6/11/23

CHAPTER- 11
DUAL NATURE OF RADIATION AND MATTER

★ DUAL NATURE OF RADIATION

In some phenomena, light, interference, diffraction, light behaves like wave but in phenomena of photoelectric effect, light behaves like particle. This proves that light has dual nature.

- **WORK FUNCTION**

Minimum energy required by an electron to escape from metal surface. It is denoted by ϕ. Its unit is eV (electron volt).

$$1\,eV = 1.6 \times 10^{-19}\,J$$

- **ELECTRON EMISSION**

The process of ejection of electron from metal surface by applying external energy is called emission or electron emission.

* TYPES OF EMISSION

There are four types of emission

1. **THERMIONIC EMISSION**

The process of ejection of electron from the metal surface by heating is called thermionic emission.

2. **PHOTOELECTRIC EMISSION**

The process of ejection of electron from the metal surface by falling light on it is called photoelectric emission.

3. **FIELD EMISSION**

The process of ejection of electron from the metal by applying high electric field is called field emission.

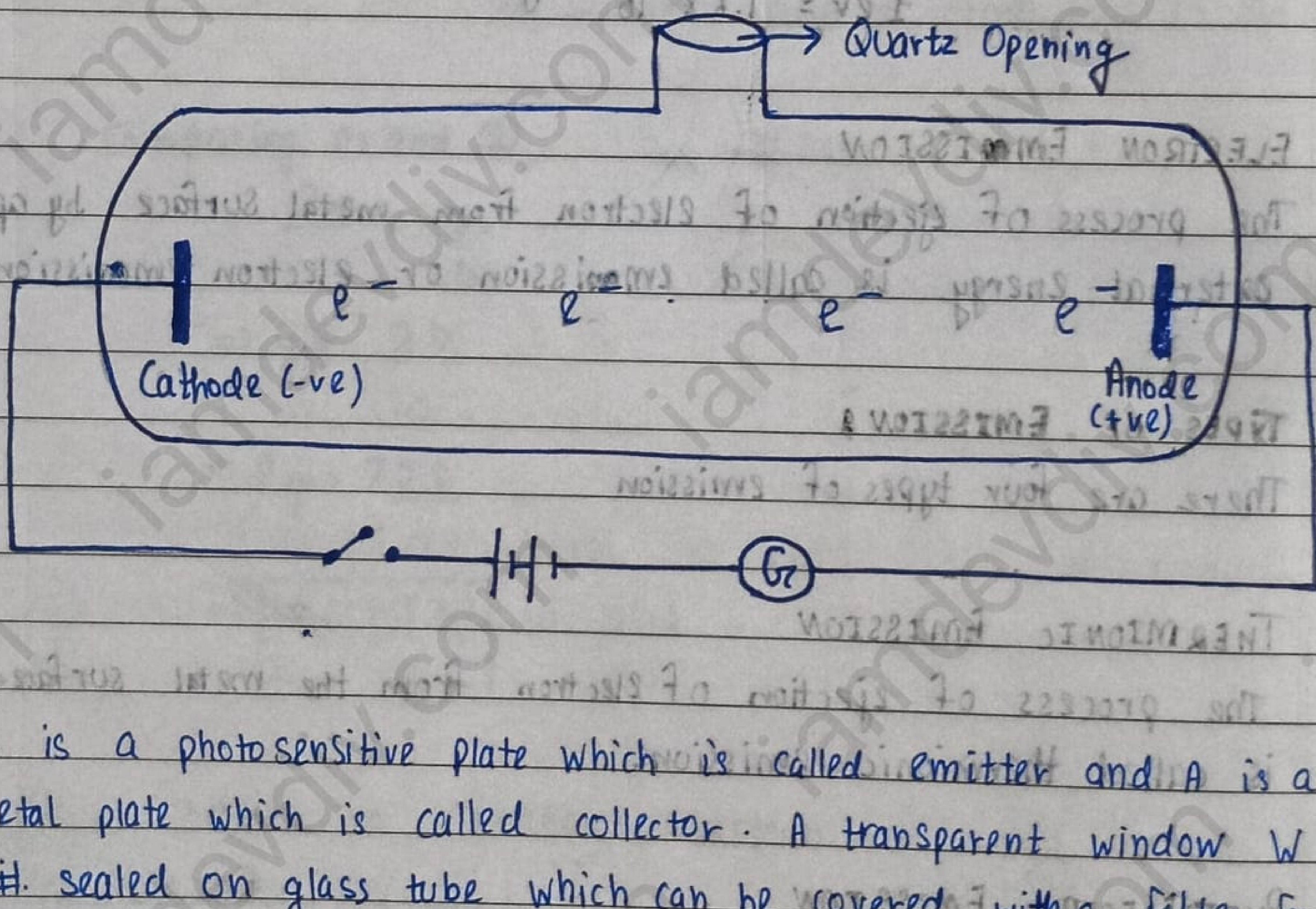
4. SECONDARY EMISSION

The process of ejection of electron from the metal surface by falling fast moving particles on it is called secondary emission.

★ PHOTOELECTRIC EFFECT

The phenomena of converting light energy into electrical energy is called photoelectric effect. The electron ejected by photoelectric effect is called photo electron. The current produced by photoelectric effect is called photo current.

• EXPERIMENTAL STUDY OF PHOTOELECTRIC EFFECT



C is a photosensitive plate which is called emitter and A is a metal plate which is called collector. A transparent window W is ~~~~ sealed on glass tube which can be covered with a filter for light of particular radiation. This will allow the light of particular wavelength to pass through it. The plane A can be of given desire, positive or negative potential with respect to plane C. Using the arrangement of battery and galvanometer is connected to measure the photo current in the circuit. When monochromatic radiation of suitable frequency obtained from the source falls on a photosensitive plate C then photoelectrons are emitted from C. Which get accelerated toward the plate A. The electron flow in the outer circuit and hence galvanometer shows deflection.

- HERTZ AND LENARD'S OBSERVATION

Lenard observed that when UV radiations were allowed to fall on the emitter plate, current flows in the circuit. As soon as the UV radiations were stopped, the current flow also stopped. These observation indicate that when UV radiation falls on plate C, electrons are ejected from it which are attracted towards the positive collector plate A by eletric field.

- LAWS OF PHOTOELECTRIC EFFECT

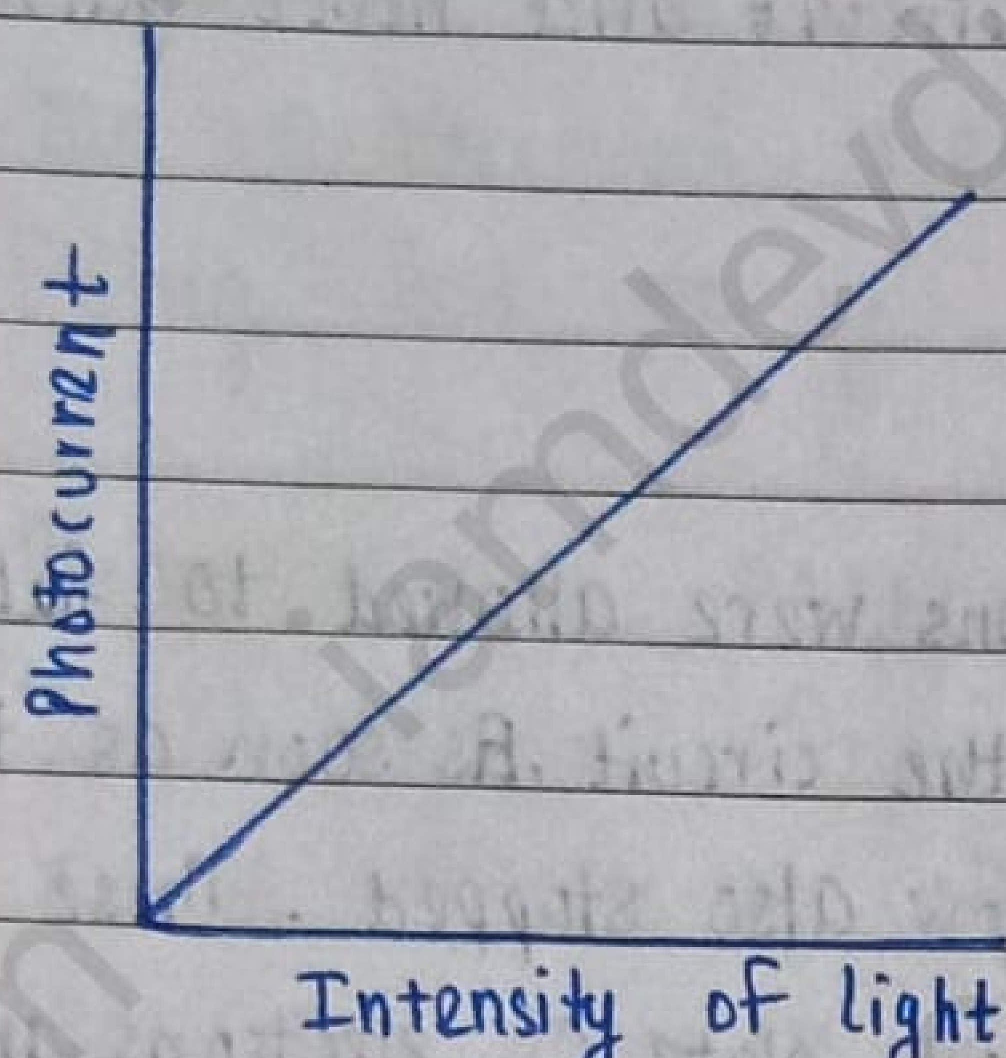
1. Kinetic energy of photo electrons depends on frequency of incident radiation.
2. Number of electrons emitted per second depends on intensity of radiation.
3. There is no time lag between incident radiation and emission of electron.
4. There is a certain frequency below which electrons cannot be emitted from metal. This frequency is called threshold frequency.

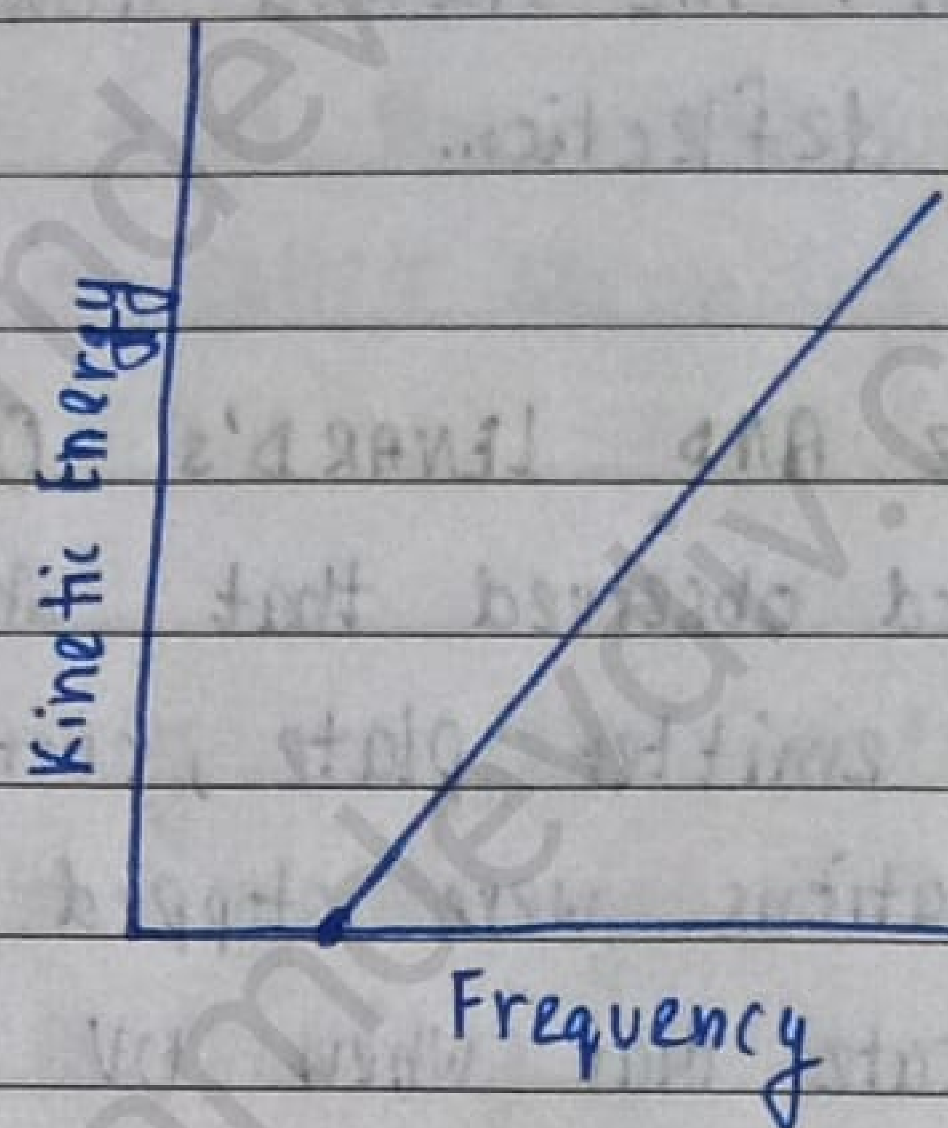
- STOPPING POTENTIAL

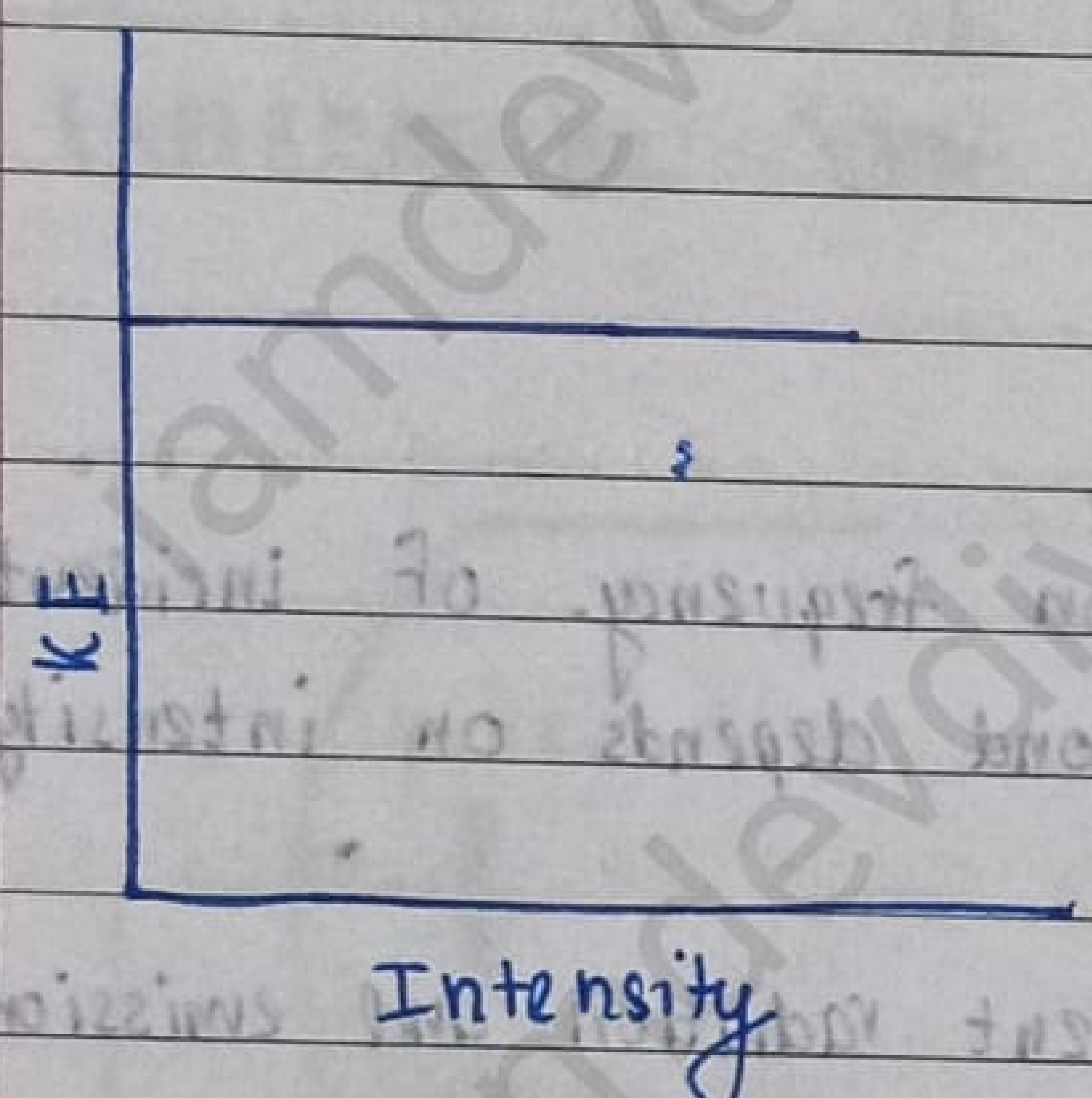
If we make the collector plate more positive, it will attract more number of electrons. Therefore, the photocurrent will increase but it will increase upto a certain point called saturation current. Now, the plate A is at negative potential. Therefore, at certain potential, the photocurrent will become zero and negative potential is called stopping potential.

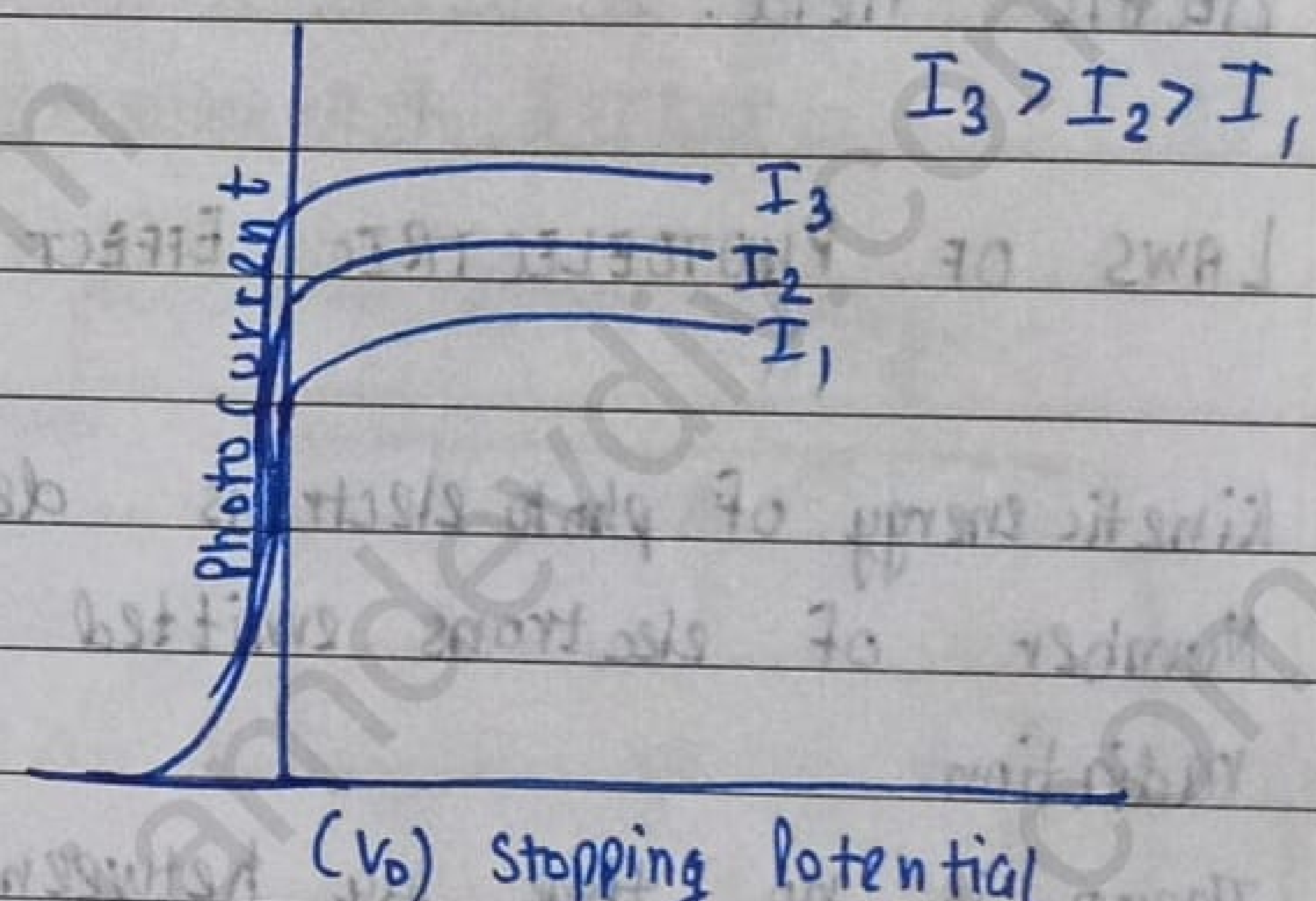
☆ GRAPHS

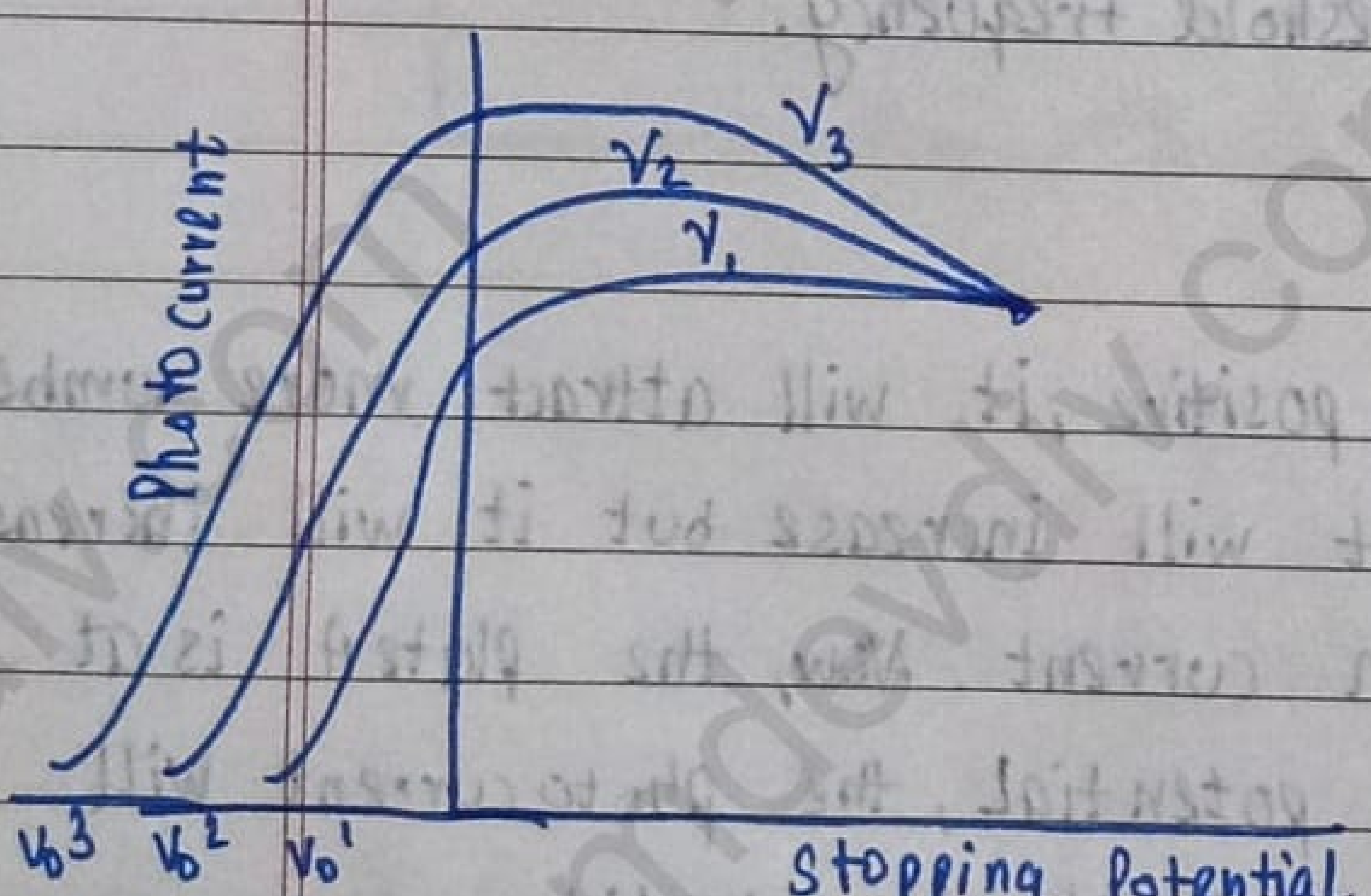
P.T.O.











☆ PHOTON

In interaction of radiation with matter, radiation behaves as it is made up of particles called photon.

1. Photons are ~~bu~~ bundle or packets of energy.
2. Photon is a massless particle.

3. $E = h\nu$

where, $h = 6.63 \times 10^{-34}$ Js
↳ Planck's Constant

4. Rest mass of photon is zero.
5. speed of photon in vacuum is 3×10^{8} m/s.

☆ EINSTEIN PHOTOELECTRIC EQUATION

When a photon of energy $h\nu$ fall on a metal surface, the energy of photon is absorbed by the electrons is used in following two ways:

1. A part of energy is used to overcome the surface barrier and electron comes out from the metal surface. This part of energy is called work function,

$$\phi_0 = h\nu_0$$

2. The remaining part of the energy is used in giving a velocity to the photoelectron. This is equal to maximum kinetic energy. According to law of conservation of energy:

$$\phi_0 = \frac{1}{2}mv^2$$

$$h\nu = h\nu_0 + \frac{1}{2}mv^2$$

$$\Rightarrow h(\nu - \nu_0) = \frac{1}{2}mv^2$$

$$\Rightarrow \boxed{h(\nu - \nu_0) = (KE)_{max}}$$

This equation is called Einstein's photoelectric equation.

- CASE 1

If ν is less than ν_0. In this case, no emission will take place.

- CASE 2

IF $\nu = \nu_0 \Rightarrow$ in this case, the emission will take place but the ejected electrons will ~~not~~ have no kinetic energy.

- CASE 3

If $\nu > \nu_0$ ⇒ In this case, emission will take place and ejected e^- will have KE.

☆ DE BROGLIE HYPOTHESIS

According to this, a moving material particle sometimes acts as a wave and sometimes acts as a particle. A wave associated with moving particle which controls the particle in every aspect. This wave is known as De Broglie wave or matter wave.

According to Einstein,

$$E = mc^2 \quad \text{—} ①$$

According to Planck,

$$E = h\nu \quad \text{—} ②$$

Equating ① and ②

$$mc^2 = h\nu$$

$$\Rightarrow mc^2 = h\frac{c}{\lambda}$$

$$\Rightarrow mc = \frac{h}{\lambda}$$

$$\Rightarrow \lambda = \frac{h}{mc}$$

$$\Rightarrow \lambda = \frac{h}{mv}$$

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

- DE BROGLIE WAVELENGTH OF AN ELECTRON

K.E of $e^- = \frac{1}{2}mv^2$

Work done on e^- = eV

$eV = \frac{1}{2} mv^2$

$v^2 = \frac{2eV}{m}$

$v = \sqrt{\frac{2eV}{m}}$ —— ①

$\lambda = \frac{h}{mv}$ —— ②

Put value of ① in ②

$\lambda = \frac{h}{m\sqrt{\frac{2eV}{m}}}$

$\Rightarrow \lambda = \frac{h}{\sqrt{\frac{2m^2 eV}{m}}}$

$\Rightarrow \lambda = \frac{h}{\sqrt{2meV}}$

$\Rightarrow \lambda = \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} V}}$

$\Rightarrow \lambda = \frac{12.27 \times 10^{-10} m}{\sqrt{V}}$

$\Rightarrow \lambda = \frac{12.27 \, A^\circ}{\sqrt{V}}$

Q Through what Potential difference should an electron be accelerated so that its De Broglie wavelength become 0.4 A°.

Sol. $\lambda = \frac{12.27 \, A^\circ}{\sqrt{V}}$

$\Rightarrow 0.4 = \frac{12.27}{\sqrt{V}}$

$\Rightarrow 0.16 = \frac{144}{16}\left(\frac{12.27}{40\sqrt{V}}\right)^2$

$\Rightarrow V = \frac{144 \times 16}{16}\left(\frac{1227}{40}\right)^2 = (3.675)^2 = 13.5\ V$ Ans

Q A proton and α-particle are moving with same kinetic energy. What is the ratio of their wavelengths?

Sol. $\lambda_p = \frac{h}{\sqrt{2m_p eV}}$ $\lambda_p \propto \frac{1}{\sqrt{m_p}}$

$\lambda_\alpha = \frac{h}{\sqrt{2m_\alpha eV}}$ $\lambda_\alpha = \frac{1}{\sqrt{m_\alpha}}$

	e^-	p	α
mass	1 :	1836 :	$4p$
charge	1 :	1 :	$2p$

$\lambda_p : \lambda_\alpha = \frac{\frac{1}{\sqrt{m_p}}}{\frac{1}{\sqrt{m_\alpha}}} = \frac{\sqrt{m_\alpha}}{\sqrt{m_p}} = \frac{\sqrt{4m_p}}{\sqrt{m_p}} = \frac{2}{1} = 2:1$ Ans

Q A proton and α-particle are accelerated through same potential. What is the ratio of their wavelength?

Sol. $\lambda_p = \frac{h}{\sqrt{2m_p e_p V}}$ $\lambda_p \propto \frac{1}{\sqrt{m_p e_p}}$

$\lambda_\alpha = \frac{h}{\sqrt{2m_\alpha e_\alpha V}}$ $\lambda_\alpha \propto \frac{1}{\sqrt{m_\alpha e_\alpha}}$

$\lambda_p : \lambda_\alpha = \frac{\frac{1}{\sqrt{m_p e_p}}}{\frac{1}{\sqrt{m_\alpha e_\alpha}}} = \frac{\sqrt{m_\alpha e_\alpha}}{\sqrt{m_p e_p}} = \frac{\sqrt{4m_p\, 2e_p}}{\sqrt{m_p e_p}} = \frac{2\sqrt{2}}{1}$

$= 2\sqrt{2} : 1$ Ans

Q A photon and electron have got same De Broglie wavelength. Which has greater total energy?

Sol. $e_1 = h\nu = \frac{hc}{\lambda}$

$e_2 = mc^2$

$\lambda = \frac{h}{mv} \Rightarrow m = \frac{h}{\lambda v}$

$\Rightarrow e_2 = \frac{h}{\lambda}\frac{c^2}{v}$

$\frac{e_1}{e_2} = \frac{\frac{hc}{\lambda}}{\frac{hc^2}{\lambda v}} = \frac{v}{c}$

~~$e_1 / e_2 = v/c$~~

$c >>>> v$

∴ Electron has greater total energy than photon