UP Board Class 12 Physics 2026 Set 346 DW 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. Two electrons in air are at a distance of 1 m. Gravitational and electrostatic forces acting between them are F_1 and F_2 respectively. If the dielectric constant of the medium between them becomes infinite, then:

(A) F_1 remains unchanged and F_2 becomes halved.

(B) F_1 remains unchanged but F_2 becomes zero.

(C) $F_1 = 0$ and $F_2 = \infty$.

(D) Both F_1 and F_2 will remain unchanged.

Correct Answer: (B) F_1 remains unchanged but F_2 becomes zero.

SOLUTION:

Step 1: Write the ratio of the forces to a medium factor.
Let the forces in air be F_1 (gravitational) and F_2^{air} (electrostatic). Only the electrostatic force carries the medium constant K in its denominator: $F_2 = F_2^{air}/K$.

Step 2: Reason physically about gravity.
Gravity is a mass-mass interaction. A dielectric between the charges polarises electrically but does nothing to the masses, so the

gravitational pull F_1 is completely independent of K and stays fixed at Gm_e^2/r^2.

Step 3: Push the dielectric constant to infinity.

A medium with $K \to \infty$ behaves like a perfect conductor that fully screens the electric field between the charges. Substituting: $F_2 = F_2^{air}/\infty = 0$. The electric force is entirely cancelled.

Step 4: Match to an option.

Gravitational force unchanged, electrostatic force reduced to zero. That is exactly statement (ii).

$$\boxed{F_1 = \text{const}, \ F_2 \to 0}$$

Quick Tip: Coulomb force in a medium is divided by the dielectric constant K, while gravitation ignores K entirely. Let $K \to \infty$.

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2. In photoelectric emission, the value of the saturation current depends on:

(A) the frequency of incident light.

(B) the work function of the surface.

(C) the intensity of incident light.

(D) the anode potential.

Correct Answer: (C) the intensity of incident light.

SOLUTION:

Step 1: Separate "how many" from "how energetic".
Photoelectric results split into two families: quantities that fix the electron count (current) and quantities that fix the electron energy (stopping potential). Saturation current belongs to the first family.

Step 2: Use the one-photon-one-electron rule.
Photoemission is a one-to-one photon-electron event. Doubling the light intensity means twice as many photons per second hit the plate, so roughly twice as many electrons are released per second, doubling the saturation current. Hence I_{sat} tracks intensity directly.

Step 3: Test each distractor.
Frequency changes the energy each electron carries away, shifting the stopping potential but not the count. Work function only sets the threshold frequency for emission. Anode potential merely collects the electrons; once all of them are collected the current saturates and extra voltage does nothing.

Step 4: Pick the answer.
Only the intensity governs the saturation current, so statement (iii) is right.

$$\boxed{\text{Intensity of incident light}}$$

Quick Tip: Saturation current counts electrons emitted per second, and each photon frees one electron, so think about what controls the photon count.

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3. A narrow electron beam passes undeviated through an electric field of 4×10^4 V/m and a magnetic field 2×10^{-3} weber/m^2 applied at the same place. The speed of the electron beam will be:

(A) 2×10^7 m/s

(B) 8×10^4 m/s

(C) 6×10^6 m/s

(D) 6×10^7 m/s

Correct Answer: (A) 2×10^7 m/s

SOLUTION:

Step 1: Recognise the setup as a velocity selector.

Perpendicular E and B fields let only one particular speed pass in a straight line. For that speed the two sideways forces are equal and opposite, so the net transverse force is zero.

Step 2: Equate the magnitudes of the forces.

Electric force magnitude $= eE$; magnetic force magnitude $= evB$. Setting them equal: $eE = evB$, and cancelling the electron charge e leaves $E = vB$.

Step 3: Rearrange and insert numbers.

$v = \dfrac{E}{B} = \dfrac{4 \times 10^4}{2 \times 10^{-3}}$. Handle the mantissa and powers of ten separately: $4/2 = 2$ and $10^4/10^{-3} = 10^7$.

Step 4: Combine.

$v = 2 \times 10^7$ m/s, so option (i) is correct.

$$\boxed{v = 2 \times 10^7 \text{ m/s}}$$

Quick Tip: For an undeviated beam in crossed fields the electric and magnetic forces cancel, so $qE = qvB \Rightarrow v = E/B$.

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4. Resistances of 10 Ω and 15 Ω are connected in parallel. The combination is connected with a battery of V volt. Choose the correct statement.

(A) Value of current in the 10 Ω resistance will be smaller than the current flowing in the 15 Ω resistance.

(B) Same current will flow in both the resistances.

(C) Potential drop in both the resistances will be different.

(D) Potential drop in both the resistances will be same.

Correct Answer: (D) Potential drop in both the resistances will be same.

SOLUTION:

Step 1: Draw the nodes.
In a parallel network the two resistors have their left ends tied together and their right ends tied together, and these two junction points are the battery terminals. Voltage is a property of the junction pair, so whatever appears across one branch appears across the other.

Step 2: Fix the common voltage.
That common voltage is simply the battery e.m.f. V. Hence $V_{10} = V_{15} = V$; the drops are identical, confirming statement (iv) and killing statement (iii).

Step 3: Compare branch currents with Ohm's law.

Current in a branch is $I = V/R$. The smaller resistance carries the bigger current, so $I_{10} = V/10$ exceeds $I_{15} = V/15$. Thus the $10\,\Omega$ current is greater (statement (i) claims the opposite, so it is false), and the currents are unequal (statement (ii) is false).

Step 4: Select.
Only the equal-potential-drop statement survives.

$$\boxed{\text{Same potential drop across both}}$$

Quick Tip: Elements in parallel share the same two terminals, so the voltage across each is identical; use $I = V/R$ to compare currents.

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5. A convex and a concave lens are placed in contact. The focal lengths (F) of both are the same. The combination will behave:

(A) as a concave lens.

(B) as a convex lens.

(C) as a planoconvex lens.

(D) as a plane plate.

Correct Answer: (D) as a plane plate.

SOLUTION:

Step 1: Use the combined-power rule.
Two thin lenses in contact form an equivalent lens whose power is the algebraic sum of the individual powers, $P = P_1 + P_2$, with power $P = 1/f$ measured in dioptres.

Step 2: Write the two powers with a common magnitude.

Both lenses have equal focal-length magnitude F. Convex gives $P_1 = +1/F$; concave gives $P_2 = -1/F$. They are equal in size but opposite in sign.

Step 3: Cancel.

Adding, $P = 1/F - 1/F = 0$. The converging action of the convex lens is exactly undone by the diverging action of the concave lens.

Step 4: Physical meaning.

Zero power corresponds to infinite focal length: rays pass through without net bending, just as through a flat sheet of glass. The combination therefore acts as a plane plate, option (iv).

$$\boxed{F_{comb} = \infty, \text{ acts as plane plate}}$$

Quick Tip: Powers add for lenses in contact; equal-magnitude convex ($+1/F$) and concave ($-1/F$) give zero net power, i.e. infinite focal length.

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6. The wavelength of the de-Broglie wave associated with a moving particle does not depend on:

(A) mass

(B) velocity

(C) charge

(D) momentum

Correct Answer: (C) charge

SOLUTION:

Step 1: Start from momentum, not charge.

Louis de Broglie linked a particle's wavelength only to its momentum: $\lambda = h/p$. Momentum for a slow particle is $p = mv$, so the wavelength is fully determined once mass and speed are known.

Step 2: Expand the variables inside the formula.

Substituting $p = mv$ gives $\lambda = h/(mv)$. This single expression already involves momentum, mass and velocity, so options (i), (ii) and (iv) all influence λ.

Step 3: Note the absent quantity.

Electric charge does not appear anywhere in $h/(mv)$. Charge affects how a particle responds to electric and magnetic fields, but not the matter-wave wavelength itself for a given momentum.

Step 4: Answer.

Therefore the de-Broglie wavelength does not depend on charge, option (iii).

$$\boxed{\lambda \text{ independent of charge}}$$

Quick Tip: Recall $\lambda = h/mv$. Which of mass, velocity, momentum or charge is absent from this formula?

7. Write formula for the position of minima in the diffraction pattern of a single slit.

Correct Answer: —

SOLUTION:

Step 1: Set up the geometry. Consider a slit of width a on which a plane wavefront of wavelength λ falls normally. Light diffracts and is observed on a distant screen (or through a converging lens). Let θ be the angle a diffracted direction makes with the normal to the slit.

Step 2: Pair-cancellation reasoning. Split the slit into two equal halves. Rays from a point in the upper half and the matching point in the lower half differ in path by $\frac{a}{2}\sin\theta$. When this equals $\frac{\lambda}{2}$ every such pair cancels, giving darkness; that means $a\sin\theta = \lambda$. Splitting into $2n$ strips generalises this.

Step 3: General result. Complete cancellation therefore happens whenever the extreme path difference is an integral multiple of λ:

$$\boxed{a\sin\theta = n\lambda, \quad n = \pm1, \pm2, \pm3, \ldots}$$

For small angles this reduces to $\theta_n \approx \dfrac{n\lambda}{a}$. The integer n names the order of the dark fringe, and $n = 0$ is left out since it corresponds to the bright central band.

Quick Tip: For a single slit, a dark fringe forms when the extreme-ray path difference across the slit width is a whole number of wavelengths.

8. Mainly on which factor does the stability of a nucleus depend?

Correct Answer: —

SOLUTION:

Step 1: Frame the competition of forces. Inside a nucleus two influences compete: the long-range Coulomb repulsion among the positively charged protons, and the strong but short-range nuclear attraction between every pair of nucleons. Neutrons are electrically neutral, so adding them boosts the binding attraction while adding no repulsion.

Step 2: Identify the controlling quantity. Because the number of neutrons decides how much extra binding is available to counter proton repulsion, the key parameter is how many neutrons accompany each proton, that is the N/Z ratio. Too few neutrons and Coulomb repulsion dominates; too many and the nucleus is neutron-rich and again unstable.

Step 3: Conclusion. Thus nuclear stability is governed chiefly by the neutron-proton ratio.

$$\boxed{\text{Chief factor} = \frac{\text{number of neutrons}}{\text{number of protons}}\ (N/Z)}$$

Quick Tip: Think about the balance between proton-proton Coulomb repulsion and the neutrons that supply extra nuclear binding.

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9. From which part of the atom are radioactive radiation emitted?

Correct Answer: —

SOLUTION:

Step 1: Recall the two zones of an atom. An atom has a tiny, massive, positively charged central core (the nucleus of protons and neutrons) surrounded by a comparatively vast cloud of orbiting electrons.

Step 2: Match radiation to its zone. Radioactive decay changes the identity of the nucleus (alpha decay removes 2 protons and 2 neutrons, beta decay converts a neutron to a proton, gamma decay releases nuclear excitation energy). All of these involve only the nucleons, so the electron cloud plays no part in producing α, β or γ radiation.

Step 3: State clearly. Hence radioactive radiation comes out of the nuclear core, not the electron shells.

$$\boxed{\text{Radioactive radiation is emitted from the atomic nucleus.}}$$

Quick Tip: Radioactivity involves changes in protons and neutrons, so look to the central core rather than the electron cloud.

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10. State the result obtained from Rutherford's α-particle scattering.

Correct Answer: —

SOLUTION:

Step 1: Summarise the observations. When alpha particles struck the thin gold foil, three things were seen: the great majority went through with little or no deflection, some turned through appreciable angles, and a rare few rebounded backwards.

Step 2: Draw conclusions from each observation. The undeflected majority tells us the atom is mostly hollow. A deflection needs a repulsive push, and a near-backward rebound needs an extremely intense push acting over a tiny region, meaning the positive charge and mass are not spread out but concentrated.

Step 3: The conclusion (nuclear model). Rutherford therefore proposed that each atom possesses a minute central nucleus that holds the whole positive charge and almost the entire mass, while the light electrons occupy the surrounding empty volume. This overturned the earlier uniform-sphere (plum-pudding) picture.

$\boxed{\text{Result: a small, heavy, positively charged nucleus exists at the atom's centre.}}$

Quick Tip: Most alpha particles passed straight through but a few bounced back, pointing to a tiny concentrated positive core.

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11. Define electromotive force of a cell.

Correct Answer: —

SOLUTION:

Step 1: Identify the source of the push. Inside a cell a non-electrostatic (chemical) action separates charge and maintains a steady potential difference between its plates. The measure of this driving action is the electromotive force.

Step 2: Give the definition as maximum potential difference. The EMF of a cell is the maximum potential difference between its two terminals, which appears when the cell is not delivering any current (open-circuit condition). At that instant no current flows, so there is no drop across the internal resistance and the full driving voltage is available.

Step 3: Restate energetically and note units. In energy terms it is the total energy the cell supplies to each coulomb of charge that passes through the whole circuit, $\varepsilon = W/q$, measured in volts.

$$\boxed{\varepsilon = \text{open-circuit terminal p.d.} = \frac{W}{q}}$$

Quick Tip: Think of the energy the cell gives to each unit charge, equal to the terminal voltage when no current is drawn.

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12. If electric field lines are mutually intersecting, then what is the meaning indicated?

Correct Answer: —

SOLUTION:

Step 1: Recall the rule connecting line and field. At every point on an electric line of force, the direction of the electric field is along the tangent to the line at that point. This fixes exactly one direction per point.

Step 2: Test the crossing idea. Suppose two lines actually met at some point P. You could then draw two tangents at P, one for each line, which means the field at P would be pointing in two directions at once. A vector quantity like $\vec{E}$ cannot simultaneously have two directions at the same location.

Step 3: Interpret the situation. Therefore mutually intersecting field lines signify a self-contradiction, two values of field direction at a single point, so such a configuration is not physically permitted; electric field lines are always drawn so that they do not cross.

$$\boxed{\text{Intersection would mean two directions of } \vec{E} \text{ at one point, which is impossible.}}$$

Quick Tip: A field line's tangent gives the field direction; a crossing would demand two directions of E at one point.

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13. What is displacement current? How is displacement current different from conduction current?

Correct Answer: —

SOLUTION:

Step 1: Why a new current was needed.
Consider charging a parallel plate capacitor. Apply Ampere's law $\oint \vec{B} \cdot d\vec{l} = \mu_0 I$ using two surfaces bounded by the same loop: one surface cut by the wire (gives current I) and one bulging surface passing between the plates (gives current 0). The two answers disagree, so the law is incomplete.

Step 2: Maxwell's fix.

Between the plates the charge $Q = \varepsilon_0 \Phi_E$, so a rising charge means a rising electric flux. Differentiating, $\dfrac{dQ}{dt} = \varepsilon_0 \dfrac{d\Phi_E}{dt}$. The right side is defined as the displacement current I_d.

Step 3: Definition.

Displacement current is the current equivalent of a changing electric flux:

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

It restores continuity, since I_d between the plates exactly equals the conduction current I_c in the wire.

Step 4: Contrast with conduction current.

Conduction current I_c needs a material with mobile charges and obeys $I_c = nAev_d$. Displacement current needs only a varying field and flows through empty space. One is transport of charge, the other is a field effect; both generate identical magnetic fields, which is why light and radio waves can travel through vacuum.

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

Quick Tip: Recall Maxwell's correction to Ampere's law: a changing electric flux acts as a current, $I_d = \varepsilon_0\, d\Phi_E/dt$, unlike conduction current which is real charge flow.

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14. A non-conducting cylinder is placed inside the electric field (E). The axis of the cylinder is parallel to the electric field. How much will be the total electric flux passing through the cylinder?

Correct Answer: —

SOLUTION:

Step 1: Use Gauss's law directly.

Gauss's law states that the net electric flux through any closed surface equals the enclosed charge divided by ε_0:

$$\Phi = \frac{q_{enclosed}}{\varepsilon_0}$$

Step 2: Charge inside the cylinder.

The field E is a uniform external field and the cylinder is non-conducting with no charge placed on or inside it. Hence $q_{enclosed} = 0$.

Step 3: Apply.

$$\Phi = \frac{0}{\varepsilon_0} = 0$$

Step 4: Physical picture.

In a uniform field every field line that enters the cylinder through one end must come out through the other end. Since as many lines enter as leave, the incoming (negative) flux cancels the outgoing (positive) flux, and the curved wall contributes nothing because the field just grazes along it. The net flux is therefore zero.

$$\boxed{\Phi_{total} = 0}$$

Quick Tip: No charge is enclosed, so by Gauss's law the net flux is zero; equivalently the flux entering one flat face equals the flux leaving the other.

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15. Assuming Earth as a spherical conductor of diameter 12,800 km, calculate its capacity.

Correct Answer: —

SOLUTION:

Step 1: Write capacitance in terms of ε_0.

For an isolated sphere, $C = 4\pi\varepsilon_0 R$. Take $\varepsilon_0 = 8.85 \times 10^{-12}\ \mathrm{C^2/N{\cdot}m^2}$, so $4\pi\varepsilon_0 = 1.112 \times 10^{-10}$ F/m.

Step 2: Radius of the Earth.

Diameter $= 12800$ km, therefore radius $R = 6400\ \mathrm{km} = 6.4 \times 10^6$ m.

Step 3: Multiply.

$$C = (1.112 \times 10^{-10})(6.4 \times 10^6)$$

$$C = 1.112 \times 6.4 \times 10^{-10+6} = 7.12 \times 10^{-4}\ \mathrm{F}$$

Step 4: Convert to microfarad.

$$C = 7.12 \times 10^{-4}\ \text{F} = 712\ \mu\text{F} \approx 711\ \mu\text{F}$$

Both routes (using 9×10^9 or $4\pi\varepsilon_0$) give the same answer, showing the Earth behaves like a capacitor of about $711\ \mu$F.

$$\boxed{C \approx 711\ \mu\text{F}}$$

Quick Tip: Use $C = 4\pi\varepsilon_0 R = R/(9 \times 10^9)$ with radius $R = 6.4 \times 10^6$ m (half the given diameter).

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16. Write the formula relating the radius and mass number of a nucleus and show that nuclear density does not depend on the mass number.

Correct Answer: —

SOLUTION:

Step 1: State the empirical relation.

The nuclear radius grows with mass number as $R = R_0 A^{1/3}$, with $R_0 \approx 1.2$ fm. Cubing gives $R^3 = R_0^3 A$, which is the key link we exploit.

Step 2: Density definition.

Density is mass per unit volume, $\rho = M/V$. For a nucleus of mass number A, the mass is $M = Am$ (with m the average nucleon mass) and the volume is that of a sphere, $V = \frac{4}{3}\pi R^3$.

Step 3: Insert the cubed radius.

Replace R^3 by $R_0^3 A$:

$$V = \frac{4}{3}\pi R_0^3 A$$

So the volume is directly proportional to A.

Step 4: Form the ratio.

$$\rho = \frac{Am}{\frac{4}{3}\pi R_0^3 A} = \frac{3m}{4\pi R_0^3}$$

Because both mass and volume rise in exact proportion to A, their ratio is constant. Numerically this comes out to about 2.3×10^{17} kg/m^3 for every nucleus.

Step 5: Interpretation.
A heavier nucleus simply occupies a proportionally larger volume, so packing of nucleons stays the same. Nuclear matter has a universal density set only by m and R_0.

$$\boxed{\rho = \frac{3m}{4\pi R_0^3} \text{ is independent of } A}$$

Quick Tip: Use $R = R_0 A^{1/3}$; then $V \propto A$ and $M \propto A$, so density M/V has A cancel out.

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17. Give Einstein's equation for photoelectric emission. The work function of a metal is 4.2 eV. Electrons are emitted due to light of wavelength 2000 Å. Find the stopping potential for the emitted electrons.

Correct Answer: —

SOLUTION:

Step 1: Set up the energy balance.

Einstein's equation says a photon's energy splits into the work function plus the electron's kinetic energy: $h\nu = W + eV_0$, where eV_0 is the energy needed to stop the fastest electron. Rearranged, $eV_0 = h\nu - W$.

Step 2: Photon energy in joules.

$$E = \frac{hc}{\lambda} = \frac{(6.6 \times 10^{-34})(3 \times 10^{8})}{2000 \times 10^{-10}}$$

$$E = \frac{1.98 \times 10^{-25}}{2 \times 10^{-7}} = 9.9 \times 10^{-19}\ \mathrm{J}$$

Step 3: Work function in joules.

$$W = 4.2\ \mathrm{eV} = 4.2 \times 1.6 \times 10^{-19} = 6.72 \times 10^{-19}\ \mathrm{J}$$

Step 4: Solve for stopping potential.

$$eV_0 = E - W = 9.9 \times 10^{-19} - 6.72 \times 10^{-19} = 3.18 \times 10^{-19}\ \mathrm{J}$$

$$V_0 = \frac{3.18 \times 10^{-19}}{1.6 \times 10^{-19}} = 1.99\ \mathrm{V} \approx 2.0\ \mathrm{V}$$

Working entirely in SI units gives the same result as the electron-volt shortcut.

$$\boxed{V_0 \approx 2.0\ \mathrm{V}}$$

Quick Tip: Photon energy $hc/\lambda = 12400/2000 = 6.2$ eV; subtract the 4.2 eV work function, and the stopping potential in volts equals the leftover energy in eV.

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18. Give the postulates of Bohr's atomic model and draw the energy level diagram for the first three lines of the Balmer series in the hydrogen atomic spectrum.

Correct Answer: —

SOLUTION:

Step 1: Restate Bohr's three assumptions.

• The electron moves in special non-radiating circular orbits; while in such an orbit it does not lose energy even though it is accelerating.

• Only orbits with angular momentum $L = mvr = n\hbar = \dfrac{nh}{2\pi}$ are allowed, so the orbits and their energies are quantised by the integer n.

• A photon is released or absorbed only during a jump between two allowed orbits, with $\Delta E = h\nu = \dfrac{hc}{\lambda}$.

Step 2: Level energies from the formula.

Using $E_n = -\dfrac{13.6}{n^2}$ eV:
$E_2 = -3.40$ eV, $E_3 = -1.51$ eV, $E_4 = -0.85$ eV, $E_5 = -0.54$ eV.

Step 3: Compute the first three Balmer photons.
All Balmer transitions land on $n = 2$.
$3 \to 2:\ \Delta E = -1.51 - (-3.40) = 1.89$ eV, so $\lambda = \dfrac{12400}{1.89} \approx 6563$ Å (red, Hα).
$4 \to 2:\ \Delta E = -0.85 - (-3.40) = 2.55$ eV, so $\lambda \approx 4861$ Å (blue-green, Hβ).
$5 \to 2:\ \Delta E = -0.54 - (-3.40) = 2.86$ eV, so $\lambda \approx 4340$ Å (violet, Hγ).

Step 4: How to sketch the diagram.
Stack horizontal energy levels with $n = 2$ at the bottom (-3.40 eV) and $n = 3, 4, 5$ crowding closer together above it as energy rises toward 0. From $n = 3$, $n = 4$ and $n = 5$ draw three separate downward arrows that all terminate on the $n = 2$ line. Label them Hα, Hβ, Hγ. The arrow from the highest level ($5 \to 2$) is the longest drop and carries the most energetic (shortest wavelength) photon.

$$\boxed{\text{Three Balmer arrows: } 3 \to 2,\ 4 \to 2,\ 5 \to 2}$$

Quick Tip: State Bohr's three postulates (stable orbits, quantised angular momentum $mvr = nh/2\pi$, photon on transition); Balmer lines are jumps to $n = 2$ from $n = 3, 4, 5$.

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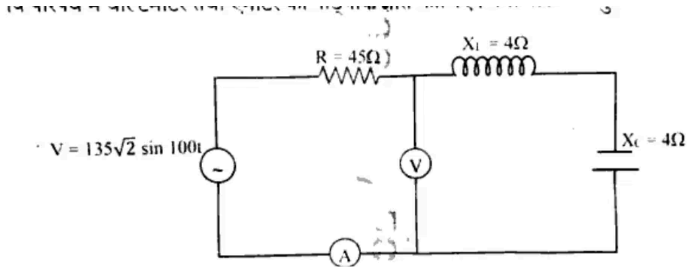
19.



Find the readings of the voltmeter and ammeter in the given AC circuit. Is the circuit in the state of resonance?

Given: $V = 135\sqrt{2}\,\sin 100t$ volt, $R = 45\,\Omega$, $X_L = 4\,\Omega$, $X_C = 4\,\Omega$. The voltmeter is connected across the series L-C combination and the ammeter is in series with the circuit.

Correct Answer: —

SOLUTION:

Step 1: Read off peak voltage and angular frequency.

From $V = 135\sqrt{2}\sin 100t$, the amplitude is $V_0 = 135\sqrt{2}$ V and $\omega = 100$ rad/s.

Step 2: Impedance from the given reactances.

Here $X_L = X_C = 4\,\Omega$, so the inductive and capacitive effects cancel. The only opposition left is the resistance, therefore $Z = R = 45\,\Omega$. Because $X_L = X_C$, the circuit satisfies the resonance condition and the current is maximum.

Step 3: Peak current, then rms.

$$I_0 = \frac{V_0}{Z} = \frac{135\sqrt{2}}{45} = 3\sqrt{2}\text{ A.}$$

The ammeter records the rms value: $I_{rms} = \dfrac{I_0}{\sqrt{2}} = \dfrac{3\sqrt{2}}{\sqrt{2}} = 3$ A.

Step 4: Voltage across L and across C.

$V_L = I_{rms} X_L = 3 \times 4 = 12$ V (leads the current by 90°).

$V_C = I_{rms} X_C = 3 \times 4 = 12$ V (lags the current by 90°).

Step 5: Net voltmeter reading.

Since V_L and V_C are equal in size but opposite in phase, their phasor sum is $|V_L - V_C| = |12 - 12| = 0$ V. The voltmeter therefore reads 0 V, confirming resonance.

$$\boxed{\text{Ammeter} = 3 \text{ A}, \ \text{Voltmeter} = 0 \text{ V}, \ \text{resonance: yes}}$$

Quick Tip: Since $X_L = X_C$, the reactances cancel, so $Z = R$ (resonance). Find $I = V_{rms}/R$ for the ammeter; the voltmeter across the L-C part reads $I(X_L - X_C) = 0$ because V_L and V_C cancel.

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20. Find the formula for the work done in rotating a magnetic dipole in a uniform magnetic field through an angle θ. What will be the work done in rotating a magnetic dipole lying parallel to the magnetic field by an angle of 180°?

Correct Answer: —

SOLUTION:

Step 1: Potential energy of a dipole in a field.

The orientation potential energy of a magnetic dipole is $U = -\vec{M} \cdot \vec{B} = -MB\cos\theta$, taking the zero of energy at $\theta = 90°$.

Step 2: Work-energy connection.

The work done by an external agent in slowly rotating the dipole equals the change in its potential energy, $W = U_{final} - U_{initial}$.

Step 3: Substitute the two orientations.
$W = (-MB\cos\theta_2) - (-MB\cos\theta_1) = MB(\cos\theta_1 - \cos\theta_2)$. This is the required general formula.

Step 4: Dipole parallel to the field, turned by 180°.
Parallel means $\theta_1 = 0°$; after a 180° turn $\theta_2 = 180°$.
$W = MB(\cos 0° - \cos 180°) = MB(1 + 1) = 2MB$.

Step 5: Physical check.
Going from the lowest-energy parallel state ($U = -MB$) to the highest-energy anti-parallel state ($U = +MB$) costs $U_2 - U_1 = MB - (-MB)$ $= 2MB$, the same result.

$$\boxed{W = MB(\cos\theta_1 - \cos\theta_2), \quad W_{180°} = 2MB}$$

Quick Tip: Use torque $\tau = MB\sin\theta$ and integrate, or use $U = -MB\cos\theta$. Both give $W = MB(\cos\theta_1 - \cos\theta_2)$; for $0° \to 180°$ this is $2MB$.

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21. What are electromagnetic waves? An electromagnetic wave is moving in the X direction and the directions of its electric and magnetic fields are Y and Z respectively. Write the general equations for the electric and magnetic fields of the wave. How are electromagnetic waves different from sound waves?

Correct Answer: —

SOLUTION:

Step 1: Definition through Maxwell's idea.

A changing electric field creates a magnetic field and a changing magnetic field creates an electric field; this mutual regeneration lets a combined electric-magnetic disturbance travel forward as an electromagnetic wave. Both fields are in phase, perpendicular to each other, and perpendicular to the travel direction, and in vacuum the wave moves at $c = 1/\sqrt{\mu_0 \varepsilon_0} = 3 \times 10^8$ m/s.

Step 2: Fix the right-handed triad.

Propagation is along X, so $\vec{E}$ and $\vec{B}$ must lie in the Y-Z plane. Given $\vec{E}$ along Y and $\vec{B}$ along Z, the set $(\vec{E}, \vec{B}, \text{direction of motion})$ forms a right-handed system since $\hat{Y} \times \hat{Z} = \hat{X}$.

Step 3: Write the travelling-wave forms.

$E_y(x,t) = E_0 \cos(kx - \omega t)$ and $B_z(x,t) = B_0 \cos(kx - \omega t)$, with $E_0 = cB_0$, $k = 2\pi/\lambda$ and $\omega = ck$. A sine or cosine form is equally valid.

Step 4: Contrast with sound.

Sound is a longitudinal mechanical wave that needs air, water or a solid to travel and moves at roughly 340 m/s in air; an EM wave is a transverse non-mechanical wave that travels even through vacuum at 3×10^8 m/s and carries oscillating fields rather than moving matter. Sound cannot be polarised, whereas EM waves can, precisely because they are transverse.

$$\boxed{E_y = E_0 \cos(kx - \omega t), \quad B_z = B_0 \cos(kx - \omega t), \quad E_0 = cB_0}$$

Quick Tip: EM waves are transverse oscillations of mutually perpendicular $\vec{E}$ and $\vec{B}$ that need no medium. With motion along X, write $E_y = E_0 \sin(kx - \omega t)$ and $B_z = B_0 \sin(kx - \omega t)$.

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22. Explain the effect of biasing on the depletion region of a p-n junction. Using a p-n junction diode, draw the circuit diagram of a half-wave rectifier and show the shape of the input and output voltage.

Correct Answer: —

SOLUTION:

Step 1: Depletion region and barrier potential.
At an unbiased p-n junction, diffusion of majority carriers leaves a thin region of uncovered immobile ions (negative on the p-side, positive on the n-side). This region has almost no free carriers and produces a barrier potential of about 0.3 V for germanium and 0.7 V for silicon.

Step 2: Forward biasing shrinks it.
Applying an external voltage with p at the higher potential pushes majority carriers toward the junction, neutralising some of the immobile ions. The depletion width and the barrier both decrease, and once the applied voltage exceeds the barrier, the current rises sharply.

Step 3: Reverse biasing widens it.
Applying the voltage the other way pulls majority carriers away from the junction, exposing more immobile ions. The depletion width and barrier both increase, and only a tiny reverse saturation current (due to minority carriers) flows.

Step 4: Half-wave rectifier arrangement.

Connect the AC source (through a step-down transformer) to a single diode in series with the load R_L. The diode acts as a one-way valve for the current.

Step 5: Output description and quality.

Because the diode conducts only when its anode (p-side) is positive, current passes during one half of each AC cycle and is blocked during the other. Hence the graph of output versus time shows only the upper (positive) humps of the input sine wave, with gaps where the negative halves were. This pulsating DC has the same frequency as the input, an average value $V_{dc} = V_m/\pi$, and needs a filter to smooth it.

$$\boxed{\text{Forward bias: thinner depletion layer; reverse bias: thicker; half-wave rectifier passes one half cycle}}$$

Quick Tip: Forward bias lowers the barrier and narrows the depletion region; reverse bias widens it. A half-wave rectifier uses one diode that conducts only in the positive half cycle, giving a pulsating DC output.

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23. For any particle, its particle nature and wave nature can be observed simultaneously. Comment. Radiation of wavelength λ is incident on a surface of negligible work function. Find the de-Broglie wavelength of the emitted electron.

Correct Answer: —

SOLUTION:

Step 1: Why both natures are not seen together.

Light and material particles show a dual character, but the two faces never appear in one and the same measurement. A which-path (particle) measurement destroys the interference (wave) pattern, and observing interference means we cannot tell which path the quantum took. This mutual exclusivity is Bohr's complementarity principle, so the given claim is false.

Step 2: All photon energy goes to the electron.

Since the surface has negligible work function, no energy is spent in freeing the electron. The photon energy hc/λ is converted entirely into the electron's kinetic energy: $\frac{1}{2}mv^2 = \dfrac{hc}{\lambda}$.

Step 3: Speed of the emitted electron.

Solving for v: $v = \sqrt{\dfrac{2hc}{m\lambda}}$.

Step 4: Apply the de-Broglie relation.

$$\lambda' = \frac{h}{mv} = \frac{h}{m\sqrt{2hc/(m\lambda)}} = \frac{h}{\sqrt{2mhc/\lambda}}.$$

Step 5: Reduce to the simplest form.

Squaring inside the root, $\lambda' = \sqrt{\dfrac{h^2\lambda}{2mhc}} = \sqrt{\dfrac{h\lambda}{2mc}}$.

$$\boxed{\lambda' = \sqrt{\frac{h\lambda}{2mc}}}$$

Quick Tip: Wave and particle natures are complementary, never seen in one experiment. With $\phi \approx 0$, all photon energy hc/λ becomes kinetic energy, so λ'

$= h/\sqrt{2m\,KE} = \sqrt{h\lambda/(2mc)}$.

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24. Explain Kirchhoff's laws related to electrical circuits.

Correct Answer: —

SOLUTION:

Kirchhoff's two rules extend Ohm's law so that complicated multi-loop circuits can be solved.

Step 1: First rule at a node.
Consider any point where several wires meet. The first rule (junction/point rule) says the currents there must balance: $I_1 + I_2 = I_3 + I_4 + \ldots$, i.e. everything arriving must depart. Written as one equation with a sign convention (inward +, outward −):

$$\sum_k I_k = 0$$

Step 2: Why the node rule holds.
A junction is just a point and can store no charge. If more charge arrived than left, charge would pile up there and grow without limit, which never happens in steady current. So the rule is simply **charge conservation** written at a point.

Step 3: Second rule around a mesh.
Pick a closed path and walk all the way around it. The second rule (mesh/loop rule) says every gain in potential (across a cell) is exactly cancelled by the losses (across resistors):

$$\sum \varepsilon = \sum IR$$

Add EMFs with a + sign when you enter the cell at − and leave at +, and subtract each IR term when you move along the current.

Step 4: Why the mesh rule holds.
Electric potential is single-valued, so a test charge taken once around the loop comes back to the same potential. The total work done on it per unit charge over the closed path is therefore zero, which is **energy conservation**.

Step 5: Using the rules.
Assign a current to each branch, write one node equation per independent junction and one loop equation per independent mesh, then solve the simultaneous equations.

$$\boxed{\text{Node rule} \rightarrow \text{charge conserved}, \qquad \text{Loop rule} \rightarrow \text{energy conserved}}$$

Quick Tip: Junction law: sum of currents at a node is zero (charge conservation). Loop law: sum of EMFs equals sum of IR drops around a closed loop (energy conservation).

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25. Reflecting telescopes are supposed to be better than refracting telescopes. Why? Draw the ray diagram for image formation by a refracting telescope. Final image is formed at infinity.
OR
What is the meaning of polarisation of light? Whether sound waves are also polarized? Explain polarization of light by refraction.

Correct Answer: —

SOLUTION:

Option 1: Reflector versus refractor.

Step 1: Advantages of the reflecting type.

Its objective is a mirror, not a lens, and this removes the main weaknesses of a refractor. A mirror reflects every wavelength identically, so images are free of colour fringing (no chromatic aberration); a parabolic profile also kills spherical aberration. A heavy mirror can rest on a full backing plate, so very large apertures are practical, giving more collected light and finer detail. Only one face needs figuring, cutting cost and defects. A refractor's lens, by contrast, disperses colours, can only be edge-mounted (so it bends under gravity when large) and needs two accurately curved faces.

Step 2: Ray path in a refractor at normal adjustment (final image at infinity).

Take a big long-focus converging objective (f_o) and a small short-focus converging eyepiece (f_e). A distant point sends in essentially parallel rays; the objective brings them to a real, inverted, small image in its focal plane. Slide the eyepiece so its own focal plane coincides with that image. Any ray leaving that focal point then exits the eyepiece parallel to the axis, so the eye (relaxed, focused at infinity) sees a large virtual image at infinity. The tube length is $L = f_o + f_e$ and the angular magnification is $M = f_o/f_e$.

Schematically: parallel rays ⇒ objective ⇒ inverted real image at common focus ⇒ eyepiece ⇒ parallel emergent rays ⇒ image at infinity.

Option 2: Polarised light.

Step 1: What polarisation means.
An electromagnetic wave vibrates its electric field at right angles to the way it travels. Natural light contains such vibrations pointing every which way around the axis of travel. Selecting or producing light whose electric vibration keeps to a single fixed plane is called polarising the light; the beam is then plane polarised. Only transverse waves allow this.

Step 2: Sound.
Sound is a pressure wave in which particles oscillate back and forth along the propagation direction, i.e. it is longitudinal. A longitudinal disturbance has no sideways vibration to single out, so **sound cannot be polarised**. Hence the ability to polarise light shows light is transverse.

Step 3: Getting polarised light on refraction.
Shine ordinary light onto glass. Part reflects, part refracts, and both come out partly polarised. There is a particular incidence angle, the Brewster or polarising angle i_p, where the reflected ray is fully plane polarised and stands at $90°$ to the refracted ray. Since the reflection strips the vibrations lying in the plane of incidence out of the reflected beam, those vibrations are pushed into the refracted beam; sending the light through several such plates in turn leaves the transmitted (refracted) beam highly polarised. The polarising angle obeys Brewster's law, with n the refractive index:

$$n = \tan i_p$$

$$\boxed{M = f_o/f_e; \qquad n = \tan i_p}$$

Quick Tip: Option 1: mirror objective avoids chromatic aberration and can be made large; refractor tube length = f_o + f_e with image at objective focus = eyepiece focus. Option 2: polarisation restricts transverse vibrations to one plane, sound is longitudinal so not polarisable, and Brewster's law is mu = tan i_p.

• • •

26. Potential difference at the ends of a conductor of length l is V. Diameter of the conductor is d. What will be the effect on the electric field inside the conductor and its resistance, if (i) V is halved? (ii) l is doubled? (iii) d is doubled?

Correct Answer: —

SOLUTION:

Step 1: Set up proportionalities.
Inside the wire the field is the potential gradient, $E = V/l$, so $E \propto V$ and $E \propto 1/l$, while E is independent of the diameter. The resistance is $R = \rho l/A$ with $A = \pi d^2/4$, giving $R = 4\rho l/(\pi d^2)$, so $R \propto l$, $R \propto 1/d^2$, and R is independent of V. I will track only the ratios.

Step 2: Halving V.
Since $E \propto V$, halving V halves the field: $E \to E/2$. Since R does not contain V at all, the resistance stays the same. So field halves, resistance constant.

Step 3: Doubling l.
Since $E \propto 1/l$, doubling l makes $E \to E/2$. Since $R \propto l$, doubling l makes

$R \to 2R$. So field halves and resistance doubles.

Step 4: Doubling d.

E has no d dependence, so the field is unaffected. Since $R \propto 1/d^2$, replacing d by $2d$ multiplies R by $1/(2)^2 = 1/4$, so $R \to R/4$. Field unchanged, resistance quartered.

Step 5: Collected results.

$$\boxed{(i)\, E \to \frac{E}{2},\ R \text{ same};\quad (ii)\, E \to \frac{E}{2},\ R \to 2R;\quad (iii)\, E \text{ same},\ R \to \frac{R}{4}}$$

Quick Tip: Use E = V/l (independent of diameter) and R = 4 rho l/(pi d^2) (independent of V). Then scale each quantity for the change asked.

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27. Derive the formula for energy loss on connecting two charged conductors through a conducting wire.

OR

Explain the meaning of polarization of a dielectric material. What will be the effect on the capacity of an air filled parallel plate capacitor on putting a dielectric material in between its plates? Equivalent capacity of two condensers in series is 7.5 μF and in parallel is 30 μF. What will be the capacity of both the capacitors separately?

Correct Answer: —

SOLUTION:

Option 1: Heat dissipated when two charged bodies share charge

Step 1: Consider spheres with capacitances C_1, C_2 raised to potentials

V_1, V_2. Their stored electrostatic energies are $U_1 = \frac{1}{2}C_1V_1^2$ and $U_2 = \frac{1}{2}C_2V_2^2$, giving initial total $U_i = U_1 + U_2$.

Step 2: A wire lets charge migrate from higher to lower potential. Total charge $Q = C_1V_1 + C_2V_2$ stays fixed, and the flow stops only when both bodies sit at one potential V_c. Because the combined plate system stores charge Q on capacitance $C_1 + C_2$, $V_c = \dfrac{Q}{C_1 + C_2} = \dfrac{C_1V_1 + C_2V_2}{C_1 + C_2}$.

Step 3: The energy afterwards can be written directly in terms of charge, $U_f = \dfrac{Q^2}{2(C_1 + C_2)} = \dfrac{(C_1V_1 + C_2V_2)^2}{2(C_1 + C_2)}$.

Step 4: A neat shortcut: the migrated charge is $\Delta q = \dfrac{C_1C_2}{C_1 + C_2}(V_1 - V_2)$, and the average driving potential difference across the wire is $\frac{1}{2}(V_1 - V_2)$. The heat produced equals charge moved times mean potential difference, $H = \Delta q \times \frac{1}{2}(V_1 - V_2)$.

Step 5: Substituting Δq,

$$H = \frac{C_1C_2}{2(C_1 + C_2)}(V_1 - V_2)^2$$

which is exactly $U_i - U_f$. The result is always positive, confirming energy is dissipated as heat and radiation in the wire.

$$\boxed{\Delta U = \frac{C_1C_2(V_1 - V_2)^2}{2(C_1 + C_2)}}$$

Option 2: Dielectric polarization and finding the two capacitors

Step 1: Polarization means the ordering of a dielectric's molecular dipoles under an applied field. Non-polar molecules develop induced dipoles, while polar molecules (already dipoles) turn to line up with the field. The result is a bound negative charge on the face where the field enters and a bound positive charge where it leaves; per unit volume this is described by the polarization vector P.

Step 2: These bound charges oppose the applied field, weakening the net field between the plates to E_0/K. With the source keeping charge fixed, the reduced field lowers the voltage, and since $C = Q/V$, the capacitance grows to K times its air value: $C = KC_0$. Thus a dielectric raises the capacitor's capacity.

Step 3: Let the capacitances be a and b. Given data: parallel combination $a + b = 30$ and series combination $\frac{ab}{a+b} = 7.5$.

Step 4: Substitute $a + b = 30$ into the series equation: $\frac{ab}{30} = 7.5 \Rightarrow ab = 225$. Now use $(a-b)^2 = (a+b)^2 - 4ab = 900 - 900 = 0$, so $a - b = 0$, i.e. $a = b$.

Step 5: With $a = b$ and $a + b = 30$, each is $15\,\mu$F. Verification of the series value: $\frac{15 \times 15}{30} = 7.5\,\mu$F. Consistent.

$$\boxed{C_1 = C_2 = 15\,\mu\text{F}}$$

Quick Tip: Energy loss = (initial stored energy) - (energy after reaching common potential); it reduces to $C_1C_2(V_1 - V_2)^2/[2(C_1 + C_2)]$. For the capacitors use $C_1 + C_2 = 30$ and $C_1C_2 = 7.5 \times 30 = 225$.

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28. Write Huygen's principle of secondary wavelets and verify laws of refraction on its basis.

OR

Explain the meaning of coherent sources and sustained interference. Why central fringe in Young's double slit experiment is always bright? In Young's double slit experiment, fringe width is 0.04 cm for light of 6000 Å. Distance of screen from slits is 1 m. Find the distance of third bright and second dark fringe from central fringe and also the separation between the slits.

Correct Answer: —

SOLUTION:

Option 1: Deriving Snell's law from wavefront geometry

Step 1: Huygens pictured a wavefront as a surface of points that are all vibrating in step. Each such point launches a small spherical wavelet forward at the local wave speed; a moment later the envelope touching all these wavelets is the advanced wavefront. This construction lets us track how a wavefront bends when the speed changes.

Step 2: Let parallel light in a rarer medium (speed v_1) meet a flat interface. Its wavefront edge B needs time t to reach the surface point C, covering $BC = v_1 t$. During the same t, the other edge at A has already crossed into the denser medium (speed v_2) and its wavelet has grown to radius $AD = v_2 t$.

Step 3: The refracted wavefront is the line CD tangent to that wavelet. The incidence angle i equals angle BAC and the refraction angle r equals angle DCA (angles measured from the surface, using the shared hypotenuse AC).

Step 4: Then $\sin i = BC/AC = v_1 t/AC$ and $\sin r = AD/AC = v_2 t/AC$. Their ratio drops the common t/AC: $\dfrac{\sin i}{\sin r} = \dfrac{v_1}{v_2} = {}_1n_2$, a constant fixed only by the two media.

Step 5: Writing speeds as $v = c/n$ gives $n_1 \sin i = n_2 \sin r$, and the whole figure lies in one plane so ray, refracted ray and normal are coplanar. Both refraction laws follow.

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

Option 2: Interference conditions and the YDSE numbers

Step 1: Coherence demands a locked phase relationship. Two independent lamps flicker randomly and cannot interfere steadily; splitting one wavefront into two slits keeps their phase tied, so they qualify as coherent.

Step 2: When coherent, equal-amplitude beams overlap, the bright and dark bands hold still instead of washing out. That fixed, time-independent pattern is what we call sustained interference.

Step 3: Right at the screen centre the two paths from the slits are identical, so the optical path difference vanishes for every colour. Zero path difference is perfect constructive interference, hence the central band is always bright.

Step 4: Convert data to SI: $\beta = 0.04$ cm $= 4 \times 10^{-4}$ m, $\lambda = 6000$ Å $= 6 \times 10^{-7}$ m, $D = 1$ m. From $\beta = \lambda D/d$, the slit gap is $d = \lambda D/\beta = (6 \times 10^{-7})(1)/(4 \times 10^{-4}) = 1.5 \times 10^{-3}$ m, i.e. 1.5 mm.

Step 5: Bright fringes sit at integer multiples of β; the third one lies at $3 \times 0.04 = 0.12$ cm. Dark fringes sit at half-integer multiples; the second dark one lies at $\frac{3}{2} \times 0.04 = 0.06$ cm from the centre.

$$\boxed{d = 1.5\text{ mm}, \quad y_{3B} = 0.12\text{ cm}, \quad y_{2D} = 0.06\text{ cm}}$$

Quick Tip: Use Huygens' wavelet envelope: $\sin i/\sin r = v_1/v_2$. For the numerical, $\beta = \lambda D/d$, bright fringe distance $= n\beta$, dark fringe distance $= (2n - 1)\beta/2$.

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29. Derive the formula for magnetic field due to an infinitely long current carrying conducting wire using Biot-Savart law.
OR
Differentiate between self-induction and mutual induction. The current in primary coil becomes zero in 10^{-3} s and an induced e.m.f. of 1500 volts is produced in secondary. Mutual inductance of coils is 0.5 H. Find the value of initial current in the primary.

Correct Answer: —

SOLUTION:

Option 1: Straight-wire field via the angle form of Biot-Savart

Step 1: The Biot-Savart law states each element $I\,dl$ contributes $dB = \frac{\mu_0}{4\pi}\frac{I\,dl\sin\theta}{r^2}$ at a field point, directed perpendicular to the plane of dl and r.

Step 2: Place point P at perpendicular distance a. Instead of the length variable, use the angle ϕ that r makes with the perpendicular. Then $l = a\tan\phi$, $dl = a\sec^2\phi\,d\phi$, and $r = a\sec\phi$. Also the angle between element and r gives $\sin\theta = \cos\phi$.

Step 3: Substituting, $dB = \frac{\mu_0 I}{4\pi}\frac{(a\sec^2\phi\,d\phi)(\cos\phi)}{a^2\sec^2\phi} = \frac{\mu_0 I}{4\pi a}\cos\phi\,d\phi$. The awkward geometry collapses to a simple cosine.

Step 4: For an infinitely long wire the angle ϕ sweeps from $-90°$ to $+90°$: $B = \frac{\mu_0 I}{4\pi a}\int_{-\pi/2}^{+\pi/2}\cos\phi\,d\phi = \frac{\mu_0 I}{4\pi a}[\sin\phi]_{-\pi/2}^{+\pi/2} = \frac{\mu_0 I}{4\pi a}(1-(-1))$.

Step 5: This gives $B = \frac{\mu_0 I}{2\pi a}$, matching Ampere's-law result, with circular field lines wrapping the wire (right-hand grip rule).

$$\boxed{B = \frac{\mu_0 I}{2\pi a}}$$

Option 2: Comparing inductions and back-calculating the current

Step 1: Self-induction acts within one coil: a changing current makes its own flux change and it induces an opposing e.m.f. on itself, measured by self-inductance L ($e = -L\,dI/dt$).

Step 2: Mutual induction acts across two coils: a changing current in the primary alters the flux threading a nearby secondary, inducing an e.m.f. there, measured by mutual inductance M ($e_2 = -M\,dI_1/dt$). So the distinction is one coil versus a pair of magnetically linked coils.

Step 3: Only the magnitude matters here. The secondary e.m.f. is $e = M\left|\frac{\Delta I}{\Delta t}\right|$, and $\Delta I = I_{\text{final}} - I_{\text{initial}} = 0 - I = -I$, so $|\Delta I| = I$.

Step 4: Rearranging for the unknown initial current: $I = \frac{e\,\Delta t}{M}$. Insert $e = 1500$ V, $\Delta t = 10^{-3}$ s, $M = 0.5$ H.

Step 5: $I = \frac{1500 \times 10^{-3}}{0.5} = \frac{1.5}{0.5} = 3$ A. The primary was carrying 3 A before it dropped to zero.

$$\boxed{I = 3\text{ A}}$$

Quick Tip: Integrate the Biot-Savart element $dB = \frac{\mu_0}{4\pi}\frac{I\,dl\sin\theta}{r^2}$ over the whole wire to get $B = \mu_0 I/2\pi a$. For the coil, $e = M\,\Delta I/\Delta t \Rightarrow I = e\,\Delta t/M$.

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30. Explain the difference between conductor, insulator and semiconductor on the basis of energy band in solids.

OR

Define diamagnetic, paramagnetic and ferromagnetic materials. Explain that a current carrying solenoid behaves as a bar magnet.

Correct Answer: —

SOLUTION:

Option 1: Band picture separating the three classes of solids

Step 1: When atoms crowd together in a crystal, their sharp energy levels smear into wide bands. The topmost occupied band is the valence band and the next allowed band is the conduction band; between them may lie a forbidden gap E_g where no electron states exist. Electrical conduction needs electrons that are free to accept energy in the conduction band.

Step 2: A metal is a natural conductor because either its conduction and valence bands overlap or its conduction band is only half full. There is effectively no gap to cross, so a sea of electrons drifts freely and resistance is low.

Step 3: An insulator has a filled valence band capped by an empty conduction band with a wide barrier, several electron-volts high. Thermal energy at room temperature is far too small to lift electrons across, so charge cannot flow.

Step 4: A semiconductor shares the insulator layout but its gap is narrow, near 1 eV. Modest heating (or doping) promotes a handful of electrons upward, each leaving a mobile hole, so it conducts weakly; warming it further frees more carriers, so its resistance falls with rising temperature.

Step 5: Ranking the gap widths captures everything: zero for conductors, about 1 eV for semiconductors, and above roughly 3 eV for insulators.

$$\boxed{\text{conductor } (E_g \approx 0) \;<\; \text{semiconductor } (\sim 1 \text{ eV}) \;<\; \text{insulator } (\gtrsim 3 \text{ eV})}$$

Option 2: Three magnetic behaviours and the electromagnet analogy

Step 1: Diamagnetic substances lack any permanent atomic magnet. An applied field induces a tiny opposing moment (Lenz-like), so they are pushed gently out of strong-field regions; their susceptibility is small and negative and μ_r is just below 1. Bismuth and copper are typical.

Step 2: Paramagnetic substances do carry permanent atomic moments but these point randomly. A field nudges them into partial alignment, producing a weak attraction; susceptibility is small and positive, μ_r slightly above 1. Aluminium and platinum fit here.

Step 3: Ferromagnetic substances have neighbouring moments locked into domains. An external field swings whole domains around, giving intense magnetisation that survives after the field is removed; susceptibility is large and positive, μ_r enormous. Iron, cobalt and nickel are the classic examples.

Step 4: Now consider a solenoid carrying current. Every loop is a magnetic dipole, and stacking many loops makes their axial fields reinforce, so a strong, nearly uniform field runs down the tube and loops back outside, matching a bar magnet's field exactly. The face where field lines stream out is the north pole and the opposite face is the south pole.

Step 5: Quantitatively the solenoid's dipole moment is $m = NIA$ for N turns of area A carrying current I; suspended freely it settles along the geographic north-south line, and reversing the current swaps its poles, confirming it truly acts as a bar magnet.

$$\boxed{m = NIA}$$

Quick Tip: Compare the forbidden energy gap: zero for conductors, about 1 eV for semiconductors, more than 3 eV for insulators. For magnetism, classify by susceptibility sign/size and recall each solenoid turn is a dipole giving m = NIA.