# Quantum Physics

## Photon

- ☑ A small packet of energy of electromagnetic radiation.
- ☑ The energy is directly proportional to the frequency of radiation.
- ☑ $E = hf$ where E: energy of a photon, h: Plank's constant, f: frequency

$E \propto f$

$E = hf$

- f → frequency
- E → energy of one photon
- h → Plank's Constant, $h = 6.63 \times 10^{-34}\ Js$

as $v = f\lambda$ so $c = f\lambda$ & $f = \frac{c}{\lambda}$

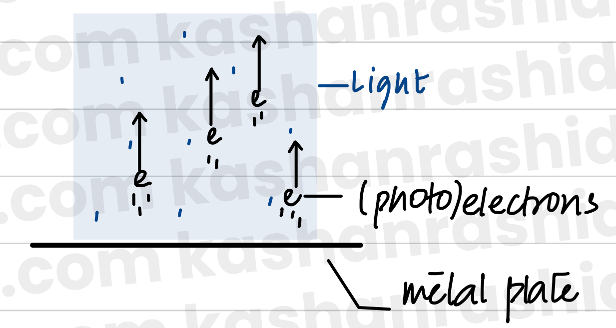
$E = \frac{hc}{\lambda}$

- c → speed of light in vacuum
- λ → wavelength

γ-rays X-rays UV LIGHT (VIBGYOR) IR MW RW

→ increasing wavelength
decreasing frequency
decreasing energy

## Photoelectric Effect




"It is the phenomenon of emission of electrons from the surface of metal by the incidence of light."

This phenomenon was able to prove the particle

## Properties of Photoelectric Effect

1. Not all frequencies of Electromagnetic radiations were able to produce a photoelectric effect.
2. One photon interacts with one electron only.

3. If the energy of photon is less than the Work Function energy
( frequency is less than threshold frequency)
- no photoelectric effect (no emission of electrons)
- temp of the plate rises

electron absorbs photon and excite. It collides with the neighbouring atoms and electrons and transfer its energy to them. Therefore the vibrations of atoms increase and temperature rises.

4. If energy of photon is greater than the Work Function energy
( frequency is greater than threshold frequency)

| Energy of photon | = | Work function energy | + | Max kinetic energy of electron |
|---|---|---|---|---|

$$E = \phi + E_{K_{max}}$$

$$hf = \phi + E_{K_{max}}$$

$$\frac{hc}{\lambda} = \phi + E_{K_{max}}$$

Part of the photon's energy is used to do work against the pull of nuclei and the extra energy is converted to kinetic energy of electron.

## Work-Function Energy ( $\phi$ )

It is the minimum energy of photon required to remove electron from the surface of metal having negligible kinetic energy.

It is the property of the metal as nuclei of different metals hold their electrons with different force.

## Threshold frequency ( $f_0$ )

The minimum frequency of electromagnetic radiation required to remove electrons from the surface of metal having negligible kinetic energy.

$E = hf$   if $f = f_0$   $E = \phi$

$$\phi = hf_0$$

$$\phi = \frac{hc}{\lambda_0}$$

$\lambda_0$ → Threshold Wavelength (maximum wavelength . . . . )

if $\lambda$ is greater than $\lambda_0$, photon energy would be less than $\phi$ & no photoelectric effect would occur.

5. There is no time delay between the incidence of light and the emission of electrons if frequency is greater than the threshold frequency. (Evidence for the particle nature of light)

$$\text{Intensity} = \frac{\text{Energy}}{\text{Area} \times \text{time}} \longrightarrow \text{Intensity} \propto \text{Energy}$$

Energy = No. of photons × Energy of each photon

No. of photons ↓ Brightness

Energy of each photon ↓ frequency

- Photoelectric Current is the rate of emission of electrons

6. If the frequency of the incident radiation is increased (wavelength decreased / red light replaced with blue light)

$Ek_{max}$ : increased (photon energy increased & $\phi$ same)

Photoelectric current : stays same (rate of arrival of photons are same)

7. If the intensity of the incident frequency is increased (Only brightness increased ⟶ no. of photons increased)

$Ek_{max}$ : stays the same (photon energy is same)

Photoelectric Current : increase (rate of arrival of photons increase)

8. If the frequency of the incident radiation is increased, keeping intensity constant. (No. of photons decreased to keep Intensity same)

$Ek_{max}$ : Increase (photon energy increased)

Photoelectric Current : decrease (no. of photons decreased)

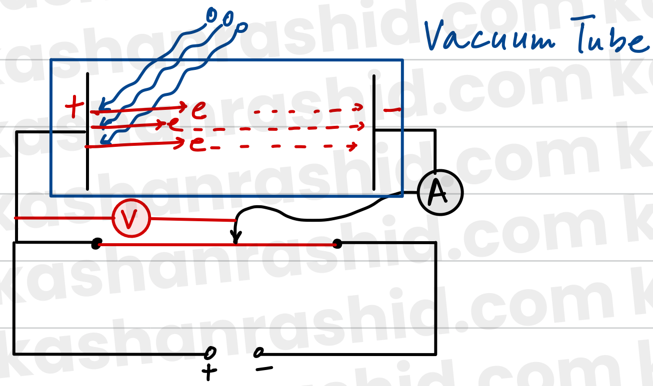
## How does Photoelectric effect rejects the wave theory of light.

1. According to wave theory, radiation of any frequency can cause a photoelectric effect if incident for a longer duration of time. However, radiations only with frequencies higher than threshold frequency caused photoelectric effect.

2. According to wave theory, there should be a time delay between the incidence of light and emission of electrons. However there was no time delay and the emission was instantaneous.

3. According to wave theory, increasing intensity of radiation will increase the max kinetic energy of electrons. However, intensity has no effect on $E_K$ max, rather increases the photoelectric current.

## Stopping Potential




Workdone in stopping electron = Max kinetic energy of electron

$V_s \times q = E_{K\,max}$

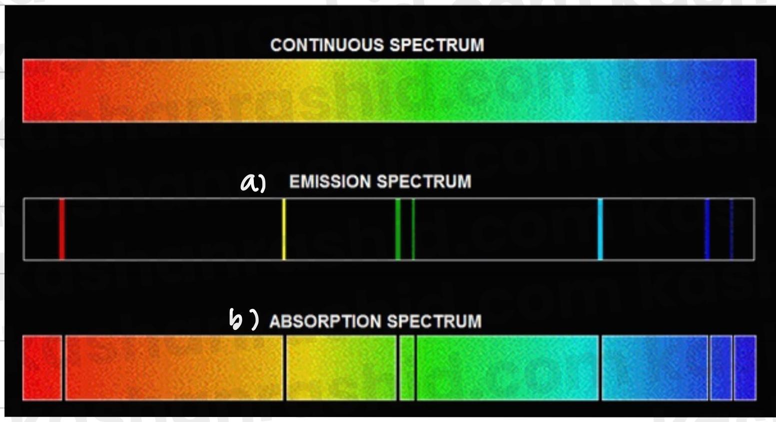
$$E_{K_{max}} = V_s \times q$$

☑ If the intensity of the incident frequency is increased $V_s$ stays the same as $E_{K\,max}$ stays the same.

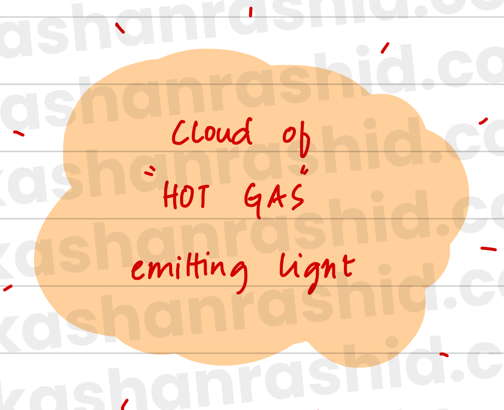
☑ If the frequency of incident radiation is increased $V_s$ increases (Photon energy increased so $E_{K\,max}$ increased)
(More work needs to be done to stop)

## Line Spectrum

a) Emission Line Spectrum
b) Absorption Line Spectrum




### a) Emission Line Spectrum.



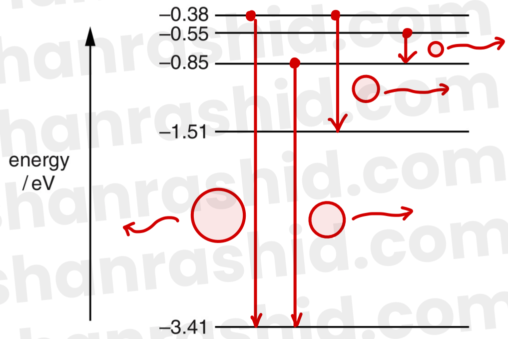




Fig. 8.2


- In a cloud of hot gas electrons exists at higher energy state due to higher temperature.
- When these electrons drop from higher to lower energy state, they emit a photon of energy equal to the energy gap between levels.
- Each color of the spectrum corresponds to the photon of discrete energy.
- As photon energies are discrete, the electron energy levels are also discrete.

- When an electron de-excites i.e. drops from a higher to a lower energy level, it emits photon of energy equal to the energy gap between level
- Energy levels exist around the nucleus due to its attractive force.
- Energy levels closer to the nucleus are more negative as electrons over there will need more energy to escape the nuclear pull.

- photon energy = 3.41 − 0.38
  = 3.03 eV

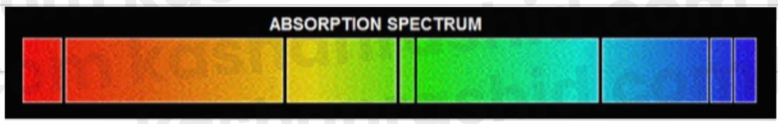
- $E = \frac{hc}{\lambda}$

$$3.03 \times 1.6\times10^{-19} = \frac{6.63\times10^{-34} \times 3\times10^{8}}{\lambda}$$

$$\lambda = 4.1\times10^{-7}\,m$$

VIBGYOR
400 nm   700nm
Blue/Violet ↑

b) Absorption Line Spectrum

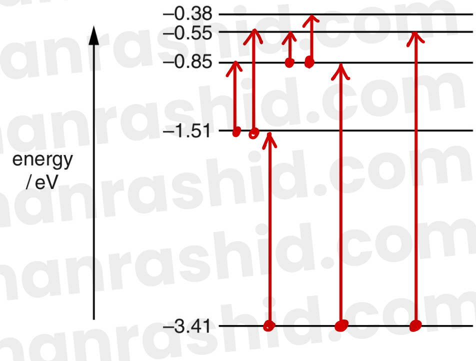




Fig. 8.2

- When white light passes through a cloud of cool gas, the electrons in the lower energy state absorb photons of energy equal to the gap between levels.
- They excite to a higher energy state and then subsequently de-excite emitting the same photons in all directions.
- Hence the intensity of those colors fall and dark lines are seen on screen.

- As the dark lines belongs to photons of discrete energies and each photon has energy equal to the gap between levels, this shows that electron energy levels are also discrete.

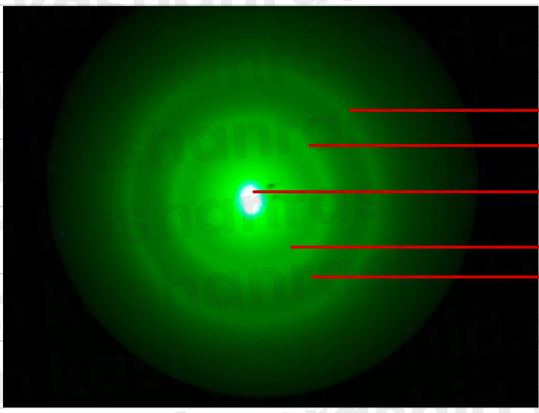
## De Broglie's Wavelength

Every moving particle has a wave associated with it and its wavelength is inversely proportional to the momentum of particle.

$E = mc^2$ $\quad E = \frac{hc}{\lambda}$

$mc^2 = \frac{hc}{\lambda}$ $\quad mc = \frac{h}{\lambda}$

$$p = \frac{h}{\lambda} \quad \text{or} \quad \lambda = \frac{h}{p}$$



Constructive Interference

Destructive Interference

When electrons were passed through a diffraction grating made of Graphite, the electrons diffracted and interfered forming rings on the flourescent screen

Work done by Acc. Voltage = Gain in Kinetic energy

$$V \times q = \frac{p^2}{2m}$$

$$p = \sqrt{2mVq}$$

$$n\lambda = d\sin\theta$$

$$\downarrow \lambda \propto \sin\theta \downarrow$$

If acc. voltage is increased → momentum of electron inc. → λ will decrease → less diffraction "Rings get closer" radius of rings decrease.