SOME NOTES ON LEARNING THE FRANK-HERTZ EXPERIENCE

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Annotations:
This article describes the methodology of teaching a topic dedicated to the Frank-Hertz experience in the course of atomic physics.

Keywords: Atom, energy levels, discreteness, spectrum, Frank-Hertz, radiation, elastic, nonelastic, collision.

The rapid development of new technologies around the world is mainly due to the achievements of natural sciences. Among the natural sciences, physics as a subject that studies the basic laws of nature and natural phenomena occupies a special place and thus is the basis of many new industrial technologies. It is known that more than 50% of scientific research conducted in the world currently relates to nuclear physics and its applications. As a result of these studies, nuclear technologies are being increasingly introduced not only in industry but also in everyday life, medicine, customs and agriculture.

In this regard, there is a need to train specialists who possess nuclear knowledge and manage new nuclear physics installations. On the other hand, these circumstances place a special responsibility on pedagogical universities, where future physics teachers are trained.

This article describes the methodology of teaching the topic devoted to the experiments of Frank-Hertz in the course of atomic physics. The study of atomic and nuclear physics as the physics of the microcosm has its own characteristics. When teaching invisible and intangible phenomena, mental representations and correct interpretation of the results of experience are important. One of the important experiments in the origins of atomic physics is the experiments of Frank and Hertz, who proved the quantum nature of atoms.

The experiments of Frank and Hertz are relatively simple in their implementation and are therefore used in physical education.

But on the other hand, there are some points in the simplicity of experience, the misinterpretation of which leads to misconceptions of future physicists. To identify such moments, first consider the essence of the experiment. Figure - 1 a, b shows the tube circuits and the results of the Frank-Hertz experiment. The electrons emitted by the cathode K are accelerated in region 1 under the action of an accelerating potential difference φ between the cathode and the grid C1.In region 2, electrons pass through mercury vapor and reach the anode A. The graphs published by Frank and Hertz (Fig.1b) show the dependence of the electric current flowing from the anode on the electric potential between the grid and the cathode.

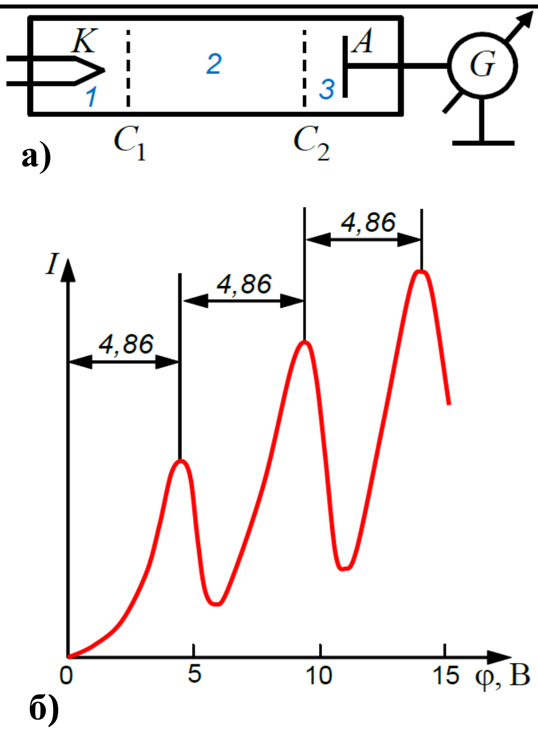

Figure 1. Scheme (a) experimental results (b) of the Frank-Hertz experiment

With small potential differences — up to 4.9 V — the current through the tube is constantly increasing with an increase in the potential difference. This behavior is typical for real electronic lamps that do not contain mercury vapor; higher voltages lead to a higher current, limited by the spatial charge. At 4.9 V, the current drops sharply to almost zero. Then the current increases monotonously again as the voltage increases further, until a voltage of 9.8 V is reached (exactly 4.9 + 4.9 V). At 9.8 V, there is a similar sharp decline. Although this is not demonstrated in the original figure, this series of current dips in steps of about 4.9 V continues to potentials of at least 70 V.

In the second experiment, Frank and Hertz investigated the optical radiation of a mercury tube and found that a line corresponding to a wavelength of 255 nanometers was clearly visible in the radiation spectrum, which proved Bohr's second postulate.

When interpreting the results of the Frank-Hertz experiment, students often experience some misconceptions. This is due to the insufficient disclosure of the essence of the experiments conducted. For example, some textbooks state that dips in the volt-ampere characteristic at a voltage of 4.9, 9.8, 14.7 V indicate that there are energy levels in the atom with energies of 4.9, 9.8, 14.7 eV. After all, this is far from the case. These rules apply only to the first excited state of the mercury atom. Frank and Hertz explained their experiment by elastic and inelastic collisions between electrons and mercury atoms. Slow-moving electrons elastically collide with mercury atoms.

This means that the direction in which the electron is moving changes during the collision, but its velocity remains unchanged. The mercury atom is not affected by the collision, since it is about four hundred thousand times more massive than an electron. When the electron velocity exceeds about 1.3 • 106 m/s, collisions with the mercury atom become inelastic. This velocity corresponds to the kinetic energy absorbed by the mercury atom of 4.9 eV. At the same time, the electron velocity decreases, and the mercury atom goes into an excited state. After a short time, the energy of 4.9 eV transferred to the mercury atom is released as ultraviolet light with a wavelength of exactly 255 nm.

After the light is emitted, the mercury atom returns to its original non-excited state. If the electrons emitted by the cathode flew freely, when they reached the grid they would acquire kinetic energy proportional to the voltage applied to it. 1 eV of kinetic energy corresponds to a potential difference of 1 volt between the grid and the cathode. Elastic collisions with mercury atoms increase the time it takes for an electron to reach the grid, but the average kinetic energy of the electrons arriving there does not change much. When the voltage on the grid reaches 4.9 V, the collisions of electrons near the grid become inelastic, and the electrons slow down greatly. The kinetic energy of a typical electron entering the grid is reduced so much that it cannot move further to reach the anode, whose voltage is set to slightly repel electrons. The current of electrons reaching the anode decreases, as can be seen in the graph.

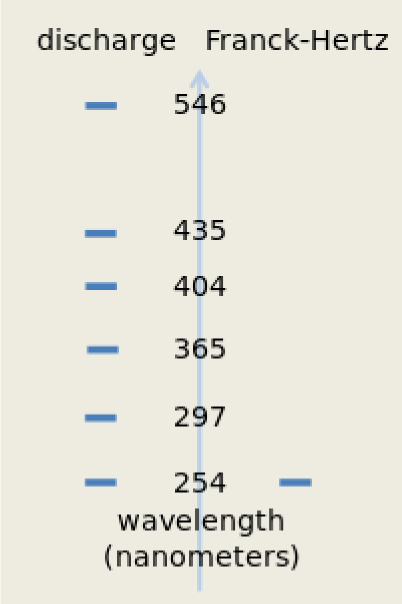

Figure 2. Energy lines in the mercury spectrum

A further increase in the grid voltage provides the electrons subjected to inelastic collisions with enough energy so that they can reach the anode again. The current increases again when the grid potential exceeds 4.9 V. At 9.8 V, the situation changes again. The electrons, which have traveled about half the way from the cathode to the grid, have already acquired enough energy to experience the first inelastic collision. As they slowly move towards the grid after the first collision, their kinetic energy increases again, so that near the grid they can experience a second inelastic collision. The current at the anode drops again. This process will be repeated at 4.9 V intervals; each time the electrons will experience one additional inelastic collision.

Thus, the current-voltage characteristic of the Frank-Hertz tube corresponds only to the first excited state of the mercury atom. The wavelengths corresponding to other lines in the mercury spectrum are shown in Figure 2. In conclusion, we can say that a thorough analysis of the subtleties of physical experiments and phenomena contributes to improving the effectiveness of teaching and thereby improving the quality of the training process for future physics teachers.

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