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

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: Concept and formula. In a uniform electric field E, the electric force on a charge q is $F = qE$, and its magnitude is $|q|E$. The force depends only on the magnitude of the charge, not on the mass of the particle.

Step 2: Write the charge of each particle. Proton has charge $+e$, electron has charge $-e$, and an α-particle (helium nucleus) has charge $+2e$.

Step 3: Substitute to get force magnitudes. $F_1 = eE$ (proton), $F_2 = eE$ (electron), $F_3 = 2eE$ (α-particle).

Step 4: Compare. Since $F_1 = F_2 = eE$ and $F_3 = 2eE$, we get $F_1 = F_2 \neq F_3$. This is option (ii).

Why other options are wrong: The field is uniform, so mass plays no role, ruling out any strict inequality ordering (options iii and iv). Option (i) is wrong because the α-particle carries double the charge, so its force is not equal to the others.

$$\boxed{F_1 = F_2 \neq F_3}$$

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.

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: Concept. In a parallel connection, both resistors have the SAME potential difference V across them. The thermal (heat) energy developed in time t is $H = \frac{V^2}{R}t$, so at fixed V and t, heat is inversely proportional to resistance.

Step 2: Write the heat in each resistor. For R: $H_R = \frac{V^2}{R}t$. For $2R$: H_{2R}

$= \frac{V^2}{2R} t.$

Step 3: Take the ratio.

$$\frac{H_R}{H_{2R}} = \frac{V^2/R}{V^2/(2R)} = \frac{2R}{R} = 2.$$

Step 4: So $H_R : H_{2R} = 2 : 1$. This is option (ii).

Why other options are wrong: Students often use $H = I^2Rt$ with the same current, which applies to SERIES, not parallel. In parallel the voltage is common, so the correct formula is V^2/R, giving 2 : 1, not 1 : 2.

$$\boxed{H_R : H_{2R} = 2 : 1}$$

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 $\frac{1}{\mu_0 \varepsilon_0}$ is:

(A) m s^{-1}

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

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

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

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

Solution:

Step 1: Concept. The speed of light in vacuum is related to the permeability μ_0 and permittivity ε_0 of free space by

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}.$$

Step 2: Square both sides.

$$c^2 = \frac{1}{\mu_0 \varepsilon_0}.$$

So $\dfrac{1}{\mu_0 \varepsilon_0}$ has exactly the units of c^2, i.e. the square of a speed.

Step 3: Substitute the unit of speed. Speed has unit $\mathrm{m\,s^{-1}}$, therefore c^2 has unit $(\mathrm{m\,s^{-1}})^2 = \mathrm{m^2\,s^{-2}}$.

Step 4: Hence the unit of $\dfrac{1}{\mu_0 \varepsilon_0}$ is $\mathrm{m^2\,s^{-2}}$, which is option (iii).

Why other options are wrong: Option (i) is the unit of speed c itself, not c^2. Options (ii) and (iv) are reciprocal-type units that do not match c^2.

$$\boxed{\mathrm{m^2\,s^{-2}}}$$

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: Concept. The average power in an AC circuit is $P = V_{rms} I_{rms} \cos\phi$, where ϕ is the phase difference between the voltage and the current.

Step 2: Find the phase difference. Given $i = 2\sin\omega t$ and $V = 5\cos\omega t$. Rewrite the voltage as $V = 5\sin(\omega t + 90^\circ)$, since $\cos\omega t = \sin(\omega t + 90^\circ)$. So the voltage leads the current by $\phi = 90^\circ$.

Step 3: Substitute the power factor. $\cos\phi = \cos 90^\circ = 0$.

Step 4: Therefore $P = V_{rms} I_{rms} \times 0 = 0$. The average power loss is zero, option (i). This is a purely reactive (wattless) circuit.

Why other options are wrong: The non-zero values (5 W, 10 W, 2.5 W) ignore the 90° phase difference; energy only oscillates back and forth and no net power is dissipated.

$$\boxed{P = 0}$$

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

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: Concept. In Young's double-slit experiment, the fringe width is

$$\beta = \frac{\lambda D}{d},$$

where λ is the wavelength of light, D is the slit-to-screen distance and d is the separation between the two slits.

Step 2: Effect of the thin sheet. Placing a thin transparent sheet in front of one slit introduces an extra optical path $(\mu - 1)t$ for that slit only. This adds a CONSTANT extra path difference for all points on the screen.

Step 3: Consequence. A constant added path difference shifts the ENTIRE fringe pattern sideways (the central bright fringe moves toward the covered slit), but it does not change λ, D or d.

Step 4: Since $\beta = \lambda D/d$ contains none of the sheet parameters, the spacing between consecutive fringes is unchanged. The fringe width remains the same, option (iii).

Why other options are wrong: The sheet only translates the pattern; it neither compresses nor expands the fringe spacing, so 'increase' and 'decrease' are wrong.

$$\boxed{\beta = \frac{\lambda D}{d} \text{ unchanged}}$$

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.

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: Concept. Conductivity of a semiconductor is $\sigma = e(n_e\mu_e + n_h\mu_h)$, where n_e, n_h are the number densities of free electrons and holes and μ_e, μ_h are their mobilities.

Step 2: Intrinsic (pure) semiconductor. In a pure semiconductor the number of free charge carriers is very small, so its conductivity is low.

Step 3: Effect of doping. Adding a pentavalent impurity (donor) supplies extra free electrons, while a trivalent impurity (acceptor) supplies extra holes. Either way, the number density of majority carriers rises sharply, often by several orders of magnitude.

Step 4: Since σ is directly proportional to the carrier density, the large increase in carriers makes the conductivity increase. Hence option (i).

Why other options are wrong: Doping never lowers or removes carriers, so it cannot decrease conductivity, keep it unchanged, or make it zero.

$$\boxed{\sigma \uparrow \ \text{(conductivity increases)}}$$

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

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: Write the concept and formula.

The magnetic moment of a current-carrying coil is given by

$$m = NIA$$

where N is the number of turns, I is the current, and A is the area of the coil. Here the coil is a single loop, so $N = 1$.

Step 2: Find the area of the coil.

The sides are $20\text{ cm} = 0.20\text{ m}$ and $10\text{ cm} = 0.10\text{ m}$.

$$A = 0.20 \times 0.10 = 0.02\text{ m}^2$$

Step 3: Substitute the values.

$$m = 1 \times 10\text{ A} \times 0.02\text{ m}^2$$

Step 4: Do the arithmetic.

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

The direction of the magnetic moment is perpendicular to the plane of the coil, given by the right-hand rule.

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

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

8. Write the unit of self-inductance.

Correct Answer: —

Solution:

Step 1: Recall the definition of self-inductance.

Self-inductance L links the induced EMF in a coil to the rate of change of current through it:

$$\varepsilon = -L\,\frac{dI}{dt}$$

Step 2: Solve for the unit of L.

Rearranging, $L = -\dfrac{\varepsilon}{dI/dt}$. So the unit is

$$[L] = \frac{\text{volt}}{\text{ampere/second}} = \frac{\text{volt} \cdot \text{second}}{\text{ampere}}$$

Step 3: Name the SI unit.

This unit is called the **henry** (symbol H). Thus $1\ \mathrm{H} = 1\ \mathrm{V \cdot s\,/\,A}$

$= 1$ Wb/A.

$$\boxed{\text{The SI unit of self-inductance is the henry (H).}}$$

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

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: State the relation between E and B in an EM wave.
In an electromagnetic wave travelling through vacuum, the peak (amplitude) values of the electric and magnetic fields are related by the speed of light c:

$$E_0 = c\, B_0$$

Step 2: List the known values.
$B_0 = 500\ \text{nT} = 500 \times 10^{-9}\ \text{T} = 5 \times 10^{-7}\ \text{T}$
$c = 3 \times 10^{8}\ \text{m/s}$

Step 3: Substitute into the formula.

$$E_0 = (3 \times 10^8) \times (5 \times 10^{-7})$$

Step 4: Do the arithmetic.

$$E_0 = 15 \times 10^1 = 150\ \mathrm{V/m}$$

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

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

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

Correct Answer: —

Solution:

Step 1: Understand the quantities.
Here i is the angle of incidence at the first face of a triangular prism and δ is the angle of deviation of the emergent ray from the original direction.

Step 2: Describe the shape of the curve.
When δ (Y-axis) is plotted against i (X-axis), the graph is a **U-shaped (concave-up) curve**. As i increases from a small value, the deviation δ

first decreases, reaches a single lowest point, and then increases again.

Step 3: Locate the minimum deviation.

The lowest point of this curve gives the **angle of minimum deviation** δ_m. At this point only one value of i produces the minimum; the ray passes symmetrically through the prism, so the angle of incidence equals the angle of emergence ($i = e$) and the refracted ray inside the prism is parallel to the base.

Step 4: The diagram.

Draw the horizontal axis labelled i and the vertical axis labelled δ. Sketch a smooth U-shaped curve. Mark the bottom of the U with a horizontal dashed line meeting the δ-axis at δ_m; this dashed level is the angle of minimum deviation.

$$\boxed{\text{The } i\text{-}\delta \text{ curve is U-shaped; its lowest point marks } \delta_m.}$$

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

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: Recall the energy relations in the Bohr model.

For an electron in a hydrogen atom, the total energy E, kinetic energy K, and potential energy U are related by

$$K = -E \qquad \text{and} \qquad U = 2E$$

and also $U = -2K$. These follow because the electron is bound by the attractive Coulomb force.

Step 2: Write the given data.

Total energy in the ground state: $E = -13.6$ eV.

Step 3: Find the kinetic energy.

$$K = -E = -(-13.6) = +13.6 \text{ eV}$$

Step 4: Find the potential energy.

$$U = 2E = 2 \times (-13.6) = -27.2 \text{ eV}$$

Step 5: Check.

$K + U = 13.6 + (-27.2) = -13.6 \text{ eV} = E$, which is consistent.

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

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

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

Correct Answer: —

Solution:

Step 1: State Einstein's mass-energy relation.

The energy equivalent of a mass m is given by

$$E = mc^2$$

where $c = 3 \times 10^8$ m/s is the speed of light.

Step 2: Convert the mass to SI units.

$$m = 1.0\text{ g} = 1.0 \times 10^{-3}\text{ kg}$$

Step 3: Substitute the values.

$$E = (1.0 \times 10^{-3}) \times (3 \times 10^8)^2$$

Step 4: Evaluate the square and multiply.

$$(3 \times 10^8)^2 = 9 \times 10^{16}\text{ m}^2/\text{s}^2$$

$$E = (1.0 \times 10^{-3}) \times (9 \times 10^{16}) = 9 \times 10^{13}\ \text{J}$$

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

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: Energy stored in a capacitor.

The energy stored in a charged parallel plate capacitor of capacitance C charged to a potential difference V is

$$U = \frac{1}{2}CV^2$$

Step 2: Substitute the capacitor parameters.

For a parallel plate capacitor with plate area A and plate separation d, the capacitance is

$$C = \frac{\varepsilon_0 A}{d}$$

The potential difference is related to the uniform field E between the plates by

$$V = E\,d$$

Step 3: Put these into the energy expression.

$$U = \frac{1}{2}\left(\frac{\varepsilon_0 A}{d}\right)(E\,d)^2 = \frac{1}{2}\,\varepsilon_0\,\frac{A}{d}\,E^2 d^2 = \frac{1}{2}\varepsilon_0 E^2 (A\,d)$$

Step 4: Divide by the volume to get energy density.

The electric field exists in the space between the plates, whose volume is **Volume** $= A\,d$. Energy density is energy per unit volume:

$$u = \frac{U}{A\,d} = \frac{\frac{1}{2}\varepsilon_0 E^2 (A\,d)}{A\,d}$$

Step 5: Result.

The area and separation cancel, giving

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

which is independent of the plate dimensions and depends only on the field, proving the result.

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.

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: Write the given data.

Radius $r = 2.0 \text{ cm} = 2.0 \times 10^{-2}$ m

Current $I = 1.0$ A

Number of turns $N = 100$

Permeability of free space $\mu_0 = 4\pi \times 10^{-7}$ T m A^{-1}

Step 2: State the formula.

The magnetic field at the centre of a circular coil of N turns is

$$B = \frac{\mu_0 N I}{2r}$$

Step 3: Substitute the values.

$$B = \frac{(4\pi \times 10^{-7})(100)(1.0)}{2 \times (2.0 \times 10^{-2})}$$

Step 4: Simplify.

Numerator $= 4\pi \times 10^{-7} \times 100 = 4\pi \times 10^{-5}$ T m.

Denominator $= 2 \times 2.0 \times 10^{-2} = 4.0 \times 10^{-2}$ m.

$$B = \frac{4\pi \times 10^{-5}}{4.0 \times 10^{-2}} = \pi \times 10^{-3} \text{ T}$$

Step 5: Final value.

$$\boxed{B = \pi \times 10^{-3}\ \mathrm{T} \approx 3.14 \times 10^{-3}\ \mathrm{T} = 3.14\ \mathrm{mT}}$$

The field is directed along the axis of the coil (given by the right-hand rule).

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

15.

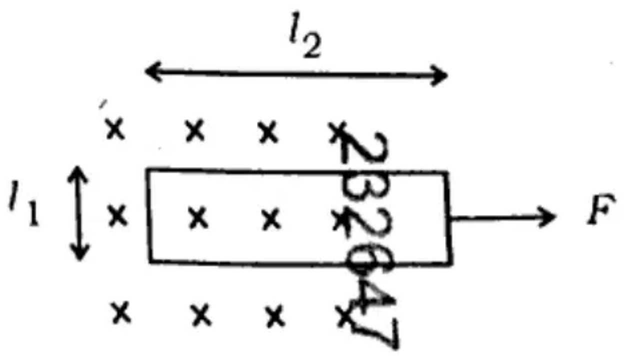

Figure shows a rectangular loop being pulled out of a magnetic field B with a velocity v by applying an external force F. Find the amount of magnetic force induced on the loop and show its direction.

Correct Answer: —

Solution:

Step 1: Identify the arm that cuts the field.

The loop (vertical side l_1, horizontal side l_2) is pulled to the right, out of a region where B points into the page. As it moves, only the left vertical arm of length l_1 is still inside the field and cuts the magnetic field lines.

Step 2: Motional EMF.

The EMF induced in this arm is

$$\varepsilon = B\, l_1\, v$$

Step 3: Induced current.

If R is the total resistance of the loop, the induced current is

$$I = \frac{\varepsilon}{R} = \frac{B\, l_1\, v}{R}$$

Step 4: Force on the current-carrying arm.

This current, flowing through the arm of length l_1 that lies in the field, experiences a force

$$F_m = B\, I\, l_1 = B\left(\frac{B\, l_1\, v}{R}\right) l_1$$

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

Step 5: Direction.

By Lenz's law the induced effects oppose the change causing them. Since the flux (into the page) is decreasing as the loop leaves, the induced force acts to oppose the withdrawal. Hence F_m points to the **left**, opposite to the applied force F and to the velocity v. To keep the loop moving at constant speed, the external force must satisfy $F = F_m$.

Quick Tip: Only the vertical arm l_1 is in the field: find the motional EMF Bl_1v, 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: Purpose of a rectifier.
A rectifier converts alternating current (AC), which reverses direction every half cycle, into direct current (DC), which flows in only one direction. A p-n junction diode is used because it conducts appreciably only when forward biased and blocks current when reverse biased.

Step 2: Circuit arrangement.
The AC supply is connected to the primary of a transformer. The secondary of the transformer is connected in series with a p-n junction diode and a load resistance R_L. The output DC voltage is taken across R_L.

Step 3: Positive half cycle.

During the half cycle in which the p-side of the diode becomes positive with respect to the n-side, the diode is **forward biased**. It offers low resistance and conducts, so current flows through R_L and a voltage appears across it.

Step 4: Negative half cycle.

During the next half cycle the polarity reverses, the diode becomes **reverse biased**, offers very high resistance and does not conduct. Practically no current flows and the output voltage is nearly zero.

Step 5: Output.

Thus the diode allows current only during alternate (positive) half cycles. The output across R_L is a pulsating unidirectional voltage present for one half of each cycle. Since only half of the AC wave is used, the device is called a **half-wave rectifier**. Its efficiency is low and the output has a large ripple.

$$\boxed{\text{Diode conducts on one half cycle only} \Rightarrow \text{pulsating DC output}}$$

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.

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

Correct Answer: —

Solution:

Step 1: Definition of relaxation time.

In a conductor the free electrons move randomly and frequently collide with the positive ions of the lattice. **Relaxation time** τ is the average time interval between two successive collisions of an electron. After each collision the electron's drift is randomised, so it effectively starts afresh.

Step 2: Force and acceleration on an electron.

When a potential difference is applied, a uniform electric field E exists in the conductor. The force on an electron of charge e is $F = eE$, giving it an acceleration

$$a = \frac{F}{m} = \frac{eE}{m}$$

where m is the mass of the electron.

Step 3: Velocity gained between collisions.

Just after a collision an electron's average velocity is zero (random directions cancel). Under the field it accelerates for an average time τ before the next collision. The extra velocity it gains is the drift velocity:

$$v_d = a\tau$$

Step 4: Substitute the acceleration.

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

Step 5: Result.

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

The drift velocity is directly proportional to the applied field E and to the relaxation time τ. (For electrons the drift is directed opposite to E.)

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

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: Write the given data.

Inductive reactance $X_L = 400\ \Omega$

Capacitive reactance $X_C = 100\ \Omega$

Resistance $R = 400\ \Omega$

Step 2: Net reactance.

In a series L-C-R circuit the net reactance is

$$X = X_L - X_C = 400 - 100 = 300\ \Omega$$

Step 3: Impedance of the circuit.

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{(400)^2 + (300)^2}$$

$$Z = \sqrt{160000 + 90000} = \sqrt{250000} = 500\ \Omega$$

Step 4: Power factor formula.

The power factor is

$$\cos\phi = \frac{R}{Z}$$

Step 5: Substitute and evaluate.

$$\cos\phi = \frac{400}{500} = 0.8$$

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

Since $X_L > X_C$, the circuit is inductive and the current lags the voltage.

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

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

Correct Answer: —

Solution:

Total Internal Reflection (TIR):
When light travels from an optically denser medium to an optically rarer medium (for example, from glass or water into air), it bends away from the normal. If the angle of incidence in the denser medium is increased, the refracted ray bends more and more towards the surface. At a certain angle of incidence called the **critical angle** θ_c, the refracted ray grazes along the boundary (angle of refraction = 90°). When the angle of incidence is made greater than the critical angle, no light is refracted; the whole of the light is reflected back into the denser medium. This complete reflection of light back into the denser medium is called **total internal reflection**.

Step 1: Conditions for TIR.
(i) Light must travel from a denser medium to a rarer medium.
(ii) The angle of incidence must be greater than the critical angle, i.e. $\theta_i > \theta_c$.

Step 2: Critical angle formula.
Applying Snell's law at the critical angle (angle of refraction = 90°):

$$\mu \sin\theta_c = 1 \times \sin 90^\circ$$

$$\sin\theta_c = \frac{1}{\mu}$$

where μ is the refractive index of the denser medium with respect to the rarer medium.

Step 3: Working of an optical fibre.

An optical fibre is a very thin, long thread of glass or plastic. It has two parts: a central **core** of higher refractive index and an outer **cladding** of lower refractive index. When a light signal enters one end of the core at a small angle, it strikes the core-cladding boundary at an angle greater than the critical angle. Therefore it suffers total internal reflection and is thrown back into the core. This happens again and again along the length of the fibre, so the light travels through the fibre by repeated total internal reflections, even if the fibre is bent, and comes out at the far end with almost no loss of energy.

Step 4: Uses.

Optical fibres are used to carry telephone, internet and television signals over long distances, and in medical instruments (endoscopes) to see inside the human body.

$$\boxed{\text{TIR occurs when } \theta_i > \theta_c,\ \ \sin\theta_c = \frac{1}{\mu};\ \text{optical fibre guides light by repeated TIR}}$$

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: Convert the energy into joules.

$$E = 10 \text{ eV} = 10 \times 1.6 \times 10^{-19} \text{ J} = 1.6 \times 10^{-18} \text{ J}$$

Step 2: Dynamic (relativistic) mass of the photon.

A photon carries energy E, and by mass-energy equivalence its effective (dynamic) mass is

$$m = \frac{E}{c^2}$$

Substituting the values:

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

$$m = 1.78 \times 10^{-35} \text{ kg}$$

Step 3: Frequency of the photon.

The photon energy is related to its frequency by Planck's relation

$$E = h\nu \quad \Rightarrow \quad \nu = \frac{E}{h}$$

Substituting the values:

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

Final answers:

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

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

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

Correct Answer: —

Solution:

Step 1: Why displacement current was needed.
The original Ampere's circuital law says the line integral of the magnetic field around a closed loop equals μ_0 times the conduction current linked with the loop:

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_c$$

Maxwell noticed a problem while charging a capacitor. In the region between the two capacitor plates there is no flow of charge, so the conduction current is zero there, yet a magnetic field still exists around that region. Thus the simple Ampere's law fails between the plates.

Step 2: Concept of displacement current.

While the capacitor is charging, the electric field between its plates keeps changing with time. Maxwell proposed that a **changing electric field** also produces a magnetic field, and behaves like a current. This equivalent current, produced by the time-varying electric field, is called the **displacement current** I_d. It is given by

$$I_d = \varepsilon_0 \frac{d\Phi_E}{dt}$$

where Φ_E is the electric flux through the loop and ε_0 is the permittivity of free space. So the displacement current keeps the total current continuous across the gap between the plates.

Step 3: Ampere-Maxwell law.

Maxwell modified Ampere's law by adding the displacement current to the conduction current:

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 (I_c + I_d)$$

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

This is the Ampere-Maxwell law. It shows that a magnetic field is produced both by a conduction current and by a changing electric field.

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

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.

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

Correct Answer: —

Solution:

Step 1: Ray diagram (description).
A compound microscope uses two convex lenses: an **objective** of small focal length f_o and an **eyepiece** of slightly larger focal length f_e, fixed at the two ends of a tube. The small object AB is placed just beyond the focus of the objective. The objective forms a **real, inverted and magnified image** $A'B'$ inside the tube, between the eyepiece and its focus. This image $A'B'$ acts as the object for the eyepiece, which works like a simple microscope and forms a **virtual, inverted and highly magnified final image** $A''B''$ at the least distance of distinct vision D (about 25 cm) from the eye.
(Ray diagram: object AB near objective focus, refracted rays meet to form real image A'B' inside tube, then rays from A'B' pass through the eyepiece and diverge, their backward extensions locating the enlarged virtual image A"B" on the same side as the object.)

Step 2: Magnifying power definition.

Magnifying power M is the ratio of the angle subtended at the eye by the final image to the angle subtended by the object when placed at distance D. It equals the product of the linear magnification of the objective m_o and the angular magnification of the eyepiece m_e:

$$M = m_o \times m_e$$

Step 3: Magnification by the objective.

$$m_o = \frac{v_o}{u_o} = \frac{L}{f_o}$$

where v_o and u_o are the image and object distances for the objective and L is the tube length (the distance between the objective image and the objective, taken nearly equal to the tube length).

Step 4: Magnification by the eyepiece.

The eyepiece acts as a simple microscope with the final image at the near point D:

$$m_e = 1 + \frac{D}{f_e}$$

Step 5: Total magnifying power.

$$M = \frac{L}{f_o}\left(1 + \frac{D}{f_e}\right)$$

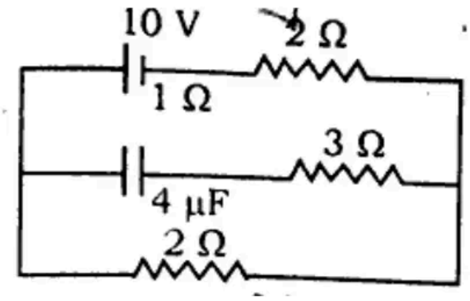
When the final image is formed at infinity (relaxed eye), $m_e = D/f_e$ and

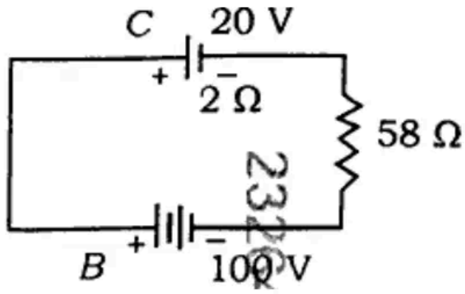
$$M = \frac{L}{f_o} \cdot \frac{D}{f_e}$$

$$\boxed{M = \frac{L}{f_o}\left(1 + \frac{D}{f_e}\right) \text{ (image at near point)}}$$

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

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):

Step 1: Behaviour of the capacitor in steady state.

In the steady state a fully charged capacitor allows no current to pass. So the branch containing the 4 μF capacitor and the lower 2 Ω resistor carries **no current**.

Step 2: Reduce the circuit.

The current therefore flows only in the loop made of the 10 V cell (internal resistance 1 Ω) in series with the 2 Ω resistor, joined across the 3 Ω resistor. All these are effectively in series in this single loop.

$$R_{total} = 1 + 2 + 3 = 6\ \Omega$$

Step 3: Current supplied by the battery.

$$I = \frac{E}{R_{total}} = \frac{10}{6} = 1.67\ \text{A}\ \left(= \tfrac{5}{3}\ \text{A}\right)$$

Step 4: Terminal voltage of the cell.

$$V = E - Ir = 10 - \frac{5}{3} \times 1 = 10 - 1.67 = 8.33\ \text{V}\ \left(= \tfrac{25}{3}\ \text{V}\right)$$

Step 5: Voltage across the capacitor.

The capacitor branch is connected across the 3 Ω resistor. Since no current flows in that branch, there is no potential drop across the lower 2 Ω resistor, so the full voltage across the 3 Ω resistor appears across the capacitor:

$$V_C = I \times 3 = \frac{5}{3} \times 3 = 5\ \text{V}$$

Step 6: Charge on the capacitor.

$$Q = C V_C = 4\,\mu\text{F} \times 5\,\text{V} = 20\,\mu\text{C}$$

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

Option 2 (cell C):

Step 1: Meaning of EMF.

The **electromotive force (EMF)** of a cell is the work done by the cell in driving a unit positive charge round the complete circuit, i.e. the energy supplied by the cell per coulomb of charge. It equals the potential difference across the cell's terminals when no current is drawn (open circuit).

Step 2: Identify the EMFs and resistances.

Cell C: $E_C = 20\,\text{V}$, internal resistance $r = 2\,\Omega$. Battery B: $E_B = 100\,\text{V}$, negligible internal resistance. External resistor $= 58\,\Omega$. In the figure the positive terminals of both C and B face the same (left) junction, so the two cells **oppose** each other.

Step 3: Net EMF and current.

$$E_{net} = E_B - E_C = 100 - 20 = 80\,\text{V}$$

$$R_{total} = 58 + 2 = 60\,\Omega$$

$$I = \frac{E_{net}}{R_{total}} = \frac{80}{60} = \frac{4}{3} = 1.33\ \text{A}$$

Step 4: Terminal voltage of cell C.

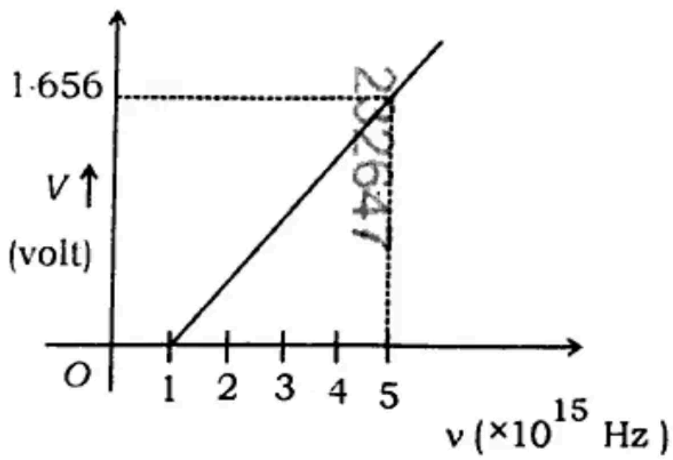
Since the stronger 100 V battery drives the current backwards through cell C, cell C is being charged; current enters its positive terminal. For a cell that is being charged the terminal voltage is greater than the EMF:

$$V_C = E_C + Ir = 20 + \frac{4}{3} \times 2 = 20 + 2.67 = 22.67\ \text{V}\ \left(= \tfrac{68}{3}\ \text{V}\right)$$

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

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 $V_C = E + Ir$.

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: Einstein's photoelectric equation in terms of stopping potential.

The maximum kinetic energy of the emitted electrons equals eV, where V is the stopping potential:

$$eV = h\nu - \phi$$

Dividing by e:

$$V = \frac{h}{e}\nu - \frac{\phi}{e}$$

This is a straight line of the form $V = m\nu + c$. So the **slope** of the V versus ν graph is h/e, and the graph cuts the frequency axis ($V = 0$) at the **threshold frequency** ν_0.

Step 2: Read two points from the graph.
The line crosses the ν-axis at $\nu_0 = 1 \times 10^{15}$ Hz (where $V = 0$), and passes through $V = 1.656$ V at $\nu = 5 \times 10^{15}$ Hz.

Step 3: Slope gives h/e.

$$\frac{h}{e} = \text{slope} = \frac{\Delta V}{\Delta \nu} = \frac{1.656 - 0}{(5-1) \times 10^{15}} = \frac{1.656}{4 \times 10^{15}}$$

$$\frac{h}{e} = 4.14 \times 10^{-16} \text{ V s}$$

Step 4: Work function from the threshold frequency.
At the threshold frequency the stopping potential is zero, so $\phi = h\nu_0$. In electron-volt units,

$$\phi\,(\text{in eV}) = \frac{h}{e}\,\nu_0 = (4.14 \times 10^{-16}) \times (1 \times 10^{15}) = 0.414 \text{ eV}$$

Converting to joules,

$$\phi = 0.414 \times 1.6 \times 10^{-19} = 6.62 \times 10^{-20} \text{ J}$$

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

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:

Concept: The nuclear force is the strong attractive force that binds protons and neutrons (nucleons) together inside a nucleus, in spite of the strong electrostatic repulsion between the positively charged protons.

Characteristics of nuclear force:

1. **Strongest force in nature:** At nuclear distances it is about 100 times stronger than the electrostatic force and about 10^{38} times stronger than the gravitational force.
2. **Short range:** It acts only up to a distance of about 2 to 3 fm (1 fm = 10^{-15} m). Beyond a few femtometres it becomes practically zero.
3. **Charge independent:** The force between neutron and neutron, proton and neutron, and proton and proton (nuclear part only) is the same. It does not depend on the charge of the nucleons.
4. **Attractive and repulsive:** It is strongly attractive for separations greater than about 0.7 fm, but becomes repulsive for separations smaller than 0.7 fm. This repulsive core keeps the nucleus from

collapsing.

5. **Saturated (short-range saturation):** A nucleon interacts only with its nearest neighbours, not with every other nucleon in the nucleus. This is why binding energy per nucleon is almost constant for medium and heavy nuclei.

6. **Non-central and spin dependent:** The force depends on the relative orientation of the spins of the nucleons, so it is not purely a central force.

Difference from gravitational force:

• Nuclear force is about 10^{38} times stronger.

• Nuclear force is very short range ($\sim$ few fm); gravitation has infinite range.

• Gravitation is always attractive and depends on mass; nuclear force can be attractive or repulsive and is independent of charge/mass type.

Difference from electric (electrostatic) force:

• Nuclear force is about 100 times stronger at nuclear distances.

• Electric force is a long-range inverse-square force; nuclear force acts only over a few fm.

• Electric force acts only between charged particles and can be attractive or repulsive depending on sign; nuclear force is charge independent and acts between all nucleons.

$$\boxed{\text{Nuclear force: strongest, short range } (\sim 2 \text{ fm}),\ \text{charge independent, saturated}}$$

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 $E_n = -\frac{13.6}{n^2}$ 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: Write the energy formula. The energy of the n^{th} level of hydrogen is

$$E_n = -\frac{13.6}{n^2} \text{ eV.}$$

Step 2: Absorption condition. When a photon is absorbed, the electron jumps from a lower level A (quantum number n_A) to a higher level B (quantum number n_B). The photon energy equals the energy difference:

$$E_{photon} = E_{n_B} - E_{n_A} = 2.55 \text{ eV.}$$

So

$$-\frac{13.6}{n_B^2} - \left(-\frac{13.6}{n_A^2}\right) = 2.55.$$

$$13.6\left(\frac{1}{n_A^2} - \frac{1}{n_B^2}\right) = 2.55.$$

$$\frac{1}{n_A^2} - \frac{1}{n_B^2} = \frac{2.55}{13.6} = 0.1875.$$

Step 3: Try $n_A = 2$. Then $\frac{1}{n_A^2} = \frac{1}{4} = 0.25$, so

$$\frac{1}{n_B^2} = 0.25 - 0.1875 = 0.0625 = \frac{1}{16} \Rightarrow n_B^2 = 16 \Rightarrow n_B = 4.$$

Step 4: Verify with actual energies. $E_2 = -\frac{13.6}{4} = -3.40$ eV and $E_4 = -\frac{13.6}{16} = -0.85$ eV.

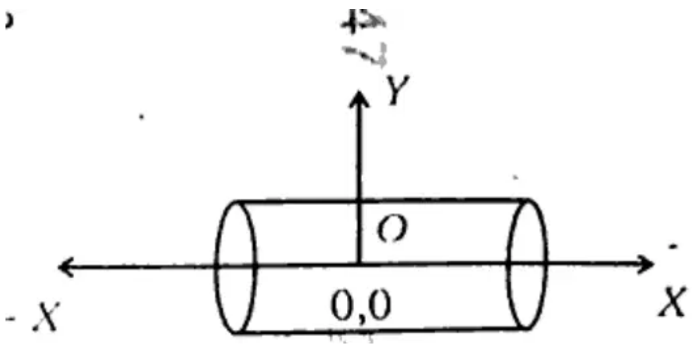
$$E_4 - E_2 = -0.85 - (-3.40) = 2.55 \text{ eV.} \checkmark$$

Step 5: Rule out other guesses. For $n_A = 1$: $\frac{1}{n_B^2} = 1 - 0.1875 = 0.8125$, giving $n_B^2 = 1.23$, not a whole number. For $n_A = 3$: $\frac{1}{n_B^2} = 0.1111 - 0.1875 < 0$, impossible. So the only valid solution is $n_A = 2,\ n_B = 4$.

$$\boxed{n_A = 2 \ \text{(state A)}, \qquad n_B = 4 \ \text{(state B)}}$$

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 flux through the cylinder

Statement of Gauss's law: The total electric flux through any closed surface equals $1/\varepsilon_0$ times the net charge enclosed by that surface:

$$\phi = \oint \vec{E} \cdot d\vec{A} = \frac{q_{enc}}{\varepsilon_0}.$$

Step 1: Geometry. The cylinder lies along the X-axis with centre O at the origin. Its two flat (plane) faces are at $x = +15$ cm and x

$= -15$ cm. Radius of each flat face $r = 3.5$ cm $= 0.035$ m.
Area of a flat face:

$$A = \pi r^2 = 3.14 \times (0.035)^2 = 3.85 \times 10^{-3}\ \mathrm{m}^2.$$

Step 2: Flux ϕ_1 through the right plane face (x > 0). Here $\vec{E} = +100\,\hat{i}$ points along $+x$ and the outward normal also points along $+x$, so the angle between them is $0°$:

$$\phi_1 = EA\cos 0^\circ = 100 \times 3.85 \times 10^{-3} = +0.385\ \mathrm{N\,m^2/C}.$$

Step 3: Flux ϕ_2 through the left plane face (x < 0). Here $\vec{E}$ is negative, i.e. it points along $-x$ with magnitude 100 N/C, and the outward normal of this face also points along $-x$. The angle between them is again $0°$:

$$\phi_2 = EA\cos 0^\circ = 100 \times 3.85 \times 10^{-3} = +0.385\ \mathrm{N\,m^2/C}.$$

Step 4: Flux ϕ_3 through the curved surface. On the curved surface the outward normal is radial (perpendicular to the X-axis), while $\vec{E}$ is along the X-axis. The angle between them is $90°$:

$$\phi_3 = EA' \cos 90^\circ = 0.$$

Step 5: Net flux.

$$\phi = \phi_1 + \phi_2 + \phi_3 = 0.385 + 0.385 + 0 = 0.770\ \mathrm{N\,m^2/C}.$$

Step 6: Net charge inside (Gauss's law).

$$q_{enc} = \varepsilon_0 \phi = (8.85 \times 10^{-12}) \times 0.770.$$

$$q_{enc} = 6.81 \times 10^{-12}\ \text{C} \approx 6.8\ \text{pC}.$$

$$\boxed{\phi_1 = \phi_2 = 0.385\ \text{N m}^2/\text{C},\ \phi_3 = 0,\ q_{enc} \approx 6.8 \times 10^{-12}\ \text{C}}$$

Option 2: Capacitance of a parallel plate capacitor partially filled with a dielectric

Step 1: Set-up. Consider a parallel plate capacitor with plate area A and plate separation d. A dielectric slab of dielectric constant K and thickness t ($t < d$) is inserted between the plates. The remaining gap of thickness $(d - t)$ is vacuum (or air).

Step 2: Field in the vacuum region. If σ is the surface charge density on the plates and Q the charge, the field in the free (vacuum) region is

$$E_0 = \frac{\sigma}{\varepsilon_0} = \frac{Q}{\varepsilon_0 A}.$$

Step 3: Field inside the dielectric. Inside the dielectric the field is reduced by the factor K:

$$E = \frac{E_0}{K} = \frac{Q}{K\varepsilon_0 A}.$$

Step 4: Potential difference between the plates. The total potential drop is the field times distance in each region:

$$V = E_0(d - t) + E\,t = E_0(d - t) + \frac{E_0}{K}t.$$

$$V = \frac{Q}{\varepsilon_0 A}\left[(d-t) + \frac{t}{K}\right].$$

Step 5: Capacitance. Using $C = \dfrac{Q}{V}$:

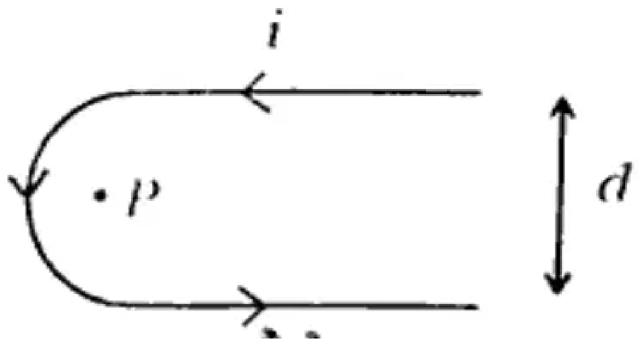
$$C = \frac{Q}{\dfrac{Q}{\varepsilon_0 A}\left[(d-t) + \dfrac{t}{K}\right]} = \frac{\varepsilon_0 A}{(d-t) + \dfrac{t}{K}}.$$

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

Check: if $t = 0$ (no dielectric), $C = \varepsilon_0 A/d$; if $t = d$ (fully filled), $C = K\varepsilon_0 A/d$, as expected.

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.

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: Magnetic field of the hairpin wire at P

Step 1: Identify the geometry. The hairpin has three parts: a semicircular arc and two long straight parallel wires. The two straight wires are separated by a distance d, and P is the centre of the semicircle. Therefore the radius of the semicircle is

$$R = \frac{d}{2}.$$

Each straight wire is at perpendicular distance $a = R = \frac{d}{2}$ from P, and P lies on the line through the end of each straight wire (each straight part is 'semi-infinite', running from the arc to infinity).

Step 2: Field due to the semicircular arc. For a full circular loop the field at the centre is $\mu_0 i/2R$; a semicircle is half of it:

$$B_{arc} = \frac{\mu_0 i}{4R} = \frac{\mu_0 i}{4\left(\frac{d}{2}\right)} = \frac{\mu_0 i}{2d}.$$

Step 3: Field due to one semi-infinite straight wire. For a straight wire the Biot-Savart result is $B = \frac{\mu_0 i}{4\pi a}(\sin\theta_1 + \sin\theta_2)$. For a semi-infinite wire whose near end is level with P, the angles are $\theta_1 = 0°$ (at the near end) and $\theta_2 = 90°$ (towards infinity):

$$B_{straight} = \frac{\mu_0 i}{4\pi a}(\sin 0° + \sin 90°) = \frac{\mu_0 i}{4\pi a} = \frac{\mu_0 i}{4\pi\left(\frac{d}{2}\right)} = \frac{\mu_0 i}{2\pi d}.$$

Step 4: Both straight wires add. By the direction of current (Right Hand Rule), both straight segments produce a field at P in the same direction as the arc's field (into or out of the plane). So the two straight wires together give

$$B_{2\,straight} = 2 \times \frac{\mu_0 i}{2\pi d} = \frac{\mu_0 i}{\pi d}.$$

Step 5: Total field at P.

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

Take $\frac{\mu_0 i}{2d}$ common; note $\frac{\mu_0 i}{\pi d} = \frac{\mu_0 i}{2d} \cdot \frac{2}{\pi}$:

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

$$\boxed{B = \frac{\mu_0 i}{2d}\left[1 + \frac{2}{\pi}\right]} \quad \text{(proved)}$$

Option 2: Radial field and moving coil galvanometer

Radial magnetic field: A radial magnetic field is one in which the field lines are always directed along the radius, so that the plane of the current-carrying coil is always parallel to the field (and the coil's normal is always perpendicular to $\vec{B}$). It is produced by using concave (cylindrically curved) pole pieces of the magnet together with a soft-iron cylindrical core inside the coil.

Working of moving coil galvanometer (MCG): A rectangular coil of N turns and area A is suspended (or pivoted on a spring) in a radial magnetic field B. When current I passes through it, the coil experiences a torque

$$\tau = NBIA \sin\theta.$$

Because the field is radial, the plane of the coil is always parallel to $\vec{B}$, so $\theta = 90°$ and $\sin\theta = 1$ at every position. Hence the deflecting torque is $NBIA$, independent of the deflection.
The suspension provides a restoring torque $k\phi$ (where k is the torsion constant and ϕ the deflection). At equilibrium:

$$NBIA = k\phi \;\Rightarrow\; I = \frac{k}{NBA}\,\phi.$$

Thus $I \propto \phi$: deflection is directly proportional to current, giving a uniform (linear) scale. This linearity is the main advantage of using a radial field.

Conversion into an ammeter: Connect a small resistance (shunt) S in parallel with the galvanometer of resistance G. If I_g is the full-scale galvanometer current and I the maximum current to be measured,

$$S = \frac{I_g G}{I - I_g}.$$

The low combined resistance keeps the ammeter's resistance small, so it is connected in series in the circuit.

Conversion into a voltmeter: Connect a high resistance R in series with the galvanometer. To read up to a maximum voltage V,

$$R = \frac{V}{I_g} - G.$$

The high total resistance makes the voltmeter draw very little current, so it is connected in parallel across the element whose voltage is measured.

$$\boxed{S = \frac{I_g G}{I - I_g}\ \text{(ammeter)}, \qquad R = \frac{V}{I_g} - G\ \text{(voltmeter)}}$$

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 $\mu_0 i/2d$.

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 focus and image distance

Step 1 (Position of focus): In a convex mirror the reflecting surface bulges towards the object. A beam of rays parallel to the principal axis, after reflection, diverges outward. When produced backward, these reflected rays appear to meet at a single point F behind the mirror. This point is the principal focus. Because the focus is virtual and lies behind the mirror, the focal length of a convex mirror is taken as positive. Ray diagram (described): draw the convex mirror with pole P; mark the focus F and centre of curvature C on the principal axis behind the mirror; a ray parallel to the axis strikes the mirror and reflects so that its backward extension passes through F, so that PF = f.

Step 2 (Given data and sign convention): Focal length $f = +2.0\,\text{m}$ (convex mirror). A convex mirror always forms a virtual, erect and diminished image, so the magnification is positive: $m = +\frac{1}{2}$.

Step 3 (Magnification relation):

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

So

$$+\frac{1}{2} = -\frac{v}{u} \Rightarrow v = -\frac{u}{2}$$

Step 4 (Mirror formula):

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$$

Substitute $v = -u/2$:

$$\frac{1}{-u/2} + \frac{1}{u} = \frac{1}{f}$$

$$-\frac{2}{u} + \frac{1}{u} = \frac{1}{f}$$

$$-\frac{1}{u} = \frac{1}{f} \Rightarrow u = -f = -2.0\,\mathrm{m}$$

Step 5 (Result): The negative sign shows the boy stands in front of the mirror. Distance from mirror $= 2.0\,\mathrm{m}$. Check: $v = -u/2 = +1.0\,\mathrm{m}$ (image 1.0 m behind the mirror, virtual and erect); $m = -v/u = -(1.0)/(-2.0) = +0.5$, i.e. half the height.

$$\boxed{u = 2.0 \text{ m from the convex mirror}}$$

Option 2: Wavefront and refraction by Huygens' principle

Step 1 (Wavefront): A wavefront is the locus of all points of a medium that are vibrating in the same phase at a given instant. The wave advances perpendicular to the wavefront, and the distance moved per unit time equals the wave speed. A point source gives spherical wavefronts, while a very distant source gives plane wavefronts.

Step 2 (Huygens' principle): (i) Every point on a wavefront acts as a fresh source of secondary wavelets that spread forward in all directions with the wave speed of the medium. (ii) The new wavefront after a time interval is the forward tangential envelope (surface of tangency) of all these secondary wavelets.

Step 3 (Set-up for refraction): Let a plane wavefront AB in medium 1 (speed v_1) reach a plane boundary XY separating it from medium 2 (speed v_2, with $v_2 < v_1$). Let the incident wavefront make angle i with the surface and the refracted wavefront make angle r.

Step 4 (Geometry): While the wavelet from B travels distance $BC = v_1 t$ in medium 1 to reach the surface at C, the wavelet from A advances distance $AD = v_2 t$ into medium 2. In the right triangles ABC and ADC (common hypotenuse AC):

$$\sin i = \frac{BC}{AC} = \frac{v_1 t}{AC}, \qquad \sin r = \frac{AD}{AC} = \frac{v_2 t}{AC}$$

Step 5 (Snell's law): Dividing the two relations,

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \frac{n_2}{n_1} = \text{constant}$$

This is Snell's law of refraction, so Huygens' principle explains the bending of waves at a boundary. Since $v_2 < v_1$, the ray bends towards the normal on entering the denser medium.

$$\boxed{\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \text{constant (Snell's law)}}$$

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 $f = +2.0\,\mathrm{m}$. 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: Formation of p-type / n-type crystals and maximum wavelength in germanium

Step 1 (n-type crystal): Start from a pure (intrinsic) tetravalent semiconductor such as silicon or germanium, in which every atom shares its 4 valence electrons in covalent bonds. Add a small amount of a pentavalent impurity (P, As, Sb or Bi). Four of the impurity's five valence electrons form bonds; the fifth is loosely bound and becomes free even at room temperature. These donated electrons make electrons the majority carriers, giving an n-type crystal.

Step 2 (p-type crystal): To the same pure semiconductor add a trivalent impurity (B, Al, In or Ga). Its 3 valence electrons complete only three of the four bonds; the missing bond is a hole that can accept an electron. These acceptor holes make holes the majority carriers, giving a p-type crystal.

Step 3 (Condition for pair creation): To lift one electron from the valence band to the conduction band (creating one electron-hole pair), the photon energy must be at least equal to the band-gap energy E_g. The largest wavelength corresponds to the smallest energy, i.e. $E = E_g$:

$$E_g = h\nu = \frac{hc}{\lambda_{max}} \Rightarrow \lambda_{max} = \frac{hc}{E_g}$$

Step 4 (Convert band-gap to joule):

$$E_g = 0.65 \text{ eV} = 0.65 \times 1.6 \times 10^{-19} \text{ J} = 1.04 \times 10^{-19} \text{ J}$$

Step 5 (Substitute): With $h = 6.6 \times 10^{-34}$ J s and $c = 3 \times 10^8$ m/s,

$$hc = 6.6 \times 10^{-34} \times 3 \times 10^8 = 1.98 \times 10^{-25} \text{ J m}$$

$$\lambda_{max} = \frac{1.98 \times 10^{-25}}{1.04 \times 10^{-19}} = 1.9 \times 10^{-6} \text{ m}$$

Step 6 (Result): $\lambda_{max} \approx 1.9 \times 10^{-6}$ m $= 1.9\ \mu$m (about 19000 Å, in the infrared region).

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

Option 2: Temperature dependence and conductivity of an n-type semiconductor

Step 1 (Metal): In a metal the number density of free electrons is fixed. On raising the temperature the lattice ions vibrate more strongly, electrons collide more often, the relaxation time τ falls, so resistance rises and conductivity decreases. Metals therefore have a positive temperature coefficient of resistance.

Step 2 (Semiconductor): In a semiconductor, raising the temperature breaks many more covalent bonds and lifts electrons across the band-gap, so the carrier density n increases roughly exponentially. This large rise in carrier number outweighs the fall in relaxation time, so resistance falls and conductivity increases. Semiconductors therefore have a negative temperature coefficient of resistance.

Step 3 (Formula): The conductivity of a doped semiconductor carrying both types of charge is

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

where n_e, n_h are the electron and hole densities and μ_e, μ_h their mobilities.

Step 4 (Products, in CGS-practical units):

$$n_e\,\mu_e = (8 \times 10^{13})(2.3 \times 10^4) = 1.84 \times 10^{18}$$

$$n_h\,\mu_h = (5 \times 10^{12})(100) = 5 \times 10^{14}$$

$$n_e\mu_e + n_h\mu_h = 1.84 \times 10^{18} + 0.0005 \times 10^{18} = 1.8405 \times 10^{18}$$

Step 5 (Substitute e = 1.6×10^{-19} C):

$$\sigma = 1.6 \times 10^{-19} \times 1.8405 \times 10^{18} = 0.294\ \Omega^{-1}\text{cm}^{-1}$$

Step 6 (Result): $\sigma \approx 0.294\ \Omega^{-1}\text{cm}^{-1} = 29.4\ \Omega^{-1}\text{m}^{-1}$ (i.e. 29.4 S/m). The electron term dominates because electrons are the majority carriers and have the far higher mobility, as expected for an n-type sample.

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

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.