Exam Date & Time: 05-Mar-2025 (10:45 AM - 12:15 PM)

MANIPAL ACADEMY OF HIGHER EDUCATION

DEPARTMENT OF PHYSICS
MIT MANIPAL

APPLIED PHYSICS FOR ENGINEERS [PHY 1072-PHY]

Marks: 30 **Duration: 90 mins.**

A

Type: MCQ

Q1. A particle of mass m is confined in a one-dimensional infinite potential well of width L. What happens to the energy levels if the width of the well is doubled? (1)

1. **The energy levels decrease by a factor of 4.
2. The energy levels remain unchanged.
3. The energy levels increase by a factor of 4.
4. The energy levels decrease by a factor of 2.

Q2. A metal surface is illuminated with monochromatic light of wavelength λ, causing the emission of photoelectrons. The stopping potential required to halt the most energetic photoelectrons is measured as V_1. If the wavelength of the incident light is halved, which of the following statements is correct regarding the new stopping potential V_2? (1)

1. **$V_2 > 2V_1$
2. $V_2 < 2V_1$
3. $V_2 = 2V_1$
4. $V_2 = V_1/2$

Q3. What is the minimum uncertainty in velocity of an electron if uncertainty in its position is 50 pm? (1)

1. Zero
2. **1.16 x 10^6 m/s
3. 1.05 x 10^{-24} m/s
4. 5.27 x 10^{-35} m/s

Q4. Choose the wrong statement from the following. (1)

1. A single mode step index optical fibre consists of a core having a uniform refractive index.
2. A multi mode step index optical fibre consists of a core having a uniform refractive index.
3. **Diameter of core is more for single mode step index optical fibre as compared to that of multi mode step index optical fibre.
4. Material dispersion in optical fiber is due to wavelength dependence of refractive index of the core.

Q5. Which of the following is NOT a method to achieve population inversion? (1)

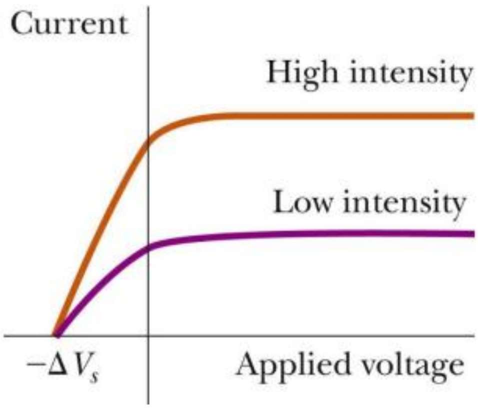
1. Optical pumping
2. Electrical discharge
3. ** Thermal equilibrium
4. Electrical injection of carriers

Type: DES

Q14. **(a)** Sketch a schematic graph of **photoelectric current vs. applied voltage** for the photoelectric effect. Explain the significance of the point where the graph intersects the **x-axis**. **(b)** Sketch a schematic graph of the **maximum kinetic energy of emitted electrons vs. the frequency of**

incident light. Explain the significance of the **slope** and **y-intercept** of the graph. (4)

(a)

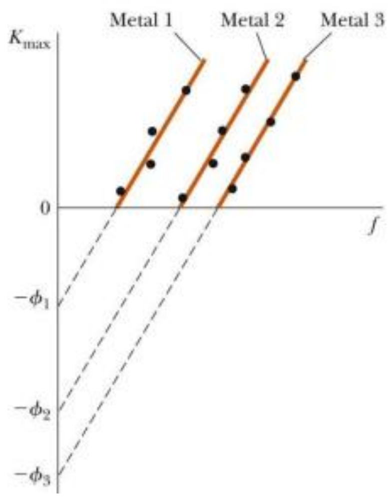


1M

(influence of intensity can be shown either on graph (as here) or in words)

The point where the graph intersects the x-axis represents the stopping potential (Vs), the minimum negative potential needed to stop the most energetic photoelectrons from reaching the anode. This point is independent of intensity of light. 1M

(b)



(showing for one metal is sufficient) 1M

Slope: The slope of the graph is **Planck's constant (h)**, which is a fundamental constant in quantum mechanics.

Y-Intercept: The y-intercept is **−ϕ** (negative work function). This indicates that no electrons are emitted if the incident frequency is below the **threshold frequency**. 1M

Q8. (a) What are the mathematical features of a wave function? (b) Write the mathematical expression that ensures the total probability of finding the particle in all space is 1. (3)

(a) The important mathematical features of a physically reasonable wave function *ψ(x)* for a system are

- *ψ(x)* may be a complex function or a real function, depending on the system.
- *ψ(x)* must be finite, continuous and single valued everywhere.
- The space derivatives of *ψ*, must be finite, continuous and single valued everywhere.
- *ψ* must be normalizable. 2M

(b) Expression showing total probability: $\int_{-\infty}^{+\infty} |\psi|^2 \, dx = 1$ 1M

Q10. A ruby laser delivers a 10 ns pulse of 1 MW average power. If the photons have a wavelength of 694.3 nm, how many are contained in the pulse? What is the length (spatial) of the pulse? (3)

$$\boldsymbol{Power = Energy\ released\ per\ unit\ time}$$

$$\boldsymbol{Power = 1 \times 10^6 W\ implies\ energy\ release\ of\ 1 \times 10^6\ \mathrm{J}/s}$$ 1 M

$$\boldsymbol{For\ 10\ ns\ pulse, total\ energy\ released = 10 \times 10^{-9}\ \times\ 1 \times 10^6\ \mathrm{J}}$$

$$\boldsymbol{Energy\ of\ one\ photon = \frac{hc}{\lambda} = \frac{6.626\ \times 10^{-34} \times 3 \times 10^8}{694.3 \times 10^{-9}} = 2.86 \times 10^{-19} J}$$ 1 M

$$\boldsymbol{Number\ of\ photons = \frac{10 \times 10^{\boxed{-3}}}{2.86 \times 10^{-19}} = 3.49 \times 10^{16}}\ \text{photons}$$ 0.5 M

$$\boldsymbol{Length\ of\ the\ pulse = c\ \times t = 3 \times 10^8 \times 10 \times 10^{-9} = 3\ m}$$ 0.5 M

Q11. You use a radiometer to measure thermal radiation from an object at 1278 K. The radiometer is set to detect peak emission and the radiometer records radiation in a wavelength interval of 12.6 nm. What is the radiation intensity within this range? (3)

The wavelength setting for the most intense radiation is determined from Wien's displacement law:

$$\lambda_{\max} = \frac{2.8978 \times 10^{-3}\ \mathrm{m \cdot K}}{T} = \frac{2.8978 \times 10^{-3}\ \mathrm{m \cdot K}}{1278\ \mathrm{K}}$$
$$= 2.267 \times 10^{-6}\ \mathrm{m} = 2267\ \mathrm{nm}$$

1 MARK

The given temperature corresponds to $kT = (8.6174 \times 10^{-5}\ \mathrm{eV/K})(1278\ \mathrm{K}) = 0.1101\ \mathrm{eV}$. The radiation intensity in this small wavelength interval is

$$I(\lambda)d\lambda = \frac{2\pi hc^2}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1} d\lambda$$
$$= 2\pi(6.626 \times 10^{-34}\ \mathrm{J \cdot s})(2.998 \times 10^8\ \mathrm{m/s})^2$$
$$\times (12.6 \times 10^{-9}\ \mathrm{m})(2.267 \times 10^{-6}\ \mathrm{m})^{-5}$$
$$\times (e^{(1240\ \mathrm{eV \cdot nm})/(2267\ \mathrm{nm})(0.1101\ \mathrm{eV})} - 1)^{-1}$$
$$= 552\ \mathrm{W/m^2}$$

2 MARKS

Q12. After a 0.800-nm x-ray photon scatters from a free electron, the electron recoils at 1.40×10^6 m/s. What is the Compton shift in the photon's wavelength? (You can treat the electron non-relativistically) (3)

(a) To compute the Compton shift, we first determine the electron's kinetic energy:

$$K = \frac{1}{2} m_e u^2 = \frac{1}{2}(9.11 \times 10^{-31}\ \mathrm{kg})(1.40 \times 10^6\ \mathrm{m/s})^2$$
$$= 8.93 \times 10^{-19}\ \mathrm{J} = 5.58\ \mathrm{eV}$$

(1 Marks)

Then,

$$E_0 = \frac{hc}{\lambda_0} = \frac{1\ 240\ \text{eV}\cdot\text{nm}}{0.800\ \text{nm}} = 1\ 550\ \text{eV}$$

$$E' = E_0 - K \quad \text{and} \quad \lambda' = \frac{hc}{E'} = \frac{1\ 240\ \text{eV}\cdot\text{nm}}{1\ 550\ \text{eV} - 5.58\ \text{eV}} = 0.803\ \text{nm}$$

(1 Marks)

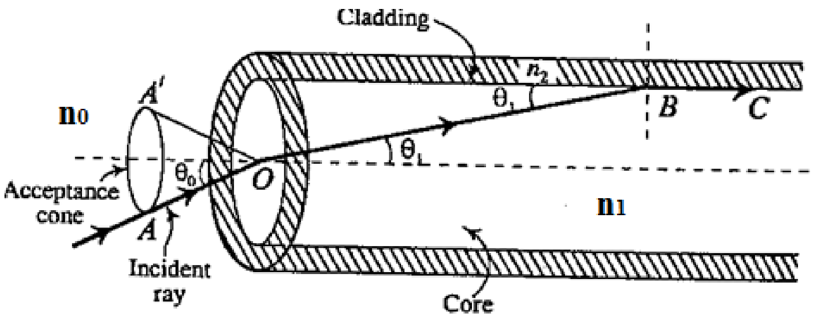
and the Compton shift is

$$\Delta\lambda = \lambda' - \lambda_0 = 0.002\ 89\ \text{nm} = \boxed{2.89\ \text{pm}}$$

(1 Marks)

Q13. With necessary diagram, derive an expression for angle of acceptance and numerical aperture. (3)

Consider an optical fibre with refractive index of the material of the core n_1 and cladding n_2 placed in a surrounding medium of refractive index n_0. Let a ray *AO* of light enter the core of the fibre at an angle θ_0. Let this ray after refraction through an angle θ_1 at *O* strikes the interface between the core and the cladding at the critical angle such that the refracted ray grazes the interface.



1M

Applying Snell's law of refraction at *O*, we have,

$$\frac{\sin\theta_0}{\sin\theta_1} = \frac{n_1}{n_0}$$

$$\therefore\ \sin\theta_0 = \frac{n_1}{n_0}\sin\theta_1 \qquad \textbf{(1)}$$

Similarly, applying Snell's law at *B*,

$$\frac{\sin(90^\circ - \theta_1)}{\sin 90^\circ} = \frac{n_2}{n_1} \qquad \textbf{or} \qquad \cos\theta_1 = \frac{n_2}{n_1}$$

$$sin\,\theta_1 = \sqrt{1-\frac{n_2^2}{n_1^2}} \qquad \textbf{(2)}$$ 1M

Substituting Eq. (2) in Eq. (1) and simplifying,

$$sin\theta_0 = \frac{1}{n_0}\sqrt{n_1^2 - n_2^2}$$

θ_0 is called the **acceptance angle** or **half angle of the acceptance cone**.

The term $n_0 \sin\theta_0$ is called **numerical aperture (*NA*)** 1M

Q6. A wavefunction is given by **Ψ (x) = A** for **0 ≤ x ≤ L** and zero elsewhere. Find the normilization constant **A**. (2)

The normalization condition for a wavefunction $\Psi(x)$ is:

$$\int_{-\infty}^{\infty} |\Psi(x)|^2 dx = 1$$

Given the wavefunction:

$$\Psi(x) = A, \quad 0 \le x \le L$$

$$\Psi(x) = 0, \quad \text{elsewhere}$$

The normalization condition simplifies to:

$$\int_0^L A^2 dx = 1$$ 1M

Evaluating the integral:

$$A^2 \int_0^L dx = 1$$

$$A^2 L = 1$$

Solving for A:

$$A = \sqrt{\frac{1}{L}}$$

Thus, the normalization constant is:

$$A = \frac{1}{\sqrt{L}}$$ 1M

Q7. 0.50 kg baseball is confined between two rigid walls of a stadium that can be modelled as a "box" of length 100 m. Calculate the minimum speed of the baseball. (2)

The minimum speed of the baseball can be estimated using the **particle in a box** model in quantum mechanics. The energy levels are given by:

$$E_n = \frac{n^2 h^2}{8mL^2}$$

where:

- $h = 6.626 \times 10^{-34}$ J·s (Planck's constant)
- $m = 0.50$ kg (mass of baseball)
- $L = 100$ m (length of the box)
- $n = 1$ (ground state, minimum energy) 1M

The minimum speed (v) is found using:

$$E_1 = \frac{1}{2} m v_{\text{min}}^2$$

The minimum speed of the baseball is approximately 6.63×10^{-36} m/s. 1M

Q9. With reference to OFC, what is material dispersion? Briefly explain. (2)

The material dispersion is due to the dependence of the refractive indices of glass and consequently the group velocity of the optical signal. A LED emits a broad spectrum of light. Whenever a LED is used as a source, the broad spectrum contains a number of wavelengths. These different wavelengths of light are travelling through optical fibre at different speeds because the refractive indices of the glass vary with wavelengths. 1M

The short wavelength waves travel slower than long wavelength waves in a material. Hence, narrow pulses of light tend to broaden as they travel down the optical fibre. This is known as **material dispersion** 1M

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