UP Board Class 12 Physics 2026 Set 346 DU Question Paper with Solutions

ZOLLEGE

General Instructions

(i) This booklet contains 30 questions, each provided with a complete, step-by-step solution.

(ii) It comprises 6 single-correct multiple-choice questions.

(iii) Attempt each question on your own before reviewing the given solution.

1. A proton, an electron and an α-particle placed in a uniform electric field experience forces F_1, F_2 and F_3 respectively. Then:

(A) $F_1 = F_2 = F_3$

(B) $F_1 = F_2 \neq F_3$

(C) $F_1 > F_2 > F_3$

(D) $F_1 < F_2 < F_3$

Correct Answer: (B) $F_1 = F_2 \neq F_3$

SOLUTION:

Step 1: Key idea. Force in a uniform field is $F = |q|E$. For a fixed field, force scales directly with charge magnitude, so we only need the ratio of charges.

Step 2: List charge magnitudes as multiples of the elementary charge e. Proton $= 1e$, electron $= 1e$, alpha particle $= 2e$.

Step 3: Form the ratio of forces. $F_1 : F_2 : F_3 = 1e : 1e : 2e = 1 : 1 : 2$.

Step 4: Read the ratio. The first two forces are equal to each other, while the third is twice as large, so $F_1 = F_2$ but F_3 is different. Hence $F_1 = F_2 \neq F_3$, matching option (ii).

$$\boxed{F_1 : F_2 : F_3 = 1 : 1 : 2}$$

Quick Tip: Force in a uniform field is $|q|E$; it depends only on charge magnitude. Compare the charges of proton, electron and α-particle.

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2. Two resistors R and $2R$ are connected in parallel in an electric circuit. The thermal energies developed in R and $2R$ are in the ratio:

(A) $1 : 2$

(B) $2 : 1$

(C) $1 : 4$

(D) $4 : 1$

Correct Answer: (B) $2 : 1$

SOLUTION:

Step 1: Set up currents. In parallel the common voltage is V. By Ohm's law the branch currents are $I_R = V/R$ and $I_{2R} = V/(2R)$, so $I_R = 2\,I_{2R}$.

Step 2: Use the power form of heating. Power dissipated is $P = I^2R$, and heat $= P\,t$ for equal time t.

Step 3: Compute each power. $P_R = I_R^2\,R = \left(\frac{V}{R}\right)^2 R = \frac{V^2}{R}$ and $P_{2R} = \left(\frac{V}{2R}\right)^2 (2R) = \frac{V^2}{2R}$.

Step 4: Divide. $\frac{P_R}{P_{2R}} = \frac{V^2/R}{V^2/2R} = 2$. Since the time is common, the heat ratio is the same, 2 : 1, which is option (ii).

$$\boxed{P_R : P_{2R} = 2 : 1}$$

Quick Tip: Parallel means equal voltage, so use $H = V^2t/R$. Heat is inversely proportional to resistance.

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3. The unit of $\dfrac{1}{\mu_0\varepsilon_0}$ is:

(A) $\mathrm{m\,s^{-1}}$

(B) $\mathrm{m^{-1}\,s}$

(C) $\mathrm{m^2\,s^{-2}}$

(D) $\mathrm{m^{-2}\,s^2}$

Correct Answer: (C) $\mathrm{m^2\,s^{-2}}$

SOLUTION:

Step 1: Recall Maxwell's result linking electromagnetism and light: the wave speed of an electromagnetic wave in vacuum is $v = 1/\sqrt{\mu_0\varepsilon_0}$, and this equals the measured speed of light c.

Step 2: Rearrange for the required quantity. Squaring gives $\dfrac{1}{\mu_0\varepsilon_0} = v^2 = c^2$.

Step 3: Dimensional check. Speed has dimension $[LT^{-1}]$, so c^2 has dimension $[L^2T^{-2}]$.

Step 4: Convert dimension to SI units: length in metre (m), time in second (s), giving $\mathrm{m^2\,s^{-2}}$. This confirms option (iii).

$$\boxed{[L^2T^{-2}] = \mathrm{m^2\,s^{-2}}}$$

Quick Tip: Recall $c = 1/\sqrt{\mu_0\varepsilon_0}$, so $1/(\mu_0\varepsilon_0)$ equals c^2. Find the unit of speed squared.

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4. In an AC circuit, if the current $i = 2\sin\omega t$ ampere and the voltage $V = 5\cos\omega t$ volt, then the power loss will be:

(A) zero

(B) 5 W

(C) 10 W

(D) 2·5 W

Correct Answer: (A) zero

SOLUTION:

Step 1: Use the instantaneous-power average. Average power is $P = \frac{1}{T}\int_0^T V\,i\,dt$ over one full cycle of period T.

Step 2: Multiply the given expressions. $V\,i = (5\cos\omega t)(2\sin\omega t) = 10\sin\omega t\cos\omega t = 5\sin 2\omega t$, using $2\sin\theta\cos\theta = \sin 2\theta$.

Step 3: Average over a cycle. The mean value of $\sin 2\omega t$ over a complete cycle is zero, so $P = 5 \times \langle \sin 2\omega t\rangle = 0$.

Step 4: Conclusion. Because the current and voltage are $90°$ out of phase, the circuit is wattless and the net power loss is zero, confirming option (i).

$$\boxed{P = \langle 5\sin 2\omega t\rangle = 0}$$

Quick Tip: A sine current with a cosine voltage means a $90°$ phase difference; the power factor $\cos 90° = 0$.

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5. A thin transparent sheet is placed in front of one slit of a Young's double slit. The fringe width will:

(A) increase

(B) decrease

(C) remain same

(D) none of these

Correct Answer: (C) remain same

SOLUTION:

Step 1: Identify what fringe width means. Fringe width is the distance between two neighbouring bright (or dark) fringes, given by $\beta = \lambda D/d$.
Step 2: Analyse the role of the sheet through path difference. Without the sheet the path difference at a point is $\Delta = d\sin\theta$. With a sheet of thickness t and refractive index μ over one slit, it becomes $\Delta' = d\sin\theta - (\mu - 1)t$, i.e. a fixed offset is subtracted.
Step 3: Find the new fringe positions. Bright fringes still occur at equal steps of $\Delta' = n\lambda$; solving, consecutive fringes are still separated by the same $\lambda D/d$, only the whole set is displaced by $(\mu - 1)tD/d$.
Step 4: Because the separation between successive maxima is untouched, the fringe width does not change, matching option (iii). Only the position of the pattern shifts.

$$\boxed{\text{Fringe width remains } \lambda D/d}$$

Quick Tip: The sheet adds a constant extra path $(\mu - 1)t$, which only shifts the pattern. Fringe width $\lambda D/d$ has no sheet term.

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6. When an impurity is doped into an intrinsic semiconductor, the conductivity of the semiconductor:

(A) increases

(B) decreases

(C) remains the same

(D) becomes zero

Correct Answer: (A) increases

SOLUTION:

Step 1: Compare carrier concentrations before and after doping. A pure (intrinsic) semiconductor has only thermally generated electron-hole pairs, so very few carriers and high resistivity.

Step 2: Introduce the dopant. Doping deliberately adds impurity atoms that release additional charge carriers (electrons in n-type, holes in p-type) at room temperature.

Step 3: Link carriers to conductivity. More free carriers mean more current for the same applied voltage, which by $\sigma = ne\mu$ directly raises the conductivity.

Step 4: Therefore doping an intrinsic semiconductor makes it a much better conductor; the conductivity increases, confirming option (i). This is precisely why devices use doped, not pure, semiconductors.

$$\boxed{\text{Doping} \Rightarrow \text{conductivity increases}}$$

Quick Tip: Doping adds extra charge carriers (electrons or holes). Since $\sigma = ne\mu$, more carriers means higher conductivity.

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7. Find out the magnetic moment of a rectangular coil of size 20 cm × 10 cm having 10 A current.

Correct Answer: —

SOLUTION:

Step 1: Recall what magnetic moment means.

A flat coil carrying current behaves like a tiny magnet. The strength of this equivalent magnet is measured by its magnetic (dipole) moment, $m = NIA$, where $N = 1$ for a single rectangular loop.

Step 2: Convert the dimensions into SI units.

Length $= 20$ cm $= 0.20$ m and breadth $= 10$ cm $= 0.10$ m.

Step 3: Compute the enclosed area.

$A = \text{length} \times \text{breadth} = 0.20 \times 0.10 = 2 \times 10^{-2}\ \text{m}^2$.

Step 4: Plug into the formula.

With $I = 10$ A,

$m = (1)(10)(2 \times 10^{-2}) = 20 \times 10^{-2}\ \text{A} \cdot \text{m}^2$.

Step 5: Simplify.

$m = 0.2\ \text{A} \cdot \text{m}^2$, directed normal to the coil plane.

$$\boxed{m = 0.2\ \text{A} \cdot \text{m}^2}$$

Quick Tip: Use the magnetic moment of a current loop, $m = NIA$, with area in square metres and one turn.

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8. Write the unit of self-inductance.

Correct Answer: —

SOLUTION:

Step 1: Start from the flux definition.

Self-inductance can also be written as $L = \dfrac{N\Phi}{I}$, where $N\Phi$ is the total magnetic flux linkage and I is the current.

Step 2: Substitute the units of each quantity.

Magnetic flux Φ is measured in weber (Wb) and current I in ampere (A). Therefore

$[L] = \dfrac{\text{weber}}{\text{ampere}} = \text{Wb/A}.$

Step 3: Identify the named unit.

One weber per ampere is defined as one **henry** (H). A coil has a self-inductance of 1 H if a current changing at 1 A/s induces an EMF of 1 V.

$$\boxed{\text{Unit of self-inductance} = \text{henry (H)}}$$

Quick Tip: Think about the unit that follows from $\varepsilon = -L\, dI/dt$; it is named after Joseph Henry.

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9. Amplitude of intensity of magnetic field of an electromagnetic wave in vacuum is 500 nT. What will be the amplitude of the intensity of electric field of the wave?

Correct Answer: —

SOLUTION:

Step 1: Use the field ratio.

For any point in a plane electromagnetic wave in free space, the ratio of the electric field magnitude to the magnetic field magnitude is constant and equals the speed of light: $\dfrac{E_0}{B_0} = c$.

Step 2: Rearrange for the electric field amplitude.

$E_0 = c\,B_0$.

Step 3: Convert the magnetic amplitude to tesla.

$B_0 = 500\ \text{nT} = 5 \times 10^{-7}\ \text{T}$ (since $1\ \text{nT} = 10^{-9}\ \text{T}$).

Step 4: Multiply.

$E_0 = (3 \times 10^{8}\ \text{m/s})(5 \times 10^{-7}\ \text{T}) = 150\ \text{V/m}$.

So the electric field oscillates with a peak value of 150 volts per metre.

$$\boxed{E_0 = 150\ \text{V/m}}$$

Quick Tip: In vacuum the field amplitudes obey $E_0 = cB_0$; convert nanotesla to tesla first.

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10. Draw (i – δ) curve for a triangular prism and show the angle of minimum deviation.

Correct Answer: —

SOLUTION:

Step 1: Set up the axes.
Take the angle of incidence i along the horizontal axis and the angle of deviation δ along the vertical axis for light passing through a triangular (60°) prism.

Step 2: Trace how deviation changes.
For a very small i the emergent ray bends a lot, so δ is large. As i grows, δ falls, hits a single minimum, and then rises again for larger i. This produces a curve that dips in the middle, like a valley.

Step 3: Meaning of the valley bottom.
The lowest point of the valley is the angle of minimum deviation δ_m. A key feature is that a given δ (except δ_m) can be produced by two different angles of incidence, but δ_m corresponds to exactly one angle of incidence, where $i = e$ and the ray inside runs parallel to the base.

Step 4: Marking on the sketch.
On the U-shaped curve, drop a horizontal dashed line from the turning point to the δ-axis and label that value δ_m; drop a vertical dashed line to the i-axis to show the corresponding incidence angle.

$$\boxed{\delta_m = \text{ordinate of the lowest point of the } i\text{-}\delta \text{ graph}}$$

Quick Tip: The plot of deviation versus incidence is a U-shaped curve; its single lowest point is δ_m, where $i = e$.

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11. Energy of hydrogen atom in ground state is −13·6 eV. What will be the kinetic energy and the potential energy of the electron in the state?

Correct Answer: —

SOLUTION:

Step 1: Use the virial theorem for a Coulomb field.
For an inverse-square attractive force, the virial theorem gives $2K = -U$, i.e. the kinetic energy is half the magnitude of the potential energy and opposite in usage.

Step 2: Combine with total energy.
Since $E = K + U$ and $U = -2K$, we get $E = K - 2K = -K$. Hence $K = -E$.

Step 3: Insert the ground-state total energy.
Given $E = -13.6$ eV, the kinetic energy is $K = -(-13.6) = 13.6$ eV.

Step 4: Get the potential energy.
From $U = -2K$, $U = -2(13.6) = -27.2$ eV. The negative sign shows the electron is bound to the nucleus.

Step 5: Verify the total.
$K + U = 13.6 - 27.2 = -13.6$ eV, matching the given total energy.

$$\boxed{K = 13.6 \text{ eV}, \quad U = -27.2 \text{ eV}}$$

Quick Tip: For hydrogen use $K = -E$ and $U = 2E$; the kinetic energy is positive and the potential energy is twice the total energy.

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12. Find out equivalent energy of 1·0 gm of a substance.

Correct Answer: —

SOLUTION:

Step 1: Identify the principle.
Mass and energy are interconvertible; a mass m completely converted to energy yields $E = mc^2$, from Einstein's special theory of relativity.

Step 2: Express the given mass in kilograms.
$1.0 \text{ gm} = 10^{-3}$ kg.

Step 3: Write c^2.
With $c = 3 \times 10^8$ m/s, $c^2 = 9 \times 10^{16}$ m^{2}s^{-2}.

Step 4: Multiply mass by c^2.
$E = 10^{-3} \times 9 \times 10^{16} = 9 \times 10^{13}$ J.

Step 5: Interpret.
Just one gram of matter, if fully converted, releases 9×10^{13} joules, an enormous amount of energy, which is why nuclear reactions are so powerful.

$$\boxed{E = 9 \times 10^{13}\ \text{J}}$$

Quick Tip: Apply $E = mc^2$ with the mass in kilograms; 1 gram is 10^{-3} kg.

13. Prove that the energy density inside a charged capacitor is $\frac{1}{2}\varepsilon_0 E^2$.

Correct Answer: —

SOLUTION:

Step 1: Start from the work done to charge the capacitor.

When charge is transferred to build up a field, the total electrostatic energy stored is $U = \dfrac{Q^2}{2C}$, where $Q = CV$ is the final charge.

Step 2: Express charge through the surface charge density.

For a parallel plate capacitor the charge is $Q = \sigma A$, where σ is the surface charge density and A the plate area. The field between the plates is related to the charge density by $E = \dfrac{\sigma}{\varepsilon_0}$, so $\sigma = \varepsilon_0 E$ and hence $Q = \varepsilon_0 EA$.

Step 3: Write capacitance and combine.

Using $C = \dfrac{\varepsilon_0 A}{d}$,

$$U = \frac{Q^2}{2C} = \frac{(\varepsilon_0 EA)^2}{2\,(\varepsilon_0 A/d)} = \frac{\varepsilon_0^2 E^2 A^2 d}{2\,\varepsilon_0 A} = \frac{1}{2}\varepsilon_0 E^2 Ad.$$

Step 4: Interpret as energy per unit volume.

The field fills the region of volume Ad between the plates. Dividing,

$$u = \frac{U}{Ad} = \frac{1}{2}\varepsilon_0 E^2.$$

Step 5: Conclusion.

This confirms the field itself stores energy with density

$$\boxed{u = \frac{1}{2}\varepsilon_0 E^2}$$

Quick Tip: Use $U = \frac{1}{2}CV^2$ with $C = \varepsilon_0 A/d$ and $V = Ed$, then divide the stored energy by the volume $A\,d$ between the plates.

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14. A circular coil of radius 2.0 cm carries a current of 1.0 A. If the coil has 100 turns, find the intensity of magnetic field at the centre of the coil.

Correct Answer: —

SOLUTION:

Step 1: Field of one turn first.

The magnetic field at the centre of a single circular loop is $B_1 = \dfrac{\mu_0 I}{2r}$. A coil of N closely wound turns produces N times this value, so $B = NB_1 = \dfrac{\mu_0 NI}{2r}$.

Step 2: Convert units.

$r = 2.0\text{ cm} = 0.02\text{ m}$, $I = 1.0\text{ A}$, $N = 100$.

Step 3: Compute the single-turn field.

$$B_1 = \frac{(4\pi \times 10^{-7})(1.0)}{2(0.02)} = \frac{4\pi \times 10^{-7}}{0.04} = \pi \times 10^{-5}\text{ T}.$$

Step 4: Multiply by number of turns.

$B = 100 \times \pi \times 10^{-5} = \pi \times 10^{-3}\text{ T}$.

Step 5: Numerical answer.

Taking $\pi = 3.14$,

$$\boxed{B \approx 3.14 \times 10^{-3}\text{ T (3.14 mT)}}$$

directed perpendicular to the plane of the coil along its axis.

Quick Tip: Apply $B = \frac{\mu_0 N I}{2r}$; remember to convert the radius from cm to metres.

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15.

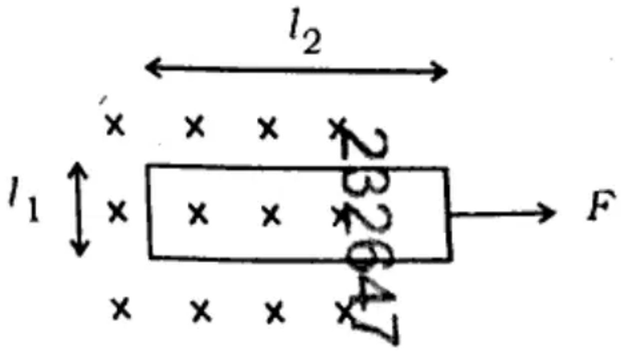

Figure shows a rectangular loop being pulled out of a magnetic field B with a velocity v by applying an external force F. Find the amount of magnetic force induced on the loop and show its direction.

Correct Answer: —

SOLUTION:

Step 1: Use the rate of change of flux.

Let the length of the loop still inside the field be x (measured horizontally), while the vertical side in the field has length l_1. The flux linked is $\phi = B\, l_1\, x$.

Step 2: Induced EMF from Faraday's law.

As the loop is pulled out, x decreases at rate $\frac{dx}{dt} = -v$. The magnitude of the induced EMF is

$$\varepsilon = \left|\frac{d\phi}{dt}\right| = B\,l_1\left|\frac{dx}{dt}\right| = B\,l_1 v.$$

Step 3: Induced current and retarding force.

Current $I = \dfrac{\varepsilon}{R} = \dfrac{Bl_1 v}{R}$. The power delivered by the retarding magnetic force equals the electrical power dissipated: $F_m\, v = I^2 R$.

Step 4: Solve for the force.

$$F_m = \frac{I^2 R}{v} = \frac{1}{v}\left(\frac{Bl_1 v}{R}\right)^2 R = \frac{B^2 l_1^2 v}{R}.$$

$$\boxed{F_m = \frac{B^2 l_1^2 v}{R}}$$

Step 5: Direction of the force.

Energy conservation and Lenz's law both demand that this magnetic force oppose the motion. It therefore acts leftward, back into the field region, directly opposing the pull F. The applied force does work that appears entirely as heat $I^2 R$ in the loop.

Quick Tip: Only the vertical arm l_1 is in the field: find the motional EMF $Bl_1 v$, then the induced current, then $F = BIl_1$; direction opposes the motion (Lenz's law).

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16. Discuss the working method of a half-wave rectifier using a p-n junction diode.

Correct Answer: —

SOLUTION:

Step 1: Key property used.

A p-n junction diode acts like a one-way valve for current: it passes current when the p-region is at higher potential (forward bias) and stops it when the n-region is at higher potential (reverse bias). This directional conduction is what makes rectification possible.

Step 2: Connections.

An input transformer steps the mains AC to the required level. One end of the secondary goes to the anode (p-side) of the diode; the cathode (n-side) connects through the load resistor R_L back to the other end of the secondary. Output is measured across R_L.

Step 3: Follow one full input cycle.

For the first half of the input cycle the anode is positive, the junction is forward biased, and a current i flows through R_L producing an output voltage $V_{out} = iR_L$.

Step 4: The blocked half.

In the second half the anode goes negative, the junction is reverse biased, only a negligible leakage current flows, and $V_{out} \approx 0$.

Step 5: Nature of the output.

The result is a series of one-directional voltage pulses, one per input cycle, i.e. pulsating DC. Because output exists for only one of the two half cycles, the arrangement is a half-wave rectifier; a filter (capacitor) can later smooth the ripple.

$$\boxed{\text{Only positive half cycles appear at the output } (V_{out} = iR_L)}$$

Quick Tip: A diode conducts only when forward biased: it passes current during one half of the AC cycle and blocks the other, giving a pulsating DC output across the load.

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17. What is relaxation time? Find the equation of the relation between drift velocity and relaxation time.

Correct Answer: —

SOLUTION:

Step 1: Meaning of relaxation time.

Electrons in a metal are in constant thermal motion and keep colliding with the vibrating lattice ions. The mean free time between one such collision and the next is called the relaxation time τ. It measures how long, on average, the field can act on an electron before a collision resets its motion.

Step 2: Set up the equation of motion.

With field E applied, each electron feels force $-eE$ (magnitude eE). Newton's law gives acceleration magnitude $a = \dfrac{eE}{m}$.

Step 3: Average over many electrons.

Let the velocity of the i-th electron just after its last collision be u_i; these are random so $\langle u_i \rangle = 0$. After time t_i since that collision its velocity is $v_i = u_i + at_i$. Averaging over all electrons, the mean of u_i vanishes and the mean of t_i is τ.

Step 4: Obtain drift velocity.

$v_d = \langle v_i \rangle = \langle u_i \rangle + a\langle t_i \rangle = 0 + a\tau = \dfrac{eE}{m}\tau.$

Step 5: Final relation.

$$\boxed{v_d = \frac{eE\tau}{m}}$$

Thus a longer relaxation time or a stronger field produces a larger drift velocity, the electrons drifting against the field direction.

Quick Tip: Relaxation time is the mean time between electron collisions; equate the velocity gained, $v_d = a\tau$, with $a = eE/m$.

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18. In an L-C-R circuit, the inductive reactance of a coil is 400 Ω and the capacitive reactance of a condenser is 100 Ω and $R = 400\ \Omega$. Find the power factor of the circuit.

Correct Answer: —

SOLUTION:

Step 1: Recall what power factor means.
The power factor $\cos\phi$ is the cosine of the phase angle between the applied voltage and the current, and equals the ratio of resistance to impedance.

Step 2: Find the phase angle directly.
The phase angle in a series L-C-R circuit satisfies

$$\tan\phi = \frac{X_L - X_C}{R} = \frac{400 - 100}{400} = \frac{300}{400} = 0.75.$$

Step 3: Build the right triangle.

With opposite side $= 300$ and adjacent side $= 400$, the hypotenuse (impedance) is $\sqrt{300^2 + 400^2} = \sqrt{90000 + 160000} = 500\ \Omega$.

Step 4: Compute the cosine.

$\cos\phi = \dfrac{\text{adjacent}}{\text{hypotenuse}} = \dfrac{400}{500}$.

Step 5: Result.

$$\boxed{\cos\phi = 0.8}$$

Equivalently $\phi \approx 36.9°$, with the voltage leading the current because the circuit is net inductive.

Quick Tip: Compute impedance $Z = \sqrt{R^2 + (X_L - X_C)^2}$; power factor $\cos\phi = R/Z$.

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19. Explain total internal reflection. Discuss the working of an optical fibre.

Correct Answer: —

SOLUTION:

Step 1: Idea of total internal reflection.

Consider a ray of light going out of a dense medium (say water) into air. Because air is rarer, the ray moves away from the normal. As we tilt the ray to larger and larger incidence, the emerging ray leans more towards the water surface. The special incidence at which the emerging ray just skims the surface (refraction angle $90°$) is the critical angle θ_c. Beyond this incidence the surface behaves like a perfect mirror and reflects the entire beam back inside. This mirror-like return of the whole beam is total internal reflection.

Step 2: Getting the critical angle.

Snell's law from denser (index μ) to rarer (air, index 1) at $\theta_r = 90°$ gives $\mu \sin\theta_c = \sin 90° = 1$, hence $\sin\theta_c = 1/\mu$. So a denser material (larger μ) has a smaller critical angle, which makes TIR easier.

Step 3: Two must-have conditions.

(a) travel from denser to rarer medium, and (b) incidence angle larger than θ_c. If either fails, ordinary refraction takes place and light escapes.

Step 4: How an optical fibre uses this.

A fibre is made of a high-index glass core surrounded by a low-index cladding. Light fed into the core hits the core-cladding wall at an angle above the critical angle, so it is totally internally reflected. Bouncing wall to wall thousands of times per metre, the signal is trapped inside the core and is piped from one end to the other with negligible leakage, even around bends. This is why fibres are used for high-speed communication and for endoscopes in medicine.

$$\boxed{\sin\theta_c = \frac{1}{\mu};\ \text{fibre} = \text{high-index core} + \text{low-index cladding guiding light by TIR}}$$

Quick Tip: Light going from a denser to a rarer medium is fully reflected when the angle of incidence exceeds the critical angle, with $\sin\theta_c = 1/\mu$; a fibre traps light in a high-index core by repeated TIR.

20. The energy of a photon is 10 eV. Determine (i) the dynamic mass of the photon, (ii) the frequency of the photon.
(Given: $h = 6.6 \times 10^{-34}$ J s, $c = 3 \times 10^8$ m/s, 1 eV $= 1.6 \times 10^{-19}$ J.)

Correct Answer: —

SOLUTION:

Step 1: Express the given energy in SI units.
Since 1 eV $= 1.6 \times 10^{-19}$ J, a 10 eV photon has $E = 1.6 \times 10^{-18}$ J.

Step 2: Find the frequency first.
From $E = h\nu$ we get $\nu = E/h$. Putting numbers,

$$\nu = \frac{1.6 \times 10^{-18}}{6.6 \times 10^{-34}} = 2.42 \times 10^{15} \text{ Hz}.$$

Step 3: Get the dynamic mass from momentum.
A photon has momentum $p = E/c$. Its dynamic mass follows from $p = mc$, so $m = p/c = E/c^2$. Hence

$$m = \frac{1.6 \times 10^{-18}}{(3 \times 10^8)^2} = \frac{1.6 \times 10^{-18}}{9 \times 10^{16}} = 1.78 \times 10^{-35} \text{ kg}.$$

Step 4: State results.
Both come from the same photon energy: the frequency uses $E = h\nu$ and the dynamic mass uses $E = mc^2$.

$$\boxed{\nu = 2.42 \times 10^{15} \text{ Hz}, \qquad m = 1.78 \times 10^{-35} \text{ kg}}$$

Quick Tip: Use $m = E/c^2$ for the dynamic mass and $\nu = E/h$ for the frequency, after converting 10 eV into joules.

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21. Explain displacement current and write the formula related to Ampere-Maxwell's law.

Correct Answer: —

SOLUTION:

Step 1: The gap in Ampere's law.

Imagine an Amperian loop around a wire feeding a charging capacitor. If we stretch the surface bounded by the loop so that it passes between the capacitor plates, no charge crosses that surface, so the conduction current through it is zero. Yet the loop still shows a magnetic field. The value of $\oint \vec{B} \cdot d\vec{l}$ cannot depend on which surface we choose, so something is missing.

Step 2: What Maxwell added.

Between the plates the charge is piling up, so the electric field E and hence the electric flux Φ_E are rising with time. Maxwell said this varying flux acts as a current, the displacement current, $I_d = \varepsilon_0 \, d\Phi_E/dt$. Its size is exactly equal to the conduction current in the connecting wire, so the current is continuous everywhere, even across the empty gap.

Step 3: The corrected (Ampere-Maxwell) law.

Adding I_d to the conduction current I_c gives

$\oint \vec{B} \cdot d\vec{l} = \mu_0 \left(I_c + \varepsilon_0 \dfrac{d\Phi_E}{dt} \right).$

A key consequence is that a changing electric field creates a magnetic field, which (together with Faraday's law) allows electromagnetic waves to exist.

$$\boxed{I_d = \varepsilon_0 \frac{d\Phi_E}{dt}, \quad \oint \vec{B} \cdot d\vec{l} = \mu_0 I_c + \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt}}$$

Quick Tip: A changing electric field between capacitor plates acts like a current, $I_d = \varepsilon_0\, d\Phi_E/dt$; add it to the conduction current in Ampere's law.

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22. Draw the ray diagram of a compound microscope. Find the expression for its magnifying power.

Correct Answer: —

SOLUTION:

Step 1: Set-up of the instrument.
Two converging lenses share a common axis inside a tube. The front lens (objective, focal length f_o) is small and close to the tiny object; the back lens (eyepiece, focal length f_e) is next to the eye. The object AB sits just outside the objective's focus.

Step 2: What each lens does (ray picture).
Rays from AB refract through the objective and actually cross to form a real, inverted, enlarged image $A'B'$ within the tube, positioned just inside the focus of the eyepiece. The eyepiece then treats $A'B'$ as its object and, like a magnifying glass, sends out diverging rays whose backward projections form a much larger virtual image $A''B''$ at the near point D.

Step 3: Split the magnification into two factors.
Total angular magnification $M = m_o\, m_e$. The objective gives linear magnification $m_o = v_o/u_o \approx L/f_o$, where L is the tube length. The

eyepiece, used as a simple microscope with image at D, gives $m_e = 1 + D/f_e$.

Step 4: Combine.

Multiplying the two factors,
$M = \frac{L}{f_o}\left(1 + \frac{D}{f_e}\right)$.
For a relaxed eye (final image at infinity) the eyepiece factor becomes D/f_e, giving $M = \frac{LD}{f_o f_e}$. Because both f_o and f_e are kept small, M is large.

$$\boxed{M = \frac{L}{f_o}\left(1 + \frac{D}{f_e}\right); \quad M = \frac{LD}{f_o f_e} \text{ at infinity}}$$

Quick Tip: Magnifying power is the product of objective magnification L/f_o and eyepiece magnification $(1 + D/f_e)$.

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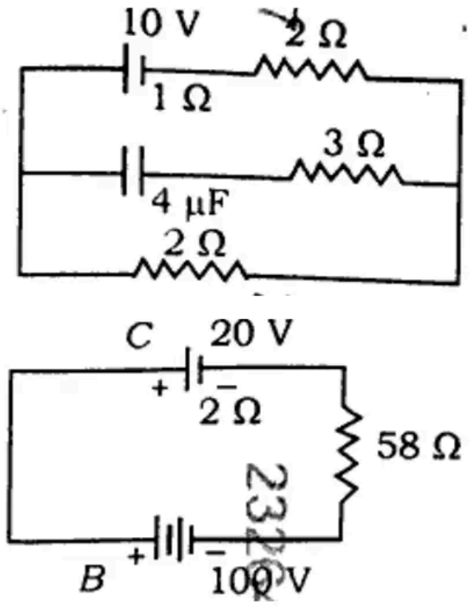
23.



Find the current supplied by the battery in the network shown in the figure. Also calculate the terminal voltage across the cell and the charge on the capacitor.

OR

What do you mean by electromotive force (EMF) of a cell? In the circuit shown, calculate the terminal voltage of the cell C. The battery B is of negligible internal resistance.

Correct Answer: —

SOLUTION:

Option 1 (main network) - loop method:

Step 1: Kill the capacitor branch.

Once things settle down, the capacitor is fully charged and blocks direct current. The branch with the 4 μF capacitor and its series 2 Ω carries zero current, so it can be ignored while finding currents.

Step 2: One simple loop remains.
What is left is a single mesh: EMF 10 V, internal resistance $1\ \Omega$, a $2\ \Omega$ resistor and the $3\ \Omega$ resistor, all in series. Applying Kirchhoff's voltage law, $10 = I(1 + 2 + 3)$, so $I = 10/6 = 1.67\text{ A}$ (this is the battery current).

Step 3: Terminal voltage.
Terminal voltage equals the EMF minus the drop on the internal resistance: $V = 10 - (5/3)(1) = 8.33\text{ V}$. (Check: it also equals the drop across the external part, $I(2 + 3) = (5/3)(5) = 8.33\text{ V}$.)

Step 4: Capacitor voltage and charge.
No current in the capacitor branch means no drop on its $2\ \Omega$ resistor, so the capacitor sits across the full $3\ \Omega$ voltage: $V_C = (5/3)(3) = 5\text{ V}$. Then $Q = CV_C = 4\,\mu\text{F} \times 5\text{ V} = 20\,\mu\text{C}$.

$$\boxed{I = 1.67\text{ A},\ V = 8.33\text{ V},\ Q = 20\,\mu\text{C}}$$

Option 2 (cell C) - Kirchhoff's voltage law:

Step 1: What EMF means.
EMF is the total energy a cell gives to each coulomb of charge as it pushes the charge around the whole loop. On open circuit (no current), the terminal voltage reads exactly the EMF; once current flows, the internal resistance changes the terminal reading.

Step 2: Write the loop equation.
Take a clockwise current I. The 100 V battery aids this direction while the 20 V cell opposes it (their positive plates face the same node). KVL

gives $100 - 20 = I(58 + 2)$, i.e. $80 = 60\,I$, so $I = 4/3 = 1.33$ A.

Step 3: Terminal voltage of C by direct drop.

Because current is forced into the positive terminal of C, C is under charging. Its terminal voltage is the EMF plus the internal drop: $V_C = 20 + I(2) = 20 + (4/3)(2) = 22.67$ V. Equivalently, going across C's terminals through the external path $V_C = 100 - I(58) = 100 - (4/3)(58) = 100 - 77.33 = 22.67$ V, the same value.

$$\boxed{I = 1.33\text{ A},\ V_C = 22.67\text{ V}}$$

Quick Tip: Main network: a steady-state capacitor passes no current, leaving a simple series loop; capacitor voltage equals the drop across the 3 Ω resistor. OR part: the two cells oppose, so net EMF = 100 − 20 V and cell C is being charged, giving $V_C = E + Ir$.

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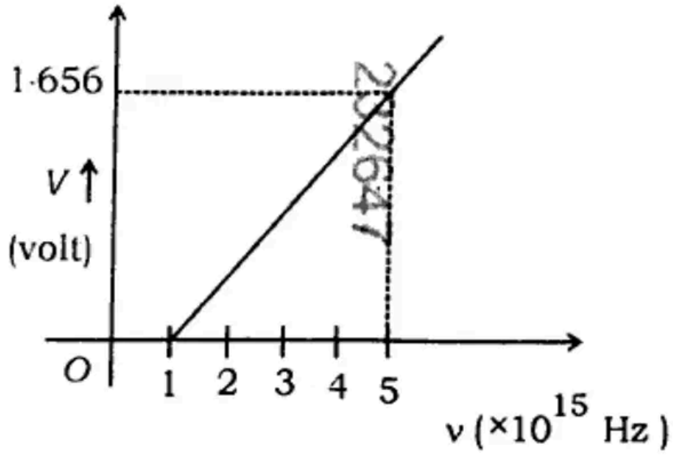
24.



In the figure, the plot of stopping potential versus frequency of light used in an experiment of the photoelectric effect is shown. Find the ratio h/e and the work function.
(From the graph: the line meets the frequency axis at $\nu_0 = 1 \times 10^{15}$ Hz, and the stopping potential is $V = 1.656$ V at $\nu = 5 \times 10^{15}$ Hz.)

Correct Answer: —

SOLUTION:

Step 1: Recognise the straight-line law.
Einstein's relation $eV = h\nu - \phi$ can be written as $V = (h/e)\nu - (\phi/e)$. Comparing with $y = mx + c$, the stopping-potential graph against frequency is a straight line whose gradient is h/e and whose x-intercept is the threshold frequency ν_0.

Step 2: Use the intercept for the work function first.
The graph meets the frequency axis at $\nu_0 = 1 \times 10^{15}$ Hz. At this point the electron just escapes with zero kinetic energy, so all the photon energy is spent on the work function: $\phi = h\nu_0$.

Step 3: Find the gradient from the marked point.

The line rises from $(1 \times 10^{15}, 0)$ to $(5 \times 10^{15}, 1.656)$. Its gradient is

$$\frac{h}{e} = \frac{1.656}{(5-1) \times 10^{15}} = \frac{1.656}{4 \times 10^{15}} = 4.14 \times 10^{-16}\ \text{V s}.$$

Step 4: Plug the gradient into the work function.

Since $\phi/e = (h/e)\nu_0$, the work function in electron-volts is $(4.14 \times 10^{-16})(1 \times 10^{15}) = 0.414$ eV, i.e. $0.414 \times 1.6 \times 10^{-19} = 6.62 \times 10^{-20}$ J.

$$\boxed{\frac{h}{e} = 4.14 \times 10^{-16}\ \text{V s},\ \phi = 0.414\ \text{eV} = 6.62 \times 10^{-20}\ \text{J}}$$

Quick Tip: On a stopping-potential vs frequency graph the slope is h/e and the frequency intercept is the threshold ν_0; the work function is $\phi = h\nu_0$.

• • •

25. Write the characteristics of nuclear force. How is it different from gravitational and electric (electrostatic) forces?

Correct Answer: —

SOLUTION:

Step 1: Place the nuclear force among the fundamental forces. Nature has four basic interactions. In increasing strength at nuclear scale they rank as gravitational < weak < electromagnetic < strong (nuclear). So the nuclear force sits at the top of this list at distances of a few femtometres.

Step 2: List its defining properties.

(a) It is the **strongest** known force, roughly $100\times$ the electric force and $\sim 10^{38}\times$ the gravitational force between two protons in contact.

(b) It has an extremely **short range**, dying out beyond $\sim$ 2–3 fm, so far-apart nucleons feel nothing.
(c) It is **charge independent**: n-n, n-p and p-p (nuclear part) bonds are identical.
(d) It shows a **repulsive hard core** below ~ 0.7 fm and attraction above it, which fixes the nucleon spacing.
(e) It **saturates**, binding only nearest neighbours, giving a nearly constant binding energy per nucleon ($\sim$ 8 MeV).
(f) It is **spin dependent and non-central**.

Step 3: Contrast with gravity and electricity. Both gravity and the electric (Coulomb) force are long-range inverse-square forces. Gravity is always attractive and set by mass; the Coulomb force depends on charge sign and can attract or repel. The nuclear force differs on every count: it is far stronger, vanishes beyond a few fm, does not care about charge, and can switch between attraction and a repulsive core.

$$\boxed{\text{Strong, short-ranged, charge-independent, saturating force} \neq \text{gravity or Coulomb force}}$$

Quick Tip: Recall that the nuclear force is the strongest force in nature, acts only over a few femtometres, is charge independent, and saturates, unlike the long-range gravitational and electric forces.

• • •

26. Energy of the n^{th} state of a hydrogen atom is $E_n = -\dfrac{13.6}{n^2}$ eV. A hydrogen sample is prepared in a particular excited state A. Photons of energy 2.55 eV get absorbed by the sample to take some electrons to a particular further excited state B. Find the quantum numbers of states A and B.

Correct Answer: —

SOLUTION:

Step 1: Tabulate the low-lying hydrogen levels. Using $E_n = -13.6/n^2$ eV:
$E_1 = -13.60$ eV, $E_2 = -3.40$ eV, $E_3 = -1.51$ eV, $E_4 = -0.85$ eV, $E_5 = -0.544$ eV.

Step 2: Search for a 2.55 eV gap. Absorption of 2.55 eV means the difference between the final and initial level equals 2.55 eV. Scan the pairs:
$E_2 \to E_3 :\ 1.89$ eV; $E_2 \to E_4 :\ 2.55$ eV; $E_1 \to E_2 :\ 10.2$ eV; $E_3 \to E_4 :\ 0.66$ eV.
Only the $2 \to 4$ transition matches exactly.

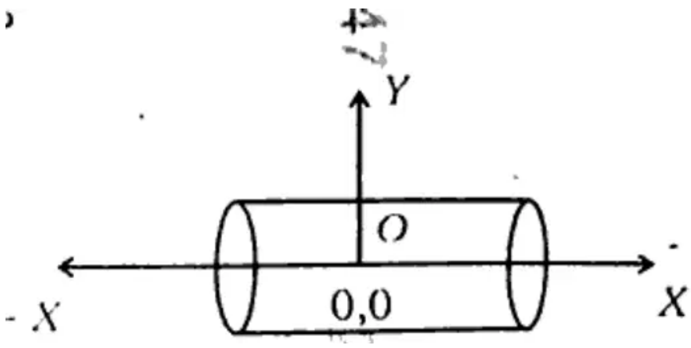
Step 3: Confirm. $E_4 - E_2 = (-0.85) - (-3.40) = 2.55$ eV, so the sample was initially in state A with $n = 2$ and the absorbed photon lifts electrons to state B with $n = 4$.

Step 4: Consistency note. Since the sample is described as 'a particular excited state', A cannot be the ground state $(n = 1)$; $n = 2$ is indeed an excited state, and $n = 4$ is a further excited state, matching the wording.

$$\boxed{\text{State A} : n = 2, \qquad \text{State B} : n = 4}$$

Quick Tip: Set the photon energy equal to $E_{n_B} - E_{n_A}$ and find whole-number levels; 2.55 eV matches the jump from $n = 2$ to $n = 4$.

27.



Option 1: What is Gauss's law? The figure shows a cylinder placed in an electric field $\vec{E} = 100\,\hat{\imath}$ N/C. $\vec{E}$ is positive when $x > 0$ and negative when $x < 0$. Length of the cylinder is 30 cm and radius of each plane surface is 3.5 cm; its centre is at O. Find the electric fluxes ϕ_1, ϕ_2 and ϕ_3 linked with each plane and the curved surface respectively. What will be the net charge inside the cylinder?

OR

Option 2: Obtain the formula for the capacitance of a parallel plate capacitor when a dielectric medium is partially filled in between its plates.

Correct Answer: —

SOLUTION:

Option 1: Gauss's law and cylinder flux (compact approach)

Step 1: Idea. Gauss's law says the closed-surface flux $\phi = q_{enc}/\varepsilon_0$. Here the field is axial ($\hat{\imath}$ direction), so only the two flat end-caps of the cylinder can catch flux; the curved wall runs parallel to the field lines.

Step 2: End-cap area. $r = 0.035$ m, so $A = \pi r^2 = \pi(0.035)^2 = 3.85 \times 10^{-3}$ m^2.

Step 3: Both caps point outward with the field. Because $\vec{E}$ points $+\hat{\imath}$ for $x > 0$ and $-\hat{\imath}$ for $x < 0$, at each end-cap the field is directed out of the cylinder, parallel to that cap's outward normal. Hence each contributes a positive flux of equal size:
$\phi_1 = \phi_2 = EA = 100 \times 3.85 \times 10^{-3} = 0.385\ \mathrm{N\ m^2/C}$.

Step 4: Curved wall. Field is tangential to the curved wall (normal is radial), so $\phi_3 = 0$.

Step 5: Net charge. Total outgoing flux $= 2EA = 0.770\ \mathrm{N\ m^2/C}$, so
$q_{enc} = \varepsilon_0(2EA) = 8.85 \times 10^{-12} \times 0.770 = 6.8 \times 10^{-12}\ \mathrm{C}$.
The positive result means a small net positive charge sits inside the cylinder.

$$\boxed{\phi_1 = \phi_2 = 0.385,\ \phi_3 = 0,\ q \approx 6.8 \times 10^{-12}\ \mathrm{C}}$$

Option 2: Partially filled capacitor (series-capacitor method)

Step 1: Split into two capacitors in series. The gap of thickness d is treated as a vacuum layer of thickness $(d - t)$ and a dielectric layer of thickness t stacked on top of each other, sharing the same charge Q; that is exactly two capacitors in series.

Step 2: Capacitance of each layer.
Vacuum layer: $C_1 = \dfrac{\varepsilon_0 A}{d - t}$.
Dielectric layer: $C_2 = \dfrac{K\varepsilon_0 A}{t}$.

Step 3: Series combination.

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{d-t}{\varepsilon_0 A} + \frac{t}{K\varepsilon_0 A} = \frac{1}{\varepsilon_0 A}\left[(d-t) + \frac{t}{K}\right].$$

Step 4: Invert.

$$\boxed{C = \frac{\varepsilon_0 A}{d - t + \dfrac{t}{K}}}$$

This matches the field-integration result and reduces correctly to $\varepsilon_0 A/d$ for $t = 0$ and $K\varepsilon_0 A/d$ for $t = d$.

Quick Tip: Gauss's law: closed-surface flux $= q/\varepsilon_0$. Only the two flat faces catch flux (curved surface gives zero); add them and multiply by ε_0. For the OR part, treat the gap as vacuum plus dielectric layers in series.

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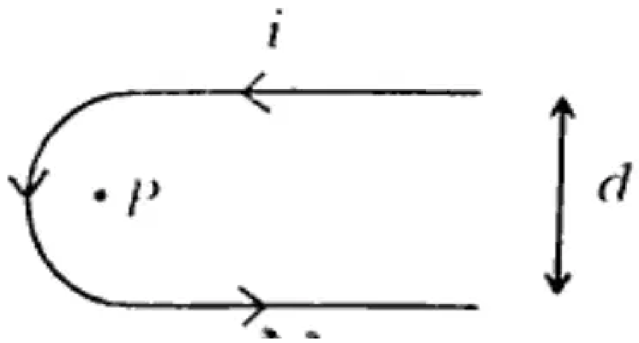
28.



Option 1: With the help of the given figure, prove that the magnetic field produced at point P is $B = \frac{\mu_0 i}{2d}\left[1 + \frac{2}{\pi}\right]$. (The wire is hairpin-shaped: a semicircular arc joined to two long straight parallel segments carrying current i; P is at the centre of the arc and the straight segments are a distance d apart.)

OR

Option 2: What is a radial magnetic field? Explain the working of a moving coil galvanometer with a suitable diagram. How can a galvanometer be converted into an ammeter and a voltmeter?

Correct Answer: —

SOLUTION:

Option 1: Hairpin field, piece-by-piece with directions

Step 1: Fix the radius. The two straight rails are a gap d apart and P sits midway on the semicircle joining them, so the arc radius is $R = d/2$ and each rail is a perpendicular distance $d/2$ from P.

Step 2: Arc contribution using the angle formula. A circular arc subtending angle ϕ at its centre gives $B = \frac{\mu_0 i}{4\pi R}\phi$. For a semicircle ϕ

$= \pi$:

$$B_{arc} = \frac{\mu_0 i}{4\pi R} \cdot \pi = \frac{\mu_0 i}{4R} = \frac{\mu_0 i}{4(d/2)} = \frac{\mu_0 i}{2d}.$$

Step 3: One rail as half of an infinite wire. An infinite straight wire gives $\dfrac{\mu_0 i}{2\pi a}$ at distance a. A semi-infinite wire ending level with the field point contributes exactly half of that:

$$B_{rail} = \frac{1}{2} \cdot \frac{\mu_0 i}{2\pi a} = \frac{\mu_0 i}{4\pi a} = \frac{\mu_0 i}{4\pi(d/2)} = \frac{\mu_0 i}{2\pi d}.$$

Step 4: Superpose. Curling the fingers of the right hand along the current shows the arc and both rails push the field the same way through P, so magnitudes add:

$$B = B_{arc} + 2B_{rail} = \frac{\mu_0 i}{2d} + 2 \cdot \frac{\mu_0 i}{2\pi d} = \frac{\mu_0 i}{2d} + \frac{\mu_0 i}{\pi d}.$$

Step 5: Factor out.

$$B = \frac{\mu_0 i}{2d}\left(1 + \frac{2}{\pi}\right).$$

$$\boxed{B = \frac{\mu_0 i}{2d}\left[1 + \frac{2}{\pi}\right]}$$

Option 2: Radial field and galvanometer (concept-first framing)

Step 1: Meaning of radial field. Shaped concave magnet poles plus a soft-iron cylindrical core make the field lines emerge radially, like spokes of a wheel. As the coil turns, its plane always stays parallel to $\vec{B}$, so the field 'follows' the coil.

Step 2: Why it matters. The torque on an N-turn coil of area A carrying current I is $\tau = NBIA \sin\theta$. In a radial field $\theta = 90°$ always, so

$\tau = NBIA$ is constant, not varying with deflection.

Step 3: Balance and read-out. The spring's restoring torque $k\phi$ balances it: $NBIA = k\phi$, giving $I = \frac{k}{NBA}\phi$. Current is proportional to deflection, so the scale is evenly spaced (linear).

Step 4: Make an ammeter. Put a tiny shunt S in parallel so most current bypasses the coil: $S = \frac{I_g G}{I - I_g}$. Net resistance is very low, so it goes in series without disturbing the circuit.

Step 5: Make a voltmeter. Put a large resistance R in series so only a trickle flows through the coil: $R = \frac{V}{I_g} - G$. Net resistance is very high, so it goes in parallel across the component.

$$\boxed{I \propto \phi; \quad S = \frac{I_g G}{I - I_g}, \quad R = \frac{V}{I_g} - G}$$

Quick Tip: Split the hairpin into a semicircular arc (field $\mu_0 i/4R$) and two semi-infinite straight wires (each $\mu_0 i/4\pi a$), with $R = a = d/2$; add them in the same direction and factor out $\mu_0 i/2d$.

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29. Show the position of focus (f) in ray diagram for convex mirror. At what distance from a convex mirror of focal length 2.0 m should a boy stand so that his image has a height equal to half the original height?

OR

What is wavefront? Explain the refraction of waves with the help of Huygens' principle.

Correct Answer: —

SOLUTION:

Option 1: Convex mirror using the m = f/(f - u) form

Step 1: A convex mirror is a diverging mirror. Its principal focus F is the virtual point behind the mirror from which the reflected rays of an incident parallel beam appear to originate. Hence in a labelled ray diagram both F and the centre of curvature C are marked behind the reflecting surface, with focal length $f = +2.0\,\text{m}$.

Step 2: For any mirror the linear magnification can be written directly in terms of focal length and object distance as

$$m = \frac{f}{f - u}$$

The required image is erect and half sized, so $m = +\frac{1}{2}$.

Step 3: Substitute the known values:

$$\frac{1}{2} = \frac{2.0}{2.0 - u}$$

Step 4: Cross multiply:

$$2.0 - u = 2 \times 2.0 = 4.0 \Rightarrow u = 2.0 - 4.0 = -2.0\,\text{m}$$

Step 5: The magnitude of the object distance is 2.0 m, so the boy must stand 2.0 m from the mirror. Image position $v = -m\,u = -(0.5)(-2.0)$ $= +1.0\,\text{m}$, i.e. 1.0 m behind the mirror, virtual, erect and half height.

$$\boxed{\text{Boy stands 2.0 m from the mirror}}$$

Option 2: Wavefront and Huygens refraction (physical description)

Step 1: Imagine dropping a stone into still water. The moving circular crest along which every water particle is at the same stage of vibration is a wavefront. Formally, a wavefront is the continuous surface joining all particles of a medium that are in the same phase of oscillation at one instant, and energy travels at right angles to it.

Step 2: Huygens pictured each such surface as a nursery of tiny sources: (a) every point of the present wavefront emits spherical secondary wavelets moving forward at the wave speed of the medium; (b) after a time t, the envelope that just touches all these wavelets on their forward side is the position of the advanced wavefront.

Step 3: Consider a plane wavefront falling obliquely on the flat interface between a rarer medium (wave speed v_1) and a denser medium (wave speed v_2, with $v_2 < v_1$). The edge of the wavefront still in medium 1 keeps moving faster than the edge that has already entered medium 2.

Step 4: In equal time t, the medium-1 wavelet advances $v_1 t$ while the medium-2 wavelet advances only $v_2 t$. Because one edge lags behind the other, the wavefront swings round and its direction of travel turns towards the normal. Taking the two right triangles that share the interface segment AC as hypotenuse gives $\sin i = v_1 t/AC$ and $\sin r = v_2 t/AC$.

Step 5: Their ratio cancels t and AC:

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = {}_1n_2$$

a constant for the given pair of media, which is exactly the experimental law of refraction. So Huygens' construction predicts both the bending of the wave and the identification of the refractive index with the ratio of speeds.

$$\boxed{\sin i/\sin r = v_1/v_2 = \text{refractive index}}$$

Quick Tip: For the convex mirror use $m = -v/u = +\frac{1}{2}$ together with the mirror formula $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$ and $f = +2.0\,\text{m}$. For the OR part, a wavefront is a surface of constant phase, and Huygens' secondary-wavelet envelope gives $\sin i/\sin r = v_1/v_2$.

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30. How can p-type and n-type crystal from pure semiconductor be formed? Find the maximum wavelength of electromagnetic radiation which can create a hole-electron pair in germanium of a band-gap 0.65 eV.

OR

How is the conductivity of a metal and semiconductor changed with raising temperature? Calculate the conductivity of an n-type semiconductor from the following data: Density of conduction electrons = 8×10^{13} /cm^3, Density of holes = 5×10^{12} /cm^3, Mobility of conduction electrons = 2.3×10^4 cm^2/V·s, Mobility of holes = 100 cm^2/V·s.

Correct Answer: —

SOLUTION:

Option 1: Doping seen through energy bands, and the threshold wavelength

Step 1: A pure semiconductor at 0 K has a completely filled valence band and an empty conduction band separated by a gap E_g. Doping inserts new allowed levels inside this gap. A pentavalent (donor) atom places filled donor levels just below the conduction band; their electrons jump up very easily, so conduction is mainly by electrons and the crystal is n-type.

Step 2: A trivalent (acceptor) atom places empty acceptor levels just above the valence band; valence electrons jump into them and leave holes behind, so conduction is mainly by holes and the crystal is p-type. In both cases only a tiny impurity fraction (about 1 atom in 10^6) changes the conductivity enormously.

Step 3: A photon can generate an electron-hole pair only if its energy is not less than the band-gap. The limiting (maximum-wavelength) photon has energy exactly E_g. Using the handy relation with energy in eV and wavelength in micrometre,

$$\lambda_{max}(\mu\text{m}) = \frac{1.24}{E_g(\text{eV})}$$

Step 4: Substitute $E_g = 0.65$ eV:

$$\lambda_{max} = \frac{1.24}{0.65} = 1.9\ \mu\text{m}$$

Step 5: Cross-check from first principles:

$$\lambda_{max} = \frac{hc}{E_g} = \frac{1.98 \times 10^{-25}}{0.65 \times 1.6 \times 10^{-19}} = 1.9 \times 10^{-6}\ \text{m}$$

Both routes agree, and the wavelength lies in the infrared.

$$\boxed{\lambda_{max} \approx 1.9\ \mu\text{m} = 1.9 \times 10^{-6}\ \text{m}}$$

Option 2: Conductivity from separate carrier channels, with a resistivity check

Step 1: The temperature behaviour has opposite sign in the two materials. In a metal the carrier number is essentially fixed while thermal vibrations scatter the electrons more strongly at higher T, so σ falls (resistance grows with temperature). In a semiconductor, extra bonds break as T rises and the carrier number soars, so σ climbs (resistance falls with temperature).

Step 2: The total conductivity is the sum of the electron and hole channels:

$$\sigma = e\, n_e\, \mu_e + e\, n_h\, \mu_h$$

Evaluate each channel on its own.

Step 3 (electron channel):

$$\sigma_e = (1.6 \times 10^{-19})(8 \times 10^{13})(2.3 \times 10^{4}) = 0.2944\ \Omega^{-1}\text{cm}^{-1}$$

Step 4 (hole channel):

$$\sigma_h = (1.6 \times 10^{-19})(5 \times 10^{12})(100) = 8.0 \times 10^{-5}\ \Omega^{-1}\text{cm}^{-1}$$

Step 5 (add):

$$\sigma = 0.2944 + 0.00008 = 0.2945 \approx 0.294\ \Omega^{-1}\text{cm}^{-1}$$

The hole channel is negligible, which confirms an n-type sample.

Step 6 (SI value and resistivity): $\sigma = 0.294\ \Omega^{-1}\text{cm}^{-1} \times 100$ $= 29.4\ \Omega^{-1}\text{m}^{-1}$, so the resistivity is $\rho = 1/\sigma \approx 3.4\ \Omega\,\text{cm}$ (about 0.034 Ω·m).

$$\boxed{\sigma \approx 0.294\ \Omega^{-1}\text{cm}^{-1} \approx 29.4\ \text{S/m}}$$

Quick Tip: Doping with a pentavalent impurity gives n-type (extra electrons) and a trivalent impurity gives p-type (holes). Use $\lambda_{max} = hc/E_g$ for the germanium part, and $\sigma = e(n_e\mu_e + n_h\mu_h)$ for the conductivity.