Compton Effect

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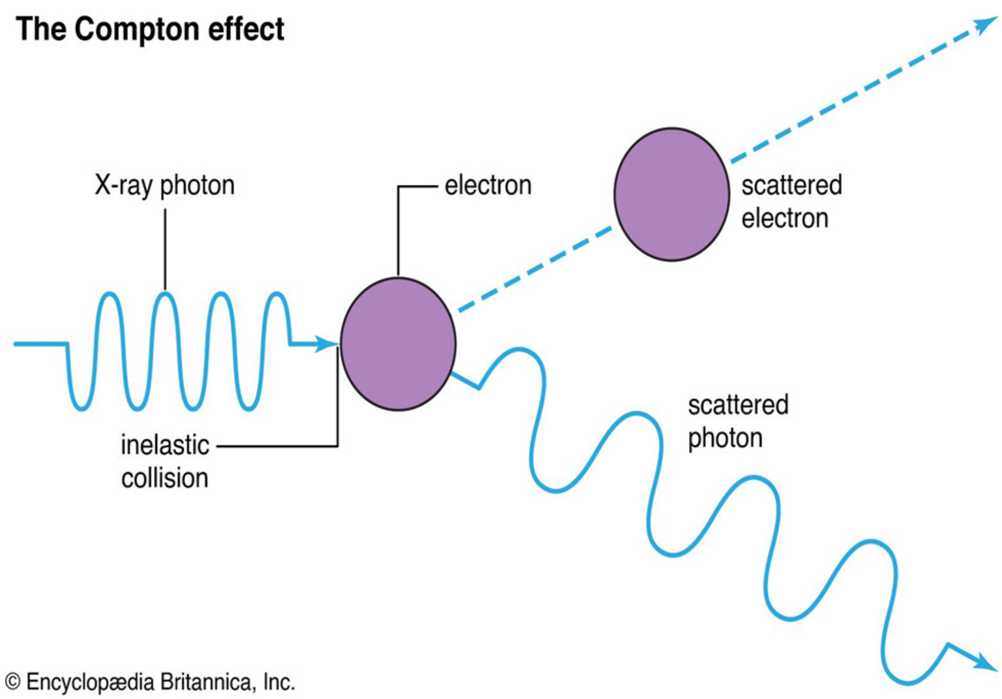
Compton scattering

Compton effect, also called Compton scattering, discovered by Arthur Holly Compton, is the scattering of a high frequency photon after an interaction with a charged particle, usually an electron. If it results in a decrease in energy (increase in wavelength) of the photon (which may be an X-ray or gamma ray photon), it is called the Compton effect. Part of the energy of the photon is transferred to the recoiling electron.

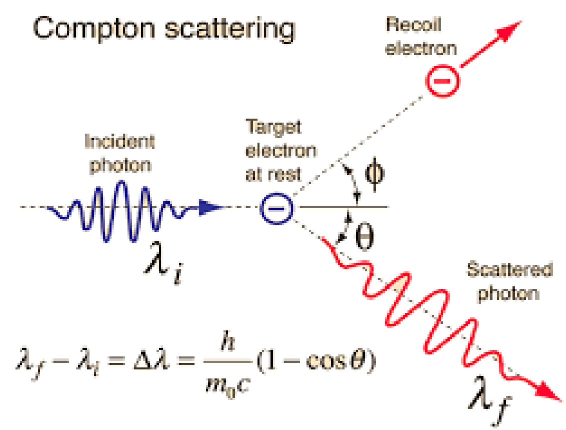


Compton scattering formula

In 1923, Compton explained the X-ray shift by attributing particle-like momentum to light quanta (Einstein had proposed light quanta in 1905 in explaining the photo-electric effect, but Compton did not build on Einstein's work). The energy of light quanta depends only on the frequency of the light. Compton derived the mathematical relationship between the shift in wavelength and the scattering angle (θ) of the X-rays by assuming that each scattered X-ray photon interacted with only one electron. He derived the following relation for change in wavelength due to scattering:

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

Where, λ - wavelength of incident X-rays
λ' - wavelength of scattered X-rays
m_e - rest mass of electron



Why is Compton effect used?

Ans. Compton scattering is considered as important as it is the most probable association of high-energy rays in living beings with atomic nuclei. It is used in radiotherapy. It is also used in material physics to promote the wave function of electrons in matter.

What is the difference between photoelectric effect and Compton effect?

Ans.

1. The photoelectric effect happens in the bound electrons, while Compton impact happens in free and loosely bound electrons.

2. In the photoelectric effect, a single electron absorbs the entire energy of an incident photon, but in the Compton effect, the incident photon only transfers a portion of its energy to one electron.

de Broglie wavelength and matter waves

Matter waves :

Matter waves are a central part of the theory of quantum mechanics and it is an example of wave–particle duality. All matter exhibits wave-like behavior. For example, a beam of electrons can be diffracted just like a beam of light or a water wave.

The concept that matter behaves like a wave was proposed by French physicist Louis de Broglie in 1924. It is also referred to as the de Broglie hypothesis. Matter waves are referred to as de Broglie waves.

de Broglie wavelength :

The *de Broglie wavelength* is the wavelength, λ, associated with a massive particle and is related to its momentum, p, through the Planck constant, h as

$$\lambda = \frac{h}{p}$$

de Broglie wavelength(non-relativistic case)

In 1924, de Broglie made a hypothesis that like an electromagnetic radiation, a material particle such as electron, proton, atom or molecule has a dual character – particle like and wave like. According to him, the momentum, p of a particle and a wavelength, λ of the associated wave are related as follows:

$$p = \frac{h}{\lambda} = \frac{h}{2\pi} x \frac{2\pi}{\lambda} = \hbar k$$

$$\Rightarrow \boxed{p = \hbar k} \longrightarrow 1$$

Where $\hbar = \frac{h}{2\pi} \longrightarrow$ the reduced Planck's constant

$$k = \frac{2\pi}{\lambda} \longrightarrow \text{the wave vector}$$

de Broglie wavelength(non-relativistic case)

If the particle has a mass 'm' and velocity 'v', then p = mv and we have

$$\boxed{\lambda = \frac{h}{mv}} \longrightarrow \quad 2$$

Suppose that the particle is an electron and has acquired a velocity v on falling through a potential difference of V volt under non-relativistic conditions.

$$\therefore \frac{1}{2} m_0 v^2 = eV, \quad m_0 \longrightarrow \text{rest mass of electron}$$

$$\Rightarrow m_0^2 v^2 = 2m_0 eV$$

$$\Rightarrow p^2 = 2m_0 eV$$

$$\Rightarrow p = \sqrt{2m_0 eV}$$

$$\therefore \boxed{\lambda = \frac{h}{\sqrt{2m_0 eV}}} \longrightarrow \quad 3$$

de Broglie wavelength(non-relativistic case)

In SI units, e = 1.6 x10^{-19} C, m_0= 9.1 x10^{-31} kg and h = 6.62 x10^{-34}J-s

$$\therefore \lambda = \frac{6.62 \text{ x}10^{-34}}{\sqrt{2\text{x}9.1 \text{ x}10^{-31}\text{x}1.6 \text{ x}10^{-19}V}} \text{ m}$$

$$= \frac{12.26 \text{ x}10^{-10}}{\sqrt{V}} \text{ m}$$

$$= \frac{12.26}{\sqrt{V}} \text{Å} \longrightarrow 4$$

At V =2.56 kV, the velocity of electron becomes 1/10th of speed of light.

So relativistic correction is not required and the equation (4) can be used for electron. The equation of de Broglie is also applicable for a light particle , called Photon.

de Broglie wavelength (relativistic case)

The relativistic mass is given by

$$m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}, \; m_0 \longrightarrow \text{rest mass of electron}$$

Using this relation, the de Broglie relation is obtained as

$$\boxed{\lambda = \frac{h}{\sqrt{2 m_0 \mathrm{eV}}} \left(1 - \frac{\mathrm{eV}}{m_0 c^2}\right)}$$

Thank You