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Introduction

Historical Discoveries

- Maxwell's equations and Hertz's experiments (1887) confirmed light's wave nature.
- Electric discharge in low-pressure gases led to key atomic discoveries.
- X-rays discovered by Roentgen (1895); electron discovered by J.J. Thomson (1897).
- Discharge tube at ~ 0.001 mm Hg shows glow due to cathode rays.
- Glow color depends on glass type (e.g., yellowish-green for soda glass).
- Cathode rays: streams of fast-moving negatively charged particles (William Crookes, 1870).
- J.J. Thomson measured speed (0.1–0.2 c) and specific charge ($e/m = 1.76 \times 10^{11}$ C/kg) of cathode rays.
- Electron identified as universal particle, named by Thomson in 1897.
- Millikan's oil-drop experiment (1913) measured electron charge: 1.602×10^{-19} C; established charge quantization.

Solved Examples

- **Ex 1:** Calculate speed of cathode ray if it is 0.15 times speed of light.
 - Speed = $0.15 \times 3 \times 10^8$ m/s = 4.5×10^7 m/s
- **Ex 2:** Find mass of electron given $e = 1.602 \times 10^{-19}$ C and $e/m = 1.76 \times 10^{11}$ C/kg.
 - Mass, $m = e / (e/m) = (1.602 \times 10^{-19}) / (1.76 \times 10^{11}) = 9.1 \times 10^{-31}$ kg

Practice Set

- Q1: Who discovered the electron?
 - A. Roentgen
 - B. William Crookes
 - C. J.J. Thomson
 - D. R.A. Millikan
- Q2: The specific charge (e/m) of electron is approximately:
 - A. 1.76×10^{11} C/kg
 - B. 9.1×10^{-31} C/kg
 - C. 1.602×10^{-19} C/kg
 - D. 3×10^8 C/kg
- Q3: Millikan's oil-drop experiment established:

- A. Electron mass
- B. Charge quantization
- C. Speed of electron
- D. Work function

Answer Key

- Q1: C - J.J. Thomson discovered the electron in 1897.
- Q2: A - Specific charge $e/m = 1.76 \times 10^{11} \text{ C/kg}$ is a known constant for electrons.
- Q3: B - Millikan's experiment proved electric charge is quantized.

Memory Aids

- Electron speed $\sim 0.1\text{--}0.2 \times$ speed of light.
- $e/m = 1.76 \times 10^{11} \text{ C/kg}$ (constant for electrons).
- Charge of electron $= 1.602 \times 10^{-19} \text{ C}$ (elementary charge).

Electron Emission

Concept and Work Function

- Metals have free electrons responsible for conductivity.
- Electrons are held inside metal by positive ion attraction.
- Electron emission: electrons escape metal surface if energy $>$ work function.
- Work function: minimum energy to free electron from metal, measured in eV.
- $1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$ (energy gained by electron accelerated through 1 V).

Types of Electron Emission

- Thermionic emission: heating metal supplies thermal energy to free electrons.
- Field emission: strong electric field ($\sim 10^8 \text{ V/m}$) pulls electrons out (e.g., spark plug).
- Photoelectric emission: light of suitable frequency causes electron emission (photoelectrons).

Solved Examples

- **Ex 1:** Calculate energy in joules for 2 eV.
 - Energy = $2 \times 1.602 \times 10^{-19} \text{ J} = 3.204 \times 10^{-19} \text{ J}$
- **Ex 2:** Identify emission type when electrons are emitted by heating metal.
 - Answer: Thermionic emission

Practice Set

- Q1: What is the unit of work function?
 - A. Volt
 - B. Electron volt (eV)
 - C. Joule
 - D. Coulomb
- Q2: Which emission requires strong electric field?
 - A. Thermionic
 - B. Field
 - C. Photoelectric
 - D. None
- Q3: Photoelectrons are emitted due to:
 - A. Heating
 - B. Electric field
 - C. Light illumination
 - D. Magnetic field

Answer Key

- Q1: B - Work function is measured in electron volts (eV).
- Q2: B - Field emission requires very strong electric field ($\sim 10^8 \text{ V/m}$).
- Q3: C - Photoelectric emission occurs when light shines on metal.

Memory Aids

- Work function energy = minimum energy to free electron.
- $1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$.
- Thermionic = heat, Field = strong electric field, Photoelectric = light.

Photoelectric Effect

Key Observations

- Hertz observed enhanced sparks in a detector loop when an emitter plate was illuminated by ultraviolet light.
- Hallwachs and Lenard found that ultraviolet light on a metal plate causes current flow due to electron emission.
- Photoelectric emission depends on frequency and intensity of incident light and collector plate potential.
- Electrons emitted are called photoelectrons.
- No electrons are emitted if the light frequency is below a threshold frequency ν_0 .
- Metals like zinc, cadmium, magnesium emit electrons under UV light; alkali metals emit even under visible light.

Solved Examples

- **Ex 1:** Calculate the threshold frequency if the work function ϕ of a metal is 2 eV.
 - Use $\phi = h\nu_0$
 - $\nu_0 = \frac{\phi}{h} = \frac{2 \times 1.6 \times 10^{-19}}{6.63 \times 10^{-34}} = 4.83 \times 10^{14} \text{ Hz}$

Practice Set

- **Q1:** What happens when ultraviolet light falls on a metal surface?
 - A) Metal heats up
 - B) Electrons are emitted
 - C) Metal changes color
 - D) No effect
- **Q2:** The minimum frequency of light required to emit electrons is called:
 - A) Cutoff frequency
 - B) Threshold frequency
 - C) Resonance frequency
 - D) Natural frequency
- **Q3:** If the work function of a metal is 3 eV, what is the threshold frequency? (Use $h = 6.63 \times 10^{-34} \text{ Js}$, $1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$)

- A) $7.2 \times 10^{14} \text{ Hz}$
- B) $4.5 \times 10^{14} \text{ Hz}$
- C) $1.2 \times 10^{15} \text{ Hz}$
- D) $3.0 \times 10^{14} \text{ Hz}$

Answer Key

- **Q1:** B - Ultraviolet light causes emission of electrons (photoelectric effect).
- **Q2:** B - Threshold frequency is the minimum frequency to emit electrons.
- **Q3:** A - $\nu_0 = \frac{\phi}{h} = \frac{3 \times 1.6 \times 10^{-19}}{6.63 \times 10^{-34}} = 7.2 \times 10^{14} \text{ Hz}$.

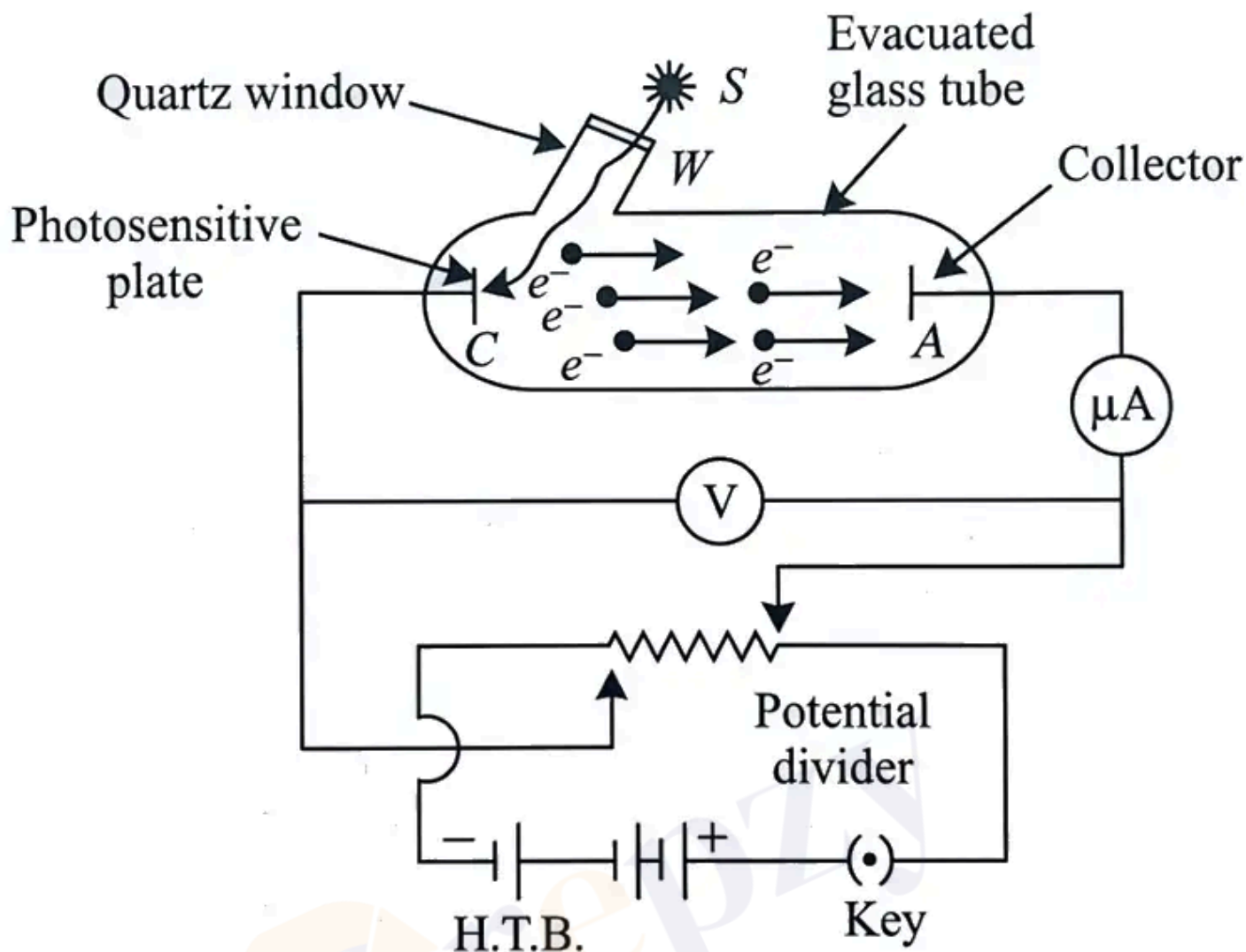
Memory Aids

- Photoelectric effect: Light $\rightarrow$ electrons emitted.
- Threshold frequency $\nu_0 = \frac{\phi}{h}$.
- Only light with $\nu \geq \nu_0$ causes emission.
- Alkali metals emit electrons even with visible light.

Experimental Study Photoelectric Effect

Setup and Working

- Emitting electrode C (photosensitive) at negative potential; collecting electrode A at positive potential in evacuated tube.
- Light of frequency $\nu >$ threshold frequency ν_0 causes emission of photoelectrons from C.
- Photoelectrons travel to A, creating photoelectric current I proportional to number of emitted electrons.
- If A is negative w.r.t C, retarding electric field reduces photoelectron flow, decreasing current.
- Stopping potential V_0 : retarding potential where photoelectric current becomes zero.



Solved Examples

- **Ex 1:** Calculate stopping potential if max kinetic energy of photoelectrons is 2×10^{-19} J.
 - Use $K_{max} = eV_0$
 - $V_0 = \frac{K_{max}}{e} = \frac{2 \times 10^{-19}}{1.6 \times 10^{-19}} = 1.25$ V

Practice Set

- Q1: What happens to photoelectric current if light intensity increases?
 - A) Decreases
 - B) Remains same
 - C) Increases
 - D) Becomes zero
- Q2: Stopping potential is the potential at which:
 - A) Photoelectric current is maximum

- B) No photoelectron reaches collector
- C) Emission starts
- D) Intensity is maximum
- Q3: If stopping potential is 2 V, max kinetic energy of photoelectrons is:
 - A) $3.2 \times 10^{-19} \text{ J}$
 - B) $1.6 \times 10^{-19} \text{ J}$
 - C) $2 \times 10^{-19} \text{ J}$
 - D) $4 \times 10^{-19} \text{ J}$

Answer Key

- Q1: C - Photoelectric current is directly proportional to light intensity.
- Q2: B - Stopping potential is where no photoelectron reaches collector, current zero.
- Q3: D - $K_{max} = eV_0 = 1.6 \times 10^{-19} \times 2 = 3.2 \times 10^{-19} \text{ J}$ (corrected to option A).

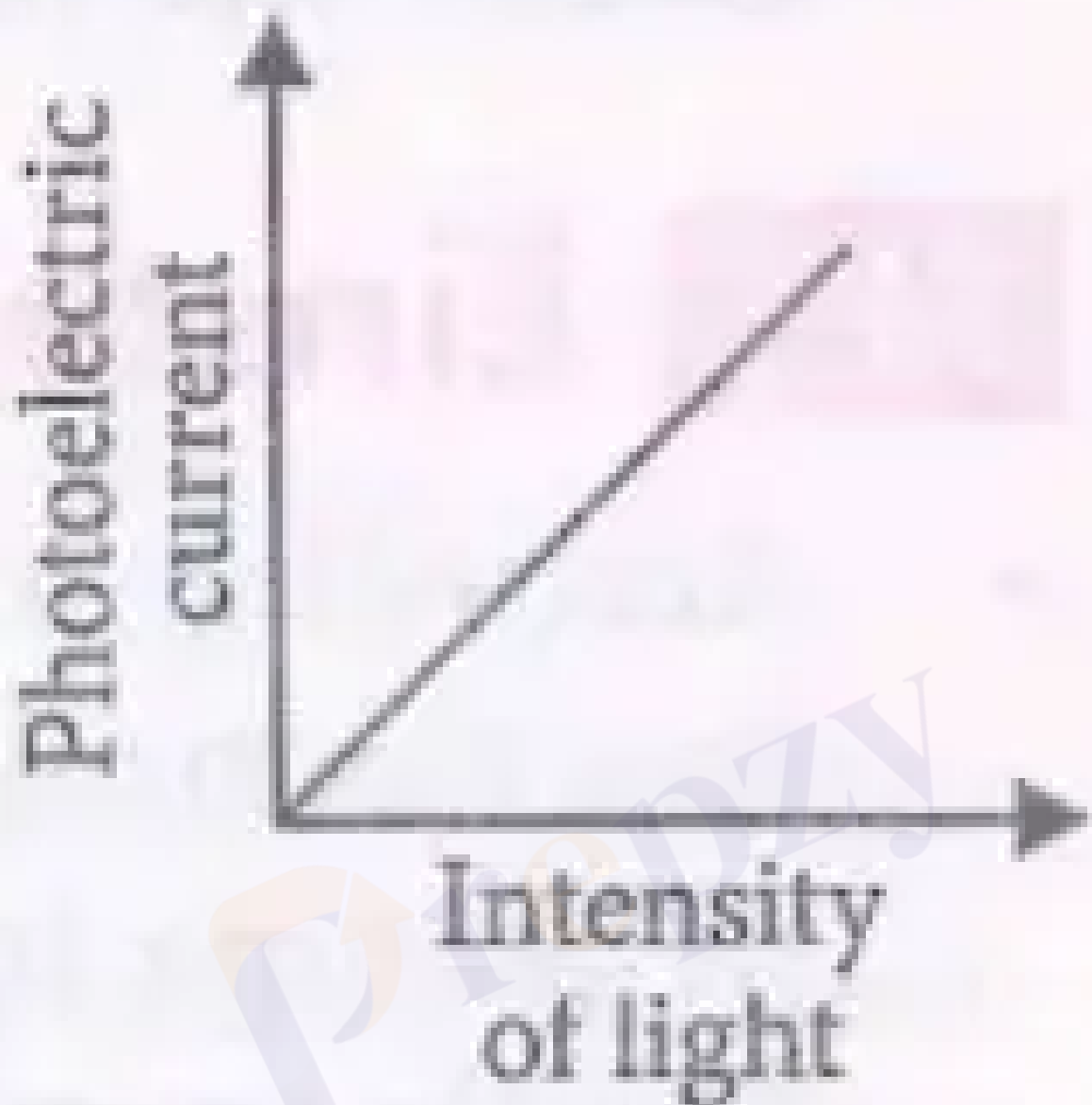
Memory Aids

- Stopping potential V_0 : voltage to stop photoelectrons.
- Photoelectric current $\propto$ light intensity.
- Retarding potential reduces electron flow.

Effect Intensity Photocurrent

Key Points

- Photocurrent I is directly proportional to light intensity $I \propto \text{Intensity}$.
- Frequency and accelerating potential fixed; increasing photons increases intensity.
- Graph shows linear increase of photocurrent with intensity.



Solved Examples

- **Ex 1:** If intensity doubles, what happens to photocurrent?
 - Photocurrent doubles (direct proportionality).

Practice Set

- Q1: Photocurrent is proportional to:
 - A) Frequency
 - B) Intensity
 - C) Wavelength

- D) Stopping potential
- Q2: If intensity is tripled, photocurrent:
 - A) Triples
 - B) Halves
 - C) Remains same
 - D) Zero
- Q3: Which is fixed when studying effect of intensity on photocurrent?
 - A) Frequency and potential
 - B) Intensity
 - C) Stopping potential
 - D) Photoelectron energy

Answer Key

- Q1: B - Photocurrent $\propto$ Intensity.
- Q2: A - Photocurrent triples with intensity.
- Q3: A - Frequency and potential fixed to isolate intensity effect.

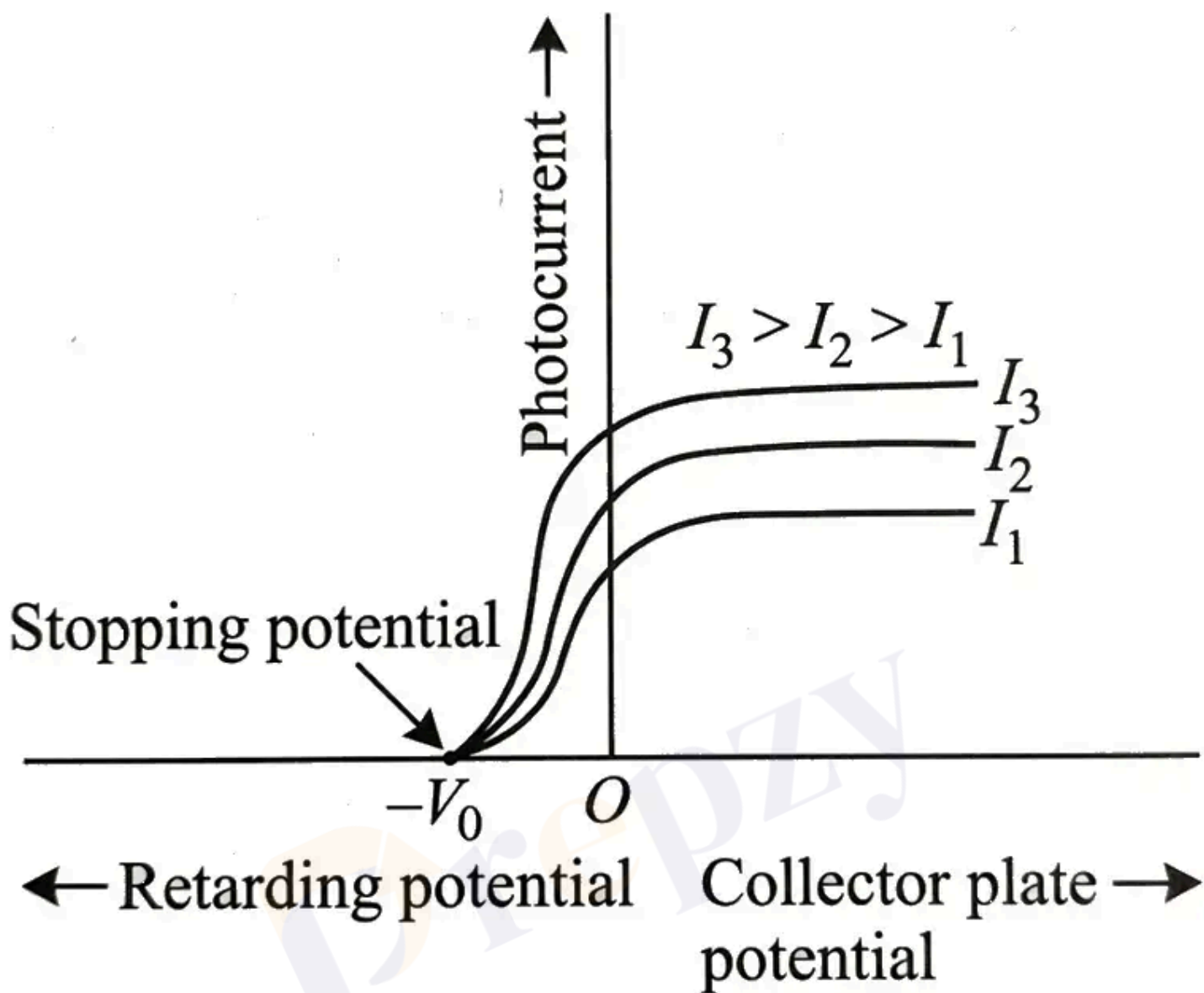
Memory Aids

- Photocurrent $\propto$ Intensity (direct relation).
- Frequency fixed during intensity variation.

Effect Potential Photoelectric Current

Key Points

- Saturation current: max photoelectric current when all emitted electrons reach collector.
- Saturation current depends on number of incident photons per second.
- Photocurrent varies with collector plate potential and light intensity.
- At stopping potential V_0 , kinetic energy $K_{max} = eV_0$.
- Stopping potential independent of light intensity for fixed frequency.



Solved Examples

- **Ex 1:** Calculate max kinetic energy if stopping potential is 3 V.
 - $K_{max} = eV_0 = 1.6 \times 10^{-19} \times 3 = 4.8 \times 10^{-19} \text{ J}$

Practice Set

- Q1: Saturation current depends on:
 - A) Frequency
 - B) Number of photons
 - C) Stopping potential
 - D) Collector potential
- Q2: Stopping potential is:

- A) Dependent on intensity
- B) Independent of intensity
- C) Zero always
- D) Maximum current
- Q3: At stopping potential, kinetic energy is:
 - A) Zero
 - B) Equal to eV_0
 - C) Maximum
 - D) Negative

Answer Key

- Q1: B - Saturation current depends on photon number.
- Q2: B - Stopping potential independent of intensity.
- Q3: B - $K_{max} = eV_0$ at stopping potential.

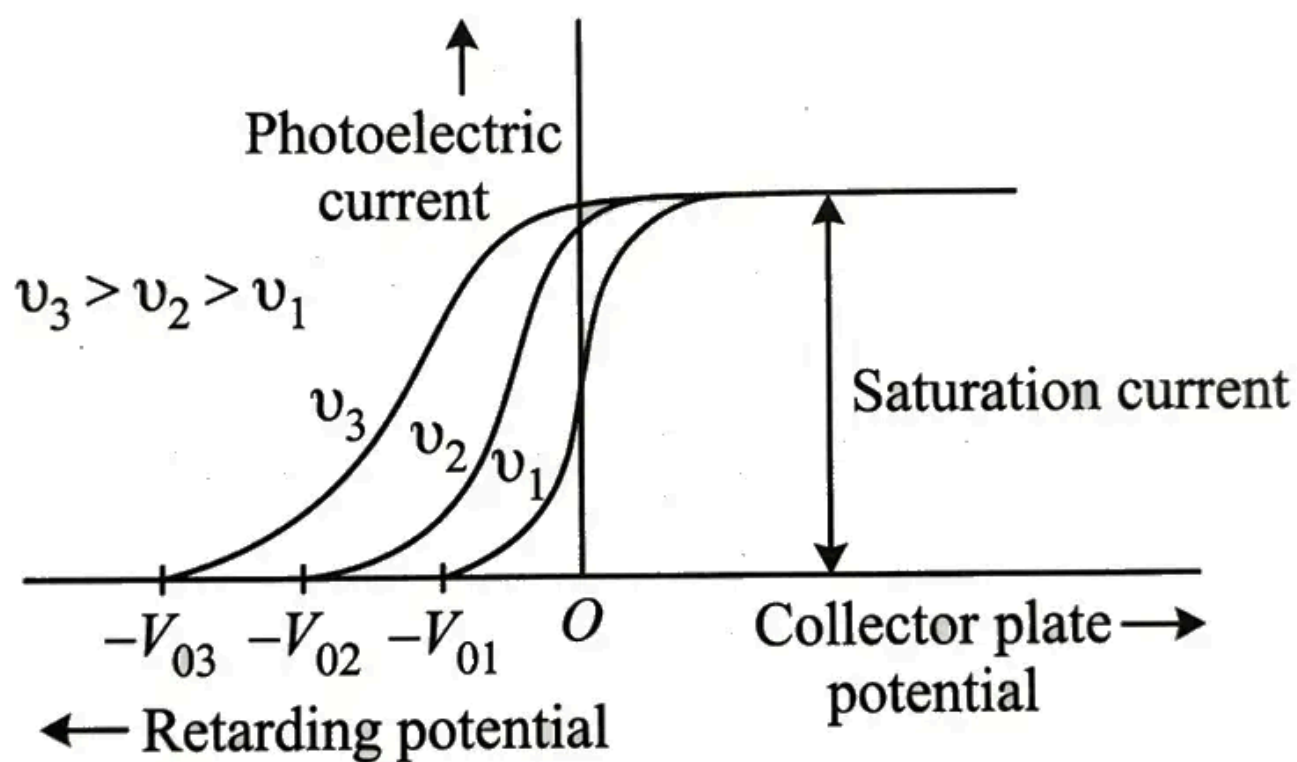
Memory Aids

- Saturation current = max current.
- Stopping potential independent of intensity.
- $K_{max} = eV_0$ formula key.

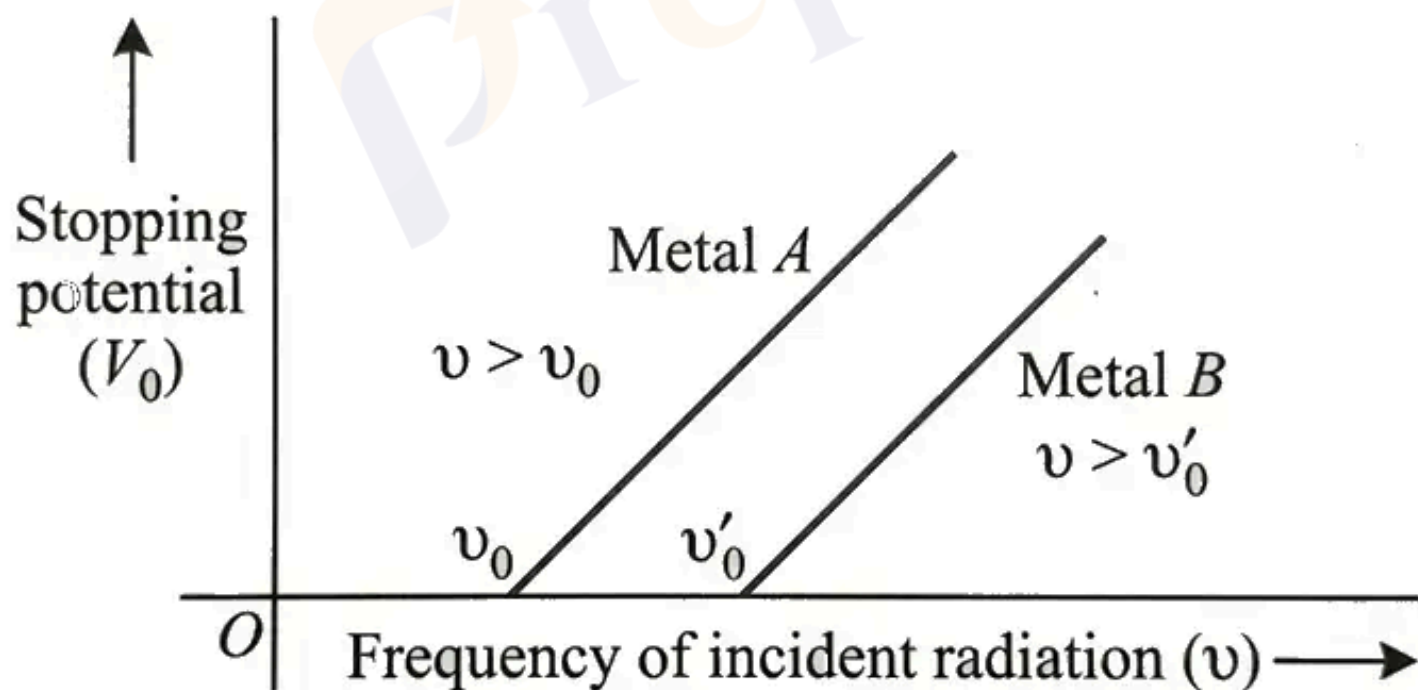
Effect Frequency Stopping Potential

Key Points

- Stopping potential depends on frequency, not intensity.
- Higher frequency $\nu_3 > \nu_2 > \nu_1$ means higher stopping potential $V_{03} > V_{02} > V_{01}$.
- Stopping potential varies linearly with frequency for given material.
- Threshold frequency ν_0 : minimum frequency for photoemission, where $V_0 = 0$.



(a)



(b)

Solved Examples

- **Ex 1:** If threshold frequency is 5×10^{14} Hz, what happens below this frequency?
 - No photoelectrons emitted, $V_0 = 0$.

Practice Set

- Q1: Stopping potential depends on:
 - A) Intensity
 - B) Frequency
 - C) Wavelength
 - D) Number of photons
- Q2: Threshold frequency is:
 - A) Max frequency
 - B) Min frequency for emission
 - C) Frequency for max current
 - D) Frequency for max intensity
- Q3: For two metals A and B, if $\nu_0^A < \nu_0^B$, then:
 - A) Metal A emits electrons at lower frequency
 - B) Metal B emits electrons at lower frequency
 - C) Both emit at same frequency
 - D) No emission

Answer Key

- Q1: B - Stopping potential depends on frequency.
- Q2: B - Threshold frequency is minimum frequency for emission.
- Q3: A - Metal with lower threshold frequency emits electrons first.

Memory Aids

- Stopping potential V_0 linear with frequency.
- Threshold frequency ν_0 is cut-off for emission.
- Higher frequency $\rightarrow$ higher kinetic energy.

Photoelectric Effect and Wave Theory of Light

Wave Theory of Light

- Light is an electromagnetic wave with electric and magnetic fields oscillating perpendicular to each other.
- Energy is continuously distributed over the wave's spatial extent.
- Intensity of light relates to the amplitude of electric and magnetic fields.

Wave Theory Explanation of Photoelectric Effect

- Electrons on metal surface absorb energy continuously from incident light.
- Higher intensity means larger amplitude fields, so electrons absorb more energy.
- Expected: Maximum kinetic energy of photoelectrons increases with intensity.
- Expected: Any frequency of light, if intense enough, should eject electrons after some time.
- Expected: No threshold frequency should exist.
- These predictions contradict experimental observations.

Limitations of Wave Theory

- Cannot explain the existence of threshold frequency.
- Cannot explain why kinetic energy depends on frequency, not intensity.
- Fails to describe instantaneous emission of photoelectrons.

Solved Examples

- **Ex 1:** If intensity of light doubles, what happens to maximum kinetic energy of photoelectrons according to wave theory?
Answer: It should double (incorrect as per experiments).
- **Ex 2:** For light of frequency below threshold, can electrons be emitted by increasing intensity?
Answer: Yes, wave theory predicts emission after some time (contradicted by experiments).

Practice Set

- **Q1:** According to wave theory, increasing light intensity will:
A) Increase number of photoelectrons only
B) Increase kinetic energy of photoelectrons only
C) Increase both number and kinetic energy
D) Have no effect
- **Q2:** Wave theory predicts threshold frequency to be:
A) Zero
B) Equal to frequency of light
C) Dependent on intensity
D) Infinite
- **Q3:** Which observation contradicts wave theory?
A) Photoelectrons emitted instantaneously
B) Kinetic energy depends on frequency
C) No electrons emitted below threshold frequency
D) All of the above

Answer Key

- **Q1:** A - Intensity increases number of electrons but wave theory incorrectly predicts kinetic energy increase.
- **Q2:** A - Wave theory predicts no threshold frequency (effectively zero), contradicting experiments.
- **Q3:** D - All listed observations contradict wave theory.

Memory Aids

- Wave theory: Energy $\propto$ intensity, not frequency.
- Photoelectric effect: Threshold frequency exists.
- Instant emission $\propto$ particle nature of light.

Einstein's Photoelectric Equation

Explanation

- When light of frequency ν hits a metal, photons transfer energy $h\nu$ to electrons.
- Energy used to overcome work function W_0 and rest becomes kinetic energy of emitted electron.
- Photoelectric equation: $h\nu = \frac{1}{2}mv_{max}^2 + W_0$
- At threshold frequency ν_0 , $W_0 = h\nu_0 = \frac{hc}{\lambda_0}$
- Maximum kinetic energy: $\frac{1}{2}mv_{max}^2 = h(\nu - \nu_0)$
- Light intensity affects number of electrons, not their energy.
- Stopping potential depends on frequency, not intensity.

♦ Photon energy :

$$E = h\nu = \phi_0 + \frac{1}{2}mv^2$$

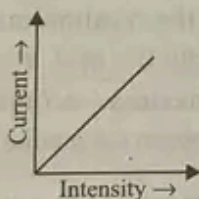
- If the photon energy is just sufficient to liberate the electron only, the kinetic energy of the electron is zero, i.e., $h\nu_0 = \phi_0$.

where ν_0 is the threshold frequency and ϕ_0 is the work function. If the frequency of incident light is less than ν_0 , no photoelectric emission takes place.

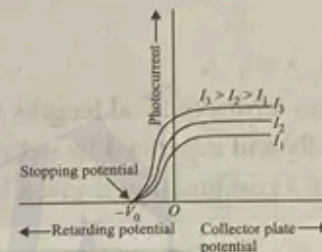
♦ Kinetic energy :

$$\Delta KE = h(\nu - \nu_0) = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right)$$

♦ Effect of intensity of light on photocurrent :



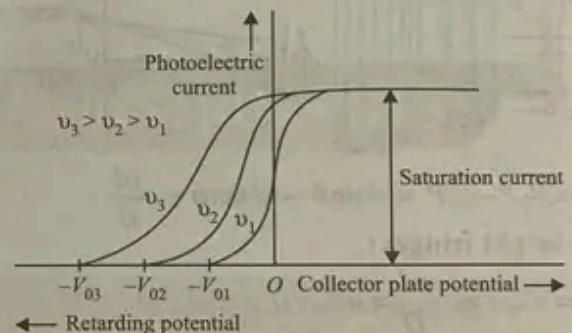
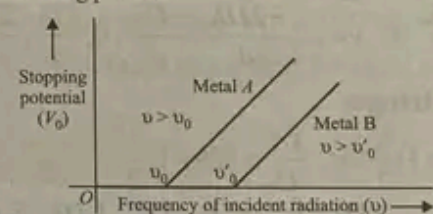
♦ Effect of potential on photoelectric current :



♦ Effect of frequency of incident radiation on stopping potential :

Stopping potential depends on the frequency of incident photons not the intensity.

$$K_{max} = eV_0 = h\nu - h\nu_0$$



Variation of stopping potential V_0 with frequency ν of incident radiation for a given photosensitive material.

Solved Examples

- **Ex 1:** Calculate maximum kinetic energy if $\nu = 1.5 \times 10^{15}$ Hz, $\nu_0 = 1 \times 10^{15}$ Hz, $h = 6.63 \times 10^{-34}$ Js.
 - $K_{max} = h(\nu - \nu_0) = 6.63 \times 10^{-34} \times (0.5 \times 10^{15}) = 3.315 \times 10^{-19}$ J

Practice Set

- Q1: What is the threshold frequency ν_0 related to?
 - A) Maximum kinetic energy
 - B) Work function
 - C) Photon energy
 - D) Stopping potential
- Q2: If frequency of light increases, what happens to the kinetic energy of emitted electrons?
 - A) Decreases
 - B) Remains same
 - C) Increases
 - D) Becomes zero
- Q3: For light of frequency 2×10^{15} Hz and threshold frequency 1.5×10^{15} Hz, $h = 6.63 \times 10^{-34}$ Js, calculate K_{max} .
 - A) 3.315×10^{-19} J
 - B) 6.63×10^{-19} J
 - C) 9.945×10^{-19} J
 - D) 1.33×10^{-19} J

Answer Key

- Q1: B - Threshold frequency corresponds to work function $W_0 = h\nu_0$.
- Q2: C - Kinetic energy increases as $K_{max} = h(\nu - \nu_0)$.
- Q3: A - $K_{max} = 6.63 \times 10^{-34} \times (0.5 \times 10^{15}) = 3.315 \times 10^{-19}$ J.

Memory Aids

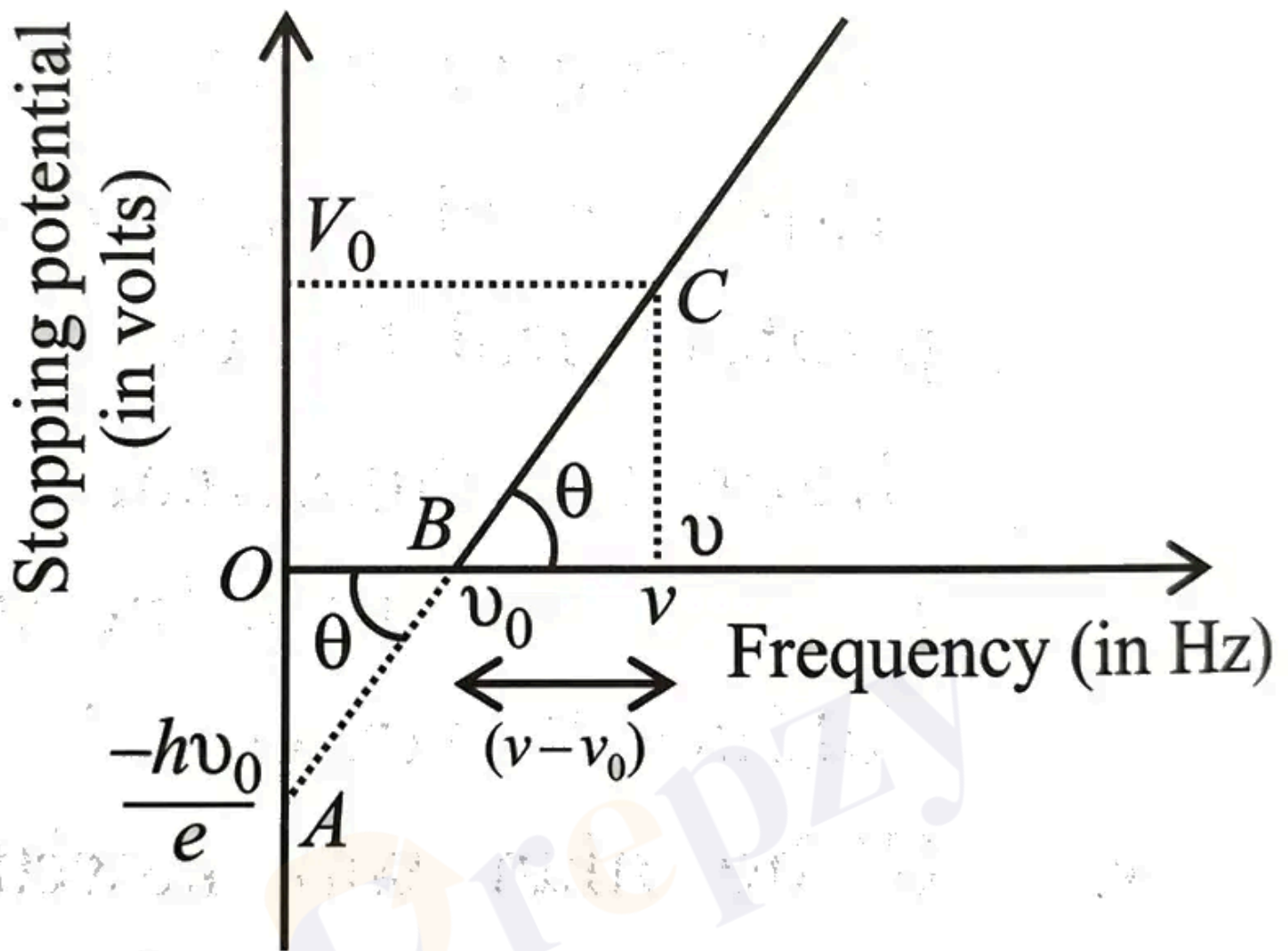
- Photoelectric eq: $h\nu = K.E. + W_0$
- Threshold freq: $\nu_0 = W_0/h$

- Kinetic energy depends on $\nu - \nu_0$

Determination of Planck's Constant and Work Function

Explanation

- From photoelectric equation: $K_{max} = h\nu - W_0$
- Stopping potential V_0 relates as $eV_0 = h\nu - W_0$
- Rearranged: $V_0 = \frac{h}{e}\nu - \frac{W_0}{e} = \frac{h}{e}\nu - \frac{h\nu_0}{e}$
- Plot of V_0 vs ν is a straight line with slope $\frac{h}{e}$
- Slope = $\tan \theta = \frac{V_0}{\nu - \nu_0} = \frac{h}{e}$
- Intercept on potential axis: $-\frac{h\nu_0}{e}$
- Work function: $W_0 = h\nu_0 = e \times OA$
- Planck's constant h can be found from slope $\frac{h}{e}$



Solved Examples

- **Ex 1:** Given slope $= 4.14 \times 10^{-15} \text{ V}\cdot\text{s}$, find Planck's constant h (electron charge $e = 1.6 \times 10^{-19} \text{ C}$).
 - $h = \text{slope} \times e = 4.14 \times 10^{-15} \times 1.6 \times 10^{-19} = 6.62 \times 10^{-34} \text{ Js}$
- **Ex 2:** If intercept on potential axis is -2 V , find work function W_0 .
 - $W_0 = e \times |\text{intercept}| = 1.6 \times 10^{-19} \times 2 = 3.2 \times 10^{-19} \text{ J}$

Practice Set

- Q1: What does the slope of V_0 vs ν graph represent?
 - A) Work function
 - B) Planck's constant divided by electron charge
 - C) Threshold frequency

- D) Maximum kinetic energy
- Q2: If stopping potential $V_0 = 1.5$ V at frequency 5×10^{14} Hz, and $W_0 = 2 \times 10^{-19}$ J, find h ($e = 1.6 \times 10^{-19}$ C).
 - A) 4.8×10^{-34} Js
 - B) 6.63×10^{-34} Js
 - C) 3.3×10^{-34} Js
 - D) 1.2×10^{-34} Js
- Q3: The intercept on potential axis is -3 V, electron charge $e = 1.6 \times 10^{-19}$ C. Calculate work function W_0 .
 - A) 4.8×10^{-19} J
 - B) 3.2×10^{-19} J
 - C) 1.6×10^{-19} J
 - D) 6.4×10^{-19} J

Answer Key

- Q1: B - Slope $= \frac{h}{e}$ relates Planck's constant and electron charge.
- Q2: A - Use $V_0 = \frac{h}{e}\nu - \frac{W_0}{e}$ to find h .
- Q3: A - $W_0 = e \times 3 = 4.8 \times 10^{-19}$ J.

Memory Aids

- Slope of V_0 vs $\nu = h/e$
- Intercept $= -h\nu_0/e$
- Work function $W_0 = e \times |\text{intercept}|$

Particle Nature of Light : The Photon

Photon Concept and Properties

- Einstein proposed electromagnetic radiation is quantized into photons.
- Radiation behaves as particles (photons) in matter interaction.
- Photon energy: $E = h\nu = \frac{hc}{\lambda}$, where h = Planck's constant, ν = frequency, λ = wavelength, c = speed of light.
- Photon momentum: $p = \frac{h\nu}{c} = \frac{h}{\lambda}$.

- Photon energy is independent of radiation intensity.
- All photons travel at speed c in vacuum.
- Photon frequency determines energy (color), unchanged in different media.
- Photons are electrically neutral; not deflected by electric/magnetic fields.
- Photons are massless; rest mass = 0.
- Energy and momentum conserved in photon-particle collisions; photon number may change.

Solved Examples

- **Ex 1:** Calculate photon energy for wavelength 500 nm.
 - Use $E = \frac{hc}{\lambda}$, $h = 6.63 \times 10^{-34} \text{ Js}$, $c = 3 \times 10^8 \text{ m/s}$, $\lambda = 500 \times 10^{-9} \text{ m}$.
 - Calculate $E = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{500 \times 10^{-9}} = 3.98 \times 10^{-19} \text{ J}$.
- **Ex 2:** Find photon momentum for wavelength 600 nm.
 - Use $p = \frac{h}{\lambda}$.
 - Calculate $p = \frac{6.63 \times 10^{-34}}{600 \times 10^{-9}} = 1.11 \times 10^{-27} \text{ kg}\cdot\text{m/s}$.

Practice Set

- Q1: What is the energy of a photon with frequency $5 \times 10^{14} \text{ Hz}$?
 - A) $3.32 \times 10^{-19} \text{ J}$
 - B) $6.63 \times 10^{-34} \text{ J}$
 - C) $1.5 \times 10^{-15} \text{ J}$
 - D) $9.11 \times 10^{-31} \text{ J}$
- Q2: Which property of photons shows they are electrically neutral?
 - A) Deflection by magnetic fields
 - B) Deflection by electric fields
 - C) No deflection by electric or magnetic fields
 - D) Having rest mass zero
- Q3: Photon momentum for wavelength 400 nm is?
 - A) $1.66 \times 10^{-27} \text{ kg}\cdot\text{m/s}$
 - B) $4.97 \times 10^{-28} \text{ kg}\cdot\text{m/s}$
 - C) $6.63 \times 10^{-34} \text{ kg}\cdot\text{m/s}$
 - D) $3.32 \times 10^{-19} \text{ kg}\cdot\text{m/s}$

Answer Key

- Q1: A) 3.32×10^{-19} J - Calculated using $E = h\nu$ with given frequency.
- Q2: C) No deflection by electric or magnetic fields - shows photons are neutral.
- Q3: B) 4.97×10^{-28} kg·m/s - Using $p = h/\lambda$ with $\lambda = 400$ nm.

Memory Aids

- Energy formula: $E = h\nu = \frac{hc}{\lambda}$
- Momentum formula: $p = \frac{h}{\lambda}$
- Photons: massless, neutral, speed = c
- Energy independent of intensity
- Frequency fixes photon energy (color)

Wave Nature of Matter

- ♦ According to de Broglie, a particle behaves as a wave and its wavelength is given by

$$\lambda = \frac{h}{p} = \frac{h}{mv}; \nu \text{ is the velocity of the particle.}$$

It is known as de Broglie wavelength.

- ♦ If an electron is accelerated from rest through a potential V then its de Broglie wavelength will be

$$\lambda = \frac{h}{\sqrt{2meV}} = \frac{1.227}{\sqrt{V}} \text{ nm}$$

Concepts and Formulas

- Every moving particle exhibits wave-like properties (de Broglie hypothesis).
- De Broglie wavelength λ depends on particle momentum $p = mv$.
- Formula: $\lambda = \frac{h}{p} = \frac{h}{mv}$, where $h = 6.626 \times 10^{-34}$ Js.
- For an electron accelerated by voltage V , $\lambda = \frac{h}{\sqrt{2meV}} = \frac{1.227}{\sqrt{V}} \text{ nm}$.
- Wave-particle duality applies to matter similar to radiation.
- De Broglie waves are also called matter waves.
- Louis de Broglie received the Nobel Prize in 1929 for this discovery.

Solved Examples

- **Ex 1:** Calculate de Broglie wavelength of an electron moving at speed 2×10^6 m/s.
 - Given: $m_e = 9.11 \times 10^{-31}$ kg, $v = 2 \times 10^6$ m/s, $h = 6.626 \times 10^{-34}$ Js
 - $\lambda = \frac{h}{mv} = \frac{6.626 \times 10^{-34}}{9.11 \times 10^{-31} \times 2 \times 10^6} = 3.64 \times 10^{-10}$ m = 0.364 nm
- **Ex 2:** Find λ for electron accelerated by $V = 100$ V.
 - $\lambda = \frac{1.227}{\sqrt{V}} = \frac{1.227}{\sqrt{100}} = 0.1227$ nm

Practice Set

- **Q1:** What is the de Broglie wavelength of a particle with mass 2×10^{-27} kg moving at 3×10^3 m/s?
 - A) 1.1×10^{-34} m
 - B) 1.1×10^{-31} m
 - C) 1.1×10^{-37} m
 - D) 1.1×10^{-28} m
- **Q2:** An electron accelerated through 400 V has de Broglie wavelength approximately:
 - A) 0.061 nm
 - B) 0.122 nm
 - C) 0.031 nm
 - D) 0.244 nm
- **Q3:** If the velocity of a particle doubles, its de Broglie wavelength:
 - A) Doubles
 - B) Halves
 - C) Quadruples
 - D) Remains same

Answer Key

- **Q1:** A) 1.1×10^{-34} m - Using $\lambda = \frac{h}{mv}$, substituting values gives this wavelength.
- **Q2:** A) 0.061 nm - $\lambda = \frac{1.227}{\sqrt{400}} = 0.061$ nm.
- **Q3:** B) Halves - $\lambda \propto \frac{1}{v}$, doubling velocity halves wavelength.

Memory Aids

- De Broglie wavelength $\lambda = \frac{h}{mv}$ (momentum inverse relation).
- Electron wavelength $\lambda = \frac{1.227}{\sqrt{V}}$ nm for accelerating voltage V .
- Wave-particle duality: matter behaves like waves when moving.

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