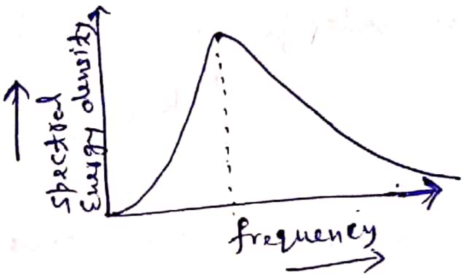
26/04/2020

Physics → Classical Physics, Quantum Physics

⇒ Inadequacies of classical Mechanics:

(i) Classical mechanics could not explain the observed spectra of blackbody radiation.



(ii) It could not explain the Photoelectric Effect.

(iii) It could not explain the existance of hydrogen atom.

(iv) It could not explain the observed variation of the specific heat of metal and gases.

Photoelectric Effect: When an electromagnetic light of sufficient frequency is directed on the metal surface then electrons are emitted. This emission of electrons is called photoelectric Effect.

* The emitted electrons are called Photoelectrons

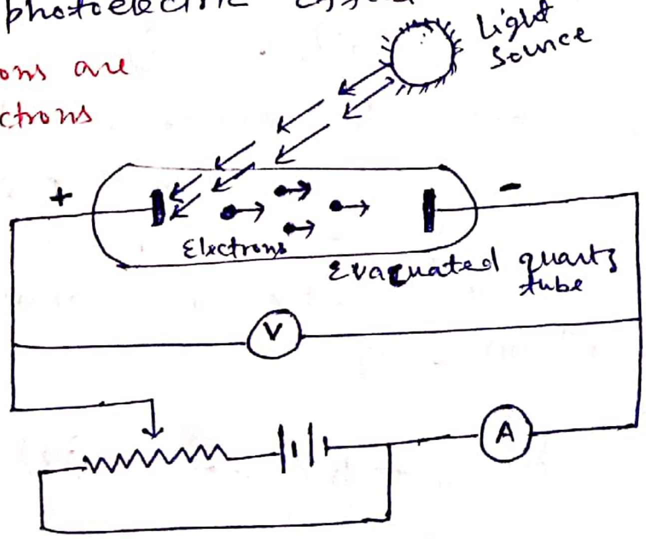


Fig. 1. Experimental setup to observe the Photoelectric Effect.

Fig 1. Shows how photoelectric effect was studied. An evacuated tube contains two electrods connected to a source of variable voltage, with the metal plate whose surface is irradiated as the anode. Those electrons which have sufficient energy will reach to the cathode despite its negative polarity. The slower electrons are repelled before they get to the cathode. When the voltage is increased to a certain value V_0, of the order of several volts, no more photoelectrons arrive and current drops to zero. This voltage (V_0) is called stopping potential and the energy corresponding to this voltage is called maximum photoelectron kinetic energy.

$$\boxed{K.E_{max} = eV_0} \quad \text{——} \; (I)$$

There is a term called workfunction (ϕ). This is defined as the minimum energy needed to remove an electron from the metal surface.

Hence photoelectric effect equation is given by

$$\boxed{h\nu = KE_{max} + \phi} \quad \text{——} \; (II)$$

where, $h\nu$ is the total energy of the photon incident at the metal surface.

The workfunction is also defined as

$$\phi = h\nu_0 \quad \text{——} \; (III)$$

when h = Planck's constant

$= 6.64 \times 10^{-34}$ J.S

ν_0 = critical frequency for photoelectric emission

So from eq^n (II) & (III)

$$h\nu = KE_{max} + h\nu_0 \quad \text{——} \; (IV)$$

or

$$\boxed{K.E_{max} = h(\nu - \nu_0)} \quad \text{——} \; (V)$$

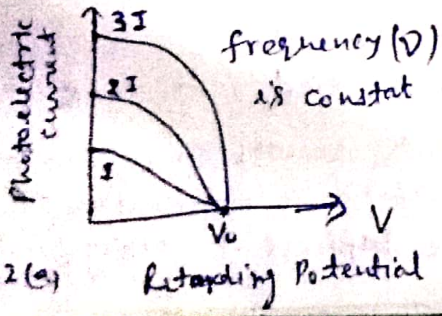


Fig. 2(a)

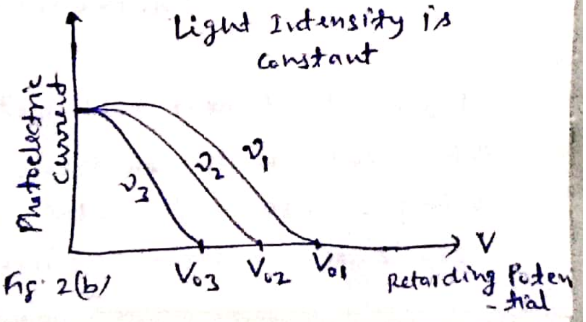


Fig. 2(b)

Compton Effect :

"According to quantum theory of light, photons behave like particles."

According to Compton Effect, there is an increase in wavelength of X-rays or gamma rays that occurs when they are scattered.

Consider an collision b/w X-ray photon and an electron at rest as shown in the fig 2. After collision the photon is scattered at an angle ϕ from its initial direction and electron at an angle θ.

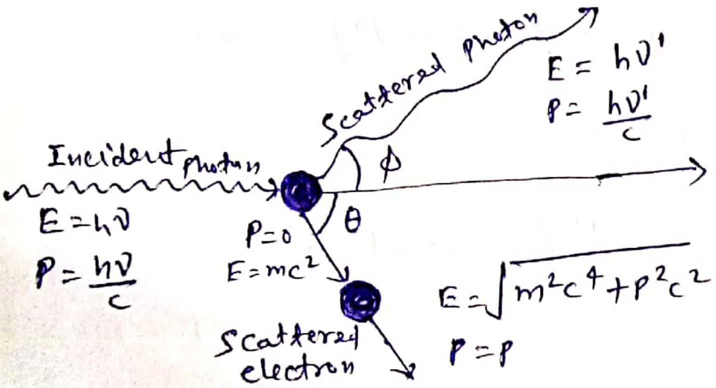


fig. 3.

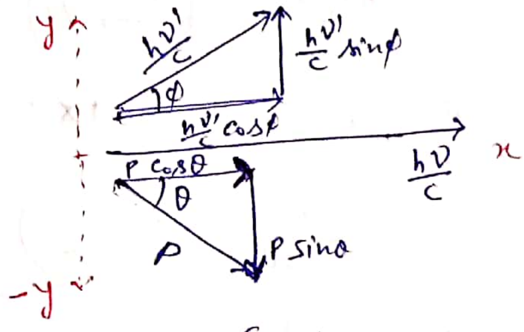


fig. 4.

Apply Conservation of Energy

Loss in photon energy = gain in electron energy

$$h\nu - h\nu' = K.E \quad \text{——— (I)}$$

Similarly

Apply Conservation of momentum

Initial momentum = final momentum.

Along x-axis

$$\frac{h\nu}{c} + 0 = \frac{h\nu'}{c}\cos\phi + P\cos\theta \quad \text{——— (II)}$$

$$\Rightarrow \frac{h\nu}{c} - \frac{h\nu'}{c}\cos\phi = P\cos\theta \quad \text{——— (III)}$$

Along y-axis

$$0 = \frac{h\nu'}{c}\sin\phi - P\sin\theta$$

$$\Rightarrow \frac{h\nu'}{c}\sin\phi = P\sin\theta \quad \text{——— (IV)}$$

From eq^n (III) + (IV)

$$p^2c^2 = (h\nu)^2 - 2h\nu(h\nu')\cos\phi + (h\nu')^2 \quad \text{——— (V)}$$

Now total energy of the electron (scattered) can be written as by two eq^n.

$$E = \sqrt{m^2c^4 + p^2c^2} \quad \text{— (VI)}$$

$$\& \quad E = K.E + mc^2 \quad \text{— (VII)}$$

$\because$ (VI) & (VII) are same so

$$(K.E + mc^2)^2 = m^2c^4 + p^2c^2$$

$$p^2c^2 = (K.E)^2 + 2mc^2 \cdot K.E \quad \text{— (VIII)}$$

$\because$ $K.E. = h\nu - h\nu'$ (from eq^n (1))

therefore eq^n (VIII) becomes

$$p^2c^2 = (h\nu - h\nu')^2 + 2mc^2(h\nu - h\nu') \quad \text{— (IX)}$$

from eq^n (V) & (IX) we get

$$\frac{mc}{h}\left(\frac{\nu}{c} - \frac{\nu'}{c}\right) = \frac{\nu}{c}\frac{\nu'}{c}(1 - \cos\phi) \quad \text{— (X)}$$

Also $\frac{\nu}{c} = \frac{1}{\lambda}$ and $\frac{\nu'}{c} = \frac{1}{\lambda'}$

where λ & λ' are the wavelengths of photon before collision and after collision respectively

So eq^n (X) becomes

$$\boxed{\lambda' - \lambda = \frac{h}{mc}(1 - \cos\phi)} \quad \text{— (XI)}$$

eq^n (XI) describes that there is the change in wavelength of x-rays or gamma ray after collision with electron. This effect was known as Compton Effect.

$$\lambda_c = \frac{h}{mc} = \text{Compton wavelength}$$

$$\lambda_c = 2.426 \times 10^{-12}\, m \quad \text{(after putting values of } h, m \,\&\, c)$$

eq^n (XI) can be written as

$$\boxed{\lambda' - \lambda = \lambda_c(1 - \cos\phi)} \quad \text{— (XII)}$$