CBSE Class 12 Physics 2026 — Set 1 — Answer Key

English Medium

Time Allowed: 3 Hours

General Instructions:

1. This is an answer key — each question is shown with its correct answer and a step-by-step explanation.
2. Questions appear in the original paper order.

Q.1

In a region, the electric potential varies as V = 10 – 50x, where V is in volts and x in meters. The electric field in the region is

(a) 10 N/C along +x

(b) 10 N/C along –x

(c) 50 N/C along +x <<

(d) 50 N/C along –x

Explanation:

E = –dV/dx = –d(10 – 50x)/dx = –(–50) = +50 N/C.

The positive value means the field is directed along the +x direction.

Answer: 50 N/C along +x.

Q.2

A conducting wire connects two charged metallic spheres A and B of radii r1 and r2 respectively. The distance between the spheres is very large compared to their radii. The ratio of electric fields, (EA/EB) at the surfaces of spheres A and B will be

(a) r1/r2

(b) r2/r1 <<

(c) $(r1/r2)^2$

(d) $(r2/r1)^2$

Explanation:

When connected, both spheres reach the same potential V.

The electric field at the surface of a sphere of radius r is E = V/r (since V = kQ/r and E = kQ/r^2).

Therefore EA = V/r1 and EB = V/r2, giving EA/EB = r2/r1.

Q.3

A long straight wire of circular cross-section (radius a) carries a steady current I. The current is uniformly distributed across this cross-section. The magnitude of the magnetic field produced at a point at a distance (a/2) from

the axis of the wire will be

(a) Zero

(b) $\mu_o I/(2\pi a)$

(c) $\mu_o I/(4\pi a)$ <<

(d) $\mu_o I/(6\pi a)$

Explanation:

Inside the wire ($r = a/2$), Ampère's law gives $B \cdot 2\pi r = \mu_o I_{enc}$, with $I_{enc} = I \cdot r^2/a^2 = I/4$.

So $B = \mu_o(I/4)/(2\pi \cdot a/2) = \mu_o I/(4\pi a)$.

Answer: (C).

Q.4

The shape of the interference fringes in Young's double-slit experiment, when the distance between the slit and the screen is very large as compared to the slit-separation, is nearly

(a) straight <<

(b) parabolic

(c) circular

(d) hyperbolic

Explanation:

The locus of points of equal path difference from two sources is a hyperbola.

However, when the screen is very far away compared to the slit separation ($D >> d$), the hyperbolic fringes approximate to straight parallel lines.

Hence the fringes appear nearly straight.

Q.5

An electromagnetic wave passes from vacuum into a dielectric medium with relative electrical permittivity (3/2) and relative magnetic permeability (8/3). Then, its

(a) wavelength is doubled and frequency remains unchanged.

(b) wavelength is doubled and frequency is halved.

(c) wavelength is halved and frequency remains unchanged. <<

(d) wavelength and frequency both will remain unchanged.

Explanation:

The refractive index n = √(εr × μr) = √(3/2 × 8/3) = √4 = 2.

Frequency is a property of the source and remains unchanged when the wave enters a medium.

The speed in the medium v = c/n = c/2.

Wavelength λ_medium = v/f = (c/2)/f = λ_vacuum/2.

So wavelength is halved and frequency remains unchanged.

Q.6

In a series LCR circuit, the voltage across the resistor, capacitor and inductor is 10 V each. If the capacitor is short circuited, the voltage across the inductor will be

(a) 10 V

(b) 5√2 V <<

(c) (5/√2) V

(d) 10√2 V

Explanation:

With VR = VL = VC = 10 V, the circuit is at resonance, so the source voltage = VR = 10 V and XL = XC, with the same current I.

From VR = IR = 10 V and VL = IXL = 10 V, we get R = XL (in terms of impedance ratios).

When C is short-circuited, the circuit has R and L in series.

Source V = 10 V.

Impedance Z = √(R² + XL²) = √(R² + R²) = R√2.

New current I' = 10/(R√2).

Voltage across inductor V_L' = I' × XL = I' × R = 10/(R√2) × R = 10/√2 = 5√2 V.

Q.7

Electromagnetic waves used in a diagnostic tool in medicine have a wavelength range

(a) 1 nm to 10^{-3} nm <<

(b) 400 nm to 1 nm

(c) 1 mm to 700 nm

(d) 0.1 m to 1 mm

Explanation:

X-rays are used in medicine for diagnostic purposes (e.g., X-ray imaging).

The wavelength range of X-rays is approximately 10^{-3} nm to 1 nm (i.e., 10^{-12} m to 10^{-9} m).

Option (A) gives 1 nm to 10^{-3} nm, which matches the X-ray range.

Q.8

The 'distance of closest approach' of an alpha-particle is 'd' when it moves with a velocity v head-on towards the target nucleus. If the velocity of alpha particle is halved, the new 'distance of closest approach' will be

(a) d/2

(b) 2d

(c) d/4

(d) 4d <<

Explanation:

At distance of closest approach, all kinetic energy converts to electrostatic potential energy: $\frac{1}{2}mv^2 = kqQ/d$, so $d \propto 1/v^2$.

If $v' = v/2$, then $d' = d \times (v/v')^2 = d \times (v/(v/2))^2 = d \times 4 = 4d$.

Q.9

A concave lens of focal length 10 cm is cut into two identical plano-concave lenses. The focal length of each lens will be

(a) 20 cm <<

(b) 30 cm

(c) 40 cm

(d) 5 cm

Explanation:

For the original biconcave lens: $1/f = (n–1)[1/R1 – 1/R2] = (n–1)[–1/R – 1/(–R)] = –2(n–1)/R$.

So $1/(–10) = –2(n–1)/R$.

When cut horizontally into two identical plano-concave pieces, each has one flat surface ($R = \infty$) and one curved surface R.

Power of each piece $= (n–1)(1/\infty – 1/(–R)) = (n–1)/R$ = half the original power.

Focal length doubles: $f_{new} = 2 \times 10 = 20$ cm.

Q.10

Four independent waves are expressed as (i) $y1 = A1 \sin \omega t$, (ii) $y2 = A2 \sin 2\omega t$, (iii) $y3 = A3 \cos \omega t$, (iv) $y4 = A4 \sin(\omega t + \pi/3)$. The interference between two of these waves is possible in

(a) (i) and (iii) only

(b) (iii) and (iv) only

(c) (i), (iii) and (iv) only <<

(d) All of them

Explanation:

Interference requires coherent sources — same frequency and a constant phase difference.

Waves (i), (iii) and (iv) all have the same angular frequency ω (noting $\cos \omega t = \sin(\omega t + \pi/2)$).

Wave (ii) has frequency 2ω, so it cannot produce a sustained interference pattern with any of the others.

Therefore interference is possible among (i), (iii) and (iv).

Q.11

Two heaters rated as (P1, V) and (P2, V) are connected in series across a dc source of V/2 volt. The power consumed by the combination will be

(a) (P1 + P2)

(b) (P1 + P2)/2

(c) P1P2/[2(P1 + P2)]

(d) P1P2/[4(P1 + P2)] <<

Explanation:

From ratings: $R1 = V^2/P1$ and $R2 = V^2/P2$.

Series combination: $R_{total} = R1 + R2 = V^2(1/P1 + 1/P2) = V^2(P1+P2)/(P1P2)$.

Applied voltage = V/2.

Power $P = (V/2)^2/R_{total} = (V^2/4) / [V^2(P1+P2)/(P1P2)] = (1/4) \times P1P2/(P1+P2) = P1P2/[4(P1+P2)]$.

Q.12

In an unbiased p-n junction, at equilibrium, which of the following statements is true?

(a) Diffusion current is zero but drift current exists.

(b) Diffusion current exists but drift current is zero.

(c) Diffusion and drift currents are equal and opposite. <<

(d) Both the diffusion and drift currents exist but are unequal.

Explanation:

At equilibrium in an unbiased p-n junction, there is no net current flow.

Both diffusion current (due to concentration gradient) and drift current (due to the built-in electric field in the depletion region) exist but are equal in magnitude and opposite in direction, so they cancel out.

Q.13

Assertion (A): All atoms have a net magnetic moment. Reason (R): A current loop does not always behave as a magnetic dipole.

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

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

(c) Assertion (A) is true, but Reason (R) is false.

(d) Both Assertion (A) and Reason (R) are false. <<

Explanation:

Assertion is FALSE: not all atoms have a net magnetic moment — atoms with completely filled shells (e.g., noble gases such as He, Ne) have paired electrons with opposing spins and orbital angular momenta, giving zero net magnetic moment.

Reason is FALSE: a current loop always behaves as a magnetic dipole.

Both A and R are false.

Q.14

Assertion (A): If accelerated electrons are passed through a narrow slit, a diffraction pattern is observed. Reason (R): Electrons behave as both particles and waves.

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

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

(c) Assertion (A) is true, but Reason (R) is false.

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

Explanation:

Assertion is TRUE: electrons passing through a narrow slit show diffraction (de Broglie wavelength of accelerated electrons is comparable to slit width).

Reason is TRUE: electrons exhibit wave-particle duality (de Broglie hypothesis, confirmed by Davisson-Germer experiment).

R correctly explains A — diffraction occurs precisely because electrons have wave nature.

Q.15

Assertion (A): The mass of a nucleus is less than the sum of the masses of the constituent nucleons. Reason (R): Energy is absorbed when the nucleons are bound together to form a nucleus.

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

(b) Both Assertion (A) and Reason (R) are true, but Reason (R) is not the

correct explanation of Assertion (A).

(c) Assertion (A) is true, but Reason (R) is false. <<

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

Explanation:

Assertion is TRUE: the mass defect — mass of nucleus is less than sum of constituent nucleon masses by the mass defect Δm, which equals the binding energy divided by c^2.

Reason is FALSE: energy is RELEASED (not absorbed) when nucleons bind together to form a nucleus (this is the binding energy).

The mass decrease corresponds to the energy released.

Hence A is true but R is false.

Q.16

Assertion (A): In Bohr model of hydrogen atom, the energy levels are discrete and quantised. Reason (R): In a hydrogen atom, the electrostatic force on the electron provides the necessary centripetal force to it to revolve around the nucleus.

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

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

(c) Assertion (A) is true, but Reason (R) is false.

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

Explanation:

Assertion is TRUE: Bohr's model gives discrete, quantised energy levels $E_n = -13.6/n^2$ eV.

Reason is TRUE: the Coulomb electrostatic force ke^2/r^2 does provide the centripetal force mv^2/r for circular orbits.

However, R does not explain the quantisation of energy levels — that comes from Bohr's quantisation condition $mvr = nh/(2\pi)$.

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

Q.17

In a photoelectric experiment, the emitter plate is irradiated with radiation of 200 nm. The photocurrent becomes zero when the collector plate potential is –0.80 V. Calculate the work function (in eV) of the emitter.

Answer: 5.42 eV

Explanation:

Stopping potential Vs = 0.80 V, so maximum KE of photoelectrons = eVs = 0.80 eV.

Energy of incident photon: $E = hc/\lambda = (6.63\times10^{-34} \times 3\times10^{8})/(200\times10^{-9}) = 19.89\times10^{-26}/200\times10^{-9} = 9.945\times10^{-19}$ J.

Converting to eV: $E = 9.945\times10^{-19}/1.6\times10^{-19} = 6.216$ eV.

By Einstein's photoelectric equation: $\varphi = E - eVs = 6.216 - 0.80 = 5.416 \approx 5.42$ eV.

Q.18

(a) A beam of light consisting of two wavelengths 400 nm and 600 nm is used to illuminate a single slit of width 1 mm. Find the least distance of the point from the central maximum where the dark fringes due to both wavelengths coincide on the screen placed 1.5 m from the slit.

Answer: 1.8 mm

Explanation:

Single slit diffraction minima: $y_m = m\lambda D/a$.

For $\lambda1 = 400$ nm: $y = n \times 400\times10^{-9} \times 1.5 / (1\times10^{-3}) = n \times 6\times10^{-4}$ m $= 0.6n$ mm.

For $\lambda2 = 600$ nm: $y = m \times 600\times10^{-9} \times 1.5 / (1\times10^{-3}) = m \times 9\times10^{-4}$ m $= 0.9m$ mm.

Coincidence: $0.6n = 0.9m \rightarrow 2n = 3m$.

Least solution: $m = 2$, $n = 3$.

$y = 0.9 \times 2 = 1.8$ mm.

OR

Q.18

OR (b) In a Young's double-slit experimental set-up with slit separation 0.6 mm, a beam of light consisting of two wavelengths 440 nm and 660 nm is used to obtain interference pattern on a screen kept 1.5 m in front of the

slits. Find the least distance of the point from the central maximum where the bright fringes due to both the wavelengths coincide.

Answer: 3.3 mm

Explanation:

YDSE bright fringes: $y = n\lambda D/d$.

For $\lambda 1 = 440$ nm: $y = n \times 440\times10^{-9} \times 1.5 / (0.6\times10^{-3}) = n \times 1.1\times10^{-3}$ m $= 1.1n$ mm.

For $\lambda 2 = 660$ nm: $y = m \times 660\times10^{-9} \times 1.5 / (0.6\times10^{-3}) = m \times 1.65\times10^{-3}$ m $= 1.65m$ mm.

Coincidence: $1.1n = 1.65m \rightarrow 2n = 3m$.

Least solution: $m = 2$, $n = 3$.

$y = 1.65 \times 2 = 3.3$ mm.

Q.19

A wire of length L is bent round into (i) a square coil having N turns and (ii) a circular coil having N turns. The coil in both cases is free to turn about a vertical axis coinciding with the plane of the coil, in a uniform, horizontal magnetic field and carry the same currents. Find the ratio of the maximum value of the torque acting on the square coil to that on the circular coil.

Answer: $\pi/4$

Explanation:

Square coil: side length $s = L/(4N)$.

Area $A_{sq} = s^2 = L^2/(16N^2)$.

Maximum torque $\tau_{sq} = NIB \times A_{sq} = NI \times L^2/(16N^2) \times B = IL^2B/(16N)$.

Circular coil: circumference $= L/N$, so radius $r = L/(2\pi N)$.

Area $A_{circ} = \pi r^2 = \pi \times L^2/(4\pi^2N^2) = L^2/(4\pi N^2)$.

Maximum torque $\tau_{circ} = NI \times L^2/(4\pi N^2) \times B = IL^2B/(4\pi N)$.

Ratio $= \tau_{sq}/\tau_{circ} = [IL^2B/(16N)] / [IL^2B/(4\pi N)] = 4\pi N/(16N) = \pi/4$.

Q.20

What is the order of magnitude of drift velocity of electrons in a conductor? Deduce the relation between the current flowing through a conductor and drift velocity of electrons in it.

Answer: Order ~10^{-3} m/s; I = nAeVd

Explanation:

Order of magnitude: typical drift velocity of electrons in a metallic conductor is of the order 10^{-3} to 10^{-4} m/s (approximately 10^{-3} m/s).

Derivation: Consider a conductor of cross-sectional area A with n free electrons per unit volume, each having drift velocity Vd.

In time dt, electrons in a cylinder of length Vd×dt pass through area A.

Number of electrons = n × A × Vd × dt.

Charge flowing = nAeVd dt.

Current I = charge/time = nAeVd.

Hence I = nAeVd.

Q.21

Draw the plot of potential energy of a pair of nucleons as a function of their separation. Write two important conclusions that can be drawn from this plot.

Answer: Plot: the potential energy is strongly positive (repulsive) for $r < r_o \approx 0.8$ fm, falls to a minimum (attractive well) at $r \approx r_o \approx 0.8$ fm, then rises towards zero and is negligible beyond about 2–3 fm. Conclusions: (i) the nuclear force is attractive and strong for separations greater than about 0.8 fm, and short-ranged (negligible beyond a few fm); (ii) it becomes repulsive for separations less than about 0.8 fm.

Explanation:

The nucleon–nucleon potential energy curve is positive and steeply rising for r < 0.8 fm (repulsive core), has its minimum near r = 0.8 fm (the stable separation, where the force is zero) and approaches zero beyond about 2–3 fm.

Hence: (i) the nuclear force is attractive for r > 0.8 fm and falls to a negligible value beyond a few fm, so it is short-ranged;

(ii) it is repulsive for r < 0.8 fm.

Q.22

(a) Using Gauss's law, deduce an expression for electric field at a point due to a uniformly charged infinite plane thin sheet. (b) Two large thin plane

sheets, each having surface charge density σ are held close and parallel to each other in air. What is the net electric field at a point (i) inside and (ii) outside, the sheets?

Answer: (a) $E = \sigma/(2\varepsilon_0)$ perpendicular to sheet; (b) inside: 0; outside: σ/ε_0

Explanation:

(a) Choose a cylindrical Gaussian surface of area A with flat faces parallel to and on either side of the sheet.

By symmetry, E is perpendicular to the sheet.

Flux = E×A + E×A = 2EA.

Charge enclosed = σA.

Gauss's law: $2EA = \sigma A/\varepsilon_0 \rightarrow E = \sigma/(2\varepsilon_0)$.

(b) Each sheet produces $E = \sigma/(2\varepsilon_0)$ directed away from it (for positive σ).

Inside (between sheets): the fields from the two sheets point in opposite directions and cancel.

$E_{inside} = \sigma/(2\varepsilon_0) - \sigma/(2\varepsilon_0) = 0$.

Outside: both sheets' fields point in the same direction.

$E_{outside} = \sigma/(2\varepsilon_0) + \sigma/(2\varepsilon_0) = \sigma/\varepsilon_0$.

OR

Q.22

OR (a) Obtain the condition of balance of a Wheatstone bridge. (b) Find net resistance of the network of resistors connected between A and B, as shown in figure.

Answer: (a) P/Q = R/S (Wheatstone bridge balance condition); (b) Net resistance between A and B = 6R

Explanation:

(a) Balance condition: P/Q = R/S.

(b) From the figure the network between M and N has five resistors, each R: M–O, O–P and P–N in series along the line, with R joined from M to P (top) and R joined from O to N (bottom).

Put 1 V across M–N (N at 0).

Node O: $(1 - V_O) + (V_P - V_O) + (0 - V_O) = 0$, so $1 + V_P = 3V_O$.

Node P: $(1 - V_P) + (V_O - V_P) + (0 - V_P) = 0$, so $1 + V_O = 3V_P$.

Hence $V_O = V_P = 1/2$ V (in units where R = 1), and the current from M is $(1 - ½)/R + (1 - ½)/R = 1/R$.

So $R_{MN} = R$.

Net resistance A to B = 2R + R + 3R = 6R.

Q.23

A parallel plate capacitor of capacitance C has a dielectric slab between its plates. It is charged to a potential difference V by connecting it across a battery. The battery is then disconnected. If the dielectric slab is now withdrawn from the capacitor, how will the following be affected? (a) Capacitance of the capacitor, (b) Energy stored in the capacitor, and (c) The potential difference between the plates of the capacitor. Justify your answer in each case.

Answer: (a) Decreases ($C \to C/K$); (b) Increases ($U \to KU$); (c) Increases ($V \to KV$)

Explanation:

Let K = dielectric constant.

Initial: capacitance = C (with dielectric), charge Q = CV (constant after battery disconnected).

When dielectric withdrawn: (a) Capacitance $C' = C/K < C$ — decreases by factor K, since $C = K\varepsilon_0 A/d$ and without dielectric $C_0 = \varepsilon_0 A/d = C/K$.

(b) Energy $U = Q^2/(2C')$.

Since Q is constant and C decreases to C/K: $U' = Q^2/(2C/K) = K \times Q^2/(2C) = K \times ½CV^2 = KU$ — energy increases.

The extra energy comes from the work done by the external agent in pulling out the dielectric against the attractive force.

(c) $V' = Q/C' = Q/(C/K) = KQ/C = KV$ — potential difference increases by factor K.

Q.24

Figure shows a narrow beam of electrons entering with a velocity of 3×10^7 m/s, symmetrically through the space between two parallel horizontal plates

P1P1' and P2P2' kept 2 cm apart. If each plate is 3 cm long, calculate the potential difference V applied between the plates so that the beam just strikes the end P2'.

Answer: ≈ 2275 V

Explanation:

Given: $v = 3\times10^{7}$ m/s (horizontal), plate separation d = 2 cm = 0.02 m, plate length L = 3 cm = 0.03 m.

Beam enters symmetrically, so vertical displacement to reach P2' = d/2 = 0.01 m.

Electric field between plates: $E_{field} = V/d$.

Vertical acceleration: $a = eE_{field}/m_e = eV/(m_e \times d)$.

Time to traverse plates: $t = L/v = 0.03/(3\times10^{7}) = 10^{-9}$ s.

Vertical displacement: $y = \frac{1}{2}at^2 \rightarrow 0.01 = \frac{1}{2} \times eV/(m_e \times d) \times (10^{-9})^2$.

Solving for V: $V = (2 \times y \times m_e \times d) / (e \times t^2) = (2 \times 0.01 \times 9.1\times10^{-31} \times 0.02) / (1.6\times10^{-19} \times 10^{-18})$.

Numerator $= 2 \times 0.01 \times 9.1\times10^{-31} \times 0.02 = 3.64\times10^{-34}$.

Denominator $= 1.6\times10^{-37}$.

$V = 3.64\times10^{-34} / 1.6\times10^{-37} = 2275$ V.

Q.25

An ac voltage Vi = 12 sin(100πt) V is applied between points A and B in a network of two ideal diodes and three resistors as shown in figure. During the positive half-cycle of the input voltage Vi supplied to the network: (a) Identify which of the two diodes will conduct and why? (b) Redraw an equivalent circuit diagram to show the flow of current. (c) Calculate the output voltage drops V0 across the three resistors when the input voltage attains its peak value.

Answer: (a) Only D_2 conducts. (b) Current path: A → D_2 → R, then through the 3 kΩ to B and also through 1 kΩ + 2 kΩ (in series) to B. (c) At peak (12 V): voltage across 3 kΩ = 12 V, across 1 kΩ = 4 V, across 2 kΩ = 8 V.

Explanation:

From the figure, D_1 has its anode at P and cathode at A, while D_2 has its anode at A and cathode at R.

During the positive half-cycle A is positive, so D_2 is forward biased and conducts;

D_1 is reverse biased and acts as an open circuit.

With D_2 ideal, node R is at the potential of A (12 V at the peak, B at 0).

R is joined to B by two parallel paths: the 3 kΩ resistor directly, and the 1 kΩ + 2 kΩ series branch (via P).

The 3 kΩ has 12 V across it.

The 1 kΩ + 2 kΩ branch (3 kΩ in total) carries 12/3 = 4 mA, so the 1 kΩ has 4 V and the 2 kΩ has 8 V.

Q.26

Briefly explain the two important processes that occur during the formation of a p-n junction.

Answer: Diffusion and Drift

Explanation:

Two processes during p-n junction formation: (1) Diffusion: Holes from the p-side diffuse to the n-side (high concentration to low concentration), and electrons from the n-side diffuse to the p-side.

This creates a depletion region near the junction depleted of free charge carriers.

(2) Drift: As diffusion occurs, positive ions are left on the n-side and negative ions on the p-side near the junction, creating a built-in electric field directed from n to p.

This field causes minority carriers to drift across the junction — electrons from p to n and holes from n to p — in the opposite direction to diffusion.

Equilibrium is reached when diffusion current equals drift current.

Q.27

(a) Draw the ray diagram to show the image formation by a refracting telescope and write the expression for angular magnification for the telescope in normal adjustment. (b) Give two reasons to explain why a reflecting telescope is preferred over a refracting telescope.

Answer: (a) m = fo/fe (normal adjustment); (b) no chromatic aberration, easier to make large aperture

Explanation:

(a) In a refracting telescope, objective lens (large focal length fo) forms a real, inverted, diminished image of a distant object at its focal plane.

The eyepiece (short focal length fe) acts as a magnifier for this image.

In normal adjustment (final image at infinity), angular magnification m = fo/fe.

(b) Two reasons reflecting telescopes are preferred: (i) No chromatic aberration — mirrors reflect all wavelengths equally;

lenses produce different focal points for different colours (chromatic aberration).

(ii) Mirrors are easier to support and grind to large diameters — large aperture improves light gathering and resolving power;

large lenses sag under their own weight and are difficult to manufacture optically perfect.

Q.28

(a) State the two conditions under which total internal reflection occurs. (b) A transparent container contains layers of three immiscible transparent liquids A, B and C of refractive indices n, (3/4)n and (2/3)n respectively. A laser beam is incident at the interface between A and B at an angle θ as shown in figure. Prove that the beam does not enter region C at all for sin θ ≥ 2/3.

Answer: Proved: if sinθ > 2/3, TIR occurs at B-C interface

Explanation:

(a) (i) Light travels from a denser to a rarer medium.

(ii) The angle of incidence is greater than or equal to the critical angle.

(b) At the A–B interface: n sin θ = (3n/4) sin θ_B, so sin θ_B = (4/3) sin θ.

At the B–C interface the critical angle satisfies sin θ_c = (2n/3)/(3n/4) = 8/9.

The beam cannot enter C if sin θ_B ≥ 8/9, i.e.

(4/3) sin θ ≥ 8/9, i.e.

sin θ ≥ 2/3.

Hence for sin θ ≥ 2/3 the beam is totally reflected at the B–C interface and does not

enter region C.

Q.0

(Case Study — Galvanometer) A galvanometer is used to detect or/and measure small currents in an electrical circuit. It essentially works on the fact that a current-carrying coil experiences a deflecting torque when placed in a magnetic field. This deflection in the coil can be measured and it is related to the current flowing in the coil, the number of turns in the coil, area of the coil and the magnetic field. A hair spring attached to the coil provides a counter torque and helps in measuring the deflection. A galvanometer can be converted to an ammeter or a voltmeter of desired range by using suitable resistances.

The torque on the coil remains constant irrespective of the coil's orientation during rotation due to

(a) use of soft iron core which increases the magnetic field.
(b) radial magnetic field <<
(c) hair spring which provides the counter torque
(d) eddy current in the iron core which causes damping.

Explanation:

In a moving coil galvanometer, a radial magnetic field is used.
The soft iron cylindrical core makes the magnetic field always parallel to the plane of the coil regardless of its orientation.
This ensures that the torque $\tau = NIAB \sin\theta$ always has $\sin\theta = 1$ ($\theta = 90°$), making the torque constant and the deflection directly proportional to current.

Q.0

(Case Study — Galvanometer) The best way to increase current sensitivity of a galvanometer is by

(a) increasing number of turns of the coil
(b) increasing area of coil and magnetic field strength <<

(c) decreasing area of coil and magnetic field strength

(d) increasing torsional constant of the hair spring

Explanation:

Current sensitivity = deflection per unit current = NAB/k, where N = turns, A = area, B = magnetic field and k = torsional constant.

Options (A) and (B) both raise it;

(B) increases two of the factors in NAB/k, so it is taken as the best way.

Option (B).

Note: this key is unconfirmed, because more turns also raises current sensitivity.

Q.0

(Case Study — Galvanometer) A moving coil galvanometer has a coil with area of cross-section 4.0×10^{-3} m² and number of turns 50. The coil is rotating in a magnetic field of 0.25 T. The torque acting on the coil when a current of 5 A passes through it is

(a) 1.0 N m

(b) 2.0 N m

(c) 0.50 N m

(d) 0.25 N m <<

Explanation:

Torque $\tau = NIAB = 50 \times 5 \times 4.0 \times 10^{-3} \times 0.25$.

Calculating: $50 \times 5 = 250$.

$250 \times 4.0 \times 10^{-3} = 1.0$.

$1.0 \times 0.25 = 0.25$ N m.

Q.0

OR (Case Study — Galvanometer) A galvanometer coil has a resistance of 15 Ω and the meter shows full scale deflection for a current of 3 mA. The value of resistance required to convert it into a voltmeter of range (0–12 V) is

(a) 4015 Ω

(b) 3985 Ω <<

(c) 415 Ω

(d) 385 Ω

Explanation:

To convert a galvanometer into a voltmeter, a high resistance R is connected in series.

At full scale: $V = I_g(G + R)$.

$R = V/I_g - G = 12/(3\times10^{-3}) - 15 = 4000 - 15 = 3985\ \Omega$.

Q.0

(Case Study — Galvanometer) A galvanometer with coil of resistance 20 Ω shows full scale deflection for a current of 5 mA. To convert it into an ammeter of range (0–10 A), a resistance of

(a) 0.05 Ω should be connected in series with it.

(b) 0.05 Ω should be connected in parallel with it.

(c) 0.01 Ω should be connected in parallel with it. <<

(d) 0.01 Ω should be connected in series with it.

Explanation:

To convert to ammeter, a shunt (low resistance S) is connected in parallel.

$I_g \times G = (I - I_g) \times S$.

$S = I_gG/(I - I_g) = (5\times10^{-3} \times 20)/(10 - 5\times10^{-3}) = 0.1/9.995 \approx 0.01\ \Omega$.

This shunt is connected in parallel.

Q.0

(Case Study — Photoelectric Effect) A researcher performs an experiment on photo-electric effect using two metals A and B with unknown work functions. She illuminates the surfaces of A and B with monochromatic radiation of various frequencies and records the value of corrosponding stopping potentials (Vs). The graph shows the variation of stopping potential (Vs) with the frequency of incident radiation (v) for metals A and B.
(See the figure.)

From the graph, the work functions of A and B are (h is Planck's constant

and e value of charge on an electron)

(a) v1 and v2

(b) V1 and V2

(c) hv1 and hv2 <<

(d) hv1/e and hv2/e

Explanation:

Einstein's equation: $eV_s = hv - \varphi$, so $V_s = 0$ at the threshold frequency and $\varphi = hv_0$.

The graph's x-intercepts are v_1 (metal A) and v_2 (metal B), so the work functions are hv_1 and hv_2.

hv_1/e and hv_2/e are potentials (in volts), not work functions.

Answer: (C).

Q.0

(Case Study — Photoelectric Effect) For radiation of frequency v > v2 incident on the surfaces of A and B, the maximum kinetic energy of ejected electron is

(a) greater for metal A because it has a smaller work function. <<

(b) greater for metal B because it has a larger work function.

(c) greater for metal B because it has higher threshold frequency.

(d) the same for both metal A and metal B because it is independent of work functions of metals.

Explanation:

$KE_{max} = hv - \varphi$.

From the graph, $v_1 < v_2$, so $\varphi_A = hv_1 < \varphi_B = hv_2$.

For the same frequency $v > v_2$, $KE_A = hv - hv_1$ is greater than $KE_B = hv - hv_2$.

Answer: (A).

Q.0

(Case Study — Photoelectric Effect) If the intensity of the incident radiation for both metals A and B is doubled keeping its frequency constant, then

(a) the slope of the parallel lines will increase.

(b) the slope of the parallel lines will decrease.

(c) the threshold frequencies for both A and B will decrease.

(d) the slope of the parallel lines will not change but more electrons will be emitted per second. <<

Explanation:

The slope of Vs vs v graph is h/e, which is a universal constant independent of intensity or metal.

Changing intensity does not change the frequency, threshold frequency, or the slope.

Doubling intensity means doubling the number of photons per second, so more photoelectrons are emitted per second (higher photocurrent).

The stopping potential (and hence KE_max) for a given frequency is unchanged.

Q.0

(Case Study — Photoelectric Effect) The threshold frequency for a metal surface is v_o. If the radiation of frequency $3v_o$ illuminates the surface, the maximum kinetic energy (KE) of photoelectrons is E1. If the frequency were increased to $6v_o$, the maximum KE of the photoelectrons becomes E2. Then E1/E2 equals

(a) 1/3

(b) 1/2

(c) 2/5 <<

(d) 3/4

Explanation:

$E1 = h(3v_o) – hv_o = 2hv_o$. $E2 = h(6v_o) – hv_o = 5hv_o$. $E1/E2 = 2hv_o/5hv_o = 2/5$.

Q.0

OR (Case Study — Photoelectric Effect) Let m be the slope of the graph line for metal B. If e is the value of electron charge, then Planck's constant 'h' is given by

(a) me <<

(b) 1/(me)

(c) m/e

(d) e/m

Explanation:

From Einstein's equation: eVs = hv – φ, so Vs = (h/e)v – φ/e.

The slope of Vs vs v graph = h/e.

If m is the slope, then m = h/e, so h = me.

Q.31

(a) An electric dipole consists of two point charges q and –q separated by a distance 2a. Derive an expression for the electric field E due to this dipole at a point distant r from the centre of the dipole on the equatorial plane. Write the expression for the electric field at a far off point, i.e. r >> a. (b) A dipole is placed in x-y plane such that charges q and –q are located at x = a and x = b respectively. There exists an electric field E = 2î N/C in the region. Calculate the force F and torque τ experienced by the dipole.

Answer: (a) $E_{eq} = -p/(4\pi\varepsilon_0(r^2+a^2)^{(3/2)})$; for r>>a: $E \approx -p/(4\pi\varepsilon_0 r^3)$; (b) F = 0, τ = 0

Explanation:

(a) Equatorial field derivation: The dipole has +q at distance a and –q at distance a from centre.

At equatorial point P at distance r: distance from each charge = $\sqrt{(r^2+a^2)}$.

Field due to +q: $E+ = kq/(r^2+a^2)$ along direction from +q to P's horizontal.

Field due to –q: $E– = kq/(r^2+a^2)$ toward –q.

The components along the equatorial line (perpendicular to dipole axis) cancel.

Components along $-\hat{p}$ direction (antiparallel to dipole moment) add: $E_{eq} = 2 \times kq/(r^2+a^2) \times \cos\theta$ where $\cos\theta = a/\sqrt{(r^2+a^2)}$.

$E_{eq} = 2kqa/(r^2+a^2)^{(3/2)} = p/(4\pi\varepsilon_0(r^2+a^2)^{(3/2)})$ directed along $-\hat{p}$ (opposite to dipole moment).

For r >> a: $E \approx p/(4\pi\varepsilon_0 r^3)$ along $-\hat{p}$.

(b) Dipole: +q at x = a, –q at x = b.

Dipole moment vector p = q(a–b)î (from –q to +q).

Uniform field E = 2î N/C.

Force on dipole in uniform field: F = 0 (equal and opposite forces on +q and –q

cancel).

Torque: τ = p × E = q(a–b)î × 2î = 0 (cross product of parallel vectors is zero).

OR

Q.31

OR (a) Two cells of emf E1 and E2 with internal resistances r1 and r2 respectively, are connected in parallel by connecting their positive terminals together and negative terminals together. Deduce an expression for equivalent emf and equivalent internal resistance of the combination. (b) A parallel combination, as stated in (a) above, of two cells of emfs E and 3E and internal resistances R each is connected across a resistance 2R. Find the current that flows through resistance 2R.

Answer: (a) E_eq = (E1r2 + E2r1)/(r1+r2), r_eq = r1r2/(r1+r2); (b) I = 4E/(5R)

Explanation:

(a) Parallel combination of cells: let terminal voltage = V.

Current from cell 1: i1 = (E1–V)/r1.

Current from cell 2: i2 = (E2–V)/r2.

Total current: I = i1 + i2 = (E1–V)/r1 + (E2–V)/r2 = E1/r1 + E2/r2 – V(1/r1 + 1/r2).

Writing as I = E_eq/r_eq – V/r_eq: E_eq/r_eq = E1/r1 + E2/r2, and 1/r_eq = 1/r1 + 1/r2.

Therefore r_eq = r1r2/(r1+r2) and E_eq = (E1r2 + E2r1)/(r1+r2).

(b) E1 = E, E2 = 3E, r1 = r2 = R.

E_eq = (E×R + 3E×R)/(R+R) = 4ER/(2R) = 2E.

r_eq = R×R/(R+R) = R/2.

External resistance = 2R.

Total current I = E_eq/(r_eq + 2R) = 2E/(R/2 + 2R) = 2E/(5R/2) = 4E/(5R).

Q.32

(a) Using the relation for refraction at a curved spherical surface, derive the expression for lens maker's formula. (b) Three lenses L1, L2 and L3, each of focal length 40 cm, are placed coaxially. The distance between L1 and L2 and between L2 and L3 are 120 cm and 20 cm respectively. An object is kept at a distance of 80 cm to the left of lens L1. Find the distance of the

final image formed from the object.

Answer: (a) 1/f = (n–1)[1/R1 – 1/R2]; (b) 260 cm from object

Explanation:

(a) Lens maker's formula derivation: For refraction at first surface (n1 = 1 air, n2 = n glass, radius R1): n/v1 – 1/u = (n–1)/R1.

For refraction at second surface (n1 = n glass, n2 = 1 air, radius R2): 1/v – n/v1 = (1–n)/R2.

Adding both equations: 1/v – 1/u = (n–1)(1/R1 – 1/R2).

For object at infinity (u = –∞), v = f: 1/f = (n–1)(1/R1 – 1/R2).

This is the lens maker's formula.

(b) For L1: u1 = –80 cm, f = 40 cm.

1/v1 = 1/f + 1/u1 = 1/40 + 1/(–80) = 2/80 – 1/80 = 1/80.

v1 = 80 cm (image 80 cm right of L1).

L2 is 120 cm right of L1, so object for L2 is at 80–120 = –40 cm from L2, i.e., u2 = –40 cm.

1/v2 = 1/40 + 1/(–40) = 0.

v2 = ∞ (rays emerge parallel from L2).

Object for L3 is at u3 = –∞.

1/v3 = 1/40 + 0 = 1/40.

v3 = 40 cm right of L3.

L3 is 120 + 20 = 140 cm right of L1.

Final image is 140 + 40 = 180 cm right of L1 = 180 + 80 = 260 cm from the original object.

OR

Q.32

OR (a) Draw a ray diagram to show the image formation by a concave mirror when the object is kept between its focus and the centre of curvature. Using this diagram, derive the mirror formula. (b) A concave mirror produces a two times magnified virtual image of an object kept 10 cm in front of it. Calculate the focal length of the mirror.

Answer: (a) Mirror formula: 1/v + 1/u = 1/f; (b) f = –20 cm (focal length 20 cm)

Explanation:

(a) Mirror formula derivation: For object between F and C of concave mirror, the image is real, inverted, and magnified beyond C.

Using similar triangles from ray diagram with incident ray parallel to principal axis and one through centre of curvature: Δ A'B'F ~ Δ MPF and Δ A'B'F ~ Δ ABF.

From geometry: using sign convention (distances measured from pole, negative for real objects/images): 1/v + 1/u = 1/f = 2/R.

(b) Virtual image, magnification m = +2 (erect, virtual).

m = –v/u = 2, so v = –2u.

Object u = –10 cm (in front), so v = –2×(–10) = +20 cm (behind mirror — virtual image).

Mirror formula: 1/f = 1/v + 1/u = 1/20 + 1/(–10) = 1/20 – 2/20 = –1/20.

f = –20 cm.

Focal length of concave mirror = 20 cm.

Q.33

(a) State Faraday's law of electromagnetic induction. (b) Derive an expression for the self-inductance of an air-filled long solenoid of length l and cross-sectional area A having N turns. (c) A conducting rod of length 50 cm, with one end pivoted, is rotated with angular speed of 60 rpm in a uniform magnetic field of 4.0 mT directed perpendicular to the plane of rotation of rod. Find the emf induced in the rod.

Answer: (a) $e = -d\Phi/dt$; (b) $L = \mu_0 N^2 A/l$; (c) emf ≈ 3.14×10^{-3} V (= $\pi \times 10^{-3}$ V)

Explanation:

(a) Faraday's law: The magnitude of the induced emf in a circuit is equal to the rate of change of magnetic flux through the circuit: $|e| = |d\Phi/dt|$.

The negative sign (Lenz's law) indicates the induced emf opposes the change in flux: $e = -d\Phi/dt$.

(b) Self-inductance of solenoid: Magnetic field inside solenoid $B = \mu_0 nI$ where $n = N/l$.

Flux through one turn: $\Phi 1 = BA = \mu_0(N/l)IA$.

Total flux linkage: $N\Phi = N \times \mu_0(N/l)IA = \mu_0 N^2 IA/l$.

Self-inductance $L = N\Phi/I = \mu_0 N^2 A/l$.

(c) Rod of length l = 0.5 m, ω = 60 rpm = 60 × 2π/60 = 2π rad/s, B = 4.0×10^{-3} T

perpendicular to plane.

EMF for rotating rod (one end pivoted): $e = \frac{1}{2}B\omega l^2 = \frac{1}{2} \times 4.0\times10^{-3} \times 2\pi \times (0.5)^2 = \frac{1}{2} \times 4.0\times10^{-3} \times 2\pi \times 0.25 = \frac{1}{2} \times 4.0\times10^{-3} \times 0.5\pi = \frac{1}{2} \times 2\pi\times10^{-3} = \pi\times10^{-3} \approx 3.14\times10^{-3}$ V.

OR

Q.33

OR (a) Draw a labelled diagram of a step-up transformer. State the principle on which it works and obtain the ratio of secondary voltage to primary voltage in terms of number of turns and currents in the two coils. (b) The ratio of the number of turns in the primary to the secondary of an ideal transformer is 1:5. If 5 kW power at 200 V is supplied to the primary, find (i) current in the primary, and (ii) output voltage.

Answer: (a) $V_s/V_p = N_s/N_p = I_p/I_s$ (transformer relation); (b) (i) $I_p = 25$ A, (ii) $V_s = 1000$ V

Explanation:

(a) A step-up transformer has more turns in the secondary ($N_s > N_p$).

Principle: Mutual electromagnetic induction — changing current in primary coil induces changing flux in the iron core, which induces emf in the secondary coil.

For ideal transformer: $V_s/V_p = N_s/N_p$.

Energy conservation (no losses): $V_pI_p = V_sI_s$, so $V_s/V_p = I_p/I_s = N_s/N_p$.

(b) $N_p:N_s = 1:5$.

Power $P = 5$ kW $= 5000$ W, $V_p = 200$ V.

(i) $I_p = P/V_p = 5000/200 = 25$ A.

(ii) $V_s = V_p \times (N_s/N_p) = 200 \times 5 = 1000$ V.