UP Board Class 12 Physics 2026 Set 346 DS 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. If the critical angle in a medium is α, then for total internal reflection the angle of incidence β should be:

(A) $\beta < \alpha$

(B) $\beta > \alpha$

(C) $\beta = \alpha$

(D) $\beta \leq \alpha$

Correct Answer: (B) $\beta > \alpha$

SOLUTION:

Step 1: Start from Snell's law at the denser-to-rarer boundary.
For a ray going from a medium of refractive index n (denser) into air, $n \sin\beta = \sin r$, where β is the incidence angle and r the refraction angle. Since $n > 1$, r is always larger than β.

Step 2: Push the refracted ray to its limit.
As β increases, r increases faster and reaches its maximum possible value $90°$. The incidence angle at which this happens is defined as the critical angle α, so $n \sin\alpha = \sin 90° = 1$.

Step 3: Go beyond the limit.

If we make β even larger than α, the equation $\sin r = n \sin \beta$ would demand $\sin r > 1$, which is mathematically impossible. Nature responds by not transmitting the ray at all; instead it reflects the entire beam back inside the denser medium.

Step 4: Conclusion.

This complete reflection (total internal reflection) begins only once β exceeds α. Hence the required condition is that the incidence angle be greater than the critical angle.

$$\boxed{\beta > \alpha}$$

Quick Tip: Total internal reflection happens only when the ray goes from denser to rarer medium and the angle of incidence exceeds the critical angle.

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2. The number of electrons that must be removed from a piece of metal to give it a charge of 1×10^{-7} coulomb will be:

(A) 10^7

(B) 1.6×10^{19}

(C) 6.25×10^{11}

(D) 9×10^{12}

Correct Answer: (C) 6.25×10^{11}

SOLUTION:

Step 1: Think in terms of charge per electron.

Each electron carries a charge of magnitude $e = 1.6 \times 10^{-19}$ C. To build up a total charge of $Q = 1 \times 10^{-7}$ C we simply count how many such packets fit into Q.

Step 2: Set up the division.

$$\text{Number of electrons} = \frac{\text{total charge}}{\text{charge of one electron}} = \frac{1 \times 10^{-7}}{1.6 \times 10^{-19}}.$$

Step 3: Handle the powers of ten first.

$10^{-7} \div 10^{-19} = 10^{12}$. The numerical coefficient is $1 \div 1.6 = 0.625$.

Step 4: Combine.

$0.625 \times 10^{12} = 6.25 \times 10^{11}$ electrons.

Step 5: Verify by reverse multiplication.

$6.25 \times 10^{11} \times 1.6 \times 10^{-19} = 10 \times 10^{-8} = 1 \times 10^{-7}$ C, which is exactly the required charge. The answer is confirmed.

$$\boxed{n = 6.25 \times 10^{11}}$$

Quick Tip: Charge is quantised: use $n = Q/e$ with $e = 1.6 \times 10^{-19}$ C.

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3. In Rutherford's scattering experiment, the path of a scattered α-particle is:

(A) circular

(B) parabolic

(C) elliptical

(D) hyperbolic

Correct Answer: (D) hyperbolic

SOLUTION:

Step 1: Compare with planetary motion.
In gravitation, a planet bound to the Sun by an attractive inverse-square force moves in a closed ellipse. The α-particle problem has the same inverse-square mathematics, but with two key differences that change the shape of the orbit.

Step 2: Note the two differences.
(a) The Coulomb force here is repulsive, not attractive, because both the α-particle and the nucleus are positive. (b) The α-particle arrives from infinity with positive kinetic energy, so its total mechanical energy is positive, meaning it is unbound.

Step 3: Deduce the conic.
For a central inverse-square force, positive total energy always corresponds to a hyperbolic trajectory. The particle swings once around the nucleus and departs to infinity, never returning.

Step 4: State the result.
Therefore the scattered α-particle follows a hyperbolic path with the repelling nucleus situated at the focus of the hyperbola. This is exactly what Rutherford used to analyse large-angle scattering.

$\boxed{\text{Hyperbola}}$

Quick Tip: An unbound particle under a repulsive inverse-square Coulomb force traces an open conic; recall which conic corresponds to positive total energy.

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4. The unit of $\sqrt{LC}$ (where L is inductance and C is capacitance) is:

(A) second

(B) henry

(C) farad

(D) ampere

Correct Answer: (A) second

SOLUTION:

Step 1: Use the time-period formula of an LC circuit.

The natural time period of oscillation of an inductor-capacitor circuit is $T = 2\pi\sqrt{LC}$. Since T is a time, it is measured in seconds.

Step 2: Isolate $\sqrt{LC}$.

Dividing by the pure number 2π does not change the physical dimension, so $\sqrt{LC} = \dfrac{T}{2\pi}$ still carries the unit of time.

Step 3: Confirm dimensionally.

The dimension of L is $[ML^2T^{-2}A^{-2}]$ and of C is $[M^{-1}L^{-2}T^4A^2]$. Multiplying, the mass, length and current dimensions cancel, leaving $[T^4 \cdot T^{-2}] = [T^2]$. Taking the square root gives $[T]$.

Step 4: Conclude.

A quantity with dimension of time is measured in seconds, so the unit of $\sqrt{LC}$ is the second.

$$\boxed{\text{second}}$$

Quick Tip: Remember the LC-oscillation relation $\omega = 1/\sqrt{LC}$ (or $T = 2\pi\sqrt{LC}$); $\sqrt{LC}$ has the dimension of time.

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5. In the depletion layer of a p-n junction diode, there are:

(A) only electrons

(B) only holes

(C) both electrons and holes

(D) neither electrons nor holes

Correct Answer: (D) neither electrons nor holes

SOLUTION:

Step 1: Focus on the word depletion.

The very name of the layer tells the answer: to deplete means to empty out. So by definition this region has been emptied of something, and that something is the mobile charge carriers.

Step 2: Track where the carriers went.

Right after the junction is made, electrons near the boundary fall into nearby holes (recombination). Within a very thin strip, every free electron finds a hole and vice versa, so both disappear from that strip.

Step 3: Identify what stays.
The donor and acceptor atoms that gave up these carriers are now charged ions locked in the crystal lattice. They cannot move, so they form a fixed space-charge region and set up the built-in potential barrier, but they do not act as free carriers.

Step 4: Final answer.
Hence, inside the depletion layer there are no mobile electrons and no mobile holes available for conduction.

$$\boxed{\text{Neither electrons nor holes}}$$

Quick Tip: The depletion region is depleted of mobile carriers; only fixed ionised donor and acceptor atoms remain there.

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6. Among the following, the electromagnetic wave of minimum frequency is:

(A) ultraviolet rays

(B) X-rays

(C) γ-rays

(D) microwaves

Correct Answer: (D) microwaves

SOLUTION:

Step 1: Use the relation between frequency and wavelength.
All electromagnetic waves travel at the same speed c in vacuum, and $c = \nu\lambda$, so frequency $\nu = c/\lambda$. This means the wave with the largest wavelength has the smallest frequency.

Step 2: Compare typical wavelengths of the options.
Microwaves have wavelengths of the order of millimetres to centimetres; ultraviolet rays are around 10^{-8} m; X-rays around 10^{-10} m; and γ-rays even shorter, around 10^{-12} m or less.

Step 3: Identify the longest wavelength.
Clearly the microwaves have by far the longest wavelength among these four.

Step 4: Conclude.
Since $\nu = c/\lambda$, the longest-wavelength wave has the lowest frequency, so microwaves are the electromagnetic wave of minimum frequency.

$$\boxed{\text{Microwaves}}$$

Quick Tip: Order the spectrum by frequency; the wave with the longest wavelength (using $\nu = c/\lambda$) has the least frequency.

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7. An electron of energy 10 eV is revolving round a circular path in a uniform magnetic field of 10^{-5} tesla. Determine the radius of the circular path.
(Given: mass of electron $m = 9.1 \times 10^{-31}$ kg, charge $e = 1.6 \times 10^{-19}$ C)

Correct Answer: —

SOLUTION:

Step 1 (Set up): For a charge q moving with speed v perpendicular to a field B, the circular radius is $r = \frac{mv}{qB}$. Instead of finding v first, we can express v through the energy in one shot.

Step 2 (Link speed to energy): Since $E = \frac{1}{2}mv^2$, we get $mv = \sqrt{2mE}$. Substituting this into the radius formula gives a single compact expression:

$$r = \frac{\sqrt{2mE}}{qB}$$

Step 3 (Insert values): Here $E = 10$ eV $= 1.6 \times 10^{-18}$ J, $m = 9.1 \times 10^{-31}$ kg, $q = 1.6 \times 10^{-19}$ C, $B = 10^{-5}$ T.

$$2mE = 2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-18} = 2.912 \times 10^{-48}$$

$$\sqrt{2mE} = 1.706 \times 10^{-24} \text{ kg·m/s}$$

Step 4 (Divide by qB): $qB = 1.6 \times 10^{-19} \times 10^{-5} = 1.6 \times 10^{-24}$.

$$r = \frac{1.706 \times 10^{-24}}{1.6 \times 10^{-24}} = 1.07 \text{ m}$$

The radius comes out the same, confirming the result.

$$\boxed{r \approx 1.07 \text{ m}}$$

Quick Tip: The magnetic force provides the centripetal force, so $r = \frac{mv}{qB}$. Get v from $E = \frac{1}{2}mv^2$, or use $r = \frac{\sqrt{2mE}}{qB}$ directly.

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8. Write the definitions of electrical conductivity and specific conductivity.

Correct Answer: —

SOLUTION:

Step 1 (Start from resistance ideas): Every conductor opposes current through its resistance R; the material itself opposes current through its resistivity ρ. Conductivity terms are just the opposites (reciprocals) of these two.

Step 2 (Electrical conductivity, i.e. conductance): It tells how good a given conductor is at carrying current and is defined as the reciprocal of resistance, $G = 1/R$. A large G means current passes easily. Because current $I = GV$, its unit siemens equals ampere per volt.

Step 3 (Specific conductivity): It tells how good the material is, independent of the sample's dimensions, and is defined as the reciprocal of resistivity, $\sigma = 1/\rho$. In terms of microscopic quantities $\sigma = \frac{ne^2\tau}{m}$, where n is free-electron density, τ the relaxation time.

Step 4 (Units): G is in ohm^{-1} (siemens); σ is in ohm^{-1}m^{-1} (siemens per metre).

$$\boxed{G = \frac{1}{R}, \qquad \sigma = \frac{1}{\rho}}$$

Quick Tip: Conductance is the reciprocal of resistance ($1/R$, unit siemens); specific conductivity is the reciprocal of resistivity ($1/\rho$, unit S/m).

9. The work function of a metal is 3.3 eV. Calculate the minimum frequency of photon that will emit the photoelectron.
(Given: $h = 6.6 \times 10^{-34}$ J·s, 1 eV $= 1.6 \times 10^{-19}$ J)

Correct Answer: —

SOLUTION:

Step 1 (Threshold condition): The least energetic photon that can still knock out an electron is the one whose energy exactly matches the work function W_0. Any lower frequency carries too little energy and no emission occurs. Thus the cut-off frequency is $\nu_0 = W_0/h$.
Step 2 (Keep energy in eV, convert h to eV·s): Using $h = 6.6 \times 10^{-34}\ \text{J·s} = \dfrac{6.6 \times 10^{-34}}{1.6 \times 10^{-19}} = 4.125 \times 10^{-15}$ eV·s.
Step 3 (Divide work function by this h):

$$\nu_0 = \frac{W_0}{h} = \frac{3.3\ \text{eV}}{4.125 \times 10^{-15}\ \text{eV·s}}$$

Step 4 (Compute):

$$\nu_0 = 8.0 \times 10^{14}\ \text{Hz}$$

Same answer, obtained without first converting eV to joule.

$$\boxed{\nu_0 = 8.0 \times 10^{14}\ \text{Hz}}$$

Quick Tip: At the threshold the photon energy just equals the work function: $h\nu_0 = W_0$, so $\nu_0 = W_0/h$. Convert 3.3 eV to joule first.

10. By giving the examples, explain the meaning of diamagnetic and paramagnetic materials.

Correct Answer: —

SOLUTION:

Step 1 (Judge by the magnetic response): Classify a material by watching what a magnet does to it and what happens to field lines inside it.
Step 2 (Diamagnetic): A magnet pushes it away (weak repulsion). Field lines are pushed out of the material, so susceptibility χ is small and negative and μ_r is a shade below 1. This behaviour arises because the material has no net atomic magnetic moment; the field only induces a tiny opposing moment. Everyday examples are bismuth, copper and water.
Step 3 (Paramagnetic): A magnet pulls it in (weak attraction). Field lines crowd slightly into the material, so χ is small and positive and μ_r is a shade above 1. Here each atom already carries a permanent moment that lines up partly with the field, though thermal motion keeps the alignment weak. Examples are aluminium, platinum and oxygen.

$$\boxed{\text{Dia: repelled, } \chi < 0; \quad \text{Para: attracted, } \chi > 0}$$

Quick Tip: Diamagnetic substances are weakly repelled ($\mu_r < 1$, e.g. bismuth, copper); paramagnetic substances are weakly attracted ($\mu_r > 1$, e.g. aluminium, platinum).

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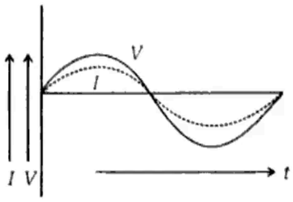
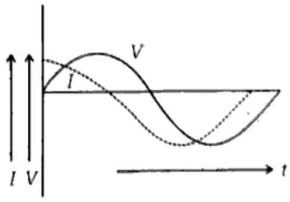
11.





The variation between V and I with time (t) in two alternative circuits is shown in the above graphs. Which one of the curves of circuit is capacitive and which one is resistive?

Correct Answer: —

SOLUTION:

Step 1 (Write the waveforms): Let the applied voltage be $V = V_0 \sin \omega t$. For a resistor, Ohm's law gives $I = \frac{V_0}{R} \sin \omega t$, so I has the same $\sin \omega t$ form as V (phase angle 0). For a capacitor, $I = C\frac{dV}{dt} = \omega C V_0 \cos \omega t = \omega C V_0 \sin(\omega t + 90°)$, so I is shifted ahead of V by $90°$.

Step 2 (Match forms to the pictures): A zero phase shift means the two sine curves sit on top of each other in timing, which is exactly the left graph. A $+90°$ shift means the current sine starts and peaks earlier than the voltage sine, which is exactly the right graph.

Step 3 (Assign the circuits): Since I and V are together on the left, that circuit obeys $I \propto \sin \omega t$ and is resistive. Since I leads V on the right, that circuit obeys $I \propto \sin(\omega t + 90°)$ and is capacitive.

$$\boxed{\text{Left} = \text{Resistive}, \quad \text{Right} = \text{Capacitive}}$$

Quick Tip: In a resistor V and I are in phase; in a capacitor the current leads the voltage by $90°$. Look for which graph shows I peaking before V.

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12. In which the power of a lens will be large, in air or water?

Correct Answer: —

SOLUTION:

Step 1 (Why the medium matters): A lens works only because light bends at its surfaces, and bending depends on how different the lens's refractive index is from the surrounding medium. The closer the medium's index is to the lens's index, the weaker the bending.
Step 2 (Air versus water): Water ($n = 1.33$) is optically much closer to glass ($n = 1.5$) than air ($n = 1$) is. So when the lens sits in water, the relative index n_l/n_m drops from 1.5 to about 1.13, and the refracting power of each surface shrinks.
Step 3 (Effect on power): Because $P = 1/f$ and a weaker bend means a longer focal length, the focal length grows in water and the power falls. In air the contrast in indices is largest, so the focal length is shortest and the power is greatest.

$$\boxed{\text{Power is greater in air than in water.}}$$

Quick Tip: Use $\frac{1}{f} = \left(\frac{n_l}{n_m} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$; the smaller the difference between lens and medium index, the smaller the power.

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13. Draw a graph between voltage and current of a p-n junction diode in forward bias.

Correct Answer: —

SOLUTION:

Step 1: Set up the experiment.
Connect the diode in forward bias (p to battery $+$, n to battery $-$) with a variable voltage source, a milliammeter to read current I, and a voltmeter to read the applied voltage V.

Step 2: Take readings.
Slowly increase V from zero. Note that up to a certain small voltage the current recorded by the milliammeter is negligibly small, because the junction barrier field still opposes the flow of majority carriers.

Step 3: Identify the threshold.
At the threshold or cut-in voltage the barrier is effectively cancelled. For silicon this is near 0.7 V and for germanium near 0.3 V. After this point even a tiny increase in V causes a large increase in I.

Step 4: Plot the trace.
Taking V on the horizontal axis and I on the vertical axis, the plotted points give a curve that clings to the voltage axis at first and then swings upward almost vertically after the cut-in voltage. This upward-bending, exponential-looking curve is the forward characteristic of the diode.

$$\boxed{I \text{ is very small below } V_k \text{ and increases rapidly above } V_k}$$

Quick Tip: Recall that a forward-biased diode conducts only after the knee/threshold voltage (~0.7 V for Si, ~0.3 V for Ge); the I-V curve stays flat then rises steeply.

14. State the working principle of a transformer and mention the energy losses occurring in it.

Correct Answer: —

SOLUTION:

Step 1: The core idea.
A transformer transfers electrical energy from one coil to another without any electrical connection between them, relying entirely on a shared, time-varying magnetic field. This coupling of two coils through a changing flux is called **mutual induction**, which is the working principle of the device.

Step 2: How the voltage changes.
The alternating primary current sets up an alternating flux in the soft-iron core. Since both coils are wound on the same core, the same flux threads each turn of the secondary, and the secondary voltage scales with the ratio of turns, $E_s/E_p = N_s/N_p$.

Step 3: List the ways energy is wasted.
• Winding (copper) loss: Joule heating I^2R in the coil wires.
• Eddy-current loss: circulating currents induced in the core; minimised by laminating the core.
• Hysteresis loss: energy spent in reversing the core's magnetisation each cycle; minimised by using soft iron of low coercivity.
• Magnetic flux leakage: not all primary flux reaches the secondary.
• Acoustic/humming loss: vibration of the core produces sound.

$$\boxed{\text{Mutual induction; losses} = \text{copper} + \text{eddy} + \text{hysteresis} + \text{leakage} + \text{humming}}$$

Quick Tip: The principle is mutual induction between two coils on a common core; think about the four heat/energy drains: copper, eddy current, hysteresis, and flux leakage.

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15. Define mass defect and binding energy.

Correct Answer: —

SOLUTION:

Step 1: Frame the idea of missing mass.
Imagine building a nucleus by bringing Z protons and $(A-Z)$ neutrons together. When you weigh the finished nucleus, it is lighter than the sum you started with. That shortfall in mass is the **mass defect** Δm, given by $\Delta m = [Zm_p + (A-Z)m_n] - M$, where M is the measured nuclear mass.

Step 2: Where the mass went.
The vanished mass has not disappeared; it has been converted into energy that holds the nucleus together. By Einstein's relation $E = mc^2$, this energy equals $E_b = \Delta m\, c^2$. This is the **binding energy**: the work needed to pull the nucleus apart into free, at-rest nucleons.

Step 3: Convenient conversion.
Using $1\,\text{u} \equiv 931.5$ MeV, the binding energy in MeV is simply $E_b = \Delta m(\text{in u}) \times 931.5$. The greater this value (especially per nucleon), the more tightly bound and stable the nucleus is.

$$\boxed{E_b = \Delta m\, c^2 = \Delta m(\text{u}) \times 931.5\ \text{MeV}}$$

Quick Tip: Mass defect is the difference between the summed mass of free nucleons and the actual nuclear mass; the binding energy is that mass defect converted to energy via E = (mass defect) c squared.

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16. Two point charges $+10\,\mu C$ and $-10\,\mu C$ are situated 2 cm apart. This dipole is placed in a uniform electric field of 1×10^5 volt/metre. Calculate the energy required to rotate the dipole from the position of $0°$ to $180°$.

Correct Answer: —

SOLUTION:

Step 1: Use potential energy of a dipole.

The potential energy of a dipole making angle θ with a uniform field is $U(\theta) = -pE\cos\theta$. The energy required to rotate it equals the change in potential energy, $W = U(\theta_2) - U(\theta_1)$.

Step 2: Compute the dipole moment.

With $q = 1 \times 10^{-5}$ C and arm $2a = 0.02$ m,

$p = q(2a) = 1 \times 10^{-5} \times 0.02 = 2 \times 10^{-7}$ C·m.

Step 3: Energy at each position.

At $\theta_1 = 0°$: $U_1 = -pE\cos 0° = -pE$.

At $\theta_2 = 180°$: $U_2 = -pE\cos 180° = +pE$.

Step 4: Change in energy.

$W = U_2 - U_1 = pE - (-pE) = 2pE$.

$W = 2 \times (2 \times 10^{-7}) \times (1 \times 10^5)$.

Step 5: Evaluate.

$W = 2 \times 2 \times 10^{-2} = 4 \times 10^{-2}$ J.

$$\boxed{W = 0.04\ \text{J}}$$

Quick Tip: Find the dipole moment p = q(2a), then use W = pE(cos0 − cos180) = 2pE for a rotation from 0 to 180 degrees.

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17. What are electromagnetic waves? Draw their propagation diagram. Show the electric field amplitude and magnetic field amplitude in the propagation diagram.

Correct Answer: —

SOLUTION:

Step 1: Explain what they are.

An electromagnetic wave is a self-sustaining disturbance made of coupled oscillating electric and magnetic fields. A changing electric field generates a magnetic field and a changing magnetic field regenerates the electric field, so the pair keeps each other going and marches forward through space, even where there is no matter.

Step 2: State their nature.

Because both fields point at right angles to the travel direction, the wave is transverse. In vacuum every such wave moves at $c = 1/\sqrt{\mu_0 \varepsilon_0}$ $= 3 \times 10^8$ m/s, and the field magnitudes obey $E_0/B_0 = c$, the two fields peaking together (in phase).

Step 3: Picture the wave.

Let the direction of propagation be the x-axis. Draw a sinusoidal curve for $\vec{E}$ oscillating along the y-axis, its crest labelled with amplitude E_0. Alongside it, in the perpendicular x-z plane, draw a second sinusoid for $\vec{B}$ oscillating along the z-axis, its crest labelled B_0. Both curves rise and fall together along x, and $\vec{E} \times \vec{B}$ gives the forward direction of the wave.

$$\boxed{E,\ B,\ \text{and propagation are mutually perpendicular; } c = E_0/B_0}$$

Quick Tip: Electromagnetic waves are transverse waves of mutually perpendicular oscillating E and B fields; in the diagram show E along one axis (amplitude E0), B along the perpendicular axis (amplitude B0), both perpendicular to the propagation direction.

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18. Resistance of a wire is R. If the length of the wire is stretched by n times the original length, then what will be the new resistance of the wire?

Correct Answer: —

SOLUTION:

Step 1: Note how R depends on dimensions.
Resistance is $R = \rho L/A$. When a wire is stretched, both L (increases) and A (decreases) change, while resistivity ρ and the volume of metal stay fixed.

Step 2: Write R using volume instead of area.
Since volume $V = AL$, we have $A = V/L$. Substituting,
$$R = \rho \frac{L}{V/L} = \frac{\rho L^2}{V}.$$
This shows that at constant volume, $R \propto L^2$.

Step 3: Apply the length change.

The new length is $L' = nL$, so the new resistance is

$$\frac{R'}{R} = \left(\frac{L'}{L}\right)^2 = \left(\frac{nL}{L}\right)^2 = n^2.$$

Step 4: Result.

Therefore $R' = n^2 R$; for example, doubling the length ($n = 2$) makes the resistance four times as large.

$$\boxed{R' = n^2 R}$$

Quick Tip: Volume of the wire stays constant on stretching, so R is proportional to length squared; increasing length n times raises resistance by n squared.

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19. Explain nuclear fission and nuclear fusion with examples.

Correct Answer: —

SOLUTION:

Step 1: Idea behind both processes.

Both fission and fusion are ways of reaching a more stable nucleus, that is a nucleus with a higher binding energy per nucleon. Iron (mass number about 56) sits at the peak of the binding-energy-per-nucleon curve, so nuclei move toward it to release energy.

Step 2: Fission described.

Very heavy nuclei lie on the right of that peak. If such a heavy nucleus is broken into two medium-sized nuclei, the fragments have a higher binding energy per nucleon than the parent, so energy is set free. This breaking of a heavy nucleus into two comparable parts (triggered by a slow neutron) is called nuclear fission. A representative reaction is ${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{144}_{56}Ba + {}^{89}_{36}Kr + 3\,{}^{1}_{0}n$, liberating nearly 200 MeV and extra neutrons that sustain a chain reaction.

Step 3: Fusion described.

Very light nuclei lie on the left of the peak. If two of them are joined into a slightly heavier nucleus, again the binding energy per nucleon rises and energy is released. This joining of light nuclei is called nuclear fusion. A representative reaction is the deuterium-deuterium reaction ${}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}He + {}^{1}_{0}n + 3.27$ MeV, and inside stars four protons ultimately fuse into one helium nucleus.

Step 4: Why fusion is hard to start.

Fusion requires temperatures of the order of millions of kelvin so that the positively charged nuclei have enough kinetic energy to come close enough for the strong nuclear force to bind them, overcoming Coulomb repulsion. Fission needs only a slow neutron, which carries no charge and is not repelled.

Step 5: Common conclusion.

In each case a small mass difference between reactants and products is the true fuel, released as energy through $E = \Delta mc^2$.

$$\boxed{\text{Both raise binding energy per nucleon and release energy}}$$

Quick Tip: Fission splits a heavy nucleus into two lighter ones; fusion joins two light nuclei into a heavier one. In both the mass defect is released as energy through $E = \Delta mc^2$.

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20. The focal length of a glass ($n_g = 3/2$) plano-convex lens in air is 10 cm. What will be the focal length and its nature when it is immersed in carbon disulphide ($n_c = 5/3$)?

Correct Answer: —

SOLUTION:

Step 1: Fix the actual radius of curvature first.

The lens is plano-convex, so one face is flat. Taking the curved face with radius R and the flat face with $R_2 = \infty$, the geometry factor is $\frac{1}{R_1} - \frac{1}{R_2} = \frac{1}{R}$.

Step 2: Use the air data to get R.

In air, $\frac{1}{f} = (n_g - 1)\frac{1}{R}$, so $\frac{1}{10} = \left(\frac{3}{2} - 1\right)\frac{1}{R} = \frac{1}{2R}$. Hence $R = 5$ cm.

The lens is a definite piece of glass with a 5 cm curved face.

Step 3: Effective index inside carbon disulphide.

Refraction depends only on the ratio of the two media. Inside carbon disulphide the effective index of the glass is $\mu' = \frac{n_g}{n_c} = \frac{3/2}{5/3} = 0.9$, which is less than 1. An index less than 1 means light bends the opposite way at the surfaces.

Step 4: Recompute the focal length.

$\frac{1}{f'} = (\mu' - 1)\frac{1}{R} = (0.9 - 1)\frac{1}{5} = \frac{-0.1}{5} = -0.02\ \text{cm}^{-1}$. Therefore $f' = \frac{1}{-0.02} = -50$ cm.

Step 5: Interpret the sign.

Because $\mu' < 1$, the once-converging lens turns into a diverging lens, and its focal length grows five times in magnitude to 50 cm.

$$\boxed{f' = -50 \text{ cm, acts as a diverging lens}}$$

Quick Tip: Use $\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ with μ taken relative to the medium. In carbon disulphide $\mu = n_g/n_c = 9/10 < 1$, so the lens turns diverging.

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21. Deduce the formula of force acting between two parallel current carrying conductors.

Correct Answer: —

SOLUTION:

Step 1: Look at the force on the first wire instead.

Take the same two long parallel wires separated by d, carrying I_1 and I_2. This time compute the field made by the second wire at the location of the first.

Step 2: Field of the second wire.

Using Ampere's circuital law for a long straight wire, the field produced by current I_2 at distance d is $B_2 = \dfrac{\mu_0 I_2}{2\pi d}$, directed perpendicular to the first wire.

Step 3: Force on the first wire.

A length l of the first wire carrying I_1 sits in this field at right angles, so it experiences $F_1 = B_2 I_1 l = \dfrac{\mu_0 I_2}{2\pi d} I_1\, l = \dfrac{\mu_0 I_1 I_2 l}{2\pi d}$.

Step 4: Force per unit length.

Dividing by the length, $\dfrac{F_1}{l} = \dfrac{\mu_0 I_1 I_2}{2\pi d}$. This is identical to the force per unit length on the second wire, confirming the mutual (action-reaction) nature of the force.

Step 5: Definition of the ampere.

Putting $I_1 = I_2 = 1$ A and $d = 1$ m gives $\dfrac{F}{l} = \dfrac{\mu_0}{2\pi} = 2 \times 10^{-7}$ N/m. Thus one ampere is that steady current which, in two infinitely long parallel wires 1 m apart, produces a force of 2×10^{-7} N per metre of length.

$$\boxed{\frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi d}}$$

Quick Tip: Find the field of one wire at the other, $B = \mu_0 I/2\pi d$, then use $F = BIl$ on the second wire. The force per unit length is $\mu_0 I_1 I_2/2\pi d$.

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22. What do you understand by free electron and drift velocity? Deduce Ohm's law on the basis of the principle of drift velocity.

Correct Answer: —

SOLUTION:

Step 1: Meaning of the two terms.

Free electrons are the detached valence electrons of a metal that wander through the lattice at high random (thermal) speeds but with zero net displacement. Drift velocity is the tiny net forward speed, of the order of 10^{-4} m/s, that these electrons pick up along the wire once a battery sets up a field inside it.

Step 2: Start from current density.

Define current density $j = I/A$. In one relaxation time an electron gains drift speed $v_d = \frac{eE\tau}{m}$, so the current density is $j = nev_d = \frac{ne^2\tau}{m}E$.

Step 3: Recognise conductivity.

Write $j = \sigma E$ where $\sigma = \frac{ne^2\tau}{m}$ is the electrical conductivity. Since n, e, m and τ are fixed for a given metal at a fixed temperature, σ is a constant. This is the microscopic form of Ohm's law, $j = \sigma E$.

Step 4: Convert to the everyday form.

Put $j = I/A$ and $E = V/l$: $\frac{I}{A} = \sigma\frac{V}{l}$, which gives $V = \frac{l}{\sigma A}I$.

Step 5: Identify resistance.

The bracket $\frac{l}{\sigma A}$ is a constant for the given wire, and is its resistance $R = \frac{l}{\sigma A} = \frac{ml}{ne^2\tau A}$. Hence $V = IR$ with R constant, so current is proportional to voltage, which is Ohm's law.

$$\boxed{j = \sigma E \;\Rightarrow\; V = IR}$$

Quick Tip: Free electrons drift with $v_d = eE\tau/m$; use $I = neAv_d$ and $E = V/l$ to reach $V = IR$ with R a constant.

23. The distance between any two sources of light is 24 cm. Determine where a convergent lens of focal length 9 cm be placed so that the image of both sources be formed at one point.

Correct Answer: —

SOLUTION:

Step 1: Name the unknown.

Let the lens sit at distance a from source S_1; the remaining distance to S_2 is $b = 24 - a$. The images formed by the two beams passing through the lens are required to land on the very same point.

Step 2: Apply the lens formula to each beam.

Taking the standard convention, the image distance of S_1 is v_1 with $\frac{1}{v_1} = \frac{1}{9} - \frac{1}{a}$, and the image distance of S_2 is v_2 with $\frac{1}{v_2} = \frac{1}{9} - \frac{1}{b}$.

Step 3: Coincidence condition by distances.

Since the beams enter from opposite sides, their images meet at one point when the image of the first lies on the same physical spot as the image of the second, giving $v_1 = -v_2$. Substituting $b = 24 - a$ and simplifying the equation $\frac{9a}{a-9} + \frac{9(24-a)}{15-a} = 0$ leads to $a^2 - 24a + 108 = 0$.

Step 4: Factor the quadratic.

$a^2 - 24a + 108 = (a-6)(a-18) = 0$, so $a = 6$ cm or $a = 18$ cm. These are the same setup seen from the two sources.

Step 5: Verify with the 18 cm placement.

Take $a = 18$ cm: image of S_1 is $v_1 = \frac{9 \times 18}{18 - 9} = 18$ cm (real, on far side), and for S_2 at $b = 6$ cm, $v_2 = \dfrac{9 \times 6}{6 - 9} = -18$ cm (virtual, same far side), so once again both images meet 18 cm from the lens. The placement is therefore 6 cm from one source and 18 cm from the other.

$$\boxed{a = 6 \text{ cm or } 18 \text{ cm from a source}}$$

Quick Tip: Put the lens at distance x from one source and $24 - x$ from the other, apply the lens formula to each, and set the images to coincide ($v_1 = -v_2$). You get $x = 6$ cm or 18 cm.

• • •

24. Prove that the electric potential energy per unit volume of a charged condenser is $\frac{1}{2}\varepsilon_0 E^2$, where symbols have their usual meaning.

Correct Answer: —

SOLUTION:

Step 1: Start from charge instead of voltage.

The energy of a charged capacitor can also be written as $U = \dfrac{Q^2}{2C}$, where Q is the charge on either plate.

Step 2: Insert parallel-plate quantities.

For a parallel plate capacitor, the surface charge density is $\sigma = \dfrac{Q}{A}$, so $Q = \sigma A$, and the capacitance is $C = \dfrac{\varepsilon_0 A}{d}$.

Step 3: Substitute.

$$U = \frac{Q^2}{2C} = \frac{(\sigma A)^2}{2\left(\frac{\varepsilon_0 A}{d}\right)} = \frac{\sigma^2 A^2 d}{2\varepsilon_0 A} = \frac{\sigma^2 A d}{2\varepsilon_0}.$$

Step 4: Divide by the volume Ad.

$u = \dfrac{U}{Ad} = \dfrac{\sigma^2}{2\varepsilon_0}.$

Step 5: Replace σ by the field.

The field between the plates is related to the surface charge density by $E = \dfrac{\sigma}{\varepsilon_0}$, so $\sigma = \varepsilon_0 E$. Substituting, $u = \dfrac{(\varepsilon_0 E)^2}{2\varepsilon_0} = \dfrac{\varepsilon_0^2 E^2}{2\varepsilon_0} = \dfrac{1}{2}\varepsilon_0 E^2$. This is the energy stored per unit volume of the electric field, and it holds for any electric field, not just inside a capacitor.

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

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

• • •

25. The energy of hydrogen atom in ground state ($n = 1$) is -13.6 eV. To which highest energy-state the hydrogen atom can be made to reach by the photon of energy 12.09 eV?

OR

What is meant by interference? Write the conditions for constructive and destructive interference.

Correct Answer: —

SOLUTION:

Option 1 (Atoms):

Step 1: Read the absorbed photon as an upward transition from the ground level $n_i = 1$ to a higher level $n_f = n$. The photon energy equals the energy gap: $E_{photon} = 13.6\left(\frac{1}{n_i^2} - \frac{1}{n_f^2}\right)$ eV.

Step 2: Substitute: $12.09 = 13.6\left(1 - \frac{1}{n^2}\right)$.

Step 3: $1 - \frac{1}{n^2} = \frac{12.09}{13.6} = 0.889$, so $\frac{1}{n^2} = 0.111$.

Step 4: $n^2 = \frac{1}{0.111} = 9.0 \Rightarrow n = 3$. The highest reachable level is the third one.

$$\boxed{n = 3}$$

Option 2 (Interference):

Step 1: When two coherent waves $y_1 = a\sin\omega t$ and $y_2 = a\sin(\omega t + \phi)$ meet, their amplitudes combine to give a resultant amplitude $R = 2a\cos(\phi/2)$, and the intensity follows $I \propto R^2$.

Step 2: Maximum intensity (constructive) needs $\cos(\phi/2) = \pm 1$, i.e. phase difference $\phi = 2n\pi$, which is a path difference of $n\lambda$.

Step 3: Minimum intensity (destructive) needs $\cos(\phi/2) = 0$, i.e. $\phi = (2n-1)\pi$, which is a path difference of $(2n-1)\lambda/2$.

$$\boxed{\text{Bright: path diff } n\lambda; \text{ Dark: path diff } (2n-1)\lambda/2}$$

Quick Tip: For the atom, add the photon energy to the ground-state energy and match it to $-13.6/n^2$. For interference, recall the path-difference conditions $n\lambda$ and $(2n-1)\lambda/2$.

• • •

26. What is meant by mutual inductance? Define coefficient of mutual inductance and write its unit.

Correct Answer: —

SOLUTION:

Step 1: Take two coils placed close to each other. Mutual induction is the property by which each coil opposes a change of current in the other by inducing an emf in it; the coils are then said to be magnetically coupled.

Step 2: Define the coefficient of mutual inductance M through the induced emf. If the primary current changes at a rate dI_1/dt, the secondary emf is $\varepsilon_2 = -M\,\dfrac{dI_1}{dt}$.

Step 3: Rearranging, $M = \dfrac{|\varepsilon_2|}{|dI_1/dt|}$. So M is numerically the emf (in volt) induced in the secondary when the primary current changes at the rate of 1 ampere per second.

Step 4: The coefficient is symmetric, $M_{12} = M_{21} = M$, so one number describes the coupling in either direction.

Step 5: From $M = \dfrac{\varepsilon_2}{dI_1/dt}$ the unit is $\dfrac{\text{volt}}{\text{ampere/second}}$ $= \text{volt·second/ampere} = \text{henry}.$

$$\boxed{M \text{ is measured in henry (H)}}$$

Quick Tip: Relate the flux in the second coil to the current in the first, $\phi_2 = MI_1$; the induced emf gives $M = -\varepsilon_2/(dI_1/dt)$, and the SI unit is the henry.

• • •

27. Write the Bohr's postulates for hydrogen atom. How did Bohr remove the drawbacks of Rutherford's model of atom?

OR

Derive the formula for the electric field outside a charged hollow sphere with the help of Gauss's law.

Correct Answer: —

SOLUTION:

Option 1 (Bohr's model):

Idea 1: In a hydrogen atom the single electron moves in special circular paths around the nucleus. In each such path the Coulomb attraction supplies the centripetal force, $\frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2} = \frac{mv^2}{r}$, and the electron loses no energy while it stays there. These are the stationary, non-radiating orbits.

Idea 2: Not every orbit is permitted. Bohr kept only those for which the electron's angular momentum is quantised, $mvr = \frac{nh}{2\pi}$, with n a positive integer.

Idea 3: Light is emitted or absorbed only during a jump between two permitted orbits, the photon carrying the energy difference, $h\nu = E_i - E_f$.

How the drawbacks vanish: Rutherford's accelerating electron would radiate, lose energy and crash into the nucleus in about 10^{-8} s, and would emit every frequency (a continuous spectrum). Because Bohr's electron radiates nothing while in a stationary orbit, the atom stays stable; because it can release only fixed energy differences, hydrogen shows sharp spectral lines instead of a continuous band.

$$\boxed{mvr = \frac{nh}{2\pi}, \quad h\nu = E_i - E_f}$$

Option 2 (Field outside a charged hollow sphere):

Step 1: Let a thin spherical shell of radius R carry charge q spread evenly over its surface. Choose an imaginary Gaussian sphere of radius r (with $r > R$), concentric with the shell, passing through the external point where the field is wanted.

Step 2: Because the charge distribution is spherically symmetric, the field must point radially and have one and the same magnitude E everywhere on this Gaussian surface.

Step 3: The electric flux through the Gaussian sphere is $\Phi = E \cdot (4\pi r^2)$, since $\vec{E}$ is everywhere perpendicular to the surface.

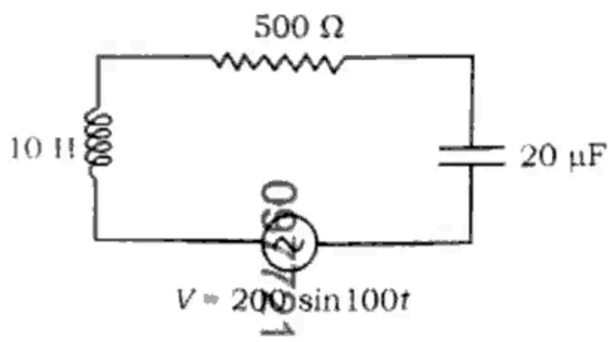
Step 4: Gauss's law sets this flux equal to the enclosed charge over ε_0. The full charge q lies inside, so $E \cdot 4\pi r^2 = \dfrac{q}{\varepsilon_0}$.

Step 5: Solving, $E = \dfrac{q}{4\pi\varepsilon_0 r^2}$. This is exactly the field of a point charge q at the centre, so an external observer cannot tell a uniformly charged shell from a point charge.

$$\boxed{E = \frac{q}{4\pi\varepsilon_0 r^2}}$$

Quick Tip: Bohr: stationary orbits, quantised angular momentum $mvr = nh/2\pi$, and $h\nu = E_i - E_f$; these cure Rutherford's instability and continuous-spectrum problems. For the shell, apply Gauss's law over a concentric sphere of radius $r > R$.

28.



What is the meaning of wavefront? Explain the laws of reflection on the basis of Huygens' principle of wavefront.

OR

Determine the following for the given A.C. circuit: (i) impedance, (ii) power factor, and (iii) phase difference between voltage and current. (Series combination of resistance $R = 500\ \Omega$, inductance $L = 10$ H and capacitance $C = 20\ \mu$F connected to an A.C. source $V = 200\sin 100t$.)

Correct Answer: —

SOLUTION:

Option 1 (Wavefront and laws of reflection):

What a wavefront is: Picture a disturbance spreading through a medium. At any chosen instant, join every particle that is at the same stage of vibration (same phase); the surface so formed is the wavefront. It may be spherical (near a point source), cylindrical (near a line source) or plane (far from the source). The normal to the wavefront gives the direction of travel.

Huygens' construction: Treat each point of a given wavefront as a tiny secondary source sending out spherical wavelets that move forward at speed v; after a time t their forward common tangent is the next wavefront.

Getting $i = r$:

Step 1: A plane wavefront AB strikes a mirror XY. Corner A arrives first, while the far corner B must still cover the distance BC to reach the surface.

Step 2: Let this take time t, so $BC = vt$. Meanwhile the secondary wavelet started from A has grown to radius $AD = vt$ on the reflected side.

Step 3: The tangent CD drawn from C to this wavelet is the reflected wavefront, with $CD = vt$.

Step 4: Right triangles ABC and CDA share the hypotenuse AC and have equal sides $BC = AD = vt$, so they are congruent. This makes the angle of incidence equal to the angle of reflection, $i = r$.

Step 5: The same geometry keeps the incident ray, the normal and the reflected ray in one plane. Both laws of reflection follow.

$$\boxed{\text{angle of incidence } i = \text{angle of reflection } r}$$

Option 2 (A.C. series circuit):

Step 1: From $V = 200 \sin 100t$, the peak voltage is $V_0 = 200$ V and the angular frequency is $\omega = 100$ rad/s. Given $R = 500\ \Omega$, $L = 10$ H, $C = 20 \times 10^{-6}$ F.

Step 2: Express the reactances as phasors. Inductor: $X_L = \omega L = 1000\ \Omega$ (voltage 90° ahead of current). Capacitor: $X_C = 1/(\omega C) = 1/(100 \times 20 \times 10^{-6}) = 500\ \Omega$ (voltage 90° behind current).

Step 3: The net reactance is $X = X_L - X_C = 1000 - 500 = 500\ \Omega$, which is positive, so the circuit is net inductive.

Step 4: The impedance is the phasor sum $Z = \sqrt{R^2 + X^2}$ $= \sqrt{500^2 + 500^2} = 500\sqrt{2} \approx 707\ \Omega$.

Step 5: From the impedance triangle the power factor is $\cos\phi = R/Z$

$= 500/(500\sqrt{2}) = 0.707$ and the phase angle is $\phi = \tan^{-1}(X/R)$ $= \tan^{-1}(1) = 45°$, with the applied voltage leading the current.

$$\boxed{Z \approx 707\ \Omega,\ \ \cos\phi \approx 0.707,\ \ \phi = 45°}$$

Quick Tip: Wavefront = surface of constant phase; use Huygens' secondary wavelets and congruent triangles to prove $i = r$. For the circuit, find $X_L = \omega L$ and $X_C = 1/\omega C$, then $Z = \sqrt{R^2 + (X_L - X_C)^2}$, $\cos\phi = R/Z$, $\tan\phi = (X_L - X_C)/R$.

• • •

29. Explain full wave rectifying action of p-n junction diode with the help of circuit diagram.

OR

Draw the diffraction pattern of light due to single slit and write the expression for position of minima. On what factors does the width of central maxima depend?

Correct Answer: —

SOLUTION:

Option 1: Full Wave Rectifier

Step 1: Principle. A junction diode is a one-way device: it passes current only in forward bias. To obtain DC over the whole AC cycle, one diode must take over exactly when the other switches off. This handover is arranged with a centre-tapped transformer feeding two diodes.

Step 2: Components. Secondary of the transformer with a central tap C; upper end A goes to diode D_1; lower end B goes to diode D_2; the free ends of D_1 and D_2 are tied together and taken to the load R_L, whose other end returns to C. Output is read across R_L.

Step 3: Cycle-by-cycle account.
First half of input: A is positive, so D_1 is ON and D_2 is OFF. Path of current: A to D_1 to R_L to C.
Second half of input: B is positive, so D_2 is ON and D_1 is OFF. Path of current: B to D_2 to R_L to C.
In both halves the load current enters R_L from the same terminal, so its direction never reverses.

Step 4: Output waveform. The load therefore carries current during every half cycle in one fixed direction. The result is a unidirectional but pulsating voltage whose ripple frequency is $2f$, double the mains frequency f. A shunt capacitor filter can flatten this into nearly steady DC.

Step 5: Merit over half wave. Because no half of the input is thrown away, the rectifier efficiency (about 81.2%) is twice that of a half wave rectifier (about 40.6%), and the output is easier to smooth.

$$\boxed{D_1 \text{ and } D_2 \text{ conduct in turn} \Rightarrow \text{continuous DC through } R_L}$$

Option 2: Single Slit Diffraction

Step 1: Split the slit. Take a slit of width a. To find the first dark fringe, imagine the slit divided into two equal halves, each of width $a/2$. Pair every point in the upper half with the point exactly $a/2$ below it in the lower half.

Step 2: First minimum. Each such pair cancels when its path difference is $\lambda/2$: $(a/2)\sin\theta = \lambda/2$, which gives $a\sin\theta = \lambda$. Dividing the slit into $2n$ equal strips and pairing them the same way generalises this to the full minima condition

$$a\sin\theta = n\lambda, \quad n = 1, 2, 3, \dots$$

Step 3: Screen position. With slit-screen distance D and small θ, $\sin\theta \approx x_n/D$, so

$$x_n = \frac{n\lambda D}{a}$$

The dark fringes are almost evenly spaced by $\lambda D/a$.

Step 4: Central maximum. The bright centre is bounded by the two first-order minima ($n = 1$) at $x = \pm\lambda D/a$. Hence its width is

$$W = \frac{2\lambda D}{a}$$

which is twice the spacing of the neighbouring fringes.

Step 5: Dependence. Since $W \propto \lambda$, $W \propto D$ and $W \propto 1/a$, a longer wavelength, a larger screen distance, or a narrower slit each widens the central maximum. Conversely, if a is made very large, $W \to 0$ and we recover the sharp geometrical shadow of ray optics.

$$\boxed{a\sin\theta = n\lambda, \quad W = \frac{2\lambda D}{a}}$$

Quick Tip: Option 1: in a centre-tapped full wave rectifier the two diodes conduct in alternate half cycles but push current through the load in the same direction, giving pulsating DC. Option 2: use $a \sin\theta = n\lambda$ for the minima and $W = 2\lambda D/a$ for the central maximum width.

• • •

30. What do you understand by electromagnetic induction? State the Faraday's laws of electromagnetic induction.

OR

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

Correct Answer: —

SOLUTION:

Option 1: Electromagnetic Induction and Faraday's Laws

Step 1: Everyday picture. Push a bar magnet towards a coil connected to a galvanometer and the needle deflects; pull the magnet away and it deflects the other way; hold the magnet still and there is no deflection. The coil generates electricity only while the magnetic field threading it is changing. This effect is called electromagnetic induction.

Step 2: The quantity that matters. What the coil responds to is the magnetic flux $\Phi = BA\cos\theta$. It can be changed in three ways: by altering the field B, the area A, or the orientation angle θ, and equivalently by moving the magnet and coil relative to each other.

Step 3: Faraday's first law (existence). An emf is induced in a circuit whenever the flux linked with it changes, and this emf exists only for the duration of the change. A faster change gives a bigger effect; no change means no emf.

Step 4: Faraday's second law (magnitude). The induced emf equals the time rate of change of flux linkage. For N turns,

$$e = -N\frac{d\Phi}{dt}$$

and over a finite time interval the average emf is $e = -N\dfrac{\Delta\Phi}{\Delta t}$.

Step 5: Sign and current. The minus sign is Lenz's law: the induced emf opposes the flux change that causes it, as required by energy conservation. In a circuit of resistance R the induced current is

$$I = \frac{e}{R} = -\frac{N}{R}\frac{d\Phi}{dt}$$

$$\boxed{e = -N\frac{d\Phi}{dt}}$$

Option 2: Parallel Plate Capacitor Partially Filled with Dielectric

Step 1: Setup. Two plates of area A are separated by a distance d and carry charges $+Q$ and $-Q$. A dielectric slab of dielectric constant K and thickness t (with $t < d$) is slipped between them; the leftover gap $(d - t)$ stays as air.

Step 2: Two regions, two fields. The surface charge density is $\sigma = Q/A$. In the air part the field is $E_0 = \sigma/\varepsilon_0 = Q/(\varepsilon_0 A)$. Inside the slab the bound (polarisation) charges weaken this field to $E = E_0/K$.

Step 3: Add the voltage drops. The potential difference is the field multiplied by the length of each region and then summed:

$$V = E_0(d-t) + \frac{E_0}{K}\,t = E_0\left[(d-t) + \frac{t}{K}\right]$$

Step 4: Insert E_0.

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

Step 5: Capacitance and limits. Using $C = Q/V$,

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

For $t = 0$ this reduces to the air capacitor $C = \varepsilon_0 A/d$, and for $t = d$ it becomes $C = K\varepsilon_0 A/d$, exactly as expected. Since $K > 1$, inserting the slab always increases the capacitance.

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

Quick Tip: Option 1: the induced emf equals the rate of change of magnetic flux, $e = -N\,d\Phi/dt$, and exists only while the flux changes. Option 2: add the potential drops across the air gap $(d-t)$ and the dielectric slab of thickness t, then use $C = Q/V$.