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THE ELECTROMAGNETIC THEORY AND THE ABSTRACTION OF THE ENERGY CONCEPT AND THE CONSERVATION LAW

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Abstract

Energy is one of the most important concepts in Physics. Its construction has been the result of a long and complex process of conceptual Energy is one of the most important concepts in physics. Its construction has been the result of a long and complex process of conceptual abstraction and a compendium of various fields of science that begins with the Huygens's idea of 'vis viva' to the concept we currently know and that was established in early last century. The principle of energy conservation emerges as one of the unifying pillars of physics and its generalization can be synthesized in many areas such as mechanics, thermodynamics, electromagnetism and modern physics. In this work, we present a brief historical and epistemological introduction of the concept of energy, focusing on the electromagnetic field. We shows how the field theory made contributions to energy conservation, and how the use of history has didactic implications in favor of the teaching and understanding of conservation, transformation, transferring and dissipation of energy in physical processes.

Key words: Physics, conservation of energy, electromagnetism, teaching and learning of energy.

LA TEORÍA ELECTROMAGNÉTICA Y LA ABSTRACCIÓN DEL CONCEPTO DE ENERGÍA Y EL PRINCIPIO DE CONSERVACIÓN

Resumen

La energía es uno de los conceptos más importantes en física. Su construcción ha sido consecuencia de un largo y complejo proceso de abstracción conceptual y un compendio de varios campos de la ciencia, que se inicia con la idea de Huygens de la “vis viva” hasta el concepto que hoy conocemos y que se estableció a comienzos del siglo pasado. El principio de conservación de la energía surge como uno de los pilares unificadores de la física y su generalización se puede sintetizar en muchas áreas como la mecánica, la termodinámica, el electromagnetismo y la física moderna. En este trabajo, se hace una breve introducción histórica y epistemológica del concepto de energía, enfocado en el campo electromagnético para hacer notar como la teoría de campos hizo aportes a la conservación de la energía. Adicionalmente, es discutido como la utilización de la historia tiene implicaciones didácticas que favorecen la comprensión de la conservación, transformación, transferencia y degradación de la energía en los procesos físicos.

Palabras clave: Física, conservación de la energía, electromagnetismo, enseñanza y aprendizaje de la energía.

A TEORIA ELETROMAGNÉTICA E A ABSTRAÇÃO DO CONCEITO DE ENERGIA E PRINCÍPIO DE CONSERVAÇÃO

Resumo

A energia é um dos conceitos mais importantes em física. Sua construção tem sido consequência de um longo e complexo processo de abstração conceitual e um compendio de vários campos da ciência, que se inicia com a ideia de Huygens da “vis viva” até o conceito que hoje conhecemos e que foi estabelecido a inicios do século passado. O princípio de conservação da energia surge como um dos pilares unificadores da física e sua generalização se pode sintetizar em muitas áreas como a mecânica, a termodinâmica, o eletromagnetismo e a física moderna. Neste trabalho, presenta-se uma breve introdução histórica e epistemológica do conceito de energia, focando no campo eletromagnético para fazer notar como a teoria de campos fez aportes à conservação da energia. Adicionalmente, é discutido como a utilização da história tem implicações didáticas que favorecem a compreensão da conservação, transformação, transferência e degradação da energia em processos físicos.

Palavras-chave: Física, conservação da energia, eletromagnetismo, ensino e aprendizado da energia

Introduction

In Physics, the concept of energy is one of the most important. Its construction has been achieved after a long and complicated process of conceptualization and synthesis that starts with the idea put forward by Aristotle in his "Nicomachean Ethics"; through the concept of "vis viva" (living force) introduced by Huygens in the seventeenth century, until to culminate in the current idea established in the early years of the last century and it was summarized in a general principle of conservation of energy applied in all fields of Physics for isolated systems i.e. those that not transfer energy to the working environment by heat, mechanical or electromagnetic waves, or any other form of energy transmission.

By solving the total energy of a system it is considered the following kinds of energy: energy of the free particles, energy of the free fields, energy of interactions between particles and fields. Each of them can change over time becoming one of the other classes, but the result does not change, it is preserved. However, when teaching the concept of energy, usually a generalized concept that leaves explain all movements in nature is used. In this regard, in the early 1960s Richard Feynman said the following at a conference dictated for undergraduates at the California Institute of Technology on the concept of energy: "There is a reality, or if you want, a law that governs natural phenomena that are known so far. There is no known exception to this law; it is accurate to our knowledge. This law is called the conservation of energy; it states that there is a certain amount, which we call energy that does not change in many changes that Nature experiences. That is, it is a very abstract idea, because it is a mathematical principle; it says that there is a numerical quantity which does not change when something happens. It is not a description of a mechanism, or anything concrete; it is just a strange fact that we can calculate some number, and when we finish watching Nature bear their tricks and calculating the number again, it is the same. "This abstraction or generalization ignores the difficulties of students to achieve meaningful learning of the energy concept and also it hinders the use of the history of Physics as an aid to better grasp the idea. These difficulties may be the identification of the concept of work with effort, to confuse energy and power; to assign a material to relate character to energy, to relate it only to movement or activity, considering that energy is spent or saved as a result of everyday language, since it is saturated with terms like "energy consumption" or "energy crisis"; confusing forms of energy sources as well as ignoring variations in the internal energy, to consider the heat in terms of a substance or a form of energy; to confuse heat and temperature, etc.

This can be corroborated by the fact that the historical development of the concept of energy has been a long process of generalization that can be summarized in four main periods: the conservation of energy in mechanics, conservation of energy in thermodynamics, energy in the electromagnetic field, and finally, the energy in Modern Physics. In this work we interested in analyzing the evolution of the concept of energy in the third phase, i.e. the establishment of electromagnetic theory which led to the importance of the fields and radiation as a new process of energy transfer. However, we state that it is from the obstacles that come along in the history of Physics that you can get information about the difficulties of the students also to help us to find more positive attitudes toward Physics and their learning and to enable students to use their own scientific work strategies.

Historical compendium of the process of abstraction of the concept of energy and its conservation

The word energy, etymologically speaking, comes from the Greek “energon” meaning "doing work" where “ergon” states work, or action. Since ancient times, man has speculated that there has been something in the universe that has given life to animals and people and this idea has been expressed in many mythologies like Hindu, Greek, Chinese, Egyptian, etc. Galileo was the first to treat in XVI century the modern concept of energy by making many experiments with pendulums or balls falling on inclined planes. In "Discorsi e dimostrazioni intorno matematiche a due nove science attenanti alla mecanica i movimenti locali" written in 1638, he stated regarding the movement of a body falling freely, it reached the same height from which it left if collided elastically against a surface and it did not take into account the friction with the air. Although he made no observation or energy conservative type, these experiences have been considered as one of the first demonstrations of the conservation of "vis viva" (living force) (Holton, 1979) that later in the century XVII try Leibniz, Huygens and Wallis in his experiments with elastic collisions. They thought that the "vis viva" was the magnitude remained constant in the crash, thus emerging for the first time in the history of Physics, an energy amount that not varied and it was kept for the phenomena of mechanics. The validity of this concept spread in the eighteenth century when Daniel Bernoulli developed his Hydrodynamics from the fact of conservation of living forces in fluids (Taton, 1972), an idea which then he applied to a set of objects that attract or move to a common point, in obedience to a law which is a function of distance. In the seventeenth and eighteenth centuries it is shown in an implicit way, the idea of potential energy in Galileo, Huygens, Leibniz and Bernoulli that relate to the life force, stress, etc. The concept of potential arises in 1777 when Lagrange solved a problem related to a system of particles that attract each other by interaction of gravity. Upon completion of the eighteenth century the concept of energy conservation, as stated in their way of "vis viva" was an established principle of mechanics. However, its epistemological character was still very confused (Truesdell, 1975). D'Alambert thought at that time that the conservation of living forces could be deduced from the laws of motion for systems with certain restrictions. To Lagrange, this law was a corollary of the ideas in his Mécanique Analytique when the bonds are independent of time and there is no friction. Daniel Bernoulli promoted to the rank of fundamental principle, not deductible from the laws of mechanics. It also appeared that was not held in phenomena such as inelastic collisions or where friction occurs.

The non-conservation of "vis viva" in inelastic collisions led to introduce the concept of internal energy and the first law of Thermodynamics in the nineteenth century. Prior to this, it had already revised the caloric theory, it had established the concept of “temperature” and it had developed some thermometric scales and it had appeared some thermometers (water, alcohol, mercury), as well as the concept of “specific heat” was introduced and the way how to determine it. Black (1728-1799) noted that, in the changes of state, it was absorbed or it was yielded an amount of heat without the temperature varies. He called this heat “latent heat” and he created a technique to measure it (Taton, 1972). The second law of thermodynamics stated that in processes where energy is transformed part of it tended to dissipate heat, therefore the energy available to do work decreased in closed systems. This increased disorder was coined by R. Clausius as entropy. Clausius stated the two laws of thermodynamics as follows: "The energy of the universe is constant. The entropy of the universe tends to a maximum "(Harman, 1990). A mechanical notion of energy with work as its fundamental measure excelled in physics in the mid nineteenth century. This was reflected in the many stories of thermodynamics that were written before the end of the century causing many discussions and debates about the priority of its discoverers and on the scientific and philosophical significance of the different formulations of its laws.

At mid-nineteenth century it was established simultaneously and independently by Mayer (1814-1878), Joule (1818-1889) and Helmholtz (1821), the principle of conservation of energy. The result of this principle was a long and complex process; it was the combined efforts of various schools of thought: the German philosophical doctrine known as Naturphilosophie, the interconvertibility of certain phenomena, the progress of work and conceptual equivalence of work and heat (Kuhn, 1982). In the second half of the same century the issue of thermal radiation is treated using the theoretical model of black body. This situation was based on Thermodynamics and Electromagnetic Theory, but it could not explain the energy distribution of the black body that had known experimental techniques. This event led to the quantization as a new facet of the energy and the emergence of Quantum Mechanics. The assumption of energy quantization was brilliantly supported by Einstein's work on the photoelectric effect and the Bohr's model. Einstein thought that the energy of the frequencies of light behaved as if they were concentrated in "packets" of energy. These "packets" were called photons in 1926. Black body analysis made clear the limitations of Mechanics, Thermodynamics and Electromagnetic Theory to explain the physical world. Some phenomena, such as the energy distribution of the black body, the photoelectric effect and the emission spectrum of hydrogen, could only be understood from the discrete nature of energy.

At the end of the nineteenth century Classical Mechanics of Newton was consolidated and marched reasonably well. But nevertheless, there were facts that did not fit well, as some topics of electromagnetism, the nature of light, its speed and the elementary structure of matter. These "mysterious" issues of Physics encouraged physicists to speculate and to think about possible solutions to these questions. By this time it was believed the existence of ether as an axiom, and by means of this model it is expected to find the absolute velocity of a dependent object of a universal reference system. The Michelson-Morley experiment performed in 1887 was to measure the speed of the earth about this fluid, but the results were negative and directly caused the Theory of Relativity of Einstein who enunciated two assumptions: first, all the laws of Physics also including the electrodynamics must be invariant in inertial frames; second, the speed of light is constant and independent of the motion of the observer or the source. Based on these postulates Einstein developed the Special Theory of Relativity which consisted of a total revision of the concepts of space, time and simultaneity, as well as the discovery of the rest energy, which is the energy of the mass in the famous equation $E = mc^2$. This concept allowed explaining the origin of the energy released in radioactive decay and nuclear reactions. Later, Einstein generalized this result to include the gravitational mass.

Finally, it is important to note that the deeper meaning of the law of conservation of energy was implanted with Noether's theorem where the relationship between the invariance of the equations under certain transformations and conservation principles appears. According to this theorem, if the equations that solve the dynamic behavior of a system remain unchanged, at performing a mathematical transformation, it exists for each of them, a physical quantity that remains constant over time. In our case, the conservation of energy arises from the temporal homogeneity, i.e., the fact that the laws of nature are invariant in temporal translations.

The electromagnetic theory and the concept of energy and its conservation

The current idea of electromagnetism we have today has its beginnings in several experiments conducted mainly during the nineteenth century in which the unification of the theories of electricity and magnetism was drawn. Before this proposal electric and magnetic phenomena were considered separately, having developed theories from ancient Greece; however, it was not until the late sixteenth century when the first scientific discoveries were made in the field. At mid-nineteenth century Newtonian Mechanics had achieved remarkable progress. But nevertheless, despite its great successes in explaining many phenomena, it was something to solve. The reciprocal interaction that occurs when two bodies interact with each other is played through the remote action taking place instantaneously. This meant an infinite speed to communicate the action and the presence of a material medium, the ether, through which the action was broadcast. The electric force between two charges, also expressed these problems. This situation could be solved by introducing Physical Field Concept, physical reality that was shown, and also tested their properties, including the energy, which in this case moves to the speed of light in an undulating harmonic pattern, thus widening the spectrum of energy and its conservation, to consider the energy of the electromagnetic field and transmitting radiation through. It was Maxwell (1831, 1879) who in his work on the Electromagnetic Field had articulated the progressive distancing of mechanical pattern (Harman, 1990), something that can be seen in his equations of electromagnetism and from which Poynting (1852, 1914) could discovered that the flow of electromagnetic field energy is proportional to the cross product of the electric and magnetic field (Whitaker, 1989), as well as, deriving a principle of conservation of energy of the electromagnetic field , whereby there is a relationship between the change of the electromagnetic energy in a given volume, the flow of the radiated energy and the work performed by the field on the charges. The study of the electromagnetic field presumes introducing free energy field itself and transfer by means of radiation.

Didactic considerations

According to the preconceptions of students studied in many works found in the literature of Experimental Physics and according to the historical evolution of the concept of energy we have shown in this study, we can conclude that there are similarities between the previous ideas of students and some historical aspects of the energy concept development. The first demonstrations of energy conservation which tested were related to the movement, while the potential energy is analyzed two hundred years later. Similarly, students relate energy to movement and they show great difficulties when they have to analyze the energy associated with the position of an object. They imagine that heat is a substance found inside the bodies and it moves from one to another when they are in contact, a situation that is similar to the caloric theory. In addition, students do not differentiate between the amount of heat and the concept of temperature, such as in Physics before the works of J. Black. Teaching experience shows that, in general, learning of electromagnetism in university basic levels shows major drawbacks in students. These difficulties are mainly manifested in the conceptual aspects of the subject. There can be many sources for these difficulties, among them, the traditional structuring of the content that has neglected the history of electromagnetism. The contributions of the Field Theory or the Modern Physics to the conservation of energy rarely it is found in textbooks. This causes difficulties to grasp the concepts of relativity. The traditional approach communicates an incomplete perception of energy and its essential aspects, and does not show that the energy is conserved in the different phenomena that are present in the fields of physics.

Conclusions

We have considered in this paper how the History of Physics can help to improve the teaching of the principle of conservation of energy and all energy-related concepts. We have also tried to make clear how this history works to overcome an ahistorical and decontextualized image on the introduction of ideas and scientific theories. This is the educational landscape that has given us a traditional approach to address the teaching and learning of electromagnetism. A structural thread that goes from simple to complex is not captivated with a rational, logical and understandable to the mind of a student who requires an efficient learning approach. The student is not motivated so that there is a correspondence between the phenomenological aspects and systematic conceptualization as it was happened to structure the electromagnetic theory. Moreover, the classical problems of implementation for this topic, where static geometric configurations of charges are presented and the field or the potential somewhere are asked, or the capricious of remote loading configurations out of his experience are requested, they help to generate in students an attitude of rejection difficult to overcome.

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