

True/untrue explanations in Physics: the Bohr's atom model



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Abstract

In this note, and inspired by an article appeared recently in this journal, we discuss an example related to the theory of the Bohr's atom, who illustrates the fact that erroneous expositions in the learning of Physics exist, considering that this concept includes the use of well internationally recognized and commonly used educational text books.

Keywords: Physics Education, History of Science, Text Books.

Resumen

En esta nota, e inspirados en un artículo aparecido recientemente en esta revista, se discute un ejemplo relacionado con la teoría del átomo de Bohr, que ilustra el hecho de que existen planteamientos erróneos en el aprendizaje de la Física, considerando que este concepto incluye el uso de libros de texto reconocidos internacionalmente y comúnmente utilizados en la práctica docente.

Palabras clave: Educación en Física, Historia de la Ciencia, Libros de Texto.

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In a recent published paper in this Journal, Wörner [1] presented some examples of erroneous common facts that often appear in physics learning. In one of them (quoted as F in the mentioned article) the author shows that when Franck and Hertz performed their well known experiment about the ionization of atoms they did not know Bohr's theory, as it is often assumed because the most physics text books present this experiment as a consequent confirmation of the quantum hypothesis proposed by Bohr. We will show in this brief article why the Bohr model of the atom, in the way that it is described in the most used text books [2, 3, 4, 5, 6, 7, 8], is an example of another untrue explanation.

As it is well known Bohr postulated that the classical radiation theory does not hold for atomic systems. He overcomes the Rutherford's model problem of an unstable atom that continuously losses energy, by applying Plank's idea of quantized energy levels to orbiting atom electrons. In the above mentioned books the authors state that in order to calculate the electrons energy in their orbits in a one electron (better say, Hydrogen) atom, Bohr have made some basic assumptions that have been resumed in three postulates, namely:

i- The electron can moves only in certain and stable circular orbits about the nucleus (proton) where does not emit energy in the form of radiation.

ii- Radiation is emitted by the atom when the electron

"jumps" from a more energetic initial orbit (energy state) to a lower orbit, or it is absorbed when an electron transition from a lower to a higher energy state takes place.

iii- The allowed orbits are those for which the electron's orbital angular momentum, L , about the nucleus is an integral multiple of $h/2\pi$, where h is the Plank's constant, i.e. $L_n = mv_n r_n = n h/2\pi$, where m is the electron mass, v_n its velocity in the n -orbit of radius r_n and n an integer number ($n = 0, 1, 2, \dots$)

One can easily see that while the first two assumptions can be justified using the above mentioned Bohr's previous knowledge of ancient atom models, including the planetary Rutherford's model, and of Plank's work on the laws of Black Body radiation (both date from the first years of the past century), the third assumption, although it can be interpreted on the basis of the wave-particle duality postulate of Louis De Broglie¹, does not have a preceding historical foundation at the moment at which Bohr developed his model, which sometimes makes difficult its acceptance: Note that the work of Bohr was developed

¹ Louis De Broglie proposed towards 1924 the relation $\lambda=h/mv$ for the wavelength of a wave associated to a particle of mass m moving with speed v . If the wave associated to the particle must "enter" one circular orbit of radius r , then the length of the orbit must agree with a multiple of an integer number of wavelengths, that is, $2\pi r_n = n\lambda_n = nh/mv_n$ from which the condition of angular momentum quantization is straightforwardly obtained.

around the 1913 whereas De Broglie published his ideas approximately 10 years later. Bohr himself used the quantization of the angular moment as an *ad hoc* condition to reproduce the formula of Balmer in the first part of his famous trilogy [9]. In both following parts he tried to look for a justification for the same condition. His third derivation, considered the deepest of all [10], begins stipulating the asymptotic coincidence, for great values of n , between the classic frequency of revolution of the electron in the orbit and the frequency of the radiation emitted in the “quantum jump” of the electron between orbits, which is known as the Principle of Correspondence.

Using this principle, the first two postulates enunciated above, and Rydberg’s formula describing the energy of the observed (measured) discrete spectral lines², Bohr’s was capable to deduce the equations that allow the calculation of the radius of the orbits, the velocity and energy of the electrons in each state, as well as the angular momentum quantization rule given in the third’s postulate mentioned before, as has been described elsewhere in detail [11, 12]. In a view words, the true explanation relies on the fact that this rule is really a consequence of Bohr’s assumptions for the description of the atoms and of the regularities observed in their emission spectra. It was not used by Bohr as a premise to obtain the characteristic parameters describing the one electron atom. Bohr, motivated to find an acceptable explanation for experimental evidences such as Rydberg’s Formula, started from the first two assumptions mentioned above, related to the existence of stationary energy levels, and from the Correspondence Principle, to reach conclusions who marked the begin of a new epoch related to the comprehension of nature: The Quantum Era.

As stated by Wörner [1], informal learning, a concept that unfortunately sometimes involve the use of well recognized and used text books, is a useful way of learning, but it is not exempt on risks. Sometimes it can be the cause of misinterpretations of historical facts, as in the example described here. Therefore, it is important to let our students know that these situations exist, even in “bestseller” text books, and we, teachers, must guide and stimulate them to consult original papers and authoritative sources of information. For this purpose we must begin to adopt this practice for ourselves.

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² In 1885 Balmer had found that the wavelengths, λ , of the visible spectral lines can be expressed by means of the formula $1/\lambda=R_H(1/2^2-1/n^2)$, where n is an integer number and $R_H=109677.5810 \text{ cm}^{-1}$ is the Rydberg’s constant, called so in honour to which generalized in 1889 the above expression to the whole spectrum writing it in the form $1/\lambda=R_H(1/n^2-1/n'^2)$, with $n' < n$. It is known as Rydberg’s Formula for the Spectral Series of the Hydrogen Atom. For $n' \leq 2$ it leads to the Series of Balmer. If $n' = 1$ the series is denominated of Lyman, and it is in the ultraviolet region. The numbers $n' = 3$ and $n' = 4$ correspond to the Series of Paschen and of Brackett respectively, both in the infrared.