VOLUME-2, ISSUE-10

WHY AN ELECTRON DOES NOT ABSORB A PHOTON

M.B.Tagaev

Professor of Karakalpak State University named after Berdak (doctor of physical and technical sciences)

I.A.Atashov

Student of Karakalpak State University named after Berdak

A.S.Kalilaev

Trainee teacher of Karakalpak State University named after Berdak

Annotation: Energy Conservation: A fundamental law stating that energy cannot be created or destroyed, only transformed. For an electron to absorb a photon, the energy of the photon must match the energy difference between two allowable electron states.

Key words: Momentum Conservation, Quantum Selection Rules, Pauli Exclusion Principle, Compton Scattering.

ПОЧЕМУ ЭЛЕКТРОН НЕ ПОГЛОЩАЕТ ФОТОН

Аннотация: Сохранение энергии - фундаментальный закон, согласно которому энергия не может быть создана или уничтожена, а только преобразована. Чтобы электрон мог поглотить фотон, энергия фотона должна соответствовать разнице энергий между двумя допустимыми электронными состояниями.

Ключевые слова: Сохранение импульса, Квантовые правила отбора, принцип исключения Паули, Комптоновское рассеяние.

The interaction between electrons and photons is a cornerstone of quantum mechanics and quantum electrodynamics (QED). While electrons can absorb and emit photons under specific conditions, there are situations where an electron does not absorb a photon. To understand why, it is essential to delve into the quantum nature of this interaction, which involves energy conservation, selection rules, and the nature of the photon itself.

1. The Nature of Electrons and Photons. An electron is a fundamental particle with mass, charge, and a wave-like nature described by quantum mechanics. Photons, on the other hand, are massless quanta of electromagnetic radiation, carrying energy proportional to their frequency (, where is Planck's constant and is the frequency).

The interaction between electrons and photons involves the absorption or emission of energy. For an electron to absorb a photon, it must meet certain physical conditions dictated by quantum rules.

2. Energy Conservation. One of the primary reasons an electron does not absorb a photon under certain circumstances is due to the law of conservation of energy. For an electron to absorb a photon, the energy of the photon must match the energy difference between two quantum states of the electron. In an atom, for example, electrons exist in discrete energy levels. A photon will only be absorbed if its energy corresponds exactly to the energy gap between these levels.

If a free electron (i.e., not bound to an atom) encounters a photon, it cannot absorb it in the same way that a bound electron can. This is because for a free electron, absorbing a photon would violate energy and momentum conservation simultaneously. In such a scenario, without a third body to conserve momentum (like a nucleus or another particle), the absorption is forbidden.

For an electron to absorb a photon, the energy of the photon must exactly match the energy difference between two quantized energy states of the electron. This principle is often applied to electrons bound in atoms.

The energy of a photon is given by:

$$E_{photon} = hv$$

The electron's energy levels in an atom are quantized, and the energy difference between two levels (for example, in the hydrogen atom) is given by:

$$\Delta E = E_n - E_m = -13,6\ eV\left(\frac{1}{n^2} - \frac{1}{m^2}\right)$$

For an electron to absorb a photon, the photon's energy must match the energy difference between two levels:

$$\Delta E = hv$$

If the photon's energy does not match this energy difference, the electron will not absorb the photon.

3. Momentum Conservation. Momentum conservation is another key factor. Photons, despite being massless, carry momentum. For an electron to absorb a photon, both energy and momentum must be conserved. In an atom, the nucleus can absorb some of the recoil momentum, making absorption possible. However, for a free electron, this mechanism is unavailable.

Consider the case of a free electron absorbing a photon. If the electron were to absorb the photon's energy and momentum, the resulting momentum and energy would not match the relativistic relationship between energy and momentum for the electron. This discrepancy prevents the absorption of a photon by a free electron.

In addition to energy conservation, momentum conservation must also be satisfied. Photons, despite being massless, carry momentum , which is related to their energy by:

$$p_{photon} = \frac{E_{photon}}{c} = \frac{hv}{c}$$

For a free electron (an electron not bound in an atom), absorbing a photon would require a simultaneous change in its energy and momentum. However, this creates a problem because the energy and momentum of the electron must also obey the relativistic energy-momentum relationship:

$$E_{electron}^2 = (p_{electron}c)^2 + (m_e c^2)^2$$

In a two-body interaction (photon and free electron), it is impossible to simultaneously conserve both energy and momentum under this relationship. As a result, a free electron cannot absorb a photon without violating these conservation laws. This is why photon absorption typically occurs in bound systems, where additional bodies (like an atomic nucleus) can participate in conserving momentum.

4. Quantum Selection Rules. In bound systems, such as electrons in atoms or molecules, transitions between energy levels are governed by quantum mechanical selection rules. These rules dictate which transitions are allowed based on the symmetry and angular momentum properties of the initial and final states of the electron.

One important selection rule involves the change in angular momentum. Photons carry one unit of angular momentum (spin), and for an electron to absorb or emit a photon, the change in the electron's angular momentum must match the photon's angular momentum. If the transition between two states does not satisfy this condition, the absorption of the photon will be forbidden. This gives rise to the rule:

$$\Delta \boldsymbol{l} = \pm \mathbf{1}$$

If a transition between two energy levels does not satisfy this selection rule, the electron will not absorb the photon. For example, an electron transition between two levels with same orbital angular momentum quantum number l (e.g., from $l = 0$ to $l = 0$) is forbidden.

5. Pauli Exclusion Principle. In multi-electron systems, such as atoms and molecules, the Pauli Exclusion Principle plays a role in photon absorption. According to this principle, no two electrons in an atom can occupy the same quantum state simultaneously. Thus, if all available states in a given energy level are already occupied, an electron cannot absorb a photon to transition to that state.

If all the quantum states at a particular energy level are already filled, an electron cannot be promoted to that level by absorbing a photon. The principle is mathematically expressed by the antisymmetric nature of the wavefunction for fermions (particles with half-integer spin, such as electrons).

$$\boldsymbol{\Psi}(\mathbf{1}, \mathbf{2}) = -\boldsymbol{\Psi}(\mathbf{2}, \mathbf{1})$$

This principle ensures that electrons must occupy distinct quantum states, thus limiting the absorption of photons under certain conditions.

6. Compton Scattering. A Different Interaction. Even though a free electron cannot absorb a photon, it can still interact with one through a process known as Compton scattering. In this process, the photon transfers some of its energy to the electron, but instead of being absorbed, the photon is scattered with reduced energy. This interaction still satisfies the conservation laws for both energy and momentum.

The energy and wavelength change of the photon after scattering are described by the Compton shift equation:

$$\Delta \boldsymbol{\lambda} = \boldsymbol{\lambda}' - \boldsymbol{\lambda} = \frac{\boldsymbol{h}}{\boldsymbol{m_e c}}(\mathbf{1} - \mathbf{cos}\,\boldsymbol{\theta})$$

Compton scattering satisfies both energy and momentum conservation, making it a valid interaction for free electrons, unlike direct photon absorption.

7. Conclusion. The inability of an electron to absorb a photon in many situations stems from fundamental conservation laws, particularly those of energy and momentum, as well as quantum mechanical rules such as selection rules and the Pauli Exclusion Principle. While electrons can absorb photons under specific conditions—most notably in bound systems—free electrons cannot do so without violating these principles. This highlights the nuanced nature of electron-photon interactions and the importance of quantum mechanics in describing them.

VOLUME-2, ISSUE-10

References:

1. Feynman, R. P., Leighton, R. B., & Sands, M. (1965). The Feynman Lectures on Physics, Vol. 3: Quantum Mechanics. Addison-Wesley.
2. Griffiths, D. J. (2017). Introduction to Quantum Mechanics (3rd ed.). Cambridge University Press.
3. Sakurai, J. J., & Napolitano, J. (2020). Modern Quantum Mechanics (3rd ed.). Cambridge University Press.
4. Loudon, R. (2000). The Quantum Theory of Light (3rd ed.). Oxford University Press.
5. Weinberg, S. (1995). The Quantum Theory of Fields (Vol. 1). Cambridge University Press.
6. Tagaev M.B., Atashov I.A., International Journal of Informatics and Data Science Research, ISSN 2997-3961(Online), Vol. 1, No. 2, March2024, Available onlineat: https://scientificbulletin.com/index.php/IJIDSR,