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METHODS OF THEORETICAL TEACHING THE TOPIC "COMPTON EFFECT" OF THE SECTION "ATOMIC PHYSICS" OF THE COURSE OF GENERAL PHYSICS IN HIGHER EDUCATIONAL INSTITUTIONS

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Abstract:. This article describes the method of theoretical teaching of the topic "Compton effect" in higher educational institutions, which refers to the section "Atomic physics" of the course of general physics. Improvements to this technique were also considered.

Keywords:. Compton, Compton experience, Compton effect, Compton formula, recoil electrons, quantum scattering, effective Compton scattering cross sections.

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When a light quantum interacts with a substance, more precisely with electrons in the atoms of this substance, three processes can occur: the photoelectric effect, the Compton effect, and the formation of electron-positron pairs. In the photoelectric effect, an electron absorbs a quantum. In the Compton effect, the quantum is scattered by these electrons. In the process of formation of electron-positron pairs, an electron and a positron appear. All these processes are quantum, that is, atomic processes. Therefore, the study of these processes, including the Compton effect, is relevant. This article describes just the method of theoretical teaching of the Compton effect in higher educational institutions.

This topic can be theoretically stated on the basis of the following plan: 1) Compton's experiment; 2) Compton formula; 3) recoil electrons; 4) analysis of the Compton formula and the effective cross section for Compton scattering; 5) inverse Compton effect; 6) application of the inverse Compton effect.

Based on this plan, the professor-teacher can present information on the topic in the following sequence. When a quantum of light falls on a substance, it interacts with the electrons in the atoms of that substance. As a result, a quantum can be absorbed by electrons or scattered by these electrons. The course of any of these processes depends on the energy of the quantum incident on the substance. This energy is basically compared to the rest energy of the electron. If this quantum energy is equal to or slightly exceeds the rest energy of the electron, but less than its double value, then the process of quantum scattering occurs in the electron. This process is called the Compton effect.

In 1923, Compton studied this scattering experimentally. The Compton setup consists of an X-ray tube with a molybdenum anticathode, a graphite scattering material, a collimator, a crystal, and an ionization chamber. A quantum of light is generated using an x-ray tube. The resulting quantum hits the scattering substance and is scattered at a certain angle. The numerical value of this scattering angle can be determined by changing the position of the x-ray tube, which can freely rotate around the vertical axis. The collimator directs the scattered quanta to the crystal. In this setup, calcium carbonate $CaCO_3$ performs the function of a scattering agent; a calcite crystal with a lattice period of $3 \cdot 10^{-8}$ cm. The wavelength of the quantum scattered by this crystal is determined on the basis of the Wolf-Bragg law formula. As the numerical value of the angle of incidence of a quantum in this formula on the crystal, the numerical value of the angle corresponding to the maximum value of the current in the ionization chamber is taken.

Based on the results of Compton's experiments, the following conclusions can be drawn: 1) in contrast to the classical scattering of a quantum, with Compton scattering, the spectrum of scattered radiation has a changed wavelength λ' in addition to the wavelength λ_0 of the radiation incident on the scattering substance. In this case, $\lambda' > \lambda_0$; 2) $\Delta\lambda = \lambda' - \lambda_0$ increases with increasing quantum scattering angle θ; 3) for a given scattering angle, $\Delta\lambda$ does not depend on λ_0; 4) $\Delta\lambda$ is an invariant quantity for all scattering substances. These laws cannot be explained on the basis of classical wave theory. According to this theory, the wavelength of the incident quantum must be equal to the wavelength of the scattered quantum. The result observed in Compton's experiment was explained by Compton and Debye on the basis of quantum theory.

Compton noticed that the first and second laws above are very similar to the elastic scattering of particles. It is known that with such elastic scattering of particles, the energy of the scattered particle would differ from the energy of the particle before scattering and would depend on the scattering angle of the particle. Based on this, Compton explained the scattering of quanta in matter on the basis of quantum theory. At the same time, he considered the radiation emerging from the x-ray tube as a stream of particles consisting of quanta. These quanta are scattered by other particles, i.e., electrons. There are electrons in all atoms, and the binding energy of these electrons with their atoms is much less than the energy of the quanta incident on them. In this case, the process under consideration can be considered as the process of scattering of a photon, that is, a quantum on a free electron, occurring in an arbitrary medium. Therefore, the scattering of a quantum by an angle does not depend on the type of the scattering substance.

Then the professor must derive Compton's formula. In this case, it is necessary to write formulas for the law of conservation of energy and momentum for the process of quantum scattering in an electron and solve these equations together. The expression for the law of conservation of energy for this scattering process is as follows: $E_\gamma = E'_\gamma + T_e$. Here is $E_\gamma = h\nu$-the energy of the quantum incident on the electron, $E'_\gamma = h\nu'$-is the energy of the scattered quantum, $T_e = m_e c^2(\frac{1}{\sqrt{1-\beta^2}} - 1)$-is the kinetic energy of the recoil electron.

If the momentum vector of the quantum incident on the electron is $\vec{p}_\gamma$, the momentum vector of the scattered quantum is $\vec{p}'_\gamma$, and the momentum vector of the recoil electron is $\vec{p}_e$, then the momentum conservation law formula is written in vector form as follows: $\vec{p}_\gamma = \vec{p}'_\gamma + \vec{p}_e$. Given that the modules of these impulses are respectively $p_\gamma = \frac{h\nu}{c}$, $p'_\gamma = \frac{h\nu'}{c}$, $p_e = \frac{m_e \beta c}{\sqrt{1-\beta^2}}$, then the equation $p_e^2 = p_\gamma^2 + p'^2_\gamma - 2p_\gamma p'_\gamma \cos\theta$ can be derived using the impulse diagram drawn for this process. Here is θ-the quantum scattering angle . If the last equation and the equation expressing the law of conservation of energy are solved together, enter the following notation $\Lambda = \frac{h}{m_e c}$, then the following formula will be obtained: $\Delta\lambda = 2\Lambda \sin^2\frac{\theta}{2}$. This formula is called the Compton formula. The constant $\Lambda = 0,0242$ $\overset{0}{A}$ is called the Compton wavelength. It follows from the Compton formula that the wavelength of the scattered quantum differs from the wavelength of the incident quantum. It also follows from this that the wavelength of the scattered quantum depends on the angle of scattering of the quantum on the electron. It also follows from this that, for a given quantum scattering angle, $\Delta\lambda$ does not depend on λ_0. It also follows from this formula that Compton scattering is not observed in long-wavelength electromagnetic radiation, but is observed in short-wavelength electromagnetic radiation. Solving Compton's formula for ν', one obtains a formula for the energy of the scattered quantum. This expression looks like this:

$$E'_\gamma = \frac{E_\gamma}{1 + \frac{E_\gamma}{m_e c^2}(1-\cos\theta)}.$$

If the quantum scattering angle is small and $E_\gamma > m_e c^2$, and also $E_\gamma << m_e c^2$, for arbitrary scattering angle values include $\frac{E_\gamma}{m_e c^2}(1-\cos\theta) << 1$ and $E'_\gamma \approx E_\gamma$. If $\frac{E_\gamma}{m_e c^2}(1-\cos\theta) >> 1$ and $E_\gamma >> m_e c^2$, then $E'_\gamma \approx \frac{m_e c^2}{1-\cos\theta}$. In the last expression, if $\theta = \frac{\pi}{2}$ is

$E'_\gamma \approx m_e c^2$, if $\theta = \pi$ is $E'_\gamma \approx m_e c^2 / 2$. This result shows that the energy of the scattered quantum decreases as the scattering angle of the quantum in the electron increases. This decrease, in turn, leads to an increase in the electron momentum and recoil energy.

After solving this problem, we can present information related to the appearance of recoil electrons in Compton scattering. It is appropriate to make the following points. In the act of collision of a quantum with any motionless electron, the quantum transfers a certain energy to the electron. Due to this, the electron moves and has a certain kinetic energy. This energy is called the recoil energy of the electron. The electron is called the recoil electron. Let's see how to calculate this energy.

From the application of the formula for the law of conservation of energy to Compton scattering, it follows that $T_e = E_\gamma - E'_\gamma = h(\nu - \nu') = h\Delta\nu$. If we take the ratio of this energy to the energy of a quantum incident on an electron, then $\frac{T_e}{E_\gamma} = \frac{h\Delta\nu}{h\nu} = \frac{\Delta\nu}{\nu}$ is formed. On the other hand, if you take $\Delta\nu = \nu - \nu' = \frac{c}{\lambda} - \frac{c}{\lambda'} = \frac{c}{\lambda} - \frac{c}{\lambda + \Delta\lambda} = \frac{c\lambda + c\Delta\lambda - c\lambda}{\lambda(\lambda + \Delta\lambda)} = \frac{c\Delta\lambda}{\lambda(\lambda + \Delta\lambda)} = \nu\frac{\Delta\lambda}{\lambda + \Delta\lambda}$ into account, you get $\frac{\Delta\nu}{\nu} = \frac{\Delta\lambda}{\lambda + \Delta\lambda}$. Then the following expression $\frac{T_e}{E_\gamma} = \frac{\Delta\lambda}{\lambda + \Delta\lambda}$ is formed. Then it can be seen that the recoil energy of the electron is $T_e = \frac{\Delta\lambda}{\lambda + \Delta\lambda} E_\gamma = E_\gamma \frac{2\Lambda \sin^2\frac{\theta}{2}}{\lambda + 2\Lambda \sin^2\frac{\theta}{2}}$. From the last formula, one can calculate what part of the quantum energy incident on the electron is given to the electron. If $\lambda = 10\Lambda$, $\theta = 90^0$ then 1/11 of the energy of the incident quantum is transferred to the electron. If $\lambda = \Lambda$, $\theta = 90^0$, then 1/2 of the energy of the incident quantum is transferred to the electron. It follows from this that a small recoil energy is imparted to the electron in Compton scattering. This is the proof that separates the recoil electron from the photoelectron. it is known that during the photoelectric effect a photoelectron appears, and this photoelectron will have all the energy of the quantum, in contrast to the recoil electron.

After that, information about the effective Compton scattering cross section can be given. The formula for the differential effective cross section for Compton scattering was derived by Klein, Nishina, and Tamm; this formula can be written as follows:

$$d\sigma(\theta) = r_e^2 \frac{1 + \cos^2\theta}{2[1 + \varepsilon(1 - \cos\theta)]^2}\{1 + \frac{\varepsilon^2(1 - \cos\theta)^2}{(1 + \cos^2\theta)[1 + \varepsilon(1 - \cos\theta)]}\}d\Omega,$$

Here $r_e = \frac{e^2}{m_e c^2}$, $\varepsilon = \frac{E_\gamma}{m_e c^2}$, $d\Omega = 2\pi \sin\theta d\theta$. If this expression is integrated, then we obtain an expression for the effective cross section of Compton scattering. This expression looks like this:

$$\sigma = 2\pi r_e^2 \{\frac{1+\varepsilon}{\varepsilon^2}[\frac{2(1+\varepsilon)}{1+2\varepsilon} - \frac{1}{\varepsilon}\ln(1+2\varepsilon)] + \frac{1}{2\varepsilon}\ln(1+2\varepsilon) - \frac{(1+3\varepsilon)}{(1+2\varepsilon)^2}\}.$$

We can consider two special cases of the last formula.

a) If the classical, that is, effective cross section of Thomson scattering is equal to $\sigma_T = \frac{8\pi}{3} r_e^2 = \frac{8\pi}{3}\frac{e^4}{m_e^2 c^4}$ and the condition $\varepsilon << 1$ is satisfied, then the expression for the effective cross section of Compton scattering takes the following form: $\sigma = \sigma_T (1 - 2\varepsilon + \frac{26}{5}\varepsilon^2 + ...)$. If we take small values of the quantum energy $(\varepsilon << 0{,}05)$, the Compton scattering cross section increases linearly with decreasing quantum energy. In the limiting case, it tends to σ_T.

b) If $\varepsilon >> 1$, then the expression for the effective cross section of Compton scattering can be written as follows: $\sigma = \pi r_e^2 \frac{1}{\varepsilon}(\ln\varepsilon + \frac{1}{2})$. It follows from this formula that the effective Compton scattering cross section ε is inversely proportional to the energy of a quantum incident on an electron. Since any atom has Z electrons, the effective Compton scattering cross section for one atom will be Z times larger, and at $\varepsilon >> 1$ equals $\sigma \sim \frac{Z}{E_\gamma}$.

After that, the professor-teacher should stop about the question about the inverse Compton effect. It can be told as follows. In the Compton scattering considered above, atomic electrons were considered immobile with respect to the incident quantum. If electrons are moving, then the quantum incident on them is scattered by these electrons. The energy of a quantum that scatters on moving electrons is derived by writing the formula $E'_\gamma = \frac{E_\gamma}{1 + \frac{E_\gamma}{m_e c^2}(1-\cos\theta)}$, written in the reference frame, related to the electron in the laboratory reference frame. This formula has the following form: $E'_\gamma = \frac{E_\gamma(1-\beta\cos\theta_1)}{1-\beta\cos\theta_2 + \frac{E_\gamma}{E_e}(1-\cos\theta)}$, here θ_1-is the angle between the incident quantum and the direction of electron motion, θ_2- is the angle between the scattered quantum and the direction of electron motion, E_e- is the energy of the moving electron.

If a quantum and an electron move towards each other, then the quantum is also scattered in this electron. This process is called the inverse Compton effect or scattering. In this case, $\theta_1 = \pi, \ \theta_2 = 0, \theta = \pi$. In addition, with the inverse Compton effect, the energy of the scattered quantum reaches its maximum value, and this energy can be greater than the energy of the incident quantum. This energy is found as follows: $(E'_\gamma)_{\max} \approx \dfrac{E_\gamma}{(\dfrac{m_e c^2}{2E_e})^2 + \dfrac{E_\gamma}{E_e}}$.

After this statement, we can touch on the question of applying the inverse Compton effect. A very interesting phenomenon can take place as a result of the scattering of soft quanta (for example, light) by ultrarelativistic electrons produced in modern betatrons. In this case, the value of the energy of the scattered quantum is comparable with the value of the energy of the moving electron. This allows light radiation to be converted into very short wavelength gamma radiation. The resulting gamma radiation is monochromatic and highly polarized. The inverse Compton effect is also used in the study of photonuclear reactions involving medium and high energy gamma rays.

You can also get information about the phenomena occurring in the universe around us, using the inverse Compton effect. It can be used to explain the origin of isotropic X-rays and the gamma background. These radiations are caused by Compton scattering of electromagnetic radiation, with a spectrum similar to the spectrum of a black body with a temperature of 2.7 K, on high-energy cosmic electrons.

It should be noted that Compton scattering can occur not only in electrons, but also in other charged particles. For example, such scattering is observed in the proton. In order to approximately calculate the effective cross section of such scattering, it is necessary to insert the mass of the proton into the formula for calculating the effective cross section for scattering by an electron, instead of the mass of the electron. The reason this is called an approximation is because the proton has an anomalous magnetic moment. If neutral particles also have a magnetic moment (for example, a neutron), then Compton scattering can also be observed in them.

Some methods of innovative pedagogical technologies can be used to consolidate students' knowledge on the topic "Compton Effect" and the formation of skills and abilities on this topic, to further increase students' interest in studying the section "Atomic Physics". One of these methods is the Cluster method. The essence of this method is as follows.

A cluster is a graphical form of organizing information, when the main semantic units are singled out, which are fixed in the form of a diagram with the designation of all the links between them. It is an image that contributes to the systematization and generalization of educational material.

The modern education system is focused on the formation of independent thinking in students. Critical thinking is a pedagogical technology that stimulates the intellectual development of students. The cluster is one of his methods (techniques).

The features of critical thinking include the presence of three stages:

-call,

- comprehension,

-reflection.

At the first stage, activation takes place, involving all members of the team in the process. The goal is to reproduce the already existing knowledge on this topic, form an associative series and raise questions that you want to find answers to. At the comprehension phase, work with information is organized: reading the text, thinking and analyzing the facts obtained. At the stage of reflection, the acquired knowledge is processed as a result of creative activity and conclusions are drawn.Cluster reception can be applied at any of the stages.

At the challenge stage, children express and record all available knowledge on the topic, their assumptions and associations. It serves to stimulate the cognitive activity of schoolchildren, motivate them to think before starting to study the topic. At the stage of reflection, the use of a cluster allows you to structure the educational material. At the reflection stage, the cluster method performs the function of systematizing the acquired knowledge.

It is possible to use the cluster throughout the lesson, in the form of a general strategy for the lesson, at all its stages. So, at the very beginning, children record all the information that they have. Gradually, during the lesson, new data is added to the schema. It is advisable to highlight them in a different color. This technique develops the ability to assume and predict, supplement and analyze, highlighting the main thing.

The cluster is made in the form of a cluster or a model of a planet with satellites. The main concept, thought, is located in the center, large semantic units are indicated on the sides, connected to the central concept by straight lines. These can be words, phrases, sentences expressing ideas, thoughts, facts, images, associations related to this topic. And already around the "satellites" of the central planet there may be less significant semantic units that more fully reveal the topic and expand logical connections. It is important to be able to specify the categories, substantiating them with the help of the opinions and facts contained in the material being studied.

Depending on the way the lesson is organized, the cluster can be drawn up on the board, on a separate sheet or in a notebook for each student when completing an individual task. When composing a cluster, it is advisable to use multi-colored crayons, pencils, pens, felt-tip pens. This will allow you to highlight some specific points and more clearly display the big picture, simplifying the process of systematizing all the information.

There are several recommendations for clustering. When creating it, you should not be afraid to state and record everything that comes to mind, even if these are just associations or assumptions. In the course of work, incorrect or inaccurate statements can be corrected or supplemented. Students can safely use their imagination and intuition by continuing to work until they run out of ideas. You should not be afraid of a significant number of semantic units, you should try to make as many connections between them as possible. In the process of analysis, everything is systematized and will fall into place.

The use of a cluster has the following advantages:

- it allows you to cover a large amount of information;
- involves all team members in the learning process, they are interested in it;
- students are active and open, because they do not have a fear of making a mistake, making an incorrect judgment.

During this work, the following skills are formed and developed:

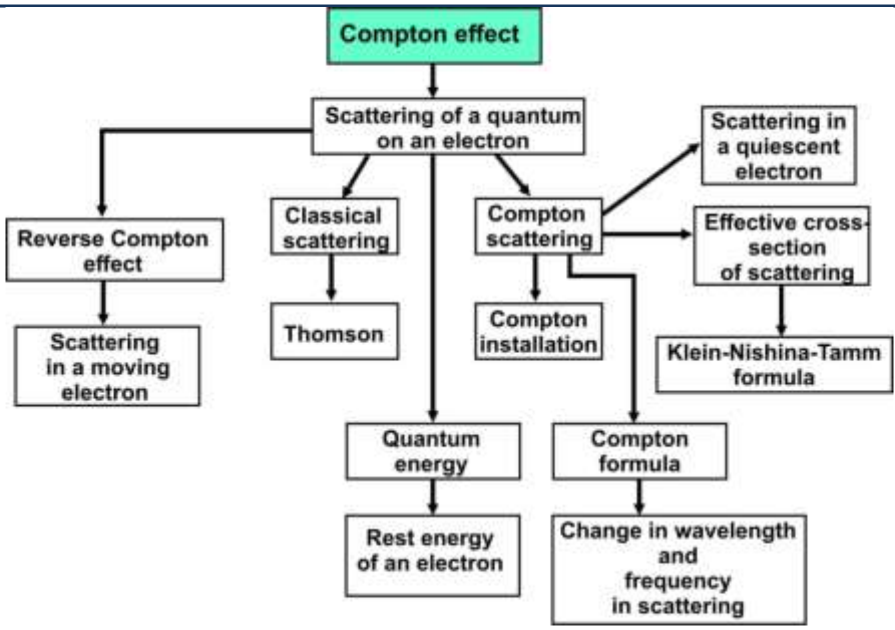
- the ability to ask questions;
- to highlight the main thing;
- establish cause-and-effect relationships and build inferences;
- move from particulars to the general, understanding the problem as a whole;
- compare and analyze;
- draw analogies.

What gives the use of the cluster method in the classroom for students? The cluster technique develops systemic thinking, teaches students to systematize not only the educational material, but also their value judgments, teaches students to develop and express their opinion, formed on the basis of observations, experience and new knowledge gained, develops the skills of simultaneously considering several positions, the ability for creative processing information.

Findings. Lessons using the cluster method give students the opportunity to express themselves, express their vision of the issue, give freedom of creative activity. In general, non-traditional technologies used in the educational process increase the motivation of students, create an atmosphere of cooperation and educate students in self-esteem, give them a sense of creative freedom.

The cluster built on the topic "Compton Effect" is as follows (Picture №1).

By presenting the topic of "Compton effect" in this way, it is possible to create great interest in students studying it. This, in turn, leads to the formation of students' knowledge, skills and abilities on this topic, and also further develops their creative thinking.



Picture №1. The cluster built on the topic "Compton Effect".

REFERENCES:

1. A.M. Xudayberganov, A.A. Maxmudov. Atom fizikasi, asosiy tushuncha, qonun, tajriba va formulalar. Toshkent. Navro'z. 2018.

2. P. Ewart. Atomic physics. Atomic physics lecture notes final. 1990.

3. E.V. Shpolskiy. Atomnaya fizika. 1-2 tom. Moskva. Atomizdat. 2008.

4. A.N. Matveev. Atomnaya fizika. Moskva. Lan. 2009.

5. I. Kalaytanova . Priyom klaster na uroke. Chto eto takoe i kak ego ispolzovat? Primeri. https://pedsovet.su/metodika/priemy/5673_metod_klaster_na_uroke.

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