QUANTUM MECHANICS

PARTICLE PROPERTIES OF WAVES

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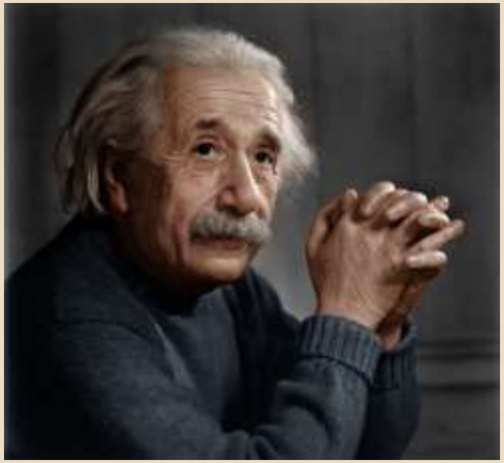
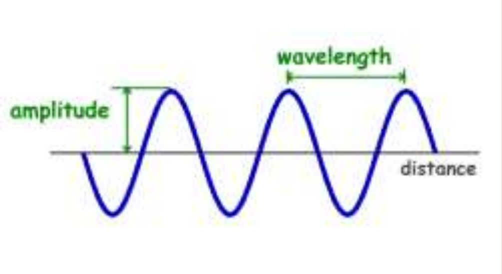


- **Particle possess position and mass – also attributes such as charge, momentum, energy**

- **Wave – propagation of energy without movement of particle**

- **Wave possess wavelength λ, frequency υ, momentum mv and exhibit phenomenon of diffraction, interference, polarization**

- **Wavicle – electron showing properties of both particle and wave – wave particle duality**

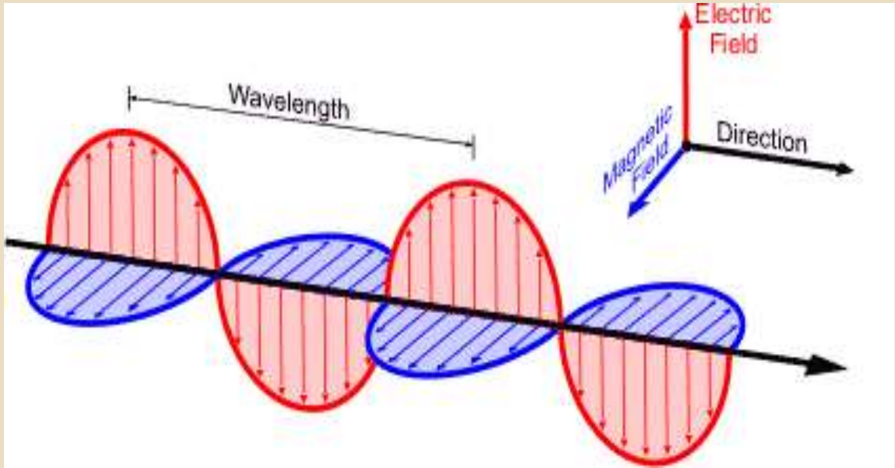


Electromagnetic waves

- 1785 – Coulomb's observation of forces between charged bodies, Gauss's law
- 1819 – discovery by Oersted that time varying current produce magnetic field followed by Biot Savart law
- 1831 – Faraday discovered time varying magnetic field produce electric field
- 1865 – Maxwell predicted existence of electro-magnetic waves
- 1888 – H.R.Hertz confirmed the existence of e.m waves by producing it based on the principle that oscillating charge gives out radiation of wavelength $\lambda = c/\upsilon$

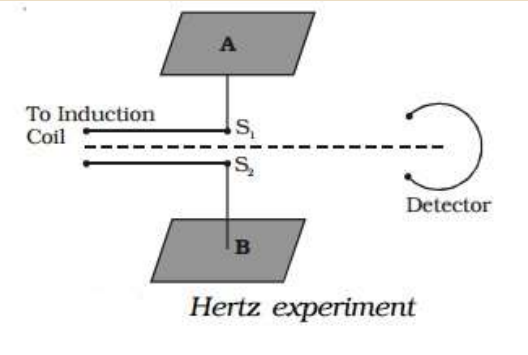
Properties of Electromagnetic waves

- Electric and magnetic components perpendicular to each other and perpendicular to direction of propagation
- Travel through empty space with speed of light $c = 1/\sqrt{\mu\varepsilon}$, $E/B = c$ velocity of light
- Obey principle of superposition, not deflected by electric and magnetic field, affect photographic plate
- Impart momentum and produce heat, could be reflected, refracted and diffracted



Hertz experiment to produce e.m waves

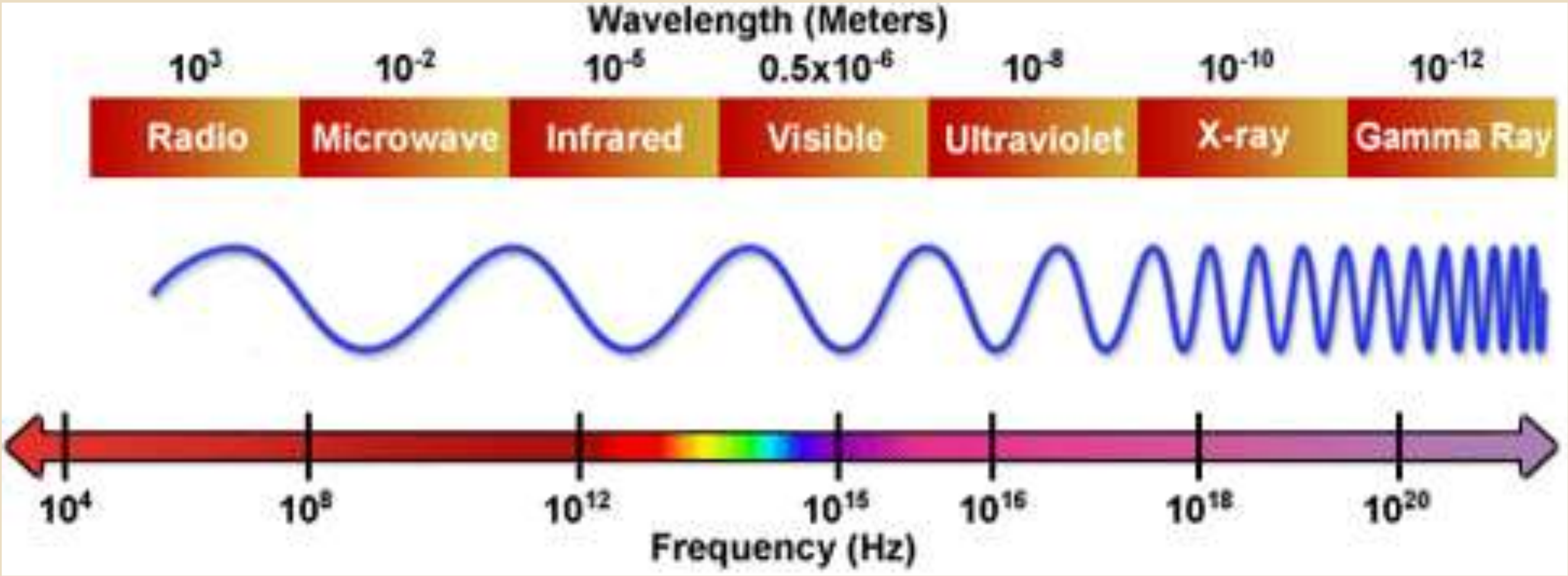
- High voltage appld aross 2 large metal plates A and B
- High voltage causes ionization of air across brass knobs S_1 and S_2
- The plates A and B act as a capacitor of low capacity



- The plates discharge across S_1 and S_2 making air gap conducting and p.d across plates falls
- Capacitor recharged by induction coil, charging discharging repeats
- The oscillating charges produce e.m waves with $\upsilon=1/(2\pi\sqrt{LC})$
- Detection of e.m waves done using an open ring with metallic spheres C and D

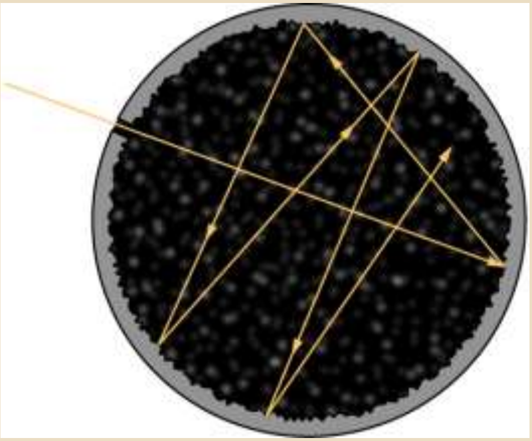
Electromagnetic spectrum

- **Orderly distribution of electromagnetic radiation according to their wavelength is known as Electromagnetic spectrum**



Black body radiation

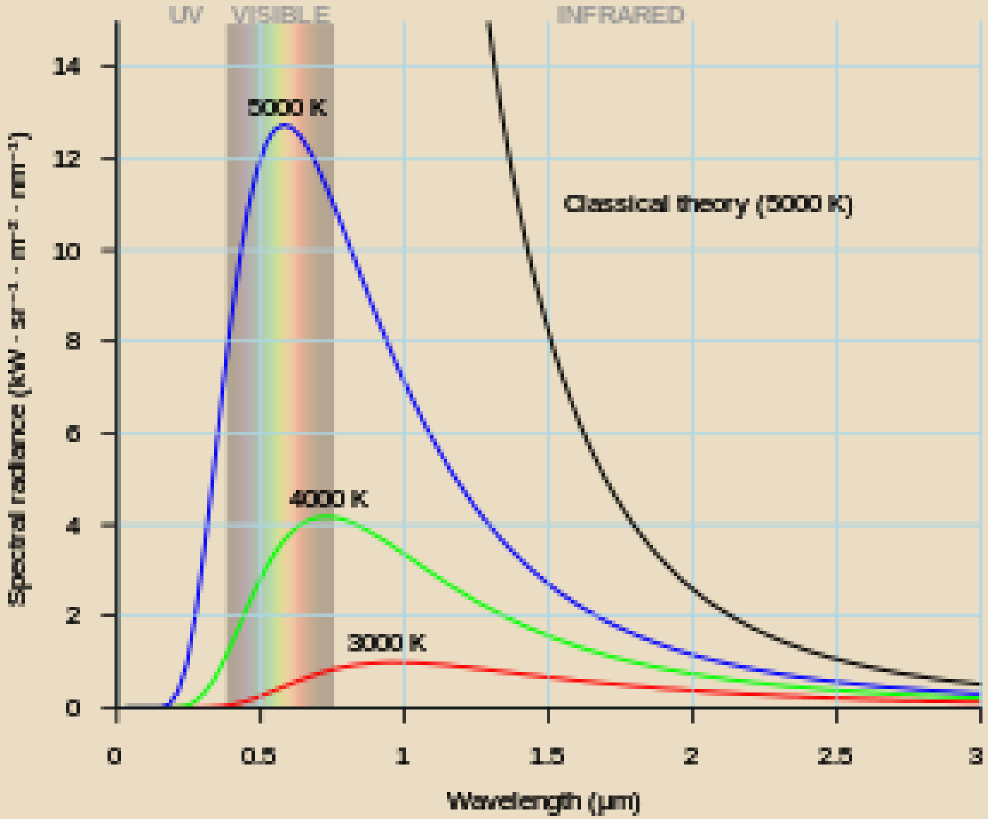
- If the body absorbs all radiation incident on it, it is called a black body
- The radiation emitted by a black body - black body is called black body radiation
- An enclosure with a small opening can act as a blackbody
- Inside the enclosure radiation get trapped due to multiple reflection



- Kirchoff (1824-1887) considered black body as perfect to study thermal radiation and formulated 2 laws (1) the radiation by a black body depend only on its temperature (2) a black body absorbs all radiation falling on it and is a good radiator.

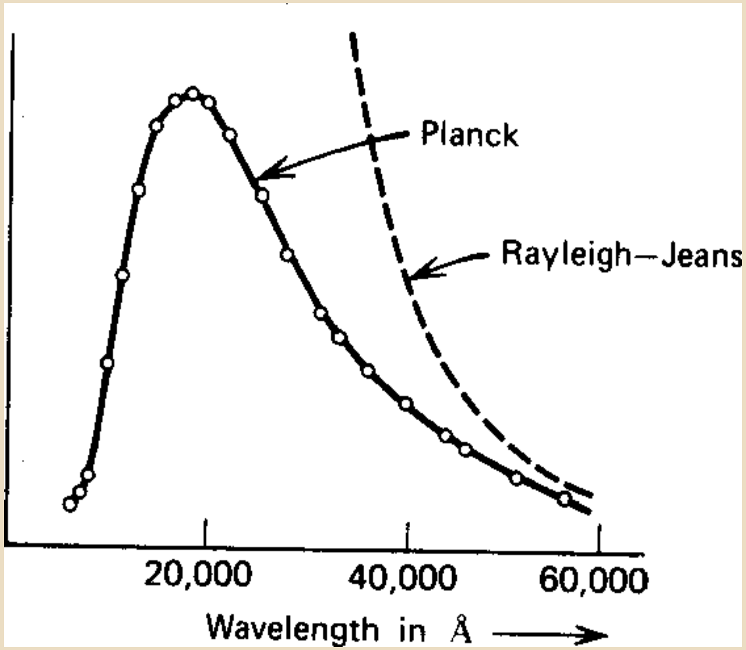
Black body radiation

- In 1884 Stefan and Boltzman showed the wavelength of radiation is proportional to 4th power of absolute temperature of the body.
- Lummer and Pringsheim studied E Vs λ graphs for different temperatures of the body



Rayleigh-Jeans formula- Ultraviolet catastrophe

They considered walls of a blackbody made up of large number of harmonic oscillators producing stand-ing waves



Number of independent Standing waves given by

$G(\upsilon)\, d\upsilon = (8\pi\upsilon^2\, d\upsilon) / C^3$

Average energy /standing wave $\varepsilon = kT$

and total energy in the range υ to $\upsilon + d\upsilon$ is given by

$u(\upsilon)\, d\upsilon = \varepsilon\, G(\upsilon)\, d\upsilon$

$= kT\, (8\pi\upsilon^2\, d\upsilon) / C^3$

$= (8\pi\, kT)/C^3\, \upsilon^2\, d\upsilon$ -Raleigh-Jeans formula

Solution to ultraviolet catastrophe by Planck

Planck introduced new term $h\upsilon/(e^{\frac{h\upsilon}{kT}} - 1)$ to modify Raleigh Jeans formula to

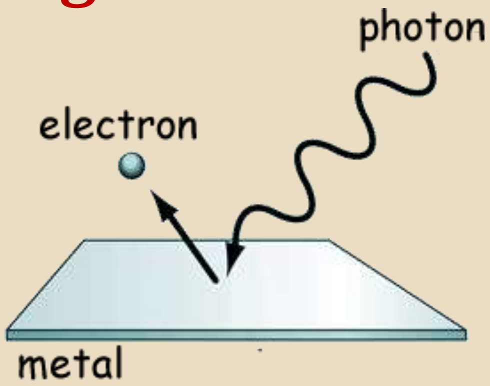
$$u(\upsilon)\,d\upsilon = \frac{8\pi h}{C^3}\,\frac{\upsilon^3\,d\upsilon}{(e^{\frac{h\upsilon}{kT}} - 1)}$$

- **At high frequencies $\upsilon \rightarrow \alpha$, $e^{\frac{h\upsilon}{kT}} \rightarrow \alpha$ faster than υ, $u(\upsilon)\,d\upsilon \rightarrow 0$**

- **At low frequencies, $e^{\frac{h\upsilon}{kT}} - 1 = 1 + h\upsilon/kT - 1 = h\upsilon/kT$**
  $u(\upsilon)\,d\upsilon = (8\pi\,kT)/C^3\,\upsilon^2\,d\upsilon$

Photoelectric effect

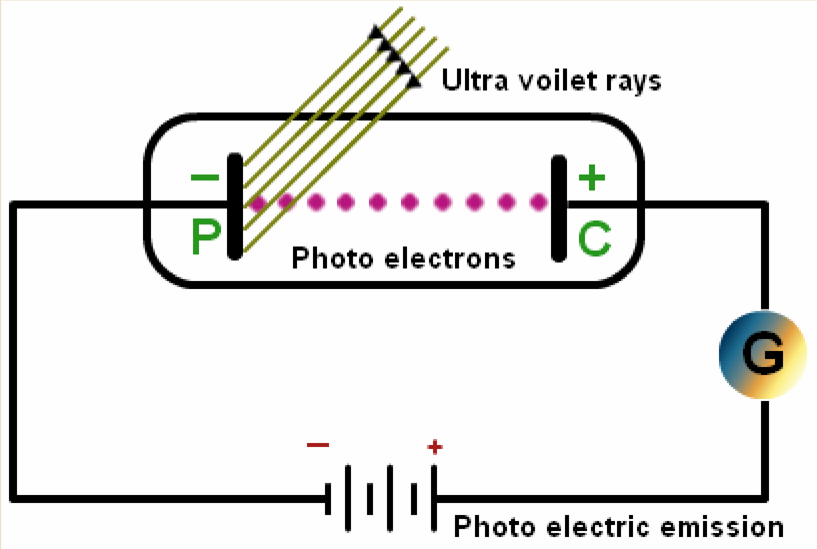
- First noticed by Hertz in 1887 when a spark observed across air gap of his transmitter on incidence of UV light, but could not explain
- Later his student Philip Lenard discovered this as due to emission of electrons when frequency of e.m. waves become sufficiently high
- Thus photoelectric effectdefined as emission of electrons from surface of metals when light is incident on it
- Different metals exhibit photoelectric effect at different frequencies of light



- Alkali metals lithium, sodium, potassium – visible light, Zinc, Cadmium, magnesium – UV light

Exptal study of Photoelectric effect by Philip Lenard

- Exptal set up consists of evacuated tube with Emitter P and a collector C connected to voltage source and a galvanometer
- On incidence of light at –ve electrode, electrons emitted and directed towards anode, current flows thru' circuit



Factors affecting photo electric effect:-

(1) **Intensity of radiation**:- number of photo electrons directly proportional to intensity of incident radiation

(2) **Frequency of radiation**:-

(3) **p.d across electrodes**

Effect of potential

- When intensity and frequency of incident radiation kept constant photoelectric current increases gradually to reach a saturation value
- When –ve potential applied to +ve electrode, photoelectric current decreases to become zero – stopping potential V_0

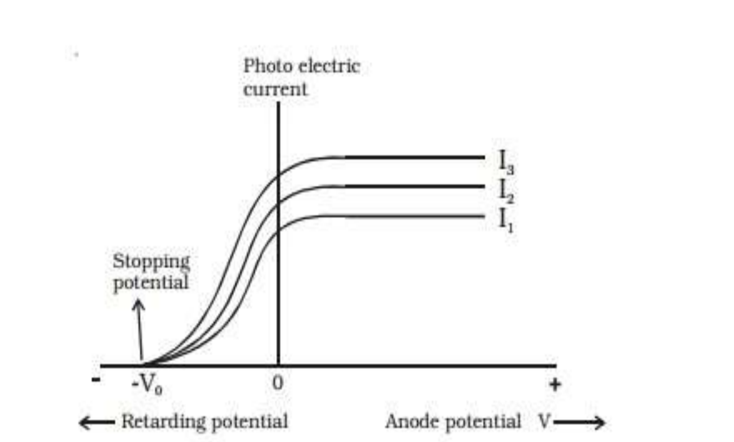


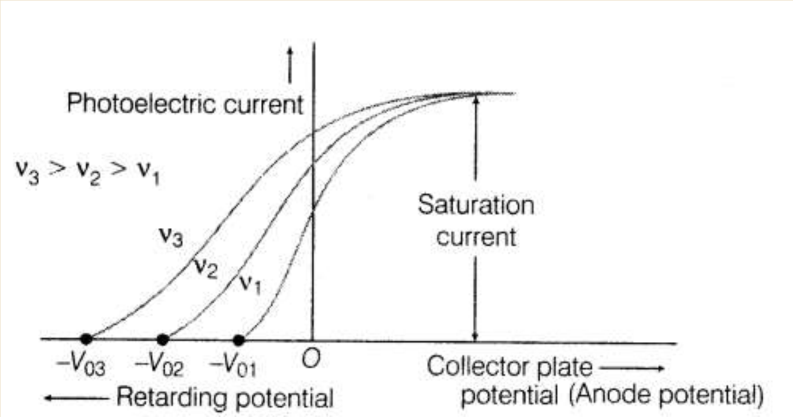
Fig Variation of photo electric current with potential difference.

- Stopping potential is independent of its intensity
- Stopping potential is measureof maximum K.E of photoelectron

$$\frac{1}{2}mv^2_{max} = eV_0$$

Effect of frequency of incident radiation

- **When frequency of incident Radiation increases stopping Potential also increases, but Saturation current remains the Same**

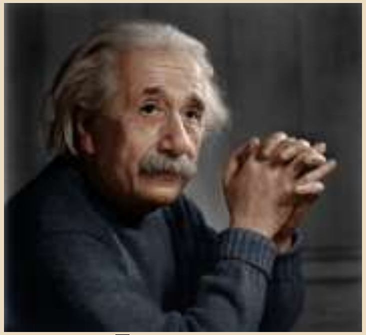


- **The minimum frequency of Incident radiation at which stopping potential is zero is called threshold frequency below which emission of photoelectrons not possible**

Laws of Photoelectric emission

- **Number of photoelectrons α to intensity (υ & metal same)**
- **mnm υ below which no emission – threshold frequency**
- **K.E of photoelectrons depend on frequency only**
- **Photoelectric emission is instantaneous-time lag 10^{-9}s**

Einsteins Photoelectric equation



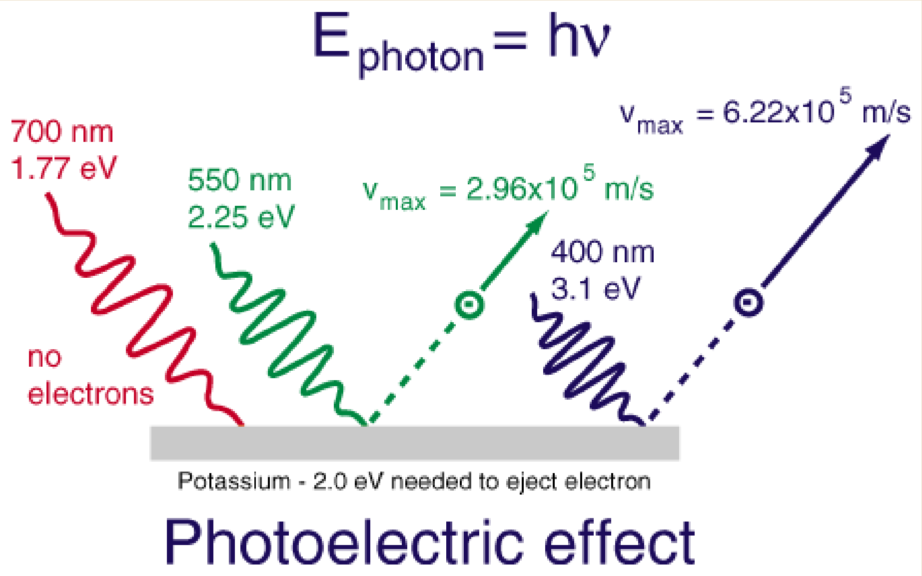
- Einstein used Planck's quantum hypothesis to explain photoelectric effect
- On absorption of light photon of frequency υ by the metal surface, the energy is used for 2 purposes (1) to liberate the electron from metal surface known as work function w_0 (2) to impart kinetic energy to photo electron

ie $$h\upsilon = w_0 + \frac{1}{2}mv^2$$

$$\frac{1}{2}mv^2 = h\upsilon - w_0$$

$$= h\upsilon - h\upsilon_0$$

$$\frac{1}{2}mv^2 = hc\left[\frac{1}{\lambda} - \frac{1}{\lambda_0}\right]$$



Explanation of Photoelectric effect by Einstein

- **Number of photoelectrons emitted proportional to intensity of incident light (no. of incident photons) - first law of photoelectric emission**
- **Kinetic energy of photo electrons depend on frequency – not on intensity – of incident radiation – 2nd law of photoelectric emission**
- **If $\upsilon < \upsilon_0$ (threshold frequency), photoelectric emission is impossible – 3rd law of photoelectric emission**
- **Photoelectric emission is due to elastic collision of photon and electron without time lag - 4th law of photoelectric emission**

Compton effect

- Photo electric effect suggests quantum nature for light
- But Compton showed when photon is scattered by an electron it shows wave nature
- Compton effect is the phenomenon of scattering of photon by an electron that results in increased wavelength for the scattered photon
- Collision between photon and electron assumed elastic where sum of momenta and energies before and after collision are separately equal
- The photon is given a dual nature and momentum is $\frac{h}{\lambda}$, energy hυ and energy of electron mc^2 before collision

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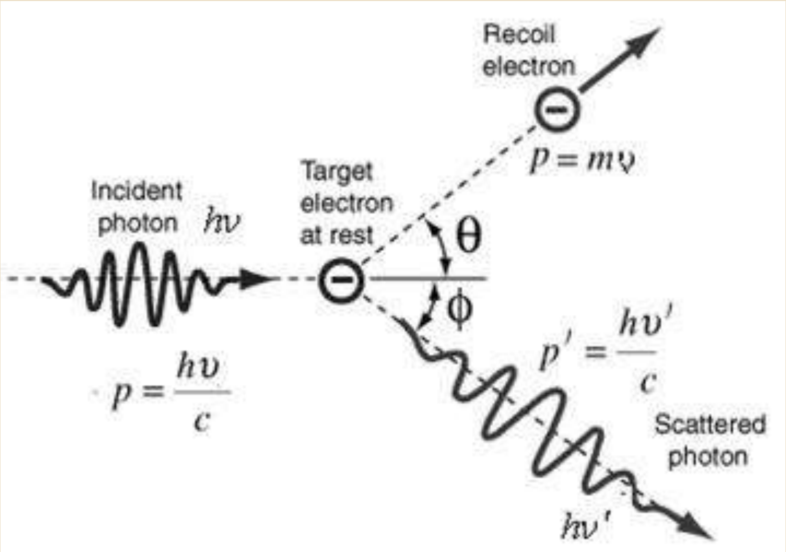


Conservation of momentum

$h/\lambda + 0 = h/\lambda' \cos\varphi + p\cos\theta$

Conservation of energy

$h\upsilon + mc^2 = h\upsilon' + E_e$

Compton effect

$$\Delta \lambda = \frac{h}{mc}(1 - \cos\varphi)$$ ….. Compton shift

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

Compton wavelength of electron

$$\lambda_c = \frac{h}{mc} = \frac{6.62 \times 10{-}34}{9.1 \times 10{-}31 \times 3 \times 108} = 2.425 \text{ pm}$$

When $\varphi = 180^o$, $\Delta \lambda$ is maximum

ie $(\Delta \lambda)_{max} = \lambda_c (1- -1) = 2 \lambda_c$

$(\Delta \lambda)_{ma} = 2 \times 2.425 \text{ pm} = 4.85 \text{ pm}$

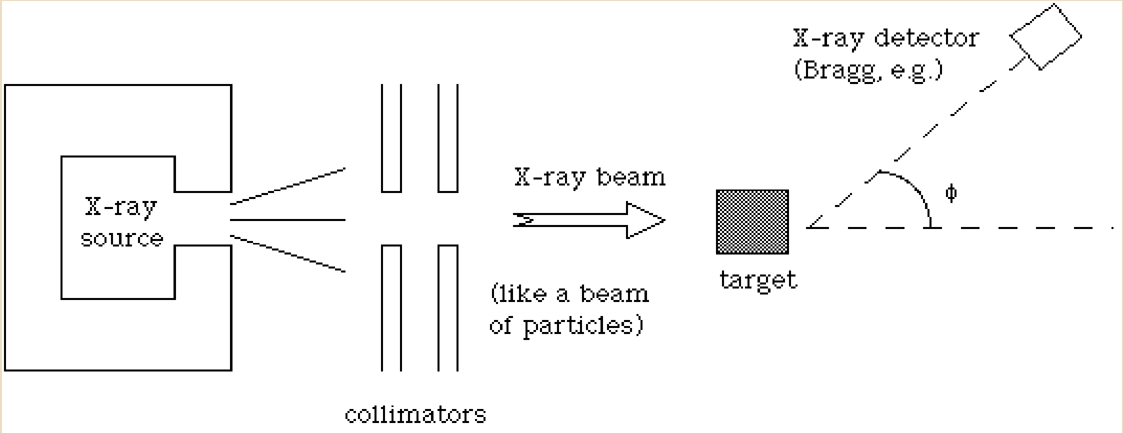
Fractional shift $= \frac{\Delta \lambda}{\lambda}$

Compton effect

Experimental demonstration of Compton effect

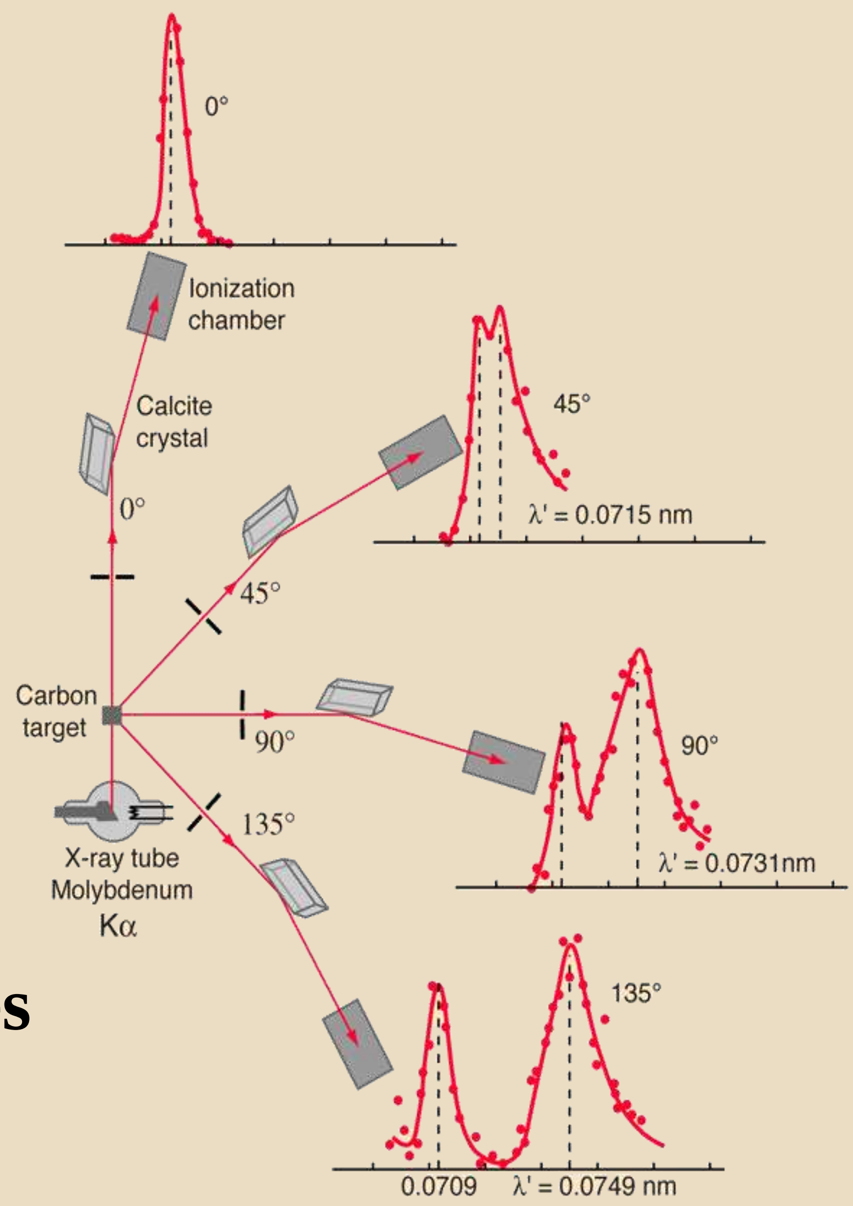
Experimental arrangement involves X-ray source, filter for Kα line, a carbon block to scatter X-ray, crystal spectrometer and ionization chamber for the analysis of the scattered X-rays

X-rays after collimation scattered by carbon block and detected by crystal spectrometer at different angle φ. The ionization chamber indicates current proportional to intensity of scattered x-rays.



Experimental demonstration of Compton effect

- Scattered radiation less penetrating (low υ)
- Contained radiation of 2 wavelengths, one identical with original, the other longer wavelength
- The peaks correspond to the wavelengths of photon
- As φ increases Δ λ increases



Thank you