CBSE Class 12 Physics Compartment 2026

Question Paper with Solutions

Conducted by the Central Board of Secondary Education (CBSE)

General Instructions

(i) This question paper contains 33 questions. All questions are compulsory.

(ii) This question paper is divided into five sections – Section A, B, C, D and E.

(iii) Section A – Questions number 1 to 16 are multiple choice type questions. Each question carries 1 mark.

(iv) Section B – Questions number 17 to 21 are very short answer type questions. Each question carries 2 marks.

(v) Section C – Questions number 22 to 28 are short answer type questions. Each question carries 3 marks.

(vi) Section D – Questions number 29 and 30 are case-based questions. Each question carries 4 marks.

(vii) Section E – Questions number 31 to 33 are long answer type questions. Each question carries 5 marks.

(viii) There is no overall choice given in the question paper. However, an internal choice has been provided in a few questions in all the sections except Section A.

(ix) Kindly note that there is a separate question paper for visually impaired candidates.

(x) Use of calculator is **not** allowed.

1. Assume that the surface charge density of the Earth is 1 electron charge/m^2. The potential of the Earth's surface (radius 6400 km) will be :

(A) -0.12 V

(B) 0.21 V

(C) +2.1 V

(D) +1.2 V

Correct Answer: (A) -0.12 V

Solution:

Step 1: Concept:

The question asks for the electric potential at the surface of the Earth, treating it as a conducting sphere, given its surface charge density and radius.

Step 2: Key Formula or Approach:

The surface charge density σ is defined as charge per unit area, given by $\sigma = \frac{Q}{4\pi R^2}$.

The electric potential V at the surface of a charged sphere is given by $V = \frac{1}{4\pi\epsilon_0}\frac{Q}{R}$.

By substituting the total charge $Q = \sigma \times 4\pi R^2$ into the potential formula, we get $V = \frac{1}{4\pi\epsilon_0}\frac{\sigma\times 4\pi R^2}{R} = \frac{\sigma R}{\epsilon_0}$.

Step 3: Detailed Explanation:

- Given the surface charge density is 1 electron charge per square meter, so $\sigma = -1.6 \times 10^{-19}\ \text{C/m}^2$.

- The radius of the Earth is given as $R = 6400\ \text{km} = 6.4 \times 10^6\ \text{m}$.

- The permittivity of free space $\epsilon_0 = 8.854 \times 10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2$.

- Substitute these given values into the simplified potential formula:

$$V = \frac{-1.6 \times 10^{-19} \times 6.4 \times 10^6}{8.854 \times 10^{-12}}$$

- First, calculate the numerator: $-1.6 \times 6.4 \times 10^{-13} = -10.24 \times 10^{-13}\ \text{C}\cdot\text{m}$.

- Now, divide by ϵ_0:

$$V = \frac{-10.24 \times 10^{-13}}{8.854 \times 10^{-12}}$$

- This gives $V \approx -0.1156$ V.

- Rounding to two decimal places, we get -0.12 V.

Step 4: Final Answer:

The potential of the Earth's surface will be approximately -0.12 V.

Quick Tip: Remember that the potential of a spherical charge distribution can be directly found from surface charge density using $V = \sigma R/\epsilon_0$, saving you from calculating the total charge first.

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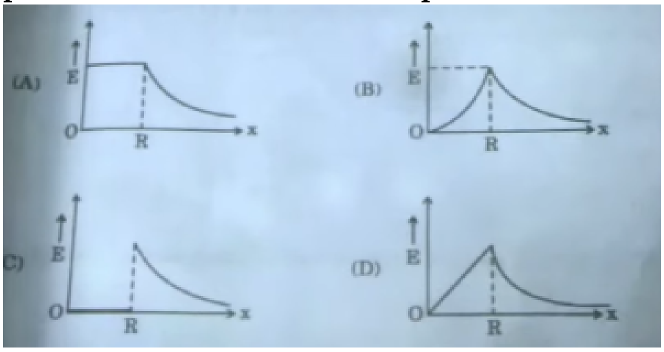
2. A conducting sphere of radius R has a charge Q on it. Which of the following graphs correctly represents the value of electric field E in the range $0 \leq x < \infty$, where x is the distance of the point from the centre of the sphere ?



(A) Graph showing E constant then linearly decreasing

(B) Graph showing E = 0 up to R, then decreasing as $1/x^2$

(C) Graph showing E linearly increasing up to R, then decreasing

(D) Graph showing E sharply increasing and decreasing linearly

Correct Answer: (B) Graph showing E = 0 up to R, then decreasing as $1/x^2$

Solution:

Step 1: Concept:

We need to identify the correct variation of the electric field E with distance x from the center of a charged conducting sphere of radius R.

Step 2: Key Formula or Approach:

For a solid conducting sphere, all excess charge resides on its outer surface.
Inside the conductor ($x < R$), the electric field is zero because charges in a conductor arrange themselves to cancel any internal field.
Outside the conductor ($x \geq R$), the sphere behaves like a point charge concentrated at its center, so $E = \frac{1}{4\pi\epsilon_0}\frac{Q}{x^2}$.

Step 3: Detailed Explanation:

- For the region $0 \leq x < R$ (inside the sphere), the electric field $E = 0$.
- At the surface $x = R$, the electric field is maximum and equals $E = \frac{1}{4\pi\epsilon_0}\frac{Q}{R^2}$.
- For the region $x > R$ (outside the sphere), the electric field varies inversely with the square of the distance, i.e., $E \propto \frac{1}{x^2}$.
- Looking at the given options, the graph in option (B) perfectly illustrates these conditions: it stays at zero until $x = R$, jumps to a maximum, and then curves downwards, representing an inverse square law decay.

Step 4: Final Answer:

The graph in option (B) correctly represents the electric field variation.

Quick Tip: For a uniformly charged non-conducting sphere, the field inside is directly proportional to distance ($E \propto x$), which would correspond to graph (C). Always note whether the sphere is conducting or non-conducting!

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3. Two infinitely long straight conductors lie along x-axis and y-axis in the plane of the page. If they carry current I each along +x-axis and +y-axis respectively, the net magnetic field at a point with position vector $\vec{r} = (3\hat{i} + 4\hat{j})$ m will be :

(A) $\frac{\mu_0 I}{6\pi}\hat{k}$
(B) $-\frac{\mu_0 I}{12\pi}\hat{k}$
(C) $-\frac{\mu_0 I}{24\pi}\hat{k}$
(D) $\frac{\mu_0 I}{48\pi}\hat{k}$

Correct Answer: (C) $-\frac{\mu_0 I}{24\pi}\hat{k}$

Solution:

Step 1: Concept:
We have two perpendicular, infinitely long wires carrying current. We need to find the net magnetic field at a specific coordinate $(3, 4)$ in the xy-plane using the principle of superposition.

Step 2: Key Formula or Approach:
The magnetic field due to an infinitely long straight wire carrying current I at a perpendicular distance r is $B = \frac{\mu_0 I}{2\pi r}$.
The direction is found using the Right-Hand Grip Rule.
The total magnetic field is the vector sum of the fields produced by each wire individually: $\vec{B}_{net} = \vec{B}_1 + \vec{B}_2$.

Step 3: Detailed Explanation:

- Let the wire along the x-axis be Wire 1. It carries current I in the $+\hat{i}$ direction. The perpendicular distance from Wire 1 to the point $(3, 4)$ is the y-coordinate, which is 4 m.

- Using the Right-Hand Grip Rule, pointing the thumb along $+\hat{i}$, the fingers curl out of the page $(+\hat{k})$ at points where $y > 0$.

$$\vec{B}_1 = \frac{\mu_0 I}{2\pi(4)}\hat{k} = \frac{\mu_0 I}{8\pi}\hat{k}$$

- Let the wire along the y-axis be Wire 2. It carries current I in the $+\hat{j}$ direction. The perpendicular distance from Wire 2 to the point $(3, 4)$ is the x-coordinate, which is 3 m.

- Using the Right-Hand Grip Rule, pointing the thumb along $+\hat{j}$, the fingers curl into the page $(-\hat{k})$ at points where $x > 0$.

$$\vec{B}_2 = \frac{\mu_0 I}{2\pi(3)}(-\hat{k}) = -\frac{\mu_0 I}{6\pi}\hat{k}$$

- The net magnetic field is the vector sum:

$$\vec{B}_{net} = \vec{B}_1 + \vec{B}_2 = \left(\frac{\mu_0 I}{8\pi} - \frac{\mu_0 I}{6\pi}\right)\hat{k}$$

- To subtract these fractions, find a common denominator, which is 24π:

$$\vec{B}_{net} = \left(\frac{3\mu_0 I}{24\pi} - \frac{4\mu_0 I}{24\pi}\right)\hat{k} = -\frac{\mu_0 I}{24\pi}\hat{k}$$

Step 4: Final Answer:

The net magnetic field at the point is $-\frac{\mu_0 I}{24\pi}\hat{k}$.

Quick Tip: A quick way to get the direction of $\vec{B}$ is by computing the cross product of the current direction vector $d\vec{l}$ and the position vector of the point relative to the wire, $\hat{r}$.

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4. In an electromagnetic wave, the electric field $(\vec{E})$ and the magnetic field $(\vec{B})$ oscillate along x-axis and y-axis respectively. The wave is propagating along :

(A) z-axis

(B) - z-axis

(C) x-axis

(D) - y-axis

Correct Answer: (A) z-axis

Solution:

Step 1: Concept:
The question asks for the direction of propagation of an electromagnetic wave given the spatial directions of its oscillating electric and magnetic fields.

Step 2: Key Formula or Approach:
In an electromagnetic wave, the vectors representing the electric field ($\vec{E}$), the magnetic field ($\vec{B}$), and the direction of wave propagation ($\vec{S}$ or $\vec{k}$) are mutually perpendicular.
The direction of propagation is given by the cross product of the electric and magnetic fields:
Direction $= \vec{E} \times \vec{B}$.

Step 3: Detailed Explanation:

- The electric field $\vec{E}$ is along the x-axis, so its direction is given by the unit vector $\hat{i}$.

- The magnetic field $\vec{B}$ is along the y-axis, so its direction is given by the unit vector $\hat{j}$.

- Applying the cross product to find the propagation direction:

$$\text{Direction} = \hat{i} \times \hat{j}$$

- According to the properties of orthogonal unit vectors in a right-handed coordinate system, $\hat{i} \times \hat{j} = \hat{k}$.

- The unit vector $\hat{k}$ represents the positive z-axis.

Step 4: Final Answer:

The electromagnetic wave is propagating along the z-axis.

Quick Tip: Always remember the cyclic relation for cross products of unit vectors: $\hat{i} \times \hat{j} = \hat{k}$, $\hat{j} \times \hat{k} = \hat{i}$, and $\hat{k} \times \hat{i} = \hat{j}$. Reversing the order introduces a negative sign.

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5. Which of the following is also referred to as 'heat waves' ?

(A) Gamma rays

(B) X-rays

(C) UV rays

(D) Infrared rays

Correct Answer: (D) Infrared rays

Solution:

Step 1: Concept:

We need to identify which segment of the electromagnetic spectrum is commonly known as "heat waves".

Step 2: Detailed Explanation:

- Gamma rays, X-rays, and UV rays possess high frequencies and high photon energies. They are primarily known for their high penetrating power and ability to cause ionization, rather than heating macroscopic bodies.

- Infrared rays are emitted by all hot bodies and molecules. When infrared radiation falls on an object, it strongly excites the rotational and vibrational modes of its molecules.

- This increased molecular agitation manifests as an increase in the object's temperature.

- Because of this predominant heating effect, infrared waves are popularly referred to as heat waves.

Step 3: Final Answer:

Infrared rays are also referred to as heat waves.

Quick Tip: Infrared radiation's frequencies closely match the natural vibrational frequencies of most molecules (like water and CO_2), making their energy transfer into heat extremely efficient.

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6. In a series LCR circuit connected to an ac source of voltage V and frequency ω, the power loss at resonance is :

(A) $I^2\omega L$

(B) $V^2/(\omega C)$

(C) V^2/R

(D) $V^2/(\omega L - \frac{1}{\omega C})$

Correct Answer: (C) V^2/R

Solution:

Step 1: Concept:

We are asked to find the mathematical expression for the power dissipated in a series LCR (Inductor-Capacitor-Resistor) circuit when it is operating at its resonant frequency.

Step 2: Key Formula or Approach:

The average power dissipated in an AC circuit is given by $P = I_{rms}^2 R = V_{rms} I_{rms} \cos\phi$, where $\cos\phi$ is the power factor.

The impedance of a series LCR circuit is $Z = \sqrt{R^2 + (X_L - X_C)^2}$, where $X_L = \omega L$ and $X_C = \frac{1}{\omega C}$.

At resonance, the inductive reactance equals the capacitive reactance ($X_L = X_C$).

Step 3: Detailed Explanation:

- In a series LCR circuit at resonance, the condition $X_L = X_C$ holds true.
- Substituting this into the impedance equation, the imaginary part cancels out, leaving purely resistive impedance: $Z = \sqrt{R^2 + 0} = R$.
- Because the circuit is purely resistive at resonance, the phase angle ϕ between voltage and current is $0°$, making the power factor $\cos(0°) = 1$.
- The rms current flowing through the circuit is $I = V/Z = V/R$.
- The power loss is purely across the resistor (since ideal inductors and capacitors do not dissipate average power).
- Using the power formula, $P = I^2 R = \left(\frac{V}{R}\right)^2 R = \frac{V^2}{R}$.

Step 4: Final Answer:

The power loss at resonance is given by V^2/R.

Quick Tip: At resonance, a series LCR circuit behaves exactly like a purely resistive AC circuit. This means current is maximized, and all applied voltage drops across the resistor.

7. If ν_X, ν_G and ν_U are frequencies of X-rays, Gamma-rays and UV rays respectively, then :

(A) $\nu_X > \nu_G > \nu_U$
(B) $\nu_G > \nu_X > \nu_U$
(C) $\nu_U > \nu_X > \nu_G$
(D) $\nu_X > \nu_U > \nu_G$

Correct Answer: (B) $\nu_G > \nu_X > \nu_U$

Solution:

Step 1: Concept:
The question asks us to arrange three types of electromagnetic radiation (X-rays, Gamma rays, and UV rays) in decreasing order of their frequencies.

Step 2: Key Formula or Approach:
This requires knowledge of the standard electromagnetic spectrum.
The order of the electromagnetic spectrum from highest frequency (shortest wavelength) to lowest frequency (longest wavelength) is: Gamma rays, X-rays, Ultraviolet (UV) rays, Visible light, Infrared (IR) rays, Microwaves, and Radio waves.

Step 3: Detailed Explanation:

- Gamma rays are produced by nuclear transitions and possess the highest energy, hence the highest frequency (ν_G) among the three.

- X-rays are generally produced by high-energy electron interactions and have slightly less energy and frequency (ν_X) than gamma rays.

- Ultraviolet (UV) rays lie just above the visible light spectrum in energy and have a much lower frequency (ν_U) than both X-rays and Gamma rays.

- Therefore, arranging them in descending order of frequency gives: Gamma rays > X-rays > Ultraviolet rays.

- Mathematically, this is written as $\nu_G > \nu_X > \nu_U$.

Step 4: Final Answer:

The correct relationship is $\nu_G > \nu_X > \nu_U$.

Quick Tip: A helpful mnemonic for the EM spectrum in decreasing frequency is "Grandma's X-ray Use Visibly Improves My Rheumatism" (Gamma, X-ray, UV, Visible, IR, Microwave, Radio).

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8. The energy of an electron in an orbit in a hydrogen atom (Bohr model) is -3.4 eV. Its angular momentum in this orbit is :

(A) $\frac{h}{\pi}$
(B) $\frac{h}{2\pi}$
(C) $\frac{h}{4\pi}$
(D) $\frac{2h}{\pi}$

Correct Answer: (A) $\frac{h}{\pi}$

Solution:

Step 1: Concept:

We are given the total energy of an electron in a specific orbit of a hydrogen atom. We need to find the quantized angular momentum of the electron in that same orbit.

Step 2: Key Formula or Approach:

According to Bohr's model of the hydrogen atom, the energy of an electron in the n-th orbit is

given by $E_n = -\frac{13.6}{n^2}$ eV.
Bohr's quantization condition for angular momentum states that $L = \frac{nh}{2\pi}$, where n is the principal quantum number.

Step 3: Detailed Explanation:

- First, we determine the principal quantum number n from the given energy.
- We equate the given energy to the formula: $-3.4 \text{ eV} = -\frac{13.6}{n^2}$ eV.
- Rearranging the terms gives $n^2 = \frac{-13.6}{-3.4}$.
- Calculating the division, we find $n^2 = 4$.
- Taking the square root, we get $n = 2$. This means the electron is in the second orbit.
- Next, we substitute $n = 2$ into the angular momentum formula.
- $L = \frac{2 \cdot h}{2\pi}$.
- Simplifying the fraction by canceling the 2s, we get $L = \frac{h}{\pi}$.

Step 4: Final Answer:
The angular momentum of the electron in this orbit is $\frac{h}{\pi}$.

Quick Tip: Memorize the first few energy levels of the hydrogen atom to save time: $E_1 = -13.6$ eV, $E_2 = -3.4$ eV, $E_3 = -1.51$ eV.

9. A ray of light is incident at an angle of 60° on face AB of prism ABC with $\angle A = 30^\circ$. The ray emerging out of the prism makes an angle of 30° with the incident ray. The angle of emergence ($\angle e$) is equal to :

(A) 0°

(B) 30°

(C) 60°

(D) 90°

Correct Answer: (A) 0°

Solution:

Step 1: Concept:

A light ray passes through a prism. We are given the prism angle, the angle of incidence, and the angle of deviation. We are required to find the angle of emergence.

Step 2: Key Formula or Approach:

The total deviation δ of a light ray traveling through a prism is related to the angle of incidence i, the angle of emergence e, and the refracting angle of the prism A by the formula: $\delta = i + e - A$.

The angle between the incident ray and the emergent ray is defined precisely as the angle of deviation δ.

Step 3: Detailed Explanation:

- From the problem statement, the angle of incidence is $i = 60^\circ$.
- The refracting angle of the prism is given as $A = 30^\circ$.
- The ray emerging out of the prism makes an angle of 30° with the incident ray, which means the angle of deviation is $\delta = 30^\circ$.

- Substitute these values into the prism deviation formula:

$$30^\circ = 60^\circ + e - 30^\circ$$

- Simplify the right side of the equation:

$$30^\circ = 30^\circ + e$$

- Subtracting 30° from both sides yields:

$$e = 0^\circ$$

- An angle of emergence of 0° implies the light ray exits the prism perpendicularly to the second refracting face.

Step 4: Final Answer:

The angle of emergence is 0°.

Quick Tip: Be careful with terminology: "angle with the incident ray" is the definition of the angle of deviation (δ). Also, $e = 0^\circ$ implies normal emergence, meaning the ray hits the second surface at 90° to the boundary.

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10. A point source in air is placed in front of convex spherical glass surface (n = 1.5 and R = 10 cm). Its real image is formed at the same distance as the surface from the source. The distance of the source from the surface is :

(A) 25 cm

(B) 50 cm

(C) 75 cm

(D) 100 cm

Correct Answer: (B) 50 cm

Solution:

Step 1: Concept:

Light travels from air (n_1) into a convex glass surface (n_2). We are told that a real image is formed at a distance from the surface that is equal to the distance of the object from the surface. We need to find this distance.

Step 2: Key Formula or Approach:

The formula for refraction at a single spherical surface is:

$$\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$$

where u is object distance, v is image distance, n_1 and n_2 are refractive indices, and R is the radius of curvature.
We must apply standard Cartesian sign convention.

Step 3: Detailed Explanation:

- Let the distance of the source from the surface be x. Since the object is placed in front of the surface, its coordinate is $u = -x$.

- The question states the image is formed at the same distance from the surface, meaning the image distance magnitude is also x. Since it is a real image formed by refraction, it forms on the other side in the denser medium, making its coordinate $v = +x$.

- The refractive indices are given as $n_1 = 1$ (air) and $n_2 = 1.5$ (glass).

- The surface is convex towards the rarer medium, so its radius of curvature is positive: $R = +10$ cm.

- Substituting all these values into the refraction formula:

$$\frac{1.5}{x} - \frac{1}{-x} = \frac{1.5 - 1}{10}$$

- Simplifying the negative signs on the left side:

$$\frac{1.5}{x} + \frac{1}{x} = \frac{0.5}{10}$$

- Combining the terms over the common denominator:

$$\frac{2.5}{x} = \frac{1}{20}$$

- Cross-multiplying to solve for x:

$$x = 2.5 \times 20$$

$$x = 50 \text{ cm}$$

Step 4: Final Answer:

The distance of the source from the surface is 50 cm.

Quick Tip: Strict adherence to the sign convention is crucial in optics problems. Remember that for a convex refracting surface, R is always positive when light is incident from the rarer medium.

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11. In forward and reverse biased silicon p-n junction, the dominant mechanisms for the motion of charge carriers are :

(A) diffusion in forward bias, drift in reverse bias

(B) drift in both forward bias and in reverse bias

(C) drift in forward and diffusion in reverse bias

(D) diffusion in both forward and reverse bias

Correct Answer: (A) diffusion in forward bias, drift in reverse bias

Solution:

Step 1: Concept:

The question tests the fundamental principles governing charge carrier transport across a p-n junction under different biasing conditions.

Step 2: Detailed Explanation:

- In a p-n junction diode, there are two primary mechanisms of charge carrier movement: diffusion (driven by a concentration gradient) and drift (driven by an electric field).
- When the junction is **forward biased**, the external voltage opposes the built-in potential barrier, effectively lowering it.
- This reduced barrier allows majority carriers (holes from the p-side and electrons from the n-side) to effortlessly diffuse across the junction due to their high concentration gradient.
- Therefore, in forward bias, the dominant mechanism is the **diffusion** of majority carriers.
- When the junction is **reverse biased**, the external voltage adds to the built-in potential, increasing the barrier height significantly.
- This huge barrier stops majority carriers from crossing. However, the strong electric field easily sweeps any minority carriers (electrons in the p-side, holes in the n-side) across the junction if they wander close to the depletion region.
- This movement of minority carriers under the influence of the electric field is called **drift**.
- Therefore, in reverse bias, the dominant current (though very small) is due to drift.

Step 3: Final Answer:

The dominant mechanisms are diffusion in forward bias and drift in reverse bias.

Quick Tip: Remember: Forward Bias = Majority Carriers = Diffusion. Reverse Bias = Minority Carriers = Drift.

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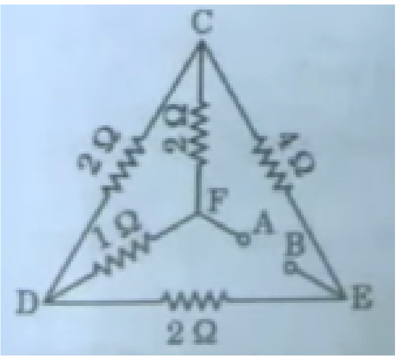
12. Five resistors are joined as shown in the figure. Between the points A and B, a battery of 6 V is connected. How much current is flowing in arm FC ?



(A) 2.0 A

(B) 1.5 A

(C) 1.0 A

(D) 0.5 A

Correct Answer: (C) 1.0 A

Solution:

Step 1: Concept:

The provided circuit diagram represents a Wheatstone bridge consisting of five resistors. A battery is connected across the input and output terminals, and we need to determine the current flowing through one specific upper branch (arm FC).

Step 2: Key Formula or Approach:

For a Wheatstone bridge to be balanced, the ratio of resistances in adjacent arms must be equal: $\frac{R_1}{R_2} = \frac{R_3}{R_4}$.
If balanced, no current flows through the central galvanometer arm. The circuit simplifies to two parallel branches, each consisting of two resistors in series.
Using Ohm's law, the current in a specific branch is calculated as $I = \frac{V_{branch}}{R_{branch}}$.

Step 3: Detailed Explanation:

- Analyzing the circuit diagram, it forms a standard Wheatstone bridge. Let's assume the main input and output nodes of the bridge are connected to the 6V battery.

- The resistances of the bridge arms are given as follows: upper-left arm $FC = 2\Omega$, upper-right arm $CB = 4\Omega$, lower-left arm $= 1\Omega$, and lower-right arm $= 2\Omega$.

- Let us check for the condition of a balanced bridge: Ratio of upper arms to lower arms or left to right.

- The ratio of the left-side resistances is $\frac{2\Omega}{1\Omega} = 2$.

- The ratio of the right-side resistances is $\frac{4\Omega}{2\Omega} = 2$.

- Since the ratios are identical $(2 = 2)$, the Wheatstone bridge is balanced.

- In a balanced bridge, the central resistor carries zero current and can be removed from our calculation.

- The circuit now consists of an upper branch (resistors 2Ω and 4Ω in series) connected in parallel with a lower branch (resistors 1Ω and 2Ω in series) across the 6V battery.

- The total resistance of the upper branch is $R_{upper} = 2\Omega + 4\Omega = 6\Omega$.

- Because the branches are in parallel across the battery, the potential difference across the entire upper branch is equal to the battery voltage, which is 6V.

- Applying Ohm's Law to the upper branch, the current $I_{upper} = \frac{V}{R_{upper}} = \frac{6\text{ V}}{6\Omega} = 1.0$ A.

- Since arm FC is part of this upper branch, the current flowing through it is 1.0 A.

Step 4: Final Answer:

The current flowing in arm FC is 1.0 A.

Quick Tip: Whenever you see a five-resistor configuration drawn as a bridge or a cross, always check for the balanced condition $P/Q = R/S$ first. It usually simplifies the problem entirely.

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13. Assertion (A) : If $\vec{B}$ be the magnetic field at a small patch of vector area $d\vec{S}$, then the magnetic flux through the patch will be $\vec{B} \cdot d\vec{S}$.

Reason (R) : The magnetic flux is a scalar quantity.

(A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A)

(B) Both Assertion (A) and Reason (R) are true and Reason (R) is not the correct explanation of Assertion (A)

(C) Assertion (A) is true but Reason (R) is false

(D) Assertion (A) is false but Reason (R) is true

Correct Answer: (B) Both Assertion (A) and Reason (R) are true and Reason (R) is not the correct explanation of Assertion (A)

Solution:

Step 1: Concept:

This is an Assertion-Reason question assessing the definition and physical nature of magnetic flux.

Step 2: Detailed Explanation:

- **Assertion (A):** The magnetic flux passing through a small area element $d\vec{S}$ in a magnetic field $\vec{B}$ is mathematically defined as the dot product $d\Phi_B = \vec{B} \cdot d\vec{S}$. This represents the number of magnetic field lines crossing the area normally. Thus, the assertion is fundamentally correct.

- **Reason (R):** The magnetic flux is the dot product of two vectors ($\vec{B}$ and $d\vec{S}$). By the mathematical rules of vector algebra, the dot product (scalar product) of any two vectors always yields a scalar quantity. Hence, magnetic flux is indeed a scalar quantity, making the reason statement true.

- **Relationship:** While both statements are true facts in physics, the reason (it being a scalar) is actually a mathematical consequence of its definition (the dot product), not the other way around. The fundamental cause of the formula $\vec{B} \cdot d\vec{S}$ is geometry (projecting the area perpendicular to field lines), not the mere fact that flux needs to be a scalar.

- Therefore, while both are true, the reason is not the fundamental explanatory cause for the assertion.

Step 3: Final Answer:

Both (A) and (R) are true, but (R) is not the correct explanation of (A).

Quick Tip: In Assertion-Reason questions, ask yourself "Does statement R explain WHY statement A happens?". If A defines a mathematical formula and R just states a property of the result, R is usually not the correct explanation.

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14. Assertion (A) : The ratio of the speeds of the electron in the second to that in the third orbit in Bohr's hydrogen atom is 3/2.
Reason (R) : The speed of the electron in n^{th} permitted orbit in hydrogen atom varies proportional to $1/n$ i.e. $v_n \propto 1/n$.

(A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A)
(B) Both Assertion (A) and Reason (R) are true and Reason (R) is not the correct explanation of Assertion (A)
(C) Assertion (A) is true but Reason (R) is false
(D) Assertion (A) is false but Reason (R) is true

Correct Answer: (A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A)

Solution:

Step 1: Concept:
This question evaluates the knowledge of the orbital speed of an electron in Bohr's model of the hydrogen atom.

Step 2: Key Formula or Approach:
In Bohr's model, the velocity of an electron in the n-th orbit of a hydrogen atom is given by $v_n = \frac{e^2}{2\epsilon_0 nh}$.
From this, it is clear that the velocity is inversely proportional to the principal quantum number n, written as $v_n \propto \frac{1}{n}$.

Step 3: Detailed Explanation:

- **Reason (R):** As established by the Bohr model formula, $v_n = \frac{2.18 \times 10^6}{n}$ m/s. Thus, the speed is indeed inversely proportional to the orbit number n. The reason statement is perfectly true.

- **Assertion (A):** Using the relationship $v_n \propto \frac{1}{n}$, we can find the speeds in the 2nd and 3rd orbits.

- For the second orbit ($n = 2$), $v_2 \propto \frac{1}{2}$.

- For the third orbit ($n = 3$), $v_3 \propto \frac{1}{3}$.

- Finding the ratio: $\frac{v_2}{v_3} = \frac{1/2}{1/3} = \frac{3}{2}$.

- This exactly matches the assertion statement, making the assertion true.

- Because the mathematical relationship stated in the reason was directly used to prove the assertion, the reason correctly explains the assertion.

Step 4: Final Answer:

Both (A) and (R) are true, and (R) correctly explains (A).

Quick Tip: Remember key proportionalities in Bohr's model: Velocity $v \propto 1/n$, Radius $r \propto n^2$, and Energy $E \propto 1/n^2$.

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15. Assertion (A) : A free neutron is not a stable particle.

Reason (R) : It decays into a proton and an electron.

(A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A)

(B) Both Assertion (A) and Reason (R) are true and Reason (R) is not the correct explanation of Assertion (A)

(C) Assertion (A) is true but Reason (R) is false

(D) Assertion (A) is false but Reason (R) is true

Correct Answer: (A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A)

Solution:

Step 1: Concept:
This question tests the understanding of radioactive beta decay, specifically the stability and decay products of an isolated neutron.

Step 2: Detailed Explanation:

- **Assertion (A):** Neutrons are stable only when bound inside a stable atomic nucleus. A free neutron outside a nucleus is unstable and undergoes spontaneous radioactive decay with a mean lifetime of about 15 minutes. Thus, the assertion is entirely true.

- **Reason (R):** A free neutron decays via the weak interaction into a proton, an electron (beta particle), and an electron antineutrino. The simplified equation is $n \to p + e^- + \bar{\nu}_e$.

- While the reason omits the antineutrino, in the context of many basic physics curricula, stating that it decays into a proton and an electron captures the primary charged products and the essence of beta-minus decay. Thus, the statement is considered functionally true in this educational context.

- Because the decay process (described in R) is the exact physical mechanism that makes the neutron unstable (described in A), the reason is the correct explanation for the assertion.

Step 3: Final Answer:

Both (A) and (R) are true, and (R) is the correct explanation of (A).

Quick Tip: While a free neutron is unstable, a bound neutron in a stable nucleus does not decay because the resulting proton would increase the energy of the nucleus to an energetically forbidden state.

---

16. Assertion (A) : Electron emission from surface of zinc occurs when yellow light is incident on it.

Reason (R) : Energy of a photon of yellow light is more than the work function of zinc.

(A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A)

(B) Both Assertion (A) and Reason (R) are true and Reason (R) is not the correct explanation of Assertion (A)

(C) Assertion (A) is true but Reason (R) is false

(D) Both Assertion (A) and Reason (R) are false

Correct Answer: (D) Both Assertion (A) and Reason (R) are false

Solution:

Step 1: Concept:

This question requires checking the validity of the photoelectric effect for a specific metal (zinc) under a specific wavelength of light (yellow).

Step 2: Key Formula or Approach:

For photoelectric emission to occur, the energy of the incident photon must be greater than or equal to the work function (Φ) of the metal: $E = \frac{hc}{\lambda} > \Phi$.

Step 3: Detailed Explanation:

- Zinc has a relatively high work function, approximately $\Phi_{Zn} \approx 4.3$ eV. To overcome this barrier, incident photons need to have at least this much energy.

- Yellow light belongs to the visible spectrum and has a wavelength of roughly 580 nm.

- We can calculate the energy of a yellow light photon using the shortcut formula $E = \frac{1240 \text{ eV}\cdot\text{nm}}{\lambda \text{ (nm)}}$.

- $E_{yellow} \approx \frac{1240}{580} \approx 2.14$ eV.

- Comparing the energies: 2.14 eV is significantly less than the 4.3 eV required.

- **Reason (R):** Because the energy of yellow light is much less than the work function, the reason statement is objectively false.

- **Assertion (A):** Since the photon energy is insufficient to eject an electron, no electron emission will occur. Thus, the assertion statement is also completely false.

Step 4: Final Answer:

Both Assertion (A) and Reason (R) are completely false.

Quick Tip: Zinc, Cadmium, and Magnesium generally require ultraviolet (UV) light for photoelectric emission, while alkali metals like Sodium and Potassium can emit electrons under visible light.

---

17. Calculate the kinetic energy of an electron which has the de Broglie wavelength of 600 nm

associated with it.

Solution:

Step 1: Concept:
We are given the de Broglie wavelength of an electron and need to calculate its corresponding kinetic energy.

Step 2: Key Formula or Approach:
The de Broglie wavelength λ is related to momentum p by the equation $\lambda = \frac{h}{p}$, which gives $p = \frac{h}{\lambda}$.
The kinetic energy K of a non-relativistic particle is related to its momentum by $K = \frac{p^2}{2m}$.
Combining these, we get a direct formula for kinetic energy: $K = \frac{h^2}{2m\lambda^2}$.

Step 3: Detailed Explanation:

- First, we identify the given constants and values:
  Planck's constant, $h = 6.63 \times 10^{-34}$ J · s.
  Mass of an electron, $m = 9.11 \times 10^{-31}$ kg.
  De Broglie wavelength, $\lambda = 600$ nm $= 600 \times 10^{-9}$ m $= 6 \times 10^{-7}$ m.

- Substitute these values into the derived kinetic energy formula:

$$K = \frac{(6.63 \times 10^{-34})^2}{2 \times 9.11 \times 10^{-31} \times (6 \times 10^{-7})^2}$$

- Calculate the square in the numerator:

$$(6.63)^2 \times 10^{-68} \approx 43.9569 \times 10^{-68}$$

- Calculate the square and multiplication in the denominator:

$$(6 \times 10^{-7})^2 = 36 \times 10^{-14}$$

$$2 \times 9.11 \times 10^{-31} \times 36 \times 10^{-14} = 18.22 \times 36 \times 10^{-45} = 655.92 \times 10^{-45}$$

- Divide the numerator by the denominator:

$$K = \frac{43.9569 \times 10^{-68}}{655.92 \times 10^{-45}} \approx 0.0670 \times 10^{-23} \text{ J}$$

- Adjusting the scientific notation gives $K \approx 6.7 \times 10^{-25}$ J.

- To convert this energy into electron-volts (eV), divide by the elementary charge (1.6×10^{-19} J/eV):

$$K(\text{in eV}) = \frac{6.7 \times 10^{-25}}{1.6 \times 10^{-19}} \approx 4.18 \times 10^{-6} \text{ eV}$$

Step 4: Final Answer:

The kinetic energy of the electron is 6.7×10^{-25} J, which is equivalent to 4.18×10^{-6} eV.

Quick Tip: For electrons, you can use the shortcut formula $\lambda(\text{in nm}) = \sqrt{\frac{1.5}{K(\text{in eV})}}$ to find the energy quickly.

18(a)(i). A monochromatic beam of light is travelling from a rarer to a denser medium. Giving reasons, explain the following: Is the frequency of the reflected and the refracted light the same as the frequency of incident light?

Solution:

Step 1: Concept:

This question tests the fundamental wave properties of light when it interacts with a boundary between two different optical media.

It specifically addresses whether the frequency, which dictates the color of light, alters during the physical processes of reflection and refraction.

Step 2: Key Formula or Approach:

The fundamental relationship for any wave is given by $v = f\lambda$, where v is the wave speed, f is

the frequency, and λ is the wavelength.
However, frequency is a property determined entirely by the source generating the wave, not the medium it travels through.

Step 3: Detailed Explanation:

- The frequency of a wave represents the number of oscillations per second.

- When a light wave strikes the boundary of a denser medium, it interacts with the atoms and molecules of that new material.

- These atoms absorb the incoming electromagnetic energy and are forced into oscillation by the alternating electric and magnetic fields of the incident light.

- Crucially, they are driven to oscillate at the exact same frequency as the incident wave.

- These oscillating atoms then act as secondary sources, re-emitting light as both the reflected wave (back into the rarer medium) and the refracted wave (into the denser medium).

- Because the "new" waves are generated by atoms oscillating at the incident frequency, the frequency of both the reflected and refracted light is perfectly identical to that of the incident light.

Step 4: Final Answer:
Yes, the frequency of both the reflected and refracted light remains exactly the same as the incident light, because frequency depends only on the source of light.

Quick Tip: Always remember: Frequency (f) is the "fingerprint" of the wave's source and never changes upon crossing a boundary.

18(a)(ii). A monochromatic beam of light is travelling from a rarer to a denser medium. Giving reasons, explain the following: Does the decrease in speed in denser medium imply a reduction in the energy carried by the light wave?

Solution:

Step 1: Concept:

This question examines the relationship between the macroscopic speed of a light wave in a medium and the microscopic energy carried by its constituent photons.

It requires distinguishing between mechanical kinetic energy and electromagnetic wave energy.

Step 2: Key Formula or Approach:

The energy of a light wave is quantized into photons, and the energy of a single photon is governed by Planck's equation: $E = hf$, where h is Planck's constant and f is the frequency.

The speed of the wave is $v = f\lambda$.

Step 3: Detailed Explanation:

- When light travels from a rarer medium (like air) into a denser medium (like glass or water), its speed indeed decreases.

- This happens because the refractive index n of the denser medium is greater than 1, and speed is $v = c/n$.

- However, the energy carried by the light wave is not analogous to the classical kinetic energy ($\frac{1}{2}mv^2$) of a massive particle.

- Instead, light energy is determined by its frequency according to $E = hf$.
- As established previously, the frequency f of light remains strictly constant when it crosses into a new medium.
- Because the frequency does not change, the energy E of each photon in the light wave also remains completely unchanged.
- What physically happens is that as the speed v decreases, the wavelength λ of the light compresses by the exact same proportion ($\lambda = \lambda_{vacuum}/n$).
- This proportional reduction in both speed and wavelength ensures their ratio (which is the frequency) remains constant, thereby preserving the wave's energy.

Step 4: Final Answer:
No, a decrease in speed does not imply a reduction in energy because the energy depends on frequency ($E = hf$), which remains constant.

Quick Tip: Do not confuse light with classical particles.
A classical car slowing down loses kinetic energy, but a photon "slowing down" in a medium just means it has a shorter wavelength; its fundamental energy (hf) stays intact.

OR

18(b)(i). The lower half of a concave mirror's reflecting surface is covered with an opaque non-reflecting material. What effect will this have on the image of an object placed in front of the mirror? Give reasons for your answer.

Solution:

Step 1: Concept:

This question tests the principles of image formation by spherical mirrors.
It explores whether a partial obstruction of the optical aperture truncates the geometry of the image or alters its energetic properties (brightness).

Step 2: Detailed Explanation:

- The laws of reflection apply to every single infinitesimal point on the surface of a concave mirror.
- When an object is placed in front of the mirror, diverging light rays from every part of the object strike every exposed part of the mirror's surface.
- Even a small, exposed fragment of the mirror possesses the correct curvature to reflect these rays and converge them to the proper image points.
- Therefore, when the lower half of the mirror is covered by an opaque material, the exposed upper half continues to function normally.
- The upper half independently receives rays from the entire object and focuses them to create a complete, fully formed image of the object at the exact same location.
- The geometry, size, and position of the image remain completely unaffected by the blockage.
- However, because half of the reflecting area is now obstructed, the total number of light rays contributing to the formation of the image is reduced by 50%.

- Since less light energy is converging at the image location, the resulting image will appear significantly less bright.

- Specifically, the intensity (brightness) of the image will be reduced to exactly half of its original value.

Step 3: Final Answer:

A complete and geometrically identical image will be formed, but its brightness (intensity) will be reduced to half because the area available for reflection is halved.

Quick Tip: Covering a part of a lens or a mirror NEVER cuts off part of the image.
It only reduces the amount of light reaching the image plane, thereby dimming the entire picture uniformly.

18(b)(ii). A lens made of glass of refractive index 1.5 disappears, when immersed in a trough of liquid. What is the refractive index of the liquid? Give reasons for your answer.

Solution:

Step 1: Concept:

This problem explores the optical conditions under which a transparent solid object becomes indistinguishable (invisible) when submerged in a liquid.
It relies heavily on the principles of refraction and the Lens Maker's Formula.

Step 2: Key Formula or Approach:

The focal length f of a lens placed in a surrounding liquid medium is given by the Lens Maker's Formula:

$$\frac{1}{f} = \left(\frac{n_{lens}}{n_{liquid}} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

where n_{lens} and n_{liquid} are the refractive indices of the lens and liquid, respectively.

Step 3: Detailed Explanation:

- An object is visible to the human eye due to the reflection, scattering, or refraction of light at its physical boundaries.
- For a perfectly transparent glass lens, its visibility in a fluid is almost entirely due to the refraction (bending) of light as it crosses the boundary between the fluid and the glass.
- If the lens "disappears" when submerged, it means that light rays pass straight through the liquid-glass boundary without undergoing any bending or deviation whatsoever.
- According to Snell's Law, light only bends if there is a difference in the optical density (refractive index) between the two adjoining media.
- Therefore, for zero refraction to occur, the refractive index of the surrounding liquid must perfectly match the refractive index of the glass lens.
- We can prove this mathematically using the Lens Maker's formula.
- If the lens doesn't bend light, its focal length f must be infinite ($f \to \infty$), meaning its optical power is zero.
- Setting $\frac{1}{f} = 0$ in the formula requires the first bracketed term to be zero:

$$\left(\frac{n_{lens}}{n_{liquid}} - 1\right) = 0$$

- Solving this equation yields:

$$\frac{n_{lens}}{n_{liquid}} = 1 \implies n_{liquid} = n_{lens}$$

- Since the problem states the glass lens has a refractive index of 1.5, the liquid must identically have a refractive index of 1.5.

Step 4: Final Answer:

The refractive index of the liquid is strictly 1.5. This is because the lens disappears when no light is refracted at its boundary, which only occurs if the media have matching refractive indices.

Quick Tip: If a lens is immersed in a liquid with a HIGHER refractive index than the lens itself, its nature flips entirely (a convex converging lens will start acting like a concave diverging lens)!

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19. Two identical circular coils A and B of radius 10 cm each are placed concentrically and mutually perpendicular in XY and YZ planes respectively. Currents of 1 A and $\sqrt{3}$ A flow anticlockwise in the coils as seen from YZ plane. Find the magnitude of the net magnetic field at the common centre of the coils.

Solution:

Step 1: Concept:

The question asks for the net magnetic field produced by two mutually perpendicular current-carrying circular coils at their common center.

The net field will be the vector sum of the individual magnetic fields generated by each coil.

Step 2: Key Formula or Approach:

The magnetic field at the center of a circular current-carrying coil of radius r is given by $B = \frac{\mu_0 I}{2r}$.

Since the coils are perpendicular to each other, their magnetic field vectors at the center will also be perfectly perpendicular.

The magnitude of the net magnetic field is calculated using the Pythagorean theorem: $B_{net} = \sqrt{B_A^2 + B_B^2}$.

Step 3: Detailed Explanation:

- Let's calculate the magnetic field due to Coil A, which lies in the XY plane.

- Its magnetic field vector will point along the normal to the XY plane, which is the Z-axis.

- Using the formula: $B_A = \frac{\mu_0 I_A}{2r}$.

- Substituting the values ($I_A = 1$ A, $r = 0.1$ m):

$$B_A = \frac{\mu_0 \times 1}{2 \times 0.1} = 5\mu_0 \text{ Tesla}$$

- Now, let's calculate the magnetic field due to Coil B, which lies in the YZ plane.

- Its magnetic field vector will point along the normal to the YZ plane, which is the X-axis.

- Using the formula: $B_B = \frac{\mu_0 I_B}{2r}$.

- Substituting the values ($I_B = \sqrt{3}$ A, $r = 0.1$ m):

$$B_B = \frac{\mu_0 \times \sqrt{3}}{2 \times 0.1} = 5\sqrt{3}\mu_0 \text{ Tesla}$$

- Because B_A is along the Z-axis and B_B is along the X-axis, the angle between them is 90°.

- The net magnetic field magnitude is:

$$B_{net} = \sqrt{(B_A)^2 + (B_B)^2}$$

$$B_{net} = \sqrt{(5\mu_0)^2 + (5\sqrt{3}\mu_0)^2}$$

$$B_{net} = \sqrt{25\mu_0^2 + 75\mu_0^2}$$

$$B_{net} = \sqrt{100\mu_0^2} = 10\mu_0$$

- Substituting the value of the permeability of free space $\mu_0 = 4\pi \times 10^{-7}$ T · m/A:

$$B_{net} = 10 \times 4\pi \times 10^{-7} = 4\pi \times 10^{-6} \text{ Tesla}$$

Step 4: Final Answer:

The magnitude of the net magnetic field at the common center is $4\pi \times 10^{-6}$ T.

Quick Tip: When adding magnetic fields from perpendicular coils, always treat them as orthogonal vectors.

The exact clockwise/anticlockwise direction determines if they point towards positive or negative axes, but the magnitude of their vector sum remains identical.

---

20. Draw a plot showing the variation of potential energy of a pair of nucleons as a function of their separation. With the help of the plot, explain why the nuclear force is attractive for $r > r_0$ and repulsive for $r < r_0$.

Solution:

Step 1: Concept:

This question demands a graphical representation of the strong nuclear force's potential energy between two nucleons.

It also requires a theoretical explanation of the dual nature (attractive and repulsive) of this force based on the slope of the potential energy curve.

Step 2: Key Formula or Approach:

The force between two conservative particles is related to their potential energy by the negative gradient: $F = -\frac{dU}{dr}$.

A negative slope ($\frac{dU}{dr} < 0$) yields a positive (repulsive) force.

A positive slope ($\frac{dU}{dr} > 0$) yields a negative (attractive) force.

Step 3: Detailed Explanation:

- **Plot Description:**

  The plot of potential energy (U) on the Y-axis versus the separation distance (r) on the X-axis starts with a sharp positive spike at very small r.

  As r increases, U drops steeply, crossing zero and reaching a deep negative minimum at a specific distance denoted as r_0 (approximately 0.8 fm).

  Beyond r_0, the potential energy gradually rises towards zero, flattening out entirely past a few femtometers (around 3 fm).

- **Explanation for $r > r_0$:**

  For separation distances greater than r_0, the curve slopes upwards towards the right.

  Mathematically, the gradient $\frac{dU}{dr}$ is positive in this region.

  Since $F = -\frac{dU}{dr}$, the force is negative, which physically represents an attractive force.

  This strong attraction holds the nucleons tightly together within the atomic nucleus.

- **Explanation for $r < r_0$:**

  For separation distances less than r_0, the curve slopes steeply downwards to the right (or rises sharply towards the left).

  Mathematically, the gradient $\frac{dU}{dr}$ is highly negative in this compressed region.

  Therefore, $F = -\frac{dU}{dr}$ yields a strongly positive force, representing a massive repulsive force.

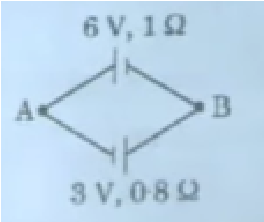
  This hard core repulsion prevents the nucleus from collapsing in on itself under the immense attractive forces.

Step 4: Final Answer:

The nuclear force is attractive for $r > r_0$ due to the positive slope of the potential energy curve, and repulsive for $r < r_0$ due to the negative slope, ensuring nuclear stability.

Quick Tip: Remember that the minimum potential energy state (r_0) represents the point of stable equilibrium where the net nuclear force is exactly zero.

21. Find the equivalent emf and the equivalent resistance between points A and B for two cells arranged as shown in the figure.



Solution:

Step 1: Concept:

The problem requires finding the single equivalent cell representation for two real batteries connected in a parallel configuration.

Step 2: Key Formula or Approach:

When two cells of emfs E_1, E_2 and internal resistances r_1, r_2 are connected in parallel with their identical polarities joined together, the equivalent emf E_{eq} is calculated using Millman's Theorem.

The formula is $E_{eq} = \frac{\frac{E_1}{r_1}+\frac{E_2}{r_2}}{\frac{1}{r_1}+\frac{1}{r_2}}$.

The equivalent internal resistance R_{eq} is simply the parallel combination of their individual internal resistances.

The formula is $\frac{1}{R_{eq}} = \frac{1}{r_1} + \frac{1}{r_2} \implies R_{eq} = \frac{r_1 r_2}{r_1+r_2}$.

Step 3: Detailed Explanation:

- From the provided circuit diagram, both positive terminals (long lines) of the cells are connected to common node A.
- Both negative terminals (short thick lines) are connected to common node B.
- This confirms a standard parallel aiding connection.

- Given values are: $E_1 = 6$ V, $r_1 = 1\,\Omega$ and $E_2 = 3$ V, $r_2 = 0.8\,\Omega$.

- First, let's calculate the equivalent internal resistance R_{eq}:

$$R_{eq} = \frac{1 \times 0.8}{1 + 0.8}$$

$$R_{eq} = \frac{0.8}{1.8} = \frac{8}{18} = \frac{4}{9}\,\Omega$$

- Converting to decimals, $R_{eq} \approx 0.44\,\Omega$.

- Now, we calculate the equivalent emf E_{eq}:

$$E_{eq} = \frac{\frac{6}{1} + \frac{3}{0.8}}{\frac{1}{1} + \frac{1}{0.8}}$$

- Simplifying the fractions:

$$E_{eq} = \frac{6 + 3.75}{1 + 1.25}$$

$$E_{eq} = \frac{9.75}{2.25}$$

- Performing the division:

$$E_{eq} = \frac{975}{225} = \frac{39}{9} = \frac{13}{3}\text{ V}$$

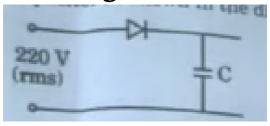
- Converting to decimals, $E_{eq} \approx 4.33$ V.

Step 4: Final Answer:

The equivalent emf is 4.33 V and the equivalent resistance is $0.44\,\Omega$.

Quick Tip: If the cells were connected with opposite polarities (e.g., positive of one to negative of the other at node A), you would assign a negative sign to one of the emfs in Millman's formula.

22(a). A diode is connected to 220 V (rms) ac source in series with a capacitor as shown in the diagram.



Find the voltage (rms) across the capacitor.

Solution:

Step 1: Concept:

This question tests the behavior of a capacitor and an ideal diode connected in series with an alternating current (AC) source.

It explores the concept of peak charging and DC voltage blocking.

Step 2: Key Formula or Approach:

The peak voltage of an AC source is related to its root-mean-square (RMS) voltage by the formula $V_{peak} = \sqrt{2} \times V_{rms}$.

An ideal capacitor charges to the maximum applied potential difference.

An ideal diode allows current to flow in only one direction.

Step 3: Detailed Explanation:

- The circuit contains an AC source with an RMS voltage of $V_{rms} = 220$ V.

- We first find the maximum (peak) voltage output of this AC source:

$$V_{peak} = \sqrt{2} \times 220 \approx 1.414 \times 220 \approx 311 \text{ V}$$

- During the positive half-cycle of the AC source, the diode becomes forward-biased and acts like a closed switch.

- The capacitor charges rapidly through the forward-biased diode until the voltage across its plates reaches the peak voltage of the source, $V_{peak} = 311$ V.

- As the AC voltage starts to decrease from its peak and enters the negative half-cycle, the capacitor tries to discharge back into the circuit.

- However, discharging would require current to flow in the reverse direction through the diode.

- Because the diode is now reverse-biased, it heavily blocks this reverse current, leaving the capacitor with nowhere to discharge its stored energy.

- Consequently, the capacitor maintains a constant, steady DC voltage equal to V_{peak} across its plates.

- The question asks for the "rms voltage" across the capacitor.

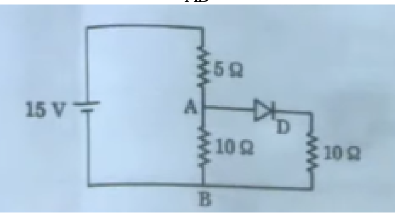
- Since the voltage across the capacitor is a pure, constant DC value (311 V), its RMS value is simply equal to this DC value itself.

Step 4: Final Answer:

The RMS voltage across the capacitor is approximately 311 V.

Quick Tip: This circuit arrangement functions as a simple peak detector.
Remember that the RMS value of a perfectly steady DC signal V_0 is always exactly V_0.

22(b). Find V_{AB} in the circuit given below.



Solution:

Step 1: Concept:

The problem requires evaluating the potential difference between two nodes in a direct current (DC) circuit that includes an ideal p-n junction diode.

Step 2: Key Formula or Approach:

Determine the biasing of the diode to see if it conducts or blocks current.

Calculate equivalent resistance R_{eq} of the parallel branches, then the total circuit resistance.

Use Ohm's Law ($V = IR$) to find total current and then the specific voltage drop V_{AB} across the parallel section.

Step 3: Detailed Explanation:

- Tracing the circuit from the positive terminal of the 15 V battery, current flows through the $5\,\Omega$ resistor to node A.

- Node A is at a higher electrical potential than node B, which is connected to the negative terminal of the battery.

- Observing diode D in the right-most branch, its triangular p-side (anode) is connected towards node A, and the straight line n-side (cathode) faces node B.

- Because the anode is at a higher potential than the cathode, the diode is forward-biased.

- Assuming it is an ideal diode (as is standard unless a barrier potential like 0.7V is specified), it acts as a short circuit with $0\,\Omega$ resistance.

- The circuit between nodes A and B consists of two purely resistive parallel branches: one with a $10\,\Omega$ resistor and the other with a $10\,\Omega$ resistor (since the diode has zero resistance).

- The equivalent resistance of this parallel combination is:

$$R_p = \frac{10 \times 10}{10 + 10} = \frac{100}{20} = 5\,\Omega$$

- The total equivalent resistance of the entire circuit is the series $5\,\Omega$ resistor added to R_p:

$$R_{total} = 5\,\Omega + 5\,\Omega = 10\,\Omega$$

- The total main current flowing out of the battery is:

$$I_{total} = \frac{V_{battery}}{R_{total}} = \frac{15\text{ V}}{10\,\Omega} = 1.5\text{ A}$$

- The potential difference V_{AB} is the voltage drop across the parallel combination, which is equal to the total current multiplied by the equivalent parallel resistance R_p:

$$V_{AB} = I_{total} \times R_p = 1.5\text{ A} \times 5\,\Omega = 7.5\text{ V}$$

Step 4: Final Answer:

The voltage V_{AB} in the circuit is 7.5 V.

Quick Tip: Always check the orientation of the diode carefully first.

If it were reverse-biased, it would behave as an open circuit, making $R_p = 10\,\Omega$ and changing the entire calculation.

23(a). Briefly explain the process of charging a parallel plate capacitor, when it is connected across a dc source.

Solution:

Step 1: Concept:

This question asks for a descriptive explanation of the physical mechanism by which an uncharged capacitor accumulates charge when attached to a Direct Current (DC) battery.

Step 2: Detailed Explanation:

- A parallel plate capacitor consists of two initially neutral metallic plates separated by a dielectric medium or vacuum.
- When a DC source (like a battery) is connected across these plates, it establishes an electric field through the connecting wires.
- The positive terminal of the battery attracts free electrons away from the plate connected to it.
- As electrons leave, this plate acquires a net positive charge $(+Q)$.
- Simultaneously, the negative terminal of the battery pushes an equal number of electrons onto the other plate, giving it a net negative charge $(-Q)$.
- The battery performs work to move these charges against the growing electrostatic repulsion from the charges already on the plates.
- As charge continues to build up, a potential difference (V) develops across the capacitor plates, proportional to the accumulated charge $(V = Q/C)$.
- This charging process continues transiently until the potential difference across the capacitor exactly equals the electromotive force (emf) of the DC source.
- Once these potentials are equal, the net electric force on the charge carriers becomes zero, current stops flowing, and the capacitor is considered fully charged.

Step 3: Final Answer:

The battery moves electrons from one plate to the other, creating equal and opposite charges until the capacitor's potential matches the battery's emf.

Quick Tip: Current only flows in the external wires during the charging transient phase.
No physical charge ever crosses the dielectric gap between the plates during standard capacitor charging.

23(b). A capacitor, of capacitance C, plate area A and plate separation d is charged to V volts by a battery. The energy stored in it is U. After some time, the battery is disconnected and a slab of dielectric constant K, is inserted to fill the space between the plates of the capacitor. Let V' and U' now be the potential difference across the plates of the capacitor and the energy stored in it respectively. Find (V'/V) and (U'/U).

Solution:

Step 1: Concept:

This problem investigates how the characteristics of an isolated capacitor (one disconnected from its charging source) change when a dielectric material is introduced into its gap.

Step 2: Key Formula or Approach:

Since the battery is disconnected, the total charge Q on the plates is trapped and must remain constant.

Initial Charge is $Q = CV$.

Initial Energy is $U = \frac{Q^2}{2C}$.

When a dielectric slab of constant K fully occupies the space, the new capacitance increases to $C' = KC$.

New potential is $V' = \frac{Q}{C'}$ and new energy is $U' = \frac{Q^2}{2C'}$.

Step 3: Detailed Explanation:

- Let the initial capacitance be C, initial voltage be V, and initial charge be $Q = CV$.

- The initial stored energy is $U = \frac{Q^2}{2C}$.

- After disconnecting the battery, the charge cannot escape, so the final charge is $Q' = Q$.

- Inserting a dielectric slab of constant K scales up the capacitance: $C' = KC$.

- We can now find the new potential difference V':

$$V' = \frac{Q'}{C'} = \frac{Q}{KC} = \frac{1}{K}\left(\frac{Q}{C}\right)$$

- Since $\frac{Q}{C} = V$, we substitute this back:

$$V' = \frac{V}{K}$$

- Therefore, the ratio of the potentials is:

$$\frac{V'}{V} = \frac{1}{K}$$

- Next, we find the new stored electrostatic energy U':

$$U' = \frac{(Q')^2}{2C'} = \frac{Q^2}{2(KC)} = \frac{1}{K}\left(\frac{Q^2}{2C}\right)$$

- Since $\frac{Q^2}{2C} = U$, we substitute this back:

$$U' = \frac{U}{K}$$

- Therefore, the ratio of the energies is:

$$\frac{U'}{U} = \frac{1}{K}$$

Step 4: Final Answer:

The ratios are $(V'/V) = 1/K$ and $(U'/U) = 1/K$.

Quick Tip: Always check the state of the battery!

If the battery is DISCONNECTED, Charge (Q) is constant.

If the battery remains CONNECTED, Voltage (V) is constant.

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24. Derive an expression for refractive index of an equilateral prism in terms of the angle of minimum deviation and the angle of the prism. Plot a graph to show the variation of the angle of deviation as a function of angle of incidence.

Solution:

Step 1: Concept:

The problem requires deriving the standard prism formula relating refractive index to the minimum deviation angle.

It also requires sketching the experimental curve relating the deviation angle to the incidence angle.

Step 2: Key Formula or Approach:

Use Snell's Law at the first interface: $1 \cdot \sin(i) = n \cdot \sin(r_1)$.

Geometry of the prism gives $A = r_1 + r_2$ and deviation $\delta = i + e - A$.

At minimum deviation ($\delta = \delta_m$), symmetry dictates that the incident ray and emergent ray behave identically, so $i = e$ and $r_1 = r_2$.

Step 3: Detailed Explanation:

- Consider a principal section ABC of a prism with refracting angle A.
- Let a light ray enter at face AB with angle of incidence i and angle of refraction r_1.
- The ray strikes face AC with angle of incidence r_2 and emerges with angle e.

- From the geometry of the normal lines intersecting inside the prism, the sum of internal angles equals the prism angle: $r_1 + r_2 = A$.

- The total angle of deviation experienced by the ray is given by $\delta = (i - r_1) + (e - r_2) = i + e - (r_1 + r_2) = i + e - A$.

- **Condition for Minimum Deviation:** Experimentally, deviation δ reaches a minimum value δ_m when the path of light is perfectly symmetric through the prism.

- This symmetry implies that the angle of incidence equals the angle of emergence ($i = e$).

- Consequently, the internal refractions are also equal ($r_1 = r_2 = r$).

- Substituting this into the geometric relation: $r + r = A \implies 2r = A \implies r = \frac{A}{2}$.

- Substituting into the deviation formula: $\delta_m = i + i - A \implies 2i = A + \delta_m \implies i = \frac{A+\delta_m}{2}$.

- Now, apply Snell's Law at the first surface (assuming surrounding medium is air with $n = 1$):

$$n = \frac{\sin(i)}{\sin(r)}$$

- Substitute the expressions for i and r derived above to get the final formula:

$$n = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

- **Graph Plot:**
  The graph plots Deviation Angle (δ) on the y-axis against Angle of Incidence (i) on the x-axis.
  It takes the shape of a slightly skewed, U-shaped parabolic curve.

The curve descends to a distinct global minimum point (δ_m) at a specific angle of incidence, after which it rises again.

Step 4: Final Answer:

The derived expression is $n = \frac{\sin((A+\delta_m)/2)}{\sin(A/2)}$.

Quick Tip: At the angle of minimum deviation, the refracted ray travelling inside the glass is completely parallel to the base of the equilateral prism.

---

25. Draw a labelled diagram of a full wave rectifier circuit. State its working principle and show the input-output waveforms.

Solution:

Step 1: Concept:

A full-wave rectifier is an essential electronic circuit that converts the whole of an input AC signal (both positive and negative half-cycles) into pulsating DC.
It heavily relies on the unidirectional conduction property of p-n junction diodes.

Step 2: Detailed Explanation:

- **Circuit Diagram:**
  The primary circuit consists of an AC source connected to the primary coil of a center-tapped transformer.
  The secondary coil has its top end connected to the anode of Diode 1 (D_1) and its bottom end connected to the anode of Diode 2 (D_2).
  The cathodes of both diodes are tied together and connected to one end of a load resistor (R_L).
  The other end of R_L connects back to the center tap of the secondary coil, completing the circuit.

- **Working Principle:**

  The fundamental principle is that a p-n junction diode conducts current robustly only when forward-biased and strongly blocks it when reverse-biased.

  During the positive half-cycle of the input AC, the top end of the secondary is positive relative to the center tap, and the bottom end is negative.

  This forward-biases D_1 and reverse-biases D_2.

  Current flows through D_1 and down through the load resistor R_L.

  During the subsequent negative half-cycle, the polarities invert: the bottom end becomes positive, and the top end becomes negative.

  Now, D_1 is reverse-biased while D_2 becomes forward-biased.

  Current flows through D_2 and again downwards through the same load resistor R_L.

  Because current flows through the load in the exact same direction during both half-cycles, full-wave rectification is achieved.

- **Waveforms:**

  The Input Waveform is a standard sine wave alternating above and below the zero axis.

  The Output Waveform consists only of positive bumps (pulsating DC).

  Every negative half-cycle from the input is flipped to become a positive half-cycle in the output.

Step 3: Final Answer:

A full-wave rectifier uses two diodes and a center-tapped transformer to ensure current flows through the load in the same direction during both AC half-cycles.

Quick Tip: The output frequency of a full-wave rectifier is exactly twice the input AC frequency because it produces two output pulses for every single input cycle.

26(a). Derive the expression for the magnetic field (near its centre) due to an air-filled long solenoid carrying a current I and having n number of turns per unit length.

Solution:

Step 1: Concept:

The derivation utilizes Ampere's Circuital Law to find the highly uniform magnetic field deep inside a long, tightly wound current-carrying solenoid.

Step 2: Key Formula or Approach:

Ampere's Circuital Law states: $\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{enclosed}$.
For an ideal long solenoid, the magnetic field is uniform and parallel to the axis inside, and practically zero strictly outside.

Step 3: Detailed Explanation:

- Consider an infinitely long solenoid with n turns per unit length, carrying a steady current I.
- Let the axis of the solenoid be along the z-direction.
- The interior magnetic field $\vec{B}$ is uniform and purely axial.
- Construct an imaginary rectangular Amperean loop PQRS partially inside and partially outside the solenoid.
- Let the side PQ of length L be completely inside and strictly parallel to the solenoid axis.
- Let side RS be completely outside, while QR and SP are perpendicular to the axis.
- Apply Ampere's Law around this closed loop:

$$\oint_{PQRS} \vec{B} \cdot d\vec{l} = \int_P^Q \vec{B} \cdot d\vec{l} + \int_Q^R \vec{B} \cdot d\vec{l} + \int_R^S \vec{B} \cdot d\vec{l} + \int_S^P \vec{B} \cdot d\vec{l}$$

- Let's evaluate each segment:

- 1) For PQ: $\vec{B}$ and $d\vec{l}$ are parallel, so $\int \vec{B} \cdot d\vec{l} = \int B\,dl = B \int dl = BL$.

- 2) For QR and SP: $\vec{B}$ is perpendicular to $d\vec{l}$, so the dot product is zero.

- Hence, their integrals are 0.

- 3) For RS: The field outside an ideal long solenoid is considered zero, so $\int \vec{B} \cdot d\vec{l} = 0$.

- Therefore, the total line integral evaluates simply to:

$$\oint \vec{B} \cdot d\vec{l} = BL$$

- Next, we determine the total current enclosed by the rectangular loop.

- The number of turns contained within the length L of the loop is $N = n \times L$.

- Since each turn carries current I, the total enclosed current is $I_{enclosed} = nLI$.

- Equating the line integral to $\mu_0 I_{enclosed}$ per Ampere's Law:

$$BL = \mu_0(nLI)$$

- Canceling the length L from both sides yields the final expression:

$$B = \mu_0 nI$$

Step 4: Final Answer:

The magnetic field near the center of the solenoid is $B = \mu_0 n I$.

Quick Tip: Remember that the parameter n in the formula is "turns per unit length" (N/L), not the total number of turns.

26(b). A charged particle moving with velocity $\vec{v}$ enters a region of uniform magnetic field $\vec{B}$. The force acting on it is non-zero. Would the particle gain any energy? Explain.

Solution:

Step 1: Concept:

This question tests the fundamental property of the magnetic force on moving charges and its relationship to the Work-Energy Theorem.

Step 2: Key Formula or Approach:

The magnetic Lorentz force on a charged particle is given by $\vec{F} = q(\vec{v} \times \vec{B})$.

Mechanical power (rate of doing work) is $P = \vec{F} \cdot \vec{v}$.

Work-Energy Theorem states that Work Done = Change in Kinetic Energy.

Step 3: Detailed Explanation:

- When a charged particle q moves with velocity $\vec{v}$ in a magnetic field $\vec{B}$, the magnetic force exerted on it is $\vec{F} = q(\vec{v} \times \vec{B})$.

- According to the mathematical properties of the cross product, the resulting force vector $\vec{F}$ is always strictly perpendicular to both the velocity vector $\vec{v}$ and the magnetic field vector $\vec{B}$.

- The work done W by a force over a small displacement $d\vec{r}$ is $dW = \vec{F} \cdot d\vec{r} = \vec{F} \cdot \vec{v}\, dt$.

- Since the force is always perpendicular to the velocity (angle $\theta = 90^\circ$), their dot product is always zero: $\vec{F} \cdot \vec{v} = Fv\cos(90^\circ) = 0$.

- Because the magnetic force performs absolutely zero work on the particle, it cannot transfer any energy to it.

- By the Work-Energy Theorem, since zero work is done, the change in the particle's kinetic energy is zero.

- The force only serves to constantly change the direction of the velocity vector (causing curved motion), while the magnitude of the velocity (speed) and kinetic energy remain perfectly constant.

Step 4: Final Answer:

No, the particle will not gain any energy because the magnetic force acts perpendicularly to the velocity, doing no work.

Quick Tip: Magnetic fields can only change the DIRECTION of a charged particle's motion, never its SPEED.

Only electric fields can do work to change a particle's speed and energy.

27(a). Draw a labelled ray diagram of a refracting telescope in normal adjustment. Briefly explain its working.

Solution:

Step 1: Concept:
An astronomical refracting telescope uses two convex lenses (objective and eyepiece) to magnify distant objects like stars or planets.
"Normal adjustment" implies that the final image is formed at infinity, which is the most relaxed viewing state for the human eye.

Step 2: Detailed Explanation:

- **Ray Diagram:**
  The diagram consists of a large Objective lens and a smaller Eyepiece lens sharing a principal axis.
  Parallel light rays from a distant object enter the objective lens at a small angle α.
  The objective lens focuses these rays to form a real, inverted, and diminished intermediate image A'B' exactly at its principal focal point (F_o).
  For normal adjustment, the eyepiece lens is physically positioned so that this intermediate image A'B' falls exactly on its own principal focal point (F_e).
  Thus, F_o and F_e coincide.
  Rays diverging from the intermediate image pass through the eyepiece and emerge strictly parallel to each other.
  These parallel emergent rays enter the eye, and the observer perceives a highly magnified, inverted final image residing at infinity.

- **Working Explanation:**
  The fundamental working principle involves a two-step optical manipulation.
  First, the large aperture objective lens gathers a massive amount of light from a distant astronomical object and converges it to create a bright real image at its focal plane.
  Second, the eyepiece acts purely as a simple magnifying glass.
  Because the real image is placed at its focal point, it magnifies this image and projects the light rays parallel to infinity.
  This significantly increases the visual angle subtended at the eye (β) compared to the naked eye (α), resulting in angular magnification.

Step 3: Final Answer:

The telescope creates a real intermediate image at the shared focal point of both lenses, which the eyepiece then magnifies into a final image at infinity.

Quick Tip: In normal adjustment, the total length of the telescope tube is $L = f_o + f_e$.

27(b). Why is the eyepiece of a telescope of short focal length, while the objective is of large focal length? Explain.

Solution:

Step 1: Concept:

The choice of focal lengths for telescope lenses is driven entirely by the need to maximize the device's resolving and magnifying capabilities.

Step 2: Key Formula or Approach:

The magnifying power (angular magnification) of a refracting telescope in normal adjustment is given by $M = \frac{f_o}{f_e}$.

Step 3: Detailed Explanation:

- **Why Large Objective Focal Length (f_o):**
  Looking at the magnification formula $M = \frac{f_o}{f_e}$, it is mathematically obvious that a larger numerator (f_o) directly yields higher magnifying power.
  Additionally, lenses with very large focal lengths are typically manufactured with much larger apertures (diameters).
  A large aperture is astronomically critical because it vastly increases the light-gathering power of the telescope, allowing incredibly dim and distant stars to be observed clearly.
  Furthermore, a large aperture directly improves the resolution limit of the telescope,

permitting the separation of closely spaced objects.

- **Why Short Eyepiece Focal Length (f_e):**
  Returning to the magnification formula, a smaller denominator (f_e) also drastically increases the total magnifying power of the instrument.
  A shorter focal length eyepiece acts as a stronger simple magnifier, providing a much wider angular spread to the light rays entering the observer's eye.

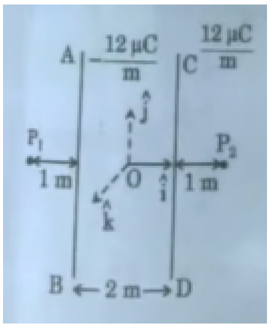
Step 4: Final Answer:

A large f_o and small f_e are chosen to maximize the magnifying power ($M = f_o/f_e$), while the correspondingly large objective aperture drastically improves light gathering and resolution.

Quick Tip: Unlike a telescope, a compound microscope requires BOTH lenses (objective and eyepiece) to have very short focal lengths to achieve high magnification.

28(a). Two infinitely long thin straight wires AB and CD with charge densities $-12\,\mu$C/m and $+12\,\mu$C/m are lying parallel to y-axis at points $(-1\text{ m}, 0, 0)$ and $(1\text{ m}, 0, 0)$ respectively, as shown in the figure.

Find the net electric field $\vec{E}$ at points $P_1(-2\text{ m}, 0, 0)$, $O(0,0,0)$ and $P_2(2\text{ m}, 0, 0)$.



Solution:

Step 1: Concept:

We need to find the total electric field vector at specific points by superimposing the individual electric fields generated by two parallel infinite line charges.

Step 2: Key Formula or Approach:

The magnitude of the electric field produced by an infinitely long straight wire with linear charge density λ at a perpendicular distance r is $E = \frac{\lambda}{2\pi\epsilon_0 r} = \frac{2k\lambda}{r}$.
The direction of the field points radially inward towards a negative line charge and radially outward away from a positive line charge.
Superposition principle: $\vec{E}_{net} = \vec{E}_1 + \vec{E}_2$.

Step 3: Detailed Explanation:

- Let Wire 1 be at $x_1 = -1$ m with $\lambda_1 = -12 \times 10^{-6}$ C/m.

- Let Wire 2 be at $x_2 = 1$ m with $\lambda_2 = +12 \times 10^{-6}$ C/m.

- We use $k = \frac{1}{4\pi\epsilon_0} = 9 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2$.

- **Electric Field at $P_1(-2\ \mathbf{m}, 0, 0)$:**
  Distance from Wire 1 is $r_1 = |-2-(-1)| = 1$ m.
  Since λ_1 is negative, the field points towards $x = -1$ from $x = -2$, which is the $+\hat{i}$ direction.
  $\vec{E}_1 = \frac{2\times(9\times10^9)\times(12\times10^{-6})}{1}\hat{i} = 216 \times 10^3\hat{i} = 2.16 \times 10^5\hat{i}$ N/C.
  Distance from Wire 2 is $r_2 = |-2-1| = 3$ m.
  Since λ_2 is positive, the field points away from $x = 1$ towards $x = -2$, which is the $-\hat{i}$ direction.
  $\vec{E}_2 = \frac{2\times(9\times10^9)\times(12\times10^{-6})}{3}(-\hat{i}) = -72 \times 10^3\hat{i} = -0.72 \times 10^5\hat{i}$ N/C.
  Net field $\vec{E}_{P1} = \vec{E}_1 + \vec{E}_2 = (2.16-0.72) \times 10^5\hat{i} = 1.44 \times 10^5\hat{i}$ N/C.

- **Electric Field at $O(0, 0, 0)$:**
  Distance from Wire 1 is $r_1 = 1$ m.
  Field from negative Wire 1 points towards $x = -1$, which is the $-\hat{i}$ direction.

$\vec{E}_1 = \frac{216\times10^3}{1}(-\hat{i}) = -2.16\times10^5\hat{i}$ N/C.

Distance from Wire 2 is $r_2 = 1$ m.

Field from positive Wire 2 points away from $x = 1$, which is also the $-\hat{i}$ direction.

$\vec{E}_2 = \frac{216\times10^3}{1}(-\hat{i}) = -2.16\times10^5\hat{i}$ N/C.

Net field $\vec{E}_O = \vec{E}_1 + \vec{E}_2 = (-2.16 - 2.16)\times10^5\hat{i} = -4.32\times10^5\hat{i}$ N/C.

- **Electric Field at $P_2(2$ m$, 0, 0)$:**

  Distance from Wire 1 is $r_1 = |2-(-1)| = 3$ m.

  Since λ_1 is negative, field points towards $x = -1$ from $x = 2$, which is the $-\hat{i}$ direction.

  $\vec{E}_1 = \frac{216\times10^3}{3}(-\hat{i}) = -0.72\times10^5\hat{i}$ N/C.

  Distance from Wire 2 is $r_2 = |2-1| = 1$ m.

  Since λ_2 is positive, field points away from $x = 1$ towards $x = 2$, which is the $+\hat{i}$ direction.

  $\vec{E}_2 = \frac{216\times10^3}{1}(\hat{i}) = 2.16\times10^5\hat{i}$ N/C.

  Net field $\vec{E}_{P2} = \vec{E}_1 + \vec{E}_2 = (-0.72 + 2.16)\times10^5\hat{i} = 1.44\times10^5\hat{i}$ N/C.

Step 4: Final Answer:

The net electric field at P_1 is $1.44\times10^5\hat{i}$ N/C, at O is $-4.32\times10^5\hat{i}$ N/C, and at P_2 is $1.44\times10^5\hat{i}$ N/C.

Quick Tip: Drawing a simple sketch and putting direction arrows for each electric field vector before starting calculations dramatically reduces sign errors.

OR

28(b). Two charges of $8\,\mu$C and $-4\,\mu$C are located at points $(-18$ cm$, 0, 0)$ and $(18$ cm$, 0, 0)$ respectively.

(i) Calculate the electrostatic potential energy of the system of the two charges.

(ii) The same system of charges is placed in a region where electrostatic potential $V(r) = \frac{A}{r}$, where $A = 9\times10^4$ V.m. Calculate the potential energy of the system.

Solution:

Step 1: Concept:

This question requires computing the mutual electrostatic potential energy between two point charges in isolation, and then calculating their total potential energy when subjected to an external electric field.

Step 2: Key Formula or Approach:

The mutual potential energy of two charges is $U_{mutual} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r_{12}}$.
When placed in an external potential $V(r)$, the total potential energy of the system is the sum of the individual potential energies of each charge in the external field plus their mutual interaction energy: $U_{total} = q_1 V(r_1) + q_2 V(r_2) + U_{mutual}$.

Step 3: Detailed Explanation:

- **Part (i): Mutual Potential Energy**
- Given $q_1 = 8 \times 10^{-6}$ C at position $x_1 = -18$ cm.
- Given $q_2 = -4 \times 10^{-6}$ C at position $x_2 = 18$ cm.
- The distance separating them is $r_{12} = |18 - (-18)| = 36$ cm $= 0.36$ m.
- Using the formula:

$$U_{mutual} = (9 \times 10^9) \times \frac{(8 \times 10^{-6}) \times (-4 \times 10^{-6})}{0.36}$$

$$U_{mutual} = \frac{9 \times (-32) \times 10^{-3}}{0.36} = \frac{-288 \times 10^{-3}}{0.36} = -800 \times 10^{-3} \text{ J}$$

- Simplifying, we get $U_{mutual} = -0.8$ Joules.

- **Part (ii): Total Energy in External Field**

- The external potential is given as $V(r) = \frac{A}{r}$ with $A = 9 \times 10^4$ V · m.

- We need the distance of each charge from the origin to evaluate $V(r)$.

- Distance of q_1 from origin is $r_1 = |-18 \text{ cm}| = 0.18$ m.

- Distance of q_2 from origin is $r_2 = |18 \text{ cm}| = 0.18$ m.

- Calculate the energy of q_1 in the external field:

$$U_1 = q_1 V(r_1) = (8 \times 10^{-6}) \times \left(\frac{9 \times 10^4}{0.18}\right) = (8 \times 10^{-6}) \times (5 \times 10^5) = 4.0 \text{ J}$$

- Calculate the energy of q_2 in the external field:

$$U_2 = q_2 V(r_2) = (-4 \times 10^{-6}) \times \left(\frac{9 \times 10^4}{0.18}\right) = (-4 \times 10^{-6}) \times (5 \times 10^5) = -2.0 \text{ J}$$

- The total potential energy of the system is the sum of these external energies and the mutual energy derived in part (i):

$$U_{total} = U_1 + U_2 + U_{mutual}$$

$$U_{total} = 4.0 + (-2.0) + (-0.8) = 4.0 - 2.8 = 1.2 \text{ J}$$

Step 4: Final Answer:

(i) The mutual electrostatic potential energy is −0.8 J.

(ii) The total potential energy of the system in the external field is 1.2 J.

Quick Tip: When calculating energies in external potentials, ensure you use the distance of the specific charge from the coordinate origin (r_1 and r_2), not the distance between the charges (r_{12}) used for mutual energy.

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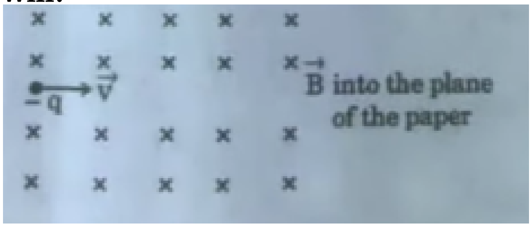
29. A particle of mass m and charge q experiences a force $\vec{F}_e$ in an electric field $\vec{E}$ and it is directed along the field. When the particle is moving with velocity $\vec{v}$ in a magnetic field $\vec{B}$, it experiences a force $\vec{F}_B$, that is perpendicular to both $\vec{v}$ and $\vec{B}$. In presence of both fields, the force acting on the particle is the vector sum of that due to $\vec{E}$ and that due to $\vec{B}$. A current-carrying conductor also experiences a force in presence of a magnetic field. The force $d\vec{F}$ acting on a current-element $Id\vec{l}$ is perpendicular to both the current element, and the magnetic field $\vec{B}$. The net force acting on a conductor of a given length is the vector sum of all $d\vec{F}$s.

29 (i). A negative ion enters a region of uniform magnetic field B as shown in the figure. It will:



(A) go straight, undeviated

(B) describe a circular path

(C) describe a semicircular path

(D) describe a helical path

Correct Answer: (B) describe a circular path

Solution:

Step 1: Concept:

This question examines the trajectory of a charged particle moving through a uniform magnetic field.

When a charged particle enters a magnetic field, it experiences a magnetic Lorentz force that dictates its subsequent path depending on the angle between its velocity and the magnetic field lines.

Step 2: Key Formula or Approach:
The magnetic force acting on a moving charge is given by the vector cross product: $\vec{F} = q(\vec{v} \times \vec{B})$.
The direction of this force is determined by the Right-Hand Rule.
If the velocity vector is strictly perpendicular to the magnetic field vector ($\theta = 90°$), the magnetic force provides a constant centripetal force, resulting in a circular trajectory.

Step 3: Detailed Explanation:

- According to the provided diagram, the uniform magnetic field $\vec{B}$ is represented by crosses ($\times$), which indicates that the field lines are directed perpendicularly into the plane of the paper (let's call this the $-z$ direction).

- The negative ion (charge $-q$) is moving horizontally to the right. Let's designate this as the $+x$ direction.

- Since the velocity is along the x-axis and the magnetic field is along the z-axis, the angle between them is exactly $90°$.

- We calculate the cross product $\vec{v} \times \vec{B}$: pointing the fingers of the right hand to the right ($+x$) and curling them into the page ($-z$) makes the thumb point upwards ($+y$).

- However, because the ion has a negative charge ($-q$), the actual force is in the opposite direction of the cross product: $\vec{F} = -q(+y) = -y$ (downwards).

- Regardless of the specific up or down direction, the crucial physics principle is that this force is strictly perpendicular to the velocity at all times.

- A force of constant magnitude that is always perpendicular to the direction of motion acts entirely as a centripetal force.

- This continuous perpendicular force forces the particle to continuously change its direction without changing its speed, compelling it to move in a perfectly circular path.

Step 4: Final Answer:
The negative ion will describe a circular path because its velocity is perpendicular to the uniform magnetic field.

Quick Tip: If the velocity had a component parallel to the magnetic field, the path would be helical. If the field is limited in space, it might trace a semicircular arc before exiting, but fundamentally the geometry of the trajectory is circular.

29(ii)(a). An electron is moving in a circular path in a uniform magnetic field of 3.14×10^{-4} T. Its period of revolution will be approximately :

(A) $0.11\,\mu s$
(B) $0.28\,\mu s$
(C) $0.014\,\mu s$
(D) $0.024\,\mu s$

Correct Answer: (A) $0.11\,\mu s$

Solution:

Step 1: Concept:
The question asks for the time period of revolution of an electron caught in a uniform magnetic field.
When an electron undergoes uniform circular motion in a magnetic field, the magnetic force

acts as the required centripetal force. The time period is independent of the electron's velocity and the radius of its path.

Step 2: Key Formula or Approach:

The magnetic force provides the centripetal force: $qvB = \frac{mv^2}{r}$, which simplifies to $r = \frac{mv}{qB}$.
The time period T is the total circumference divided by the speed: $T = \frac{2\pi r}{v}$.
Substituting the radius formula into the period formula gives the standard cyclotron period equation: $T = \frac{2\pi m}{qB}$.

Step 3: Detailed Explanation:

- First, let's identify the standard physical constants required for an electron:
  Mass of an electron, $m = 9.1 \times 10^{-31}$ kg.
  Charge magnitude of an electron, $q = 1.6 \times 10^{-19}$ C.

- The magnetic field strength is given as $B = 3.14 \times 10^{-4}$ T. Notice that 3.14 is an approximation for π, which will simplify our calculations.

- Substitute all these values into the time period formula:

$$T = \frac{2 \times \pi \times 9.1 \times 10^{-31}}{1.6 \times 10^{-19} \times 3.14 \times 10^{-4}}$$

- Since $\pi \approx 3.14$, we can cancel π in the numerator with 3.14 in the denominator.

- The simplified expression becomes:

$$T = \frac{2 \times 9.1 \times 10^{-31}}{1.6 \times 10^{-23}}$$

- Perform the multiplication in the numerator:

$$T = \frac{18.2 \times 10^{-31}}{1.6 \times 10^{-23}}$$

- Perform the division and handle the exponents ($10^{-31-(-23)} = 10^{-8}$):

$$T = 11.375 \times 10^{-8} \text{ s}$$

- To convert this time into microseconds (μs), where $1\,\mu s = 10^{-6}$ s, we adjust the decimal place:

$$T = 0.11375 \times 10^{-6} \text{ s} = 0.11375\,\mu s$$

- Rounding to two significant decimal places aligns with the given options, yielding $0.11\,\mu s$.

Step 4: Final Answer:

The period of revolution will be approximately $0.11\,\mu s$.

Quick Tip: Notice how recognizing 3.14 as π instantly simplifies the arithmetic without needing a calculator. Always look for such mathematical conveniences in physics problems.

OR

29(ii)(b). An alpha particle (mass 6.4×10^{-27} kg) moves in a circular path with a speed of 6.28×10^{5} m/s in a uniform magnetic field of 3.14×10^{-3} T. The radius of the path is :

(A) 1.00 m
(B) 2.00 m
(C) 3.00 m
(D) 4.00 m

Correct Answer: (D) 4.00 m

Solution:

Step 1: Concept:

This alternative question focuses on calculating the radius of the circular trajectory traced by an alpha particle moving perpendicularly through a uniform magnetic field.

Like the previous question, it relies on equating the magnetic Lorentz force to the centripetal force.

Step 2: Key Formula or Approach:

The centripetal force required for circular motion is provided entirely by the magnetic force.

$F_{centripetal} = F_{magnetic} \implies \frac{mv^2}{r} = qvB.$

Rearranging this equation to solve for the radius gives: $r = \frac{mv}{qB}$.

Step 3: Detailed Explanation:

- First, we must identify the properties of an alpha particle. An alpha particle is a helium nucleus, consisting of two protons and two neutrons.
- Its charge is twice that of a proton: $q = 2 \times e = 2 \times 1.6 \times 10^{-19}$ C $= 3.2 \times 10^{-19}$ C.
- The mass of the alpha particle is provided in the problem as $m = 6.4 \times 10^{-27}$ kg.
- The velocity is given as $v = 6.28 \times 10^5$ m/s. Note that 6.28 is exactly 2π.
- The magnetic field is given as $B = 3.14 \times 10^{-3}$ T. Note that 3.14 is exactly π.
- Substitute all these specific values into the radius formula:

$$r = \frac{(6.4 \times 10^{-27}) \times (6.28 \times 10^5)}{(3.2 \times 10^{-19}) \times (3.14 \times 10^{-3})}$$

- We can group the numerical coefficients and the powers of 10 separately to make the math easier:

$$r = \left(\frac{6.4}{3.2}\right) \times \left(\frac{6.28}{3.14}\right) \times \frac{10^{-27} \times 10^5}{10^{-19} \times 10^{-3}}$$

- Simplifying the grouped fractions: $\frac{6.4}{3.2} = 2$ and $\frac{6.28}{3.14} = 2$.

- Simplifying the exponents: $\frac{10^{-22}}{10^{-22}} = 1$.

- Multiplying these results together:

$$r = 2 \times 2 \times 1 = 4.00 \text{ m}$$

Step 4: Final Answer:

The radius of the alpha particle's path is 4.00 m.

Quick Tip: An alpha particle's charge is $2e$ and its mass is approximately $4m_p$. Always remember these values as they are rarely given directly in standard exam questions.

29(iii). A charged particle enters with a velocity $\vec{v} = (6 \times 10^6$ m/s$)\hat{i}$ in a region of magnetic field $\vec{B} = (0.5$ G$)\hat{j}$ and an electric field $\vec{E}$. If the particle goes straight undeviated in the region, then $\vec{E}$ equals :

(A) $(120 \text{ N/C})\hat{k}$
(B) $-(300 \text{ N/C})\hat{k}$
(C) $(600 \text{ N/C})\hat{j}$
(D) $-(150 \text{ N/C})\hat{i}$

Correct Answer: (B) $-(300 \text{ N/C})\hat{k}$

Solution:

Step 1: Concept:

This question explores the concept of a velocity selector, a setup where crossed electric and magnetic fields are used to control the path of a charged particle.

For a particle to travel in a straight, undeviated line through both fields, the net force acting on it must be absolutely zero.

Step 2: Key Formula or Approach:

The total force on a charged particle in the presence of both electric and magnetic fields is the Lorentz force: $\vec{F}_{net} = q\vec{E} + q(\vec{v} \times \vec{B})$.

For an undeviated path, $\vec{F}_{net} = 0$, which mathematically implies $q\vec{E} = -q(\vec{v} \times \vec{B})$.

Dividing out the charge q, we find the required electric field must be exactly $\vec{E} = -(\vec{v} \times \vec{B})$.

Step 3: Detailed Explanation:

- First, we need to convert the given magnetic field from Gauss (G) into the standard SI unit of Tesla (T).

- The conversion factor is $1\ \text{G} = 10^{-4}\ \text{T}$.

- Therefore, $\vec{B} = 0.5\ \text{G}\hat{j} = 0.5 \times 10^{-4}\ \text{T}\hat{j}$.

- The velocity vector is provided as $\vec{v} = 6 \times 10^6 \hat{i}$ m/s.

- Now, we calculate the cross product $\vec{v} \times \vec{B}$:

$$\vec{v} \times \vec{B} = (6 \times 10^6 \hat{i}) \times (0.5 \times 10^{-4} \hat{j})$$

- Multiply the scalar magnitudes together: $6 \times 10^6 \times 0.5 \times 10^{-4} = 3 \times 10^2 = 300$.

- Evaluate the vector cross product: $\hat{i} \times \hat{j} = \hat{k}$.

- So, $\vec{v} \times \vec{B} = 300\hat{k}$ N/C.

- As established by the condition for zero net force, the electric field must be the negative of this cross product:

$$\vec{E} = -(\vec{v} \times \vec{B})$$

$$\vec{E} = -(300\hat{k})\ \text{N/C} = -300\hat{k}\ \text{N/C}$$

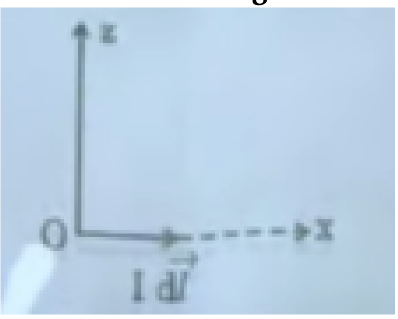
- Notice that this result is completely independent of whether the charge q is positive or negative. The fields will balance for any charge entering with that specific velocity.

Step 4: Final Answer:

The required electric field is $-(300\ \text{N/C})\hat{k}$.

Quick Tip: In crossed fields ($\vec{E} \perp \vec{B}$), the speed for an undeviated path is always $v = E/B$. Use this to quickly verify magnitudes, then use the right-hand rule to deduce the vector direction.

29(iv). A current-element ($Id\vec{l}$) of mass per unit length (m) is held in air as shown in the figure. After withdrawing the support, it will remain suspended in its position, when subjected to an external magnetic field $\vec{B}$ equal to :



(A) $\frac{mgdl}{I}\hat{k}$

(B) $\frac{mg}{I}\hat{j}$

(C) $-\frac{mg}{Idl}\hat{i}$

(D) $-(\frac{Idl}{mg})\hat{k}$

Correct Answer: (B) $\frac{mg}{I}\hat{j}$

Solution:

Step 1: Concept:

This problem deals with the magnetic levitation of a current-carrying wire.

For the wire to remain suspended in mid-air against the downward pull of gravity, an upward magnetic force of exactly equal magnitude must be generated by an external magnetic field.

Step 2: Key Formula or Approach:

The downward gravitational force is $\vec{F}_g = -Mg\hat{k}$, where M is the total mass of the element.

The upward magnetic force on a current element is given by the Biot-Savart force law: $\vec{F}_B = I(d\vec{l} \times \vec{B})$.

For equilibrium suspension, the net force must be zero: $\vec{F}_B + \vec{F}_g = 0$, meaning $\vec{F}_B = -\vec{F}_g$.

Step 3: Detailed Explanation:

- Based on the coordinate system shown in the figure, the z-axis points vertically upwards ($\hat{k}$), the x-axis points to the right ($\hat{i}$), and the y-axis points into the page ($\hat{j}$).

- The current element is oriented along the x-axis, so its vector form is $d\vec{l} = dl\,\hat{i}$.

- The problem states the "mass per unit length" is m. The total mass of the element of length dl is therefore $M = m \cdot dl$.

- The gravitational force acting on this element is directed downwards: $\vec{F}_g = -(m \cdot dl)g\hat{k}$.

- To balance this, the required magnetic force must point straight up: $\vec{F}_B = +(m \cdot dl)g\hat{k}$.

- We expand the magnetic force equation using a general magnetic field $\vec{B} = B_x\hat{i} + B_y\hat{j} + B_z\hat{k}$:

$$\vec{F}_B = I(dl\,\hat{i}) \times (B_x\hat{i} + B_y\hat{j} + B_z\hat{k})$$

- Distributing the cross product:

$$\vec{F}_B = I \cdot dl[B_x(\hat{i} \times \hat{i}) + B_y(\hat{i} \times \hat{j}) + B_z(\hat{i} \times \hat{k})]$$

- Knowing the cross product rules ($\hat{i} \times \hat{i} = 0$, $\hat{i} \times \hat{j} = \hat{k}$, $\hat{i} \times \hat{k} = -\hat{j}$):

$$\vec{F}_B = I \cdot dl(B_y\hat{k} - B_z\hat{j})$$

- We need this force to purely equal $+(m \cdot dl)g\hat{k}$. This means there can be no y-component of force, so B_z must be 0.

- Equating the z-components:

$$I \cdot dl \cdot B_y = m \cdot dl \cdot g$$

- Canceling the length element dl from both sides:

$$I \cdot B_y = m \cdot g \implies B_y = \frac{mg}{I}$$

- Therefore, the required magnetic field must be oriented purely along the y-axis with this magnitude.

Step 4: Final Answer:

The external magnetic field must be $\vec{B} = \frac{mg}{I}\hat{j}$.

Quick Tip: A quick right-hand rule check: thumb points along current $(+x)$, palm must point up for levitating force $(+z)$. To achieve this, fingers must point into the page $(+y)$. Thus, $\vec{B}$ is along $+\hat{j}$.

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30. When radiation of suitable frequency is incident on a metal surface, electrons are emitted from the surface. This phenomenon is called photoelectric effect. Einstein explained this phenomenon considering the particle nature of radiation and using the law of conservation of energy. Wave theory of light could not explain this phenomenon.

30(i)(a). A photon of 3.8 eV energy is incident on a surface of work function 1.8 eV. The maximum kinetic energy of the electron emitted from the surface will be :

(A) 3.2×10^{-19} J
(B) 1.6×10^{-19} J
(C) 1.25×10^{-19} J
(D) 2.4×10^{-18} J

Correct Answer: (A) 3.2×10^{-19} J

Solution:

Step 1: Concept:
This question tests the application of Einstein's Photoelectric Equation.
It describes how the energy of an incoming photon is split into two parts: overcoming the binding energy of the metal (work function) and providing kinetic energy to the ejected electron.

Step 2: Key Formula or Approach:
Einstein's photoelectric equation states: $K_{max} = E_{photon} - \Phi$, where K_{max} is the maximum kinetic energy, E_{photon} is the incident photon energy, and Φ is the work function.
To convert energy from electron-volts (eV) to Joules (J), multiply by the elementary charge: $1 \text{ eV} = 1.6 \times 10^{-19}$ J.

Step 3: Detailed Explanation:

- From the problem, the energy of the incident photon is given as $E_{photon} = 3.8$ eV.

- The work function (the minimum energy required just to free an electron) of the surface is given as $\Phi = 1.8$ eV.

- Substitute these values directly into Einstein's equation to find the maximum kinetic energy:

$$K_{max} = 3.8 \text{ eV} - 1.8 \text{ eV} = 2.0 \text{ eV}$$

- The question options are presented in Joules, requiring a unit conversion.

- Multiply the result in eV by the conversion factor:

$$K_{max} = 2.0 \times (1.6 \times 10^{-19} \text{ J})$$

- Performing the simple multiplication:

$$K_{max} = 3.2 \times 10^{-19} \text{ J}$$

- This matches option (A) perfectly.

Step 4: Final Answer:

The maximum kinetic energy of the emitted electron is 3.2×10^{-19} J.

Quick Tip: Always check the units of the options provided. It is very common in modern physics problems to do calculations in eV but have the final answer requested in Joules (or vice versa).

OR

30(i)(b). The work function of a photosensitive surface is 2.21 eV. The value of threshold frequency for the surface is :

(A) 4.8×10^{14} Hz

(B) 5.3×10^{14} Hz

(C) 1.9×10^{15} Hz

(D) 1.2×10^{15} Hz

Correct Answer: (B) 5.3×10^{14} Hz

Solution:

Step 1: Concept:

This alternative question focuses on the relationship between a metal's work function and its threshold frequency.

The threshold frequency is the absolute minimum frequency of incident light required to just liberate an electron, meaning the ejected electron will have zero kinetic energy.

Step 2: Key Formula or Approach:

The work function Φ is directly proportional to the threshold frequency ν_0 via Planck's constant h.

The formula is $\Phi = h\nu_0$, which can be rearranged to $\nu_0 = \frac{\Phi}{h}$.

Remember to convert the work function from eV to Joules before dividing by Planck's constant, which is in Joule-seconds.

Step 3: Detailed Explanation:

- The work function is given as $\Phi = 2.21$ eV.
- First, convert this energy into standard SI units (Joules) by multiplying by 1.6×10^{-19}:

$$\Phi = 2.21 \times 1.6 \times 10^{-19}\ \text{J} = 3.536 \times 10^{-19}\ \text{J}$$

- Planck's constant is a known universal constant: $h = 6.63 \times 10^{-34}\ \text{J} \cdot \text{s}$.
- Substitute these values into the threshold frequency formula:

$$\nu_0 = \frac{3.536 \times 10^{-19}}{6.63 \times 10^{-34}}$$

- Grouping the decimal numbers and the powers of 10:

$$\nu_0 = \left(\frac{3.536}{6.63}\right) \times \frac{10^{-19}}{10^{-34}}$$

- The power of 10 becomes $10^{-19-(-34)} = 10^{15}$.

- Dividing the decimals: $3.536/6.63 \approx 0.5333$.

- Putting it together gives:

$$\nu_0 = 0.5333 \times 10^{15} \text{ Hz}$$

- Adjusting the scientific notation to standard form (one digit before the decimal) by moving the decimal point one place to the right and decreasing the exponent by one:

$$\nu_0 = 5.333 \times 10^{14} \text{ Hz}$$

- Rounding to one decimal place to match the options gives 5.3×10^{14} Hz.

Step 4: Final Answer:

The threshold frequency for the surface is 5.3×10^{14} Hz.

Quick Tip: An alternative approach is to use h in terms of eV: $h = 4.14 \times 10^{-15}$ eV · s. Then $\nu_0 = 2.21/(4.14 \times 10^{-15}) \approx 0.533 \times 10^{15}$ Hz, saving you the unit conversion step!

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30 (ii). The saturation current for a given photosensitive material depends on :

(A) work function of the material

(B) wavelength of the incident radiation

(C) intensity of the incident radiation

(D) collector plate potential

Correct Answer: (C) intensity of the incident radiation

Solution:

Step 1: Concept:

This theoretical question asks about the factors affecting photoelectric current, specifically the maximum achievable current known as "saturation current."

It tests the fundamental distinction between the intensity and the frequency/wavelength of light in the particle model.

Step 2: Detailed Explanation:

- In a photoelectric setup, electrons are ejected from the emitter plate when illuminated by suitable light.
- If the collector plate potential is made sufficiently positive, it collects every single electron ejected by the emitter, resulting in a steady, maximum current known as the saturation current.
- Since every ejected electron is being collected, the magnitude of this saturation current is solely determined by the *number* of electrons being ejected per second.
- According to Einstein's particle theory of light, the number of photoelectrons emitted per second is directly proportional to the number of photons hitting the surface per second.
- The number of incident photons per unit time per unit area defines the **intensity** of the incident radiation.
- Therefore, increasing the intensity of the light increases the photon count, which linearly increases the electron emission rate, thereby directly increasing the saturation current.
- Modifying the work function or wavelength (as long as it remains below the threshold) only changes the kinetic energy of the ejected electrons, not their total number.

Step 3: Final Answer:

The saturation current depends fundamentally on the intensity of the incident radiation.

Quick Tip: Intensity dictates the NUMBER of electrons (Saturation Current). Frequency/Wavelength dictates the ENERGY of electrons (Stopping Potential).

---

30 (iii). The stopping potential of photoelectrons is found to be 0.40 V when light of wavelength 500 nm is incident on a surface. The work function of the surface is close to :

(A) 1.20 eV

(B) 1.48 eV

(C) 2.08 eV

(D) 6.48 eV

Correct Answer: (C) 2.08 eV

Solution:

Step 1: Concept:

This question links stopping potential, incident wavelength, and work function through the photoelectric equation.

Stopping potential is the exact negative voltage required to halt the fastest emitted photoelectrons, providing a direct measurement of their maximum kinetic energy.

Step 2: Key Formula or Approach:

The maximum kinetic energy relates to stopping potential via $K_{max} = eV_0$.

The energy of the incident photon is given by $E = \frac{hc}{\lambda}$.

Einstein's photoelectric equation: $\Phi = E - K_{max}$.

A useful shortcut for photon energy in eV is $E(\text{eV}) = \frac{1240}{\lambda(\text{nm})}$.

Step 3: Detailed Explanation:

- First, we determine the maximum kinetic energy of the emitted electrons from the given stopping potential.

- Since stopping potential $V_0 = 0.40$ V, the maximum kinetic energy in electron-volts is simply numerically identical: $K_{max} = e(0.40 \text{ V}) = 0.40$ eV.

- Next, we calculate the energy of the incident light photons.

- The wavelength is given as $\lambda = 500$ nm.

- Using the shortcut formula for energy in eV:

$$E = \frac{1240 \text{ eV} \cdot \text{nm}}{500 \text{ nm}}$$

- Performing the division:

$$E = \frac{124}{50} = 2.48 \text{ eV}$$

- Finally, we use Einstein's photoelectric equation to find the work function Φ:

$$\Phi = E - K_{max}$$

- Substitute the calculated values:

$$\Phi = 2.48 \text{ eV} - 0.40 \text{ eV} = 2.08 \text{ eV}$$

- The calculated work function matches option (C) exactly.

Step 4: Final Answer:

The work function of the surface is close to 2.08 eV.

Quick Tip: Memorize the 1240 $\text{eV}\cdot\text{nm}$ (or 1242, depending on desired precision) shortcut for photon energy. It is an immense time-saver in exams, bypassing tedious calculations with h, c, and e.

---

30 (iv). A graph between the frequency of incident radiation (ν) and the corresponding stopping potential (V_0) for a metal is a straight line. Let α and β be the value of the slope and the value of the intercept on the V_0-axis respectively. Then, according to Einstein's photoelectric equation $(\frac{\beta}{\alpha})$ is :

(A) ν_0
(B) $\frac{1}{\nu_0}$
(C) $e\nu_0$
(D) $\frac{\nu_0}{h}$

Correct Answer: (A) ν_0

Solution:

Step 1: Concept:
This question requires mapping Einstein's photoelectric equation onto the equation of a straight line graph.
By comparing the physical constants in the physics equation to the geometric parameters (slope and intercept) of the linear graph, we can deduce physical meanings.

Step 2: Key Formula or Approach:
Einstein's photoelectric equation: $K_{max} = h\nu - \Phi$.
Substituting $K_{max} = eV_0$, we get $eV_0 = h\nu - \Phi$.
Rearranging to solve for the y-axis variable (V_0): $V_0 = \left(\frac{h}{e}\right)\nu - \left(\frac{\Phi}{e}\right)$.
The equation of a straight line is $y = mx + c$, where m is slope and c is the y-intercept.

Step 3: Detailed Explanation:

- By directly comparing the rearranged photoelectric equation $V_0 = \left(\frac{h}{e}\right)\nu - \left(\frac{\Phi}{e}\right)$ with the line equation $y = mx + c$:

- The y-variable is Stopping Potential (V_0).
- The x-variable is Frequency (ν).
- The slope of the graph, defined as α, corresponds to the term multiplying ν, so $\alpha = \frac{h}{e}$.
- The y-intercept of the graph corresponds to the constant term $-\frac{\Phi}{e}$. The problem defines β as the "value" (usually implying magnitude in such ratio questions) of this intercept, so $\beta = \frac{\Phi}{e}$.

- We know that the work function Φ is fundamentally defined as $\Phi = h\nu_0$, where ν_0 is the threshold frequency.

- Substituting this into our expression for β gives $\beta = \frac{h\nu_0}{e}$.

- The question asks for the ratio of the intercept value to the slope value: $\left(\frac{\beta}{\alpha}\right)$.

- Substitute our derived expressions into this ratio:

$$\frac{\beta}{\alpha} = \frac{\left(\frac{h\nu_0}{e}\right)}{\left(\frac{h}{e}\right)}$$

- The terms h/e perfectly cancel out from the numerator and the denominator, leaving only ν_0.

- Therefore, the geometric ratio of the y-intercept to the slope physically represents the threshold frequency of the metal.

Step 4: Final Answer:

According to the equation, (β/α) is equal to the threshold frequency ν_0.

Quick Tip: In any linear graph derived from a physics formula, finding the x-intercept involves setting $y = 0$. Setting $V_0 = 0$ gives $0 = \alpha\nu - \beta \implies \nu = \beta/\alpha$. Since $V_0 = 0$ occurs exactly at the threshold frequency, the ratio β/α must equal ν_0.

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31 (a). A potential difference V is applied across the ends of a cylindrical conductor of length l, area of cross-section A and resistance R. It is gradually stretched till its length is tripled. How will (i) the drift speed of electrons in the conductor, and (ii) the resistance of the conductor be affected? Justify your answers.

Solution:

Step 1: Concept:
This question deals with the physical deformation of a wire (stretching) and its subsequent impact on fundamental electrical properties: drift velocity and macroscopic resistance. Crucially, when a solid wire is stretched, its total volume remains constant, meaning an increase in length must be accompanied by a proportional decrease in cross-sectional area.

Step 2: Key Formula or Approach:
Volume conservation: $Volume = l \times A = constant$.
Drift speed is related to applied voltage by $v_d = \frac{eE}{m}\tau = \frac{eV}{ml}\tau$.
Resistance is given by $R = \rho\frac{l}{A}$.

Step 3: Detailed Explanation:

- **Initial conditions:** Length $= l$, Area $= A$, Voltage $= V$.
- **Final conditions after stretching:** The new length is tripled, so $l' = 3l$. Because the volume V_{ol} remains constant ($V_{ol} = lA = l'A'$), the new area must be $A' = \frac{lA}{l'} = \frac{lA}{3l} = \frac{A}{3}$. The applied voltage V remains constant.
- **(i) Effect on Drift Speed (v_d):**

The drift velocity of electrons under a potential difference V across a length l is $v_d = \frac{e\tau}{m}\left(\frac{V}{l}\right)$.

Since the material (determining relaxation time τ) and the applied voltage V are unchanged, $v_d \propto \frac{1}{l}$.

The new drift velocity is $v'_d = \frac{e\tau}{m}\left(\frac{V}{l'}\right) = \frac{e\tau}{m}\left(\frac{V}{3l}\right) = \frac{1}{3}v_d$.

Justification: Tripling the length decreases the internal electric field ($E = V/l$) to one-third of its original value. A weaker electric field exerts less force on the electrons, resulting in a proportionally lower drift speed.

- **(ii) Effect on Resistance (R):**

  The resistance of the conductor is $R = \rho\frac{l}{A}$.

  The new resistance is $R' = \rho\frac{l'}{A'}$.

  Substituting the new length and area: $R' = \rho\frac{3l}{A/3} = \rho\frac{3l \times 3}{A} = 9\left(\rho\frac{l}{A}\right)$.

  Therefore, $R' = 9R$.

  Justification: The resistance increases because the wire is now three times longer (giving electrons a longer path to traverse, increasing collisions) and simultaneously three times thinner (providing a narrower path for electron flow). Both factors compound, increasing resistance by a factor of $3 \times 3 = 9$.

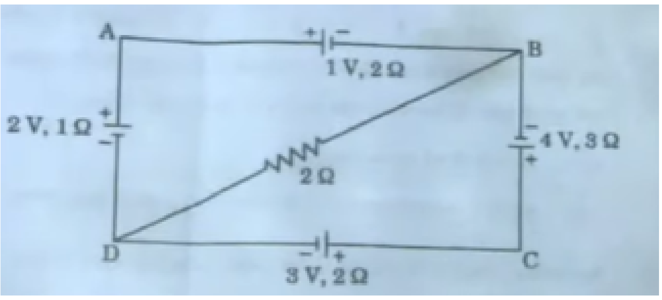
Step 4: Final Answer:

(i) The drift speed decreases to one-third (1/3) of its initial value.

(ii) The resistance increases to 9 times its initial value.

Quick Tip: For any stretching or drawing of a wire where volume is constant, the new resistance R' is always proportional to the square of the new length ratio: $R' = n^2R$, where n is the stretching factor ($l' = nl$).

31(b). In the given circuit diagram, find the potential difference between points B and D.



Solution:

Step 1: Concept:

This is a complex multi-loop circuit problem involving multiple active voltage sources.
The most efficient way to find the potential difference between two specific nodes in such a network is by employing Nodal Analysis (based on Kirchhoff's Current Law, KCL).

Step 2: Key Formula or Approach:

We will establish a reference ground node at D ($V_D = 0$).
For any node k, the sum of currents leaving the node is zero: $\sum I_{leave} = 0$.
Current leaving a node through a branch is $I = \frac{V_k - V_{neighbor} \pm V_{battery}}{R_{branch}}$. The battery sign is positive if leaving the node means going through the battery from positive to negative (voltage drop).

Step 3: Detailed Explanation:

- Let's define the nodes and polarities from the diagram:
  Node A is top-left, B is top-right, C is bottom-right, D is bottom-left.
  Branch AD: Battery 2V, $R = 1\Omega$. Long bar at A, so A is positive relative to D.
  Branch AB: Battery 1V, $R = 2\Omega$. Long bar at A, so A is positive relative to B.
  Branch BC: Battery 4V, $R = 3\Omega$. Thick bar at B, long at C, so C is positive relative to B.
  Branch DC: Battery 3V, $R = 2\Omega$. Thick bar at D, long at C, so C is positive relative to D.
  Branch BD: Resistor 2Ω. No battery.

- We set Node D as our reference ground, so $V_D = 0$ V.

- We need to find the node voltages V_A, V_B, and V_C.

- **Apply KCL at Node A:**

  Current to D + Current to B = 0

  $\frac{V_A-V_D-2}{1}+\frac{V_A-V_B-1}{2}=0$

  Since $V_D=0$: $\frac{V_A-2}{1}+\frac{V_A-V_B-1}{2}=0$

  Multiply by 2: $2(V_A-2)+(V_A-V_B-1)=0 \implies 2V_A-4+V_A-V_B-1=0 \implies 3V_A-V_B=5 \implies V_A=\frac{V_B+5}{3}$ — (Equation 1)

- **Apply KCL at Node C:**

  Current to D + Current to B = 0

  $\frac{V_C-V_D-3}{2}+\frac{V_C-V_B-4}{3}=0$

  Since $V_D=0$: $\frac{V_C-3}{2}+\frac{V_C-V_B-4}{3}=0$

  Multiply by 6: $3(V_C-3)+2(V_C-V_B-4)=0 \implies 3V_C-9+2V_C-2V_B-8=0 \implies -2V_B+5V_C=17 \implies V_C=\frac{2V_B+17}{5}$ — (Equation 2)

- **Apply KCL at Node B:**

  Current to A + Current to C + Current to D = 0

  $\frac{V_B-V_A+1}{2}+\frac{V_B-V_C+4}{3}+\frac{V_B-V_D}{2}=0$

  Multiply by 6: $3(V_B-V_A+1)+2(V_B-V_C+4)+3V_B=0$

  $3V_B-3V_A+3+2V_B-2V_C+8+3V_B=0$

  $-3V_A+8V_B-2V_C=-11$ — (Equation 3)

- Now, substitute Eq 1 and Eq 2 into Eq 3:

  $-3\left(\frac{V_B+5}{3}\right)+8V_B-2\left(\frac{2V_B+17}{5}\right)=-11$

  $-(V_B+5)+8V_B-\frac{4V_B+34}{5}=-11$

  $7V_B-5-\frac{4V_B+34}{5}=-11$

  $7V_B-\frac{4V_B+34}{5}=-6$

  Multiply entire equation by 5 to clear the fraction:

  $35V_B-(4V_B+34)=-30$

  $31V_B-34=-30$

  $31V_B=4 \implies V_B=\frac{4}{31}$ V

- Since $V_D = 0$, the potential difference between B and D is simply $V_B - V_D = 4/31$ V.

Step 4: Final Answer:

The potential difference between points B and D is 4/31 V (approx 0.129 V).

Quick Tip: Nodal analysis is vastly superior to mesh (loop) analysis for complex multi-battery bridge circuits because it often results in fewer simultaneous equations and minimizes sign errors related to clockwise/counter-clockwise loop directions.

OR

31 (a). A cell of emf E and internal resistance r is connected across a resistor of variable resistance R. Draw a plot showing the variation of (i) the current (I) in the circuit with R, and (ii) the terminal potential difference of the cell with R.

Solution:

Step 1: Concept:

This question requires an understanding of how an external load resistor affects a real battery circuit.

We must relate current and terminal voltage to the variable external resistance mathematically to determine the shape of the plots.

Step 2: Key Formula or Approach:

Ohm's law for a complete circuit gives current: $I = \frac{E}{R+r}$.

The terminal potential difference (voltage drop strictly across the external resistor) is $V = IR = \frac{ER}{R+r}$. This can be rewritten as $V = \frac{E}{1+\frac{r}{R}}$.

Step 3: Detailed Explanation:

- **(i) Plot of Current (I) vs Resistance (R):**

  From $I = \frac{E}{R+r}$, when the external resistance is virtually zero ($R = 0$, a short circuit), the current is at its absolute maximum, $I_{max} = \frac{E}{r}$.

  As the external resistance R is gradually increased, the denominator grows, causing the total current I to decrease continuously.

  As $R \to \infty$ (an open circuit), the current I approaches zero asymptotically.

  The plot is a hyperbola that starts at a high point (E/r) on the y-axis and curves downwards, smoothing out along the x-axis.

- **(ii) Plot of Terminal Potential Difference (V) vs Resistance (R):**

  From $V = \frac{E}{1+\frac{r}{R}}$, when the external circuit is shorted ($R = 0$), the ratio $r/R \to \infty$, making the denominator infinite, so the terminal voltage V is 0.

  As R begins to increase, V increases rapidly at first.

  When R precisely equals the internal resistance ($R = r$), the voltage is exactly half of the emf ($V = E/2$).

  As R becomes extremely large ($R \to \infty$), the fraction r/R approaches 0, so the denominator approaches 1, and the terminal voltage V asymptotically approaches the full emf E of the cell.

  The plot starts at the origin (0,0), curves upwards, and slowly flattens out, horizontally approaching a maximum ceiling value of E.

Step 4: Final Answer:

The Current vs R plot is a descending curve from E/r to 0. The Voltage vs R plot is an ascending curve from 0, asymptotically approaching E.

Quick Tip: Remembering the extreme boundary conditions ($R = 0$ and $R = \infty$) is the easiest way to figure out the shape of these graphs without complex calculus.

---

31 (b). The resistance of a heating coil is $100\,\Omega$ at 25°C and $120\,\Omega$ at 1025°C.

(i) Find its resistance at 425°C.

(ii) Draw a plot showing variation of its resistance as a function of increase in temperature.

Solution:

Step 1: Concept:

This problem investigates the temperature dependence of electrical resistance in metallic conductors.

For most standard metals, resistance increases linearly with temperature over moderate temperature ranges.

Step 2: Key Formula or Approach:

The formula relating resistance to temperature is $R_T = R_0[1+\alpha(T-T_0)]$.

Here, R_T is resistance at temperature T, R_0 is resistance at a reference temperature T_0, and α is the temperature coefficient of resistance.

First, use the known data points to calculate α. Then use α to find the resistance at the new specified temperature.

Step 3: Detailed Explanation:

- **(i) Finding Resistance at** $425°$**C:**

  Let our reference temperature be $T_0 = 25°\text{C}$. The corresponding reference resistance is $R_0 = 100\,\Omega$.

  We are given a second data point: at $T_1 = 1025°\text{C}$, the resistance is $R_1 = 120\,\Omega$.

  The temperature change is $\Delta T = T_1 - T_0 = 1025 - 25 = 1000°\text{C}$.

  Plug these into the resistance formula to find α:

$$120 = 100[1+\alpha(1000)]$$

$$1.2 = 1 + 1000\alpha$$

$$0.2 = 1000\alpha \implies \alpha = \frac{0.2}{1000} = 2\times 10^{-4}\ /°\text{C}$$

  Now, we want to find the resistance R_2 at the new temperature $T_2 = 425°\text{C}$.

  The new temperature change relative to the reference is $\Delta T' = 425 - 25 = 400°\text{C}$.

  Using the formula again with our newly found α:

$$R_2 = 100[1 + (2 \times 10^{-4})(400)]$$

$$R_2 = 100[1 + 0.08] = 100(1.08) = 108\,\Omega$$

- **(ii) Plot of Resistance vs Temperature:**
  The equation $R_T = R_0 + (R_0\alpha)T$ (if reference is 0°C) or $R = m\Delta T + C$ is the equation of a straight line ($y = mx + c$).
  The y-axis represents Resistance (R) and the x-axis represents Temperature (T).
  The graph is a straight line sloping upwards.
  Importantly, it does not start at the origin. At $T = 0$°C, the wire still has a positive baseline resistance. Thus, the line intercepts the positive y-axis.

Step 4: Final Answer:

(i) The resistance at 425°C is $108\,\Omega$.

(ii) The plot is a straight line with a positive slope and positive y-intercept.

Quick Tip: Using interpolation avoids calculating α: Since resistance change is linear, a 1000°C increase causes a $20\,\Omega$ rise. Therefore, a 400°C increase (40% of the way) causes a $0.4 \times 20 = 8\,\Omega$ rise. $100 + 8 = 108\,\Omega$.

---

32 (a). Using a phasor diagram, derive an expression for the impedance of a series LCR circuit connected to an ac source. What is meant by resonance in this circuit? Obtain expression for the resonant frequency of this circuit.

Solution:

Step 1: Concept:

This theoretical question asks for the derivation of the total opposition (impedance) offered by a circuit containing an inductor, capacitor, and resistor in series using vector-like phasors.

It also tests the concept of resonance, the unique state where opposing reactances cancel each other out.

Step 2: Detailed Explanation:

- **Derivation of Impedance using Phasor Diagram:**
  Consider a series LCR circuit where the same current $I = I_m \sin(\omega t)$ flows through all three components.
  The voltage drop across the resistor ($V_R = IR$) is exactly in phase with the current.
  The voltage drop across the inductor ($V_L = IX_L$) leads the current by $90°$.
  The voltage drop across the capacitor ($V_C = IX_C$) lags the current by $90°$.
  We draw a phasor diagram where the current vector $\vec{I}$ is along the x-axis.
  $\vec{V_R}$ is drawn parallel to $\vec{I}$.
  $\vec{V_L}$ is drawn on the positive y-axis ($90°$ ahead).
  $\vec{V_C}$ is drawn on the negative y-axis ($90°$ behind).
  Since $\vec{V_L}$ and $\vec{V_C}$ are exactly opposite, their net reactive voltage is a single vector of length $(V_L - V_C)$ pointing along the y-axis (assuming $V_L > V_C$).
  The total applied voltage $\vec{V}$ is the vector sum of $\vec{V_R}$ and the net reactive vector $(\vec{V_L} - \vec{V_C})$.
  By the Pythagorean theorem: $V^2 = V_R^2 + (V_L - V_C)^2$.
  Substituting $V = IZ$, $V_R = IR$, $V_L = IX_L$, and $V_C = IX_C$:
  $(IZ)^2 = (IR)^2 + (IX_L - IX_C)^2$
  Dividing out the common I^2 gives the impedance: $Z = \sqrt{R^2 + (X_L - X_C)^2}$.

- **Resonance in Series LCR Circuit:**
  Resonance is defined as a specific electrical state in an LCR circuit where the inductive reactance exactly equals the capacitive reactance ($X_L = X_C$).
  At this condition, the net reactive opposition becomes zero, making the total circuit impedance purely resistive and at its absolute minimum value ($Z_{min} = R$). Consequently, the circuit draws maximum current from the source.

- **Expression for Resonant Frequency:**
  Equate the reactances based on the definition of resonance: $X_L = X_C$.
  Substitute their frequency-dependent formulas: $\omega_r L = \frac{1}{\omega_r C}$.
  Rearranging to solve for the resonant angular frequency ω_r:

$\omega_r^2 = \frac{1}{LC} \implies \omega_r = \frac{1}{\sqrt{LC}}$.

In terms of linear frequency f_r (where $\omega = 2\pi f$): $f_r = \frac{1}{2\pi\sqrt{LC}}$.

Step 3: Final Answer:

The impedance is $Z = \sqrt{R^2 + (X_L - X_C)^2}$. Resonance occurs when $X_L = X_C$, yielding a resonant frequency of $\omega_r = 1/\sqrt{LC}$.

Quick Tip: Drawing a clear phasor diagram is worth significant partial credit in board exams even if the mathematical derivation has slight algebraic errors.

---

32 (b). Write two disadvantages of transmitting ac over long distances at low voltage and high current.

Solution:

Step 1: Concept:

This question tests the practical engineering reasons behind using step-up transformers in the national electrical power grid.

Step 2: Detailed Explanation:

- **Disadvantage 1: Massive Heat/Power Loss**

  When electrical power ($P = VI$) is transmitted at a high current (I), the power dissipated as useless heat in the transmission wires themselves is governed by Joule's Law: $P_{loss} = I^2 R$.

  Because this heat loss scales with the square of the current, transmitting at high current results in severe energy wastage over long distances, making the grid incredibly inefficient.

- **Disadvantage 2: High Material Cost and Weight**

  To safely carry high currents without the wires melting, the transmission cables must have a very low resistance ($R = \rho l/A$).

  To achieve low resistance, the wires must have a massive cross-sectional area (A).

  Extremely thick wires require vastly more copper or aluminum, making them prohibitively expensive. Furthermore, their immense weight requires stronger, more expensive transmission towers to support them.

Step 3: Final Answer:

1. Large I^2R power losses in the transmission lines.
2. Need for extremely thick, heavy, and expensive transmission wires.

Quick Tip: This is exactly why we use transformers to step up voltage to hundreds of thousands of volts for transmission, which proportionally steps down the current, effectively nullifying I^2R losses.

OR

32 (a). An ac generator consists of a coil of 500 turns and size 25 cm $\times$ 100 cm. It is rotated at an angular speed of 60 rad/s in a uniform magnetic field $B = 0 \cdot 4$ T between two fixed pole pieces. If the resistance of the circuit, including that of the coil, is $250\,\Omega$, calculate :

(I) the maximum current drawn from the generator

(II) the flux through the coil when the current is zero

Solution:

Step 1: Concept:

This problem assesses the operational parameters of an AC generator, primarily using Faraday's Law of Electromagnetic Induction to find induced EMF and current.

Step 2: Key Formula or Approach:

The instantaneous induced EMF in a rotating coil is $e = NBA\omega\sin(\omega t)$.

The maximum (peak) EMF occurs when $\sin(\omega t) = 1$, so $E_{max} = NBA\omega$.

Maximum current is $I_{max} = \frac{E_{max}}{R}$.

The magnetic flux at any instant is $\Phi = NBA\cos(\omega t)$.

Step 3: Detailed Explanation:

- First, compile and convert all given parameters into standard SI units:

  Number of turns, $N = 500$.

  Area of the coil, $A = 25 \text{ cm} \times 100 \text{ cm} = 0.25 \text{ m} \times 1.0 \text{ m} = 0.25 \text{ m}^2$.

  Angular speed, $\omega = 60$ rad/s.

  Magnetic field, $B = 0.4$ T.

  Total resistance, $R = 250\,\Omega$.

- **(I) Calculating Maximum Current:**

  Calculate the peak induced EMF:

$$E_{max} = NBA\omega = (500) \times (0.4) \times (0.25) \times (60)$$

$$E_{max} = 500 \times 0.1 \times 60 = 50 \times 60 = 3000 \text{ V}$$

  Now, apply Ohm's law to find the peak current:

$$I_{max} = \frac{E_{max}}{R} = \frac{3000}{250} = \frac{300}{25} = 12 \text{ A}$$

- **(II) Calculating Flux when Current is Zero:**

  The instantaneous current is given by $I = I_{max}\sin(\omega t)$.

  For the current to be exactly zero, the sine term must be zero: $\sin(\omega t) = 0$.

  This happens when the angle $\omega t = 0, \pi, 2\pi$, etc.

  The magnetic flux through the coil is given by the cosine function: $\Phi = NBA\cos(\omega t)$.

  When $\sin(\omega t) = 0$, the cosine term $\cos(\omega t)$ is at its maximum absolute value (± 1).

  Therefore, when the current is zero, the flux linking the coil is at its absolute maximum.

$$\Phi = NBA = (500) \times (0.4) \times (0.25) = 500 \times 0.1 = 50 \text{ Weber (Wb)}$$

Step 4: Final Answer:

(I) The maximum current drawn is 12 A.

(II) The flux through the coil when the current is zero is 50 Wb.

Quick Tip: Current (and EMF) and magnetic flux are exactly 90° out of phase in a generator. When flux is maximum (coil perpendicular to field), the rate of change of flux is zero, so induced current is zero. When flux is zero (coil parallel to field), it changes most rapidly, so current is maximum.

---

32 (b). Give two examples of commercial generators. How is rotation of armature achieved in them? Explain briefly.

Solution:

Step 1: Concept:
This question asks for real-world applications of AC generators and the mechanical methods used to supply the rotational kinetic energy needed for induction.

Step 2: Detailed Explanation:

- **Example 1: Hydroelectric Power Generators**
  In large dams, massive volumes of water are stored at a high elevation, possessing immense gravitational potential energy.
  When gates are opened, the water is channeled through narrow penstocks, converting potential energy into high-speed kinetic energy.
  This rushing water forcefully strikes the blades of large mechanical turbines, causing them to spin rapidly.
  The turbine shaft is directly coupled to the armature (coil) of the generator, transferring this mechanical rotation to induce electricity.

- **Example 2: Thermal Power Generators (Coal/Nuclear)**

In thermal power plants, a heat source (burning coal or nuclear fission) is used to intensely boil water in a massive boiler.

This produces highly pressurized, superheated steam.

This high-pressure steam is directed through nozzles to forcefully impact the finely angled blades of a steam turbine, causing high-speed rotation.

As with the hydro setup, this spinning turbine is physically linked to the generator's armature, forcing it to rotate within the magnetic field to generate electrical power.

Step 3: Final Answer:

Two examples are Hydroelectric and Thermal generators. Rotation is achieved by directing high-velocity water or pressurized steam onto turbine blades, which are mechanically coupled to the generator's armature.

Quick Tip: Regardless of the energy source (wind, nuclear, coal, hydro), nearly all commercial electricity generation relies on the exact same final step: using a fluid to spin a turbine attached to a magnetic generator.

---

33 (a). A small bulb is placed at the bottom of a tank containing water to a depth of 1.00 m. Find the area of the surface of water through which light from the bulb can emerge from. The refractive index of water is (4/3).

Solution:

Step 1: Concept:

This problem investigates the phenomenon of Total Internal Reflection (TIR).

Light rays emitted from an underwater source can only escape into the air if they strike the water's surface at an angle less than the critical angle. Rays striking at or beyond the critical angle are reflected back into the water, restricting the escaping light to a circular patch.

Step 2: Key Formula or Approach:

The critical angle C is given by $\sin C = \frac{n_{air}}{n_{water}} = \frac{1}{n}$.
From geometry, the radius r of the illuminated circular patch is related to the depth h by $r = h\tan C$.
Using trigonometric identities, $\tan C = \frac{\sin C}{\cos C} = \frac{\sin C}{\sqrt{1-\sin^2 C}}$.
The area of the circle is $Area = \pi r^2$.

Step 3: Detailed Explanation:

- The depth of the bulb is given as $h = 1.00$ m.
- The refractive index of water is $n = 4/3$.
- Calculate the sine of the critical angle:

$$\sin C = \frac{1}{n} = \frac{1}{4/3} = \frac{3}{4}$$

- Now, we find the tangent of the critical angle to find the radius:

$$\tan C = \frac{3/4}{\sqrt{1-(3/4)^2}} = \frac{3/4}{\sqrt{1-9/16}} = \frac{3/4}{\sqrt{7/16}} = \frac{3/4}{\sqrt{7}/4}$$

- The denominators cancel out, leaving:

$$\tan C = \frac{3}{\sqrt{7}}$$

- The radius of the circular surface patch is:

$$r = h\tan C = (1.00 \text{ m}) \times \frac{3}{\sqrt{7}} = \frac{3}{\sqrt{7}} \text{ m}$$

- Finally, calculate the area of this circular patch:

$$Area = \pi r^2 = \pi\left(\frac{3}{\sqrt{7}}\right)^2 = \pi\left(\frac{9}{7}\right)$$

$$Area = \frac{9\pi}{7} \text{ m}^2$$

- Using $\pi \approx 3.1416$, we can evaluate this numerically:

$$Area \approx \frac{9 \times 3.1416}{7} \approx \frac{28.274}{7} \approx 4.04 \text{ m}^2$$

Step 4: Final Answer:

The area of the surface of water through which light can emerge is approximately 4.04 m^2.

Quick Tip: A useful shortcut formula for the radius of the illuminated circle is $r = \frac{h}{\sqrt{n^2-1}}$. Plugging in $h = 1$ and $n = 4/3$ gets you $r = 1/\sqrt{16/9-1} = 1/\sqrt{7/9} = 3/\sqrt{7}$ much faster.

---

33 (b). An object is placed at a distance of 15 cm from a convex lens of focal length 10 cm. On the other side of the lens, a convex mirror is placed coaxially at a distance of 10 cm from the lens. If the image formed by this combination coincides with the object itself, draw the ray diagram and find the focal length of the convex mirror.

Solution:

Step 1: Concept:

This problem deals with a combination of optical instruments.

For the final image to form precisely back at the original object's location, the light rays must exactly retrace their original paths after reflecting off the convex mirror. This retro-reflection only occurs if the light rays strike the mirror's surface perpendicularly, meaning they must be heading straight towards the mirror's center of curvature.

Step 2: Key Formula or Approach:

Use the thin lens formula: $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$.

Determine the location where the lens attempts to form the image.

Use the geometry of the setup to find the mirror's center of curvature (R) and apply $f_m = R/2$.

Step 3: Detailed Explanation:

- **Refraction through the Lens:**

  The object distance is $u = -15$ cm (using Cartesian sign convention, object is on the left).

  The focal length of the convex lens is $f = +10$ cm.

  Apply the lens formula to find the image distance v formed by the lens alone:

$$\frac{1}{v} - \frac{1}{-15} = \frac{1}{10} \implies \frac{1}{v} + \frac{1}{15} = \frac{1}{10}$$
$$\frac{1}{v} = \frac{1}{10} - \frac{1}{15} = \frac{3-2}{30} = \frac{1}{30} \implies v = +30 \text{ cm}$$

  This means the lens converges the light rays towards a point 30 cm to its right.

- **Interaction with the Mirror:**

  A convex mirror is placed 10 cm to the right of the lens.

  The converging rays from the lens are intercepted by the mirror before they can reach the 30 cm mark.

  For the rays to retrace their path and form the final image at the object, they must fall normally (at 90°) on the convex mirror.

  A ray falls normally on a spherical mirror only if it is directed exactly towards its Center of Curvature (C).

  Therefore, the point where the lens was trying to form the image (30 cm from the lens) must be the Center of Curvature of the mirror.

  The distance from the mirror's pole to this point is the radius of curvature R.

  Since the mirror is 10 cm from the lens, $R = 30 \text{ cm} - 10 \text{ cm} = 20$ cm.

- **Focal Length of the Mirror:**

  The focal length f_m of a spherical mirror is half its radius of curvature:

$$f_m = \frac{R}{2} = \frac{20 \text{ cm}}{2} = 10 \text{ cm}$$

- **Ray Diagram:**

  Rays diverge from the object, pass through the lens, and begin converging towards a point 30cm away. They hit the convex mirror (at 10cm) perpendicularly and bounce straight back along the same path.

Step 4: Final Answer:

The focal length of the convex mirror is 10 cm.

Quick Tip: Whenever an optical problem states that the "final image coincides with the object," immediately look for the condition of normal incidence (rays hitting a mirror at exactly 90° and retracing their steps).

OR

33 (a). Differentiate between interference and diffraction of light. Two coherent light waves, each of intensity I_0 produce interference pattern on a screen. Find the intensity at a point at which the path difference between them is (i) $\lambda/3$, and (ii) $\lambda/4$.

Solution:

Step 1: Concept:

This question requires distinguishing two fundamental wave phenomena and applying the formula for the resultant intensity of two interfering coherent waves based on their path difference.

Step 2: Key Formula or Approach:

The phase difference ϕ is directly related to path difference Δx by: $\phi = \left(\frac{2\pi}{\lambda}\right)\Delta x$.

The resultant intensity of two coherent sources of equal intensity I_0 is $I = I_0 + I_0 + 2\sqrt{I_0 \cdot I_0}\cos(\phi) = 2I_0(1 + \cos\phi) = 4I_0\cos^2\left(\frac{\phi}{2}\right)$.

Step 3: Detailed Explanation:

- **Difference between Interference and Diffraction:**

  1. **Origin:** Interference is the superposition of light waves originating from two (or a finite number of) distinct coherent sources (e.g., two narrow slits). Diffraction is the

superposition of secondary wavelets originating from continuously distributed points on a single wavefront (e.g., across a single wide slit or obstacle).

2. **Fringe Width:** In an interference pattern (like YDSE), all bright fringes and dark fringes generally have equal uniform widths. In a diffraction pattern, the central bright fringe is significantly wider (usually twice as wide) than the subsequent secondary fringes.

3. **Intensity:** In interference, all bright fringes typically share the same maximum intensity. In diffraction, the central maximum is intensely bright, and the intensity of subsequent secondary maxima drops off extremely rapidly.

- **Calculating Intensities:**
  We use the formula $I = 4I_0 \cos^2\left(\frac{\phi}{2}\right)$.

- **(i) Path difference $\Delta x = \lambda/3$:**
  Calculate phase difference: $\phi = \frac{2\pi}{\lambda} \times \left(\frac{\lambda}{3}\right) = \frac{2\pi}{3}$ radians (120°).
  Calculate intensity: $I = 4I_0 \cos^2\left(\frac{120^\circ}{2}\right) = 4I_0 \cos^2(60^\circ)$.
  Since $\cos(60^\circ) = 1/2$, its square is $1/4$.
  $I = 4I_0 \times \left(\frac{1}{4}\right) = I_0$.

- **(ii) Path difference $\Delta x = \lambda/4$:**
  Calculate phase difference: $\phi = \frac{2\pi}{\lambda} \times \left(\frac{\lambda}{4}\right) = \frac{\pi}{2}$ radians (90°).
  Calculate intensity: $I = 4I_0 \cos^2\left(\frac{90^\circ}{2}\right) = 4I_0 \cos^2(45^\circ)$.
  Since $\cos(45^\circ) = 1/\sqrt{2}$, its square is $1/2$.
  $I = 4I_0 \times \left(\frac{1}{2}\right) = 2I_0$.

Step 4: Final Answer:

(i) The intensity at path difference $\lambda/3$ is I_0.

(ii) The intensity at path difference $\lambda/4$ is $2I_0$.

Quick Tip: Remember that the maximum possible intensity from two I_0 sources is $4I_0$ (constructive interference), not $2I_0$. $2I_0$ only occurs when they are exactly 90° out of phase or if they are entirely incoherent.

---

33 (b). In a Young's double-slit experiment, fringes are obtained on a screen placed at a distance D from the slits. It is observed that if the screen is moved 5 cm towards the slits, the fringe width changes by 0.03 mm. If the distance between the slits is 1 mm, calculate the wavelength of the light used.

Solution:

Step 1: Concept:

This question relies on the geometric parameters of Young's Double Slit Experiment (YDSE). It relates the physical shifting of the projection screen to the corresponding change observed in the width of the interference fringes.

Step 2: Key Formula or Approach:

The fringe width β in a YDSE is given by $\beta = \frac{\lambda D}{d}$.

Since the wavelength λ and slit separation d remain constant, a change in screen distance ΔD produces a proportional change in fringe width $\Delta\beta$.

Taking the difference: $\Delta\beta = \frac{\lambda \Delta D}{d}$.

Rearranging to solve for wavelength gives $\lambda = \frac{d \cdot \Delta\beta}{\Delta D}$.

Step 3: Detailed Explanation:

- First, we rigorously convert all given measurements into standard SI units (meters) to avoid magnitude errors.

- Change in screen distance, $\Delta D = 5 \text{ cm} = 0.05 \text{ m}$. (Moving the screen *towards* the slits means D decreases by 0.05 m, so β also decreases. We can just use the absolute magnitudes).

- Change in fringe width, $\Delta\beta = 0.03$ mm $= 0.03 \times 10^{-3}$ m $= 3 \times 10^{-5}$ m.
- Distance between the slits, $d = 1$ mm $= 1 \times 10^{-3}$ m.
- Substitute these values into the rearranged formula:

$$\lambda = \frac{(1 \times 10^{-3}\text{ m}) \times (3 \times 10^{-5}\text{ m})}{0.05\text{ m}}$$

- Multiply the numerators:

$$\lambda = \frac{3 \times 10^{-8}}{0.05}\text{ m}$$

- To make the division easier, multiply the top and bottom by 100:

$$\lambda = \frac{300 \times 10^{-8}}{5}\text{ m}$$

- Perform the division:

$$\lambda = 60 \times 10^{-8}\text{ m}$$

- Adjust the scientific notation to a more standard format for light wavelengths (nanometers):

$$\lambda = 600 \times 10^{-9}\text{ m} = 600\text{ nm}$$

Step 4: Final Answer:

The wavelength of the light used is 600 nm.

Quick Tip: Subtracting equations before plugging in numbers ($\beta_1 - \beta_2 = \frac{\lambda D_1}{d} - \frac{\lambda D_2}{d}$) is mathematically much cleaner and less error-prone than trying to solve for unknown initial variables.