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Quantum Physics Content in a Colombian Physics Textbook

Contenido de física cuántica en un libro de texto de física colombiano

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ABSTRACT

Keywords:

Quantum,
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The purpose of this research is to characterise how one of the most widely used physics textbooks in the southwest of Colombia deals with the rupture between classical physics and quantum physics. In order to achieve the proposed objective, a qualitative methodology with a documentary analysis approach was used. As units of analysis, we considered the spaces where the textbook makes explicit content associated with Modern Physics. Two levels of analysis were considered: the content associated with Quantum Theory and the crisis of Classical Physics in the face of the impossibility of explaining some quantum phenomena. The results indicated that the contents addressed in the textbook do not focus on the crisis of Classical Physics. Therefore, it is necessary for Colombian educators who use the book analysed to prepare and develop their classes to appropriate a Quantum Theory that allows them to overcome this limitation.

RESUMEN

Palabras clave:

Cuántica,
Física Clásica,
libros de texto

El propósito de esta investigación es caracterizar cómo uno de los libros de texto de física más utilizados en el suroeste de Colombia aborda la ruptura entre la física clásica y la física cuántica. Para lograr el objetivo propuesto se utilizó una metodología cualitativa con enfoque de análisis documental. Como unidades de análisis se consideraron los espacios donde el libro de texto explicita contenidos asociados a la Física Moderna. Se consideraron dos niveles de análisis: el contenido asociado a la Teoría Cuántica y la crisis de la Física Clásica ante la imposibilidad de explicar algunos fenómenos cuánticos. Los resultados indicaron que los contenidos abordados en el libro de texto no se centran en la crisis de la Física Clásica. Por lo tanto, es necesario que los educadores colombianos que utilicen el libro analizado para preparar y desarrollar sus clases se apropien de una Teoría Cuántica que les permita superar esta limitación.

Introduction

There is an urgent need to modernise the Natural Sciences curricula in Colombian educational institutions. In Physics, the area of knowledge of interest in this article, it is necessary to include elements to promote the understanding of phenomena linked to Modern Physics, especially those associated with the Theory of Relativity and Quantum Theory. This can be encouraged in secondary education (Fanaro & Otero, 2011).

The study of the Theory of Relativity and Quantum Theory are determinant for the citizen and scientific education of a country; in addition, there is a growing interest among students in Modern Science, as the following points out (Sinarcas & Solbes, 2013). On the other hand, this subject

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allows us to understand phenomena linked both to radioactivity and the atomic structure of atoms and to the electrical and magnetic properties of bodies. Key phenomena for understanding industrial, electronic and communications development (Sinarcas & Solbes, 2013).

The rupture between Classical Physics and Quantum Physics (the focus of the research) is assumed in Colombia as a conceptual gap, which leads to its non-consideration as an object of reflection in school curricula. Specifically, there is evidence of a scarce and formalist teaching where the focus is on the chronological description of atomic models (Solbes, Muñoz & Ramos, 2019). This epistemological rupture, which is configured as a lack, does not allow us to reflect on the crisis of Classical Physics, that is, to understand why it is impossible to explain the photoelectric effect, the instability of Rutherford's atom, atomic spectra and black body radiation from Classical Physics; issues which, in turn, led to the advent of Quantum Physics.

It is necessary to state that, when speaking of epistemological rupture, it is from the perspective of Thomas Kuhn who, in The Structure of Scientific Revolutions (Kuhn, 1962), postulates that the development of science does not follow a uniform and linear process, but is a complex system of revolutions and states of science, in which a revolution can occur due to a different logic of thought, as is the specific case between Classical Physics and Quantum Theory. Hence, addressing the crisis of Classical Physics denotes an epistemological rupture and requires its consideration in secondary education. This is the way for future citizens to understand classical theories and demonstrate their limits of validity (Sinarcas & Solbes, 2013), and it also allows them to demystify the idea of a linear, sequential and cumulative science (Solbes, Muñoz & Ramos, 2019) and to understand how many technological elements that surround us today work (González, Muñoz & Solbes (2020), for example: lasers, photovoltaic cells and the existence of new materials.

One of the most relevant problems in dealing with the rupture between Classical Physics and Quantum Physics is the lack of conceptual training of teachers (Fanaro & Otero, 2011). Research has shown that a conceptual and didactic foundation for teachers is necessary, this would allow the subject to be addressed in the classroom with fewer conceptual and epistemological errors (Fernández, González & Solbes, 2005; Cuesta-Beltrán, 2018).

This issue delegates a determining role to textbooks, the reasons that give rise to such selection the fact that these didactic materials evidence the educational and cultural values and traditions, which are the basis of educational systems (Pepin, Haggarty & Keynes, 2001), In addition, they constitute one of the most used teaching materials by teachers when planning, preparing and developing their math classes (Schmidt, Jorde, Cogan, Barrier, Gonzalo, Moser & Wolfe, 1996), they are considered as mediating tools that give concrete meanings to the stipulations included in the standards prescribed by the institutions that regulate educational systems (Sacristán, 2005). Therefore, textbooks become a source to identify the content taught by the teachers (Pepin, Haggarty & Keynes, 2001) and the ways in which it is presented in the classroom (Marmolejo & González, 2015; Marmolejo, 2021).

Unfortunately, conceptual problems have been revealed in these didactic materials, such as outdated content, conceptual and epistemological deficiencies, simplified or reductionist presentations, among others (Quílez, 2009). Despite this being an important conceptual and didactic problem, the few investigations that can be related to it, present an analysis of textbooks, mainly physics, addressing conceptual aspects, historical background and even images and, (Otano, 2008; Ramírez, Fleisner & Viera, 2017), but not so, epistemological shortcomings. that can be evidenced.

In short, if the aim is to update the Natural Sciences curriculum, it is therefore necessary, at least in the first instance, to explore how Physics textbooks

consider the epistemological rupture between Classical Physics and Quantum Physics (Jaimes-Ojeda, 2017; Hernández-Suárez, Prada-Núñez & Avendaño-Castro, 2020). From this perspective, the purpose of this research is to characterise how one of the most widely used Physics textbooks in the south-west of Colombia deals with the break between Classical Physics and Quantum Physics.

Materials and Methods

The methodology developed for the analysis was qualitative: the data were filtered according to the criteria of the researchers and were collected through the ways of proceeding discriminated in the study (Bisquerra, 2009). A documentary and inductive approach was considered (Bisquerra, 2009). Regarding the first aspect, a heuristic (search and compilation of information sources) and hermeneutic (reading, analysis, interpretation and critical and objective comprehension) approach was assumed. In relation to the second aspect, for the extraction of the categories of analysis, the information set out in the document analyzed was considered.

The case analyzed was a Physics book. The selection criteria were: a) being one of the most widely used books in the south-west of Colombia; b) having been published recently; and c) being aimed at students in the eleventh grade of secondary education. With regard to the first selection criterion, it is important to point out that a simple survey was applied to practicing teachers in a group of educational institutions in the south-west of Colombia (Twenty teachers of physics were asked what are the textbooks that they have used the most in their pedagogical practice?). As units of analysis, the information presented in the content of the textbook was considered.

Eight units structure the textbook analyzed in the research, namely oscillations, waves, acoustics, optics, electrostatics, electric charges in motion, electricity and magnetism, and modern physics. Each topic covered includes commentary to engage the reader's interest (historical facts of interest, properties of materials, activities related to the Science, Technology and Society component). Similarly, each unit presents a section of activities with exercises and open questions, which can be used to provide feedback or to assess the knowledge mobilized. There is also a section called: I am a natural scientist, which presents an experimentation exercise (laboratory).

Finally, as far as the analysis instrument is concerned, the documentary analysis methodology was followed, Where, the first phase (heuristics) corresponds to the selection, organization and preparation of the material that will be analyzed. which in its second phase involves taking the grid and contrasting the content of the document with the analysis sheet, in order to answer each question in the grid. For the second category of analysis, we also contrasted what the book presents, whether or not emphasis is placed on the crisis and the epistemological implications that derive from it, and the findings were recorded on analysis sheets.

Two categories of analysis were assumed: content (content associated with Quantum Theory exposed in the textbook analyzed) and crisis (crisis of Classical Physics in the face of the impossibility of explaining some quantum phenomena). The first category of analysis will allow us to answer the following questions: in the chapters of the textbook analyzed, is the study of modern Physics promoted, and if so, ¿which concepts are the object of reflection? The second category of analysis, on the other hand, will provide elements to answer questions such as the following: ¿does the textbook state the crisis of Classical Physics? Is the impossibility of Classical Physics to explain the instability of Rutherford's atom, the photoelectric effect, atomic spectra and black body radiation evident? Is emphasis placed on the rupture between Classical Physics and Modern Physics in terms of indeterminism and the duality of quantum objects?

Results and Discussion

The results of the research exclusively considered the content expressed in the last unit of the textbook analyzed, entitled Modern Physics. The contents covered and the structure of the unit are outlined in Table I.

Table I. Modern Physical Unit: structure and elements of consideration.

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Fuente: Rojas & Castaño (2016)

Table I shows that the textbook proposes as elements of study questions alluding to Relativity and Quantum Physics, as well as developing the concepts of the atomic spectrum and the photoelectric effect, among others. However, in no case is emphasis placed on the crisis of Classical Physics in the face of the impossibility of explaining the phenomena described above.

Specifically, in relation to Rutherford's atomic model, it is presented from its general perspective. That is, the idea is stated that the total mass of the atoms is concentrated in a tiny positively charged nucleus, around which the electrons (of negligible mass) revolve and in sufficient number to neutralize the charge of the nucleus. This model is referred to as the planetary model, as shown in Figure 1.

This leaves aside any attempt to emphasize the inconsistencies of Rutherford's model, especially with regard to the stability of atomic systems, which contradicts the fundamentals of Classical Mechanics. Electrodynamics explains that any movement of electrons around the nucleus must result in the loss of energy in the form of radiation. Therefore, the electrons would end up in the nucleus.

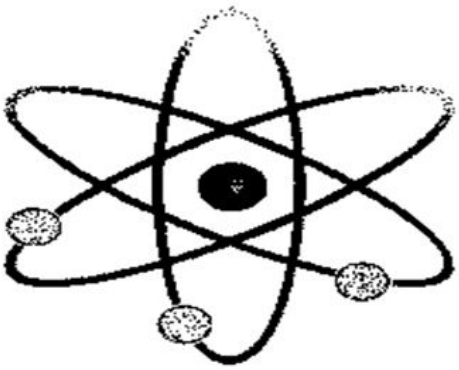
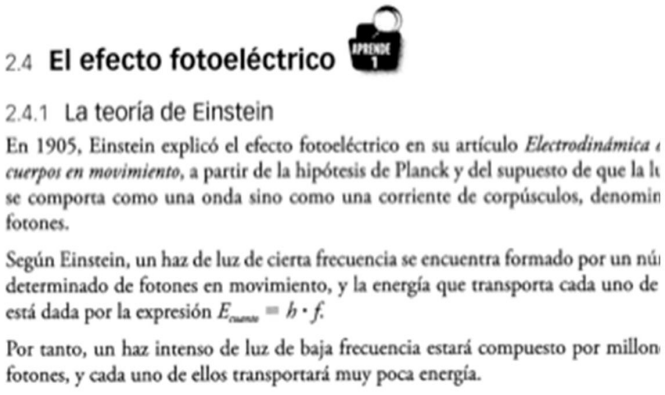


Figura 11. *Modelo atómico de Rutherford. En el núcleo central se concentra toda la carga positiva, y en la corteza se encuentra toda la carga negativa.*

Figure 1. Image of Rutherford's atomic model

Fuente: Rojas & Castaño (2016).

As for the photoelectric effect, it is presented, but no discussion is promoted to show that classical physics cannot explain it. The text, as shown in Figure 2, does not represent the phenomenon, but does not present a detailed explanation of how Einstein uses quantization of energy to explain it. A decisive issue that consolidates the birth of the Quantum Theory and that was validated by Planck's work.



2.4 El efecto fotoeléctrico

2.4.1 La teoría de Einstein

En 1905, Einstein explicó el efecto fotoeléctrico en su artículo *Electrodinámica cuerpos en movimiento*, a partir de la hipótesis de Planck y del supuesto de que la lu se comporta como una onda sino como una corriente de corpúsculos, denomin fotones.

Según Einstein, un haz de luz de cierta frecuencia se encuentra formado por un nú determinado de fotones en movimiento, y la energía que transporta cada uno de está dada por la expresión $E_{fotón} = h \cdot f$.

Por tanto, un haz intenso de luz de baja frecuencia estará compuesto por millon fotones, y cada uno de ellos transportará muy poca energía.

Figure 2. Photoelectric effect

Fuente: Rojas & Castaño (2016)

The text does not mention black body radiation. This phenomenon is a necessary starting point to introduce the subject of Quantum Physics, because, at the end of the 19th century, Classical Physics could not explain the thermal radiation emitted by a black body, the knowledge that up to that moment constituted Classical Physics did not allow it. This fact shows the limits of knowledge. A black body is one that only emits the radiation due to its thermal state; any other radiation that reaches it is absorbed by it.

The above results show that the textbook refers to Planck's work and his hypothesis. But it does not state that these hypotheses were constituted as a new theory, especially when in 1905 Einstein published the article On a Heuristic Viewpoint Concerning the Production and Transformation of Light, in which the photoelectric effect is explained quantumly (Petrucci, Geoffrey, Madura & Bissonnette, 2011).

Likewise, one would expect the textbook in presenting the Rutherford model to explain that it did not fit the Classical Electromagnetic Theory and could not explain the discontinuous spectrum of atoms. Precisely, this is another fact that put Classical Science in crisis, specifically the field of spectroscopy.

In this respect, it is important to remember that the Electromagnetic Theory at the end of the 19th century predicted the emission of light as a continuous series of colours. But, as with the predictions related to the photoelectric effect, experimentation would prove otherwise. Thus, the mystery of the spectroscopic lines constitutes another breaking point by contradicting experimentally, once again, what was predicted by the Electromagnetic Theory (Solbes, 2018).

In short, Rutherford's model was untenable, since, when applying the Laws of Electromagnetism, the electrons would emit radiation, with which the atoms would have collapsed and, therefore, the existence of matter would not be possible.

Finally, the text does not explain quantization as an ad hoc introduction: it does not fully develop the concept, which highlights the inability of Classical Electrodynamics to account for the subatomic world (Holton & Brush, 2007). In this respect, the importance of these explanations is stressed in order to consolidate the idea of the crisis of the explanatory power of classical physics and to answer the question: ¿how does the advent of quantum theory constitute a disruption in science and its logic?

Conclusions

The relevance of teaching Quantum Physics is a necessity in secondary education. This article took as a point of analysis the conceptual gap between Classical Physics and Quantum Physics determined in the teaching of the Atomic Structure of Matter in Colombian secondary education. This topic represents a conceptual gap in the teaching of the Atomic Structure of Matter through the study of Chemistry (González et al., (2020). A textbook was considered as the object of analysis, since textbooks constitute a scientific, didactic and pedagogical vector (Alzate, Lanza & Gómez, 2007).

The results of the research show that, in the analyzed book, the break between Classical Physics and Quantum Physics is not studied. So, if this characteristic does not correspond to a specific

case but to the majority of Physics textbooks on the market, and if such a question, as previously indicated, is similar in Chemistry textbooks, ¿then where does a Colombian secondary school student have the possibility of understanding the rupture between Classical Physics and Quantum Physics?

The answer could be entirely discouraging. In such a case, Colombian students would not have opportunities to demystify the absolutism of science and its treatment in the classroom, in accordance with the epistemological, scientific and technological development of the natural sciences. It is the duty, then, of educators to equip themselves with a quantum theory and to assume as their own the responsibility of promoting, through the design, experimentation and evaluation of tasks, the consideration of this epistemological rupture.

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