The reasonable ineffectiveness of Physics in teaching: the example of Thomson's atomic model

Luisa LOVISETTI, Marco GILIBERTI

Physics Department, University of Milan, via Celoria 16, 20133, Milan, Italy.

Abstract. Thomson's atomic model - as a name - is familiar to teachers and students. However, when asked about its structure, they usually only say that it is a "plum pudding" in which a positive charge is uniformly distributed and electrons are randomly arranged, not realising that it should rather be described by a precise mathematical model. The situation highlights how there is often a lack of critical mind in putting together previous knowledges in a coherent way. This proves a widespread ineffectiveness of physics education in creating the fundamental mental structures necessary to critically analyse what is taught and learned.

1. Introduction

In Italian education Thomson's atomic model is presented shortly after electrostatics issues [1-3]; nevertheless, the problem that electrons randomly arranged in a positive sphere cannot be in stable conditions unexpectedly does not arise. This lack of critical thinking undermines the very foundations of teaching concerning the nature of science. In fact, students and teachers do not usually wonder how a model - made by a great physicist - can simply be a substantially inconsistent qualitative framework rather than a precise and accurate mathematical structure, capable of both explaining known facts and making predictions.

In addition, it is widely known that an accelerated charge emits and therefore a stable planetary model is not possible [1-3]. Also in this sense, the knowledge of Thomson's model - which involves electrons in motion, to obtain stable configurations - should make us reflect on the banality of this statement, because, if the lost energy is small, it can be regained, for example, in collisions. It is therefore necessary that teachers are aware that, without calculations, the purely qualitative aspects can be sometimes misleading: the problem is not that an accelerated charge emits, but rather how much it emits.

Last but not least, the same uncritical attitude also leads to the idea that the stability problem of the atom is solved by the study in Quantum Mechanics of an electron in a Coulomb potential (hydrogen atom) [1-3], not realizing that this is due to the fact that in the Hamiltonian the radiative term is missing.

The research group of Milan believes that the presentation of concepts does not necessarily have to follow a historical approach, but a logical one. At the same time, however, it is important to provide teachers with a background of historical knowledge, especially relating to topics that can give an adequate awareness of the nature of science. The purpose of teaching physics is in fact to create a conceptual framework of the discipline (at least for teachers), rather than only convey information. The examples mentioned above thus raise serious questions about the real effectiveness of physics courses in schools and partly also in universities. In this work we will face this problem, which is not an isolated case, since also in other situations (for example, in the transition from the photoelectric effect to the Compton effect) consistency problems at an elementary level appear, without raising doubts and questions either from students or teachers.

2. Thomson's atomic model: anything but a mere plum pudding

How it was then Thomson's atomic model? In 1897, Thomson had already demonstrated that the atom was not the simplest unit of matter and, rather, it had a structure. His intent was to find a stable structure contemplating negative charged corpuscles (electrons) immersed in a sphere of positive charge, to render the atom electrically neutral and, at the same time, capable of giving an account of its chemical properties. In his work *On the Structure of the Atom* (published in 1904) [4] he presented a model consisting of a uniformly charged sphere of positive electricity (the "pudding") with discrete corpuscles (the "plums"), arranged at the vertices of regular polygons, and resting on internal circumferences concentric to the sphere. The electric forces were thus "balanced" by charges' arrangement and by the circular motion of the rotating corpuscles (whose total charge was equal and opposite to the positive cloud).

Each orbit was constrained to occupy an invariable position with respect to the aggregate, like a rigid circular path. Moreover, the negative particles were subject to their mutual repulsion and, if displaced from their equilibrium by a small amount, they were pushed back by a restoring force proportional to the displacement. If the atom had radius R and the circumference circumscribed to the regular polygon (on which the electrons are arranged) had radius r and contained n electrons of mass m and charge e, which all rotated with the same angular velocity ω, Thomson's model led to the condition of mechanical equilibrium:

$$\frac{\omega e^2 r}{2\pi r^2} = \frac{e^2}{4r^2} S_n + m r \omega^2 \quad (1)$$

$$S_n = \sum_{i=1}^{n-1} \csc\frac{i\pi}{n} \quad (2)$$

According to Thomson, such a model served thus as a heuristic device and was aimed to explain the stability and unity of atomic phenomena, both from a chemical and electrical point of view. In fact, his model was also able to provide a first physical interpretation of the periodic table of the elements. As far as radiative stability is concerned, the laws of classical electromagnetism impose that an accelerated charge must irradiate (and in Thomson's model, negative charges move on circular orbits and are therefore subject to a centripetal force). Indeed, although it involved the introduction of accelerated electrical charges, it involved only a very small radiation from the atom. In fact, if the wavelength has an order of magnitude of a few hundred nm (as it is typical for the visible part of the electromagnetic spectrum), the atomic radius is taken in the order of 1 nm (as we know today and as could already be estimated at the time from chemical considerations) and the value for the number of electrons in a circumference is taken as n=10, the value of $(R/\lambda)^{2n}$ is about 10^{-40}, effectively giving rise to a very little irradiation and, therefore, to a very small loss of energy. That energy could be "recovered" by means of "termic" interactions, for example in collisions with other atoms. The idea that, in any case, there was some electromagnetic emission, was an advantage of the model that could thus, at least qualitatively, explain the existence of atomic spectra.

In short, Thomson proposed a great model and the plum pudding image - usually mentioned in textbooks, but never used by Thomson, in any of his papers - was originally based on a deep misunderstanding. However, what it is more disconcerting is that many people think that a famous physicist as Thomson was (having won several awards and honours during his career, including a Nobel Prize in Physics in 1906) could have built a model, highly regarded at the time, without any mathematics, without providing numerical evaluations and without predicting anything new. This is clear evidence of a widespread lack of critical approach in both teaching and learning.

References

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