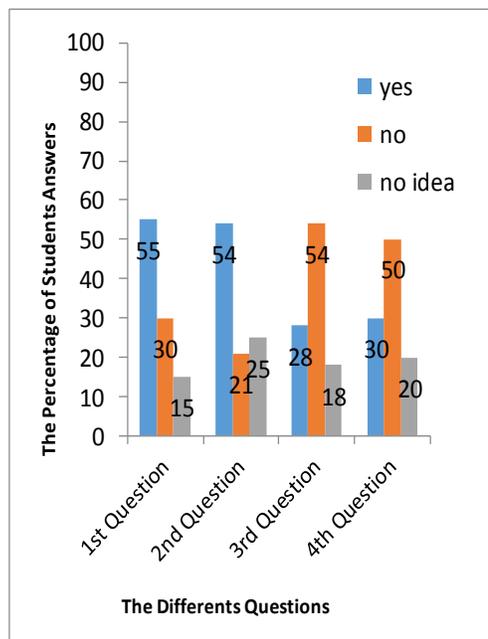


FIGURE 1. Show the students answers.

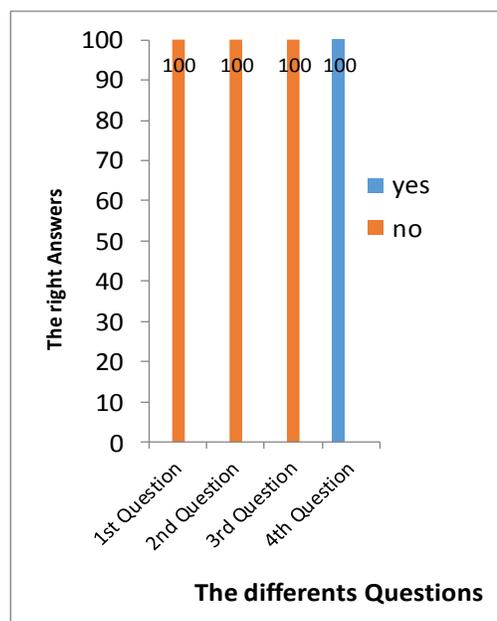


FIGURE 2. Show the right answers.

#### IV. CONCLUSION

It is well known, that after the special relativity period, which imposed the nonexistence of the ether, the space began to fill again and again: With Dirac and the standard theory, the vacuum can be drilled as a "sea" of carrier virtual particles of all the interactions between particles [8]. In this sea "vacuum" resident or exist all particles that we do not yet know [9]. The quantum physics considers the vacuum as the place of a considerable energy, at the same time it conceives this place as the fundamental state of the system of minimum energy, a state of equilibrium, state of minimum energy, but no null energy [10]. Richard Feynman considered void content in a simple light bulb would be enough to boil all the oceans of the world. The empty seat would be the most violent physical manifestations [11].

So we finish by the following: We noticed that; the vacuum concept has been introduced in physics because of an uncertain interpretation of Michelson and Morley experiment. This experiment had been conceived on the basis of the ether as being an elastic medium. We think that, before adopting a notion or a concept, it is necessary to make sure that this goes with major principles. The major principles refuse the notion of the absolute vacuum because: "which exists shows itself" but the absolute vacuum has no physical property (cannot show itself). The existence is characterized directly or indirectly.

Finally, because of the negative influence of the student's assimilation of the vacuum meaning, due to interpretation results of Michelson and Morley experiment, we suggest for teaching physics (especially electromagnetic theory) that: the vacuum word, might be replaced by the notion of physical space characterized, but imponderable.

Also we suggest an extra course of epistemology to university physics students, about the greatest principle and concepts, to improve the students' assimilation, such the following principles: final causality, last action, determinism,..., and the following concepts: vacuum, space,

time, objective existence(objectivism), Mental existence complementarity, and so on,....

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