CBSE Class 12 Physics 2024 — 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

A thin plastic rod is bent into a circular ring of radius R. It is uniformly charged with charge density λ. The magnitude of the electric field at its centre is :

(a) $\lambda / (2\varepsilon_0 R)$

(b) Zero <<

(c) $\lambda / (4\pi\varepsilon_0 R)$

(d) $\lambda / (4\varepsilon_0 R)$

Explanation:

For a uniformly charged circular ring, the electric field contributions from diametrically opposite elements cancel by symmetry.

Every small element dq has a field element dE pointing toward or away from the centre, but the symmetric element on the opposite side contributes an equal and opposite field.

The net electric field at the centre is zero.

Q.2

Ten capacitors, each of capacitance 1 μF, are connected in parallel to a source of 100 V. The total energy stored in the system is equal to :

(a) 10^{-2} J

(b) 10^{-3} J

(c) $0{\cdot}5 \times 10^{-3}$ J

(d) $5{\cdot}0 \times 10^{-2}$ J <<

Explanation:

In parallel, total capacitance $C = 10 \times 1\ \mu F = 10\ \mu F = 10 \times 10^{-6}$ F.

Energy $U = \frac{1}{2}CV^2 = \frac{1}{2} \times 10 \times 10^{-6} \times (100)^2 = \frac{1}{2} \times 10 \times 10^{-6} \times 10^4 = \frac{1}{2} \times 10^{-1} = 5 \times 10^{-2}$ J $= 5{\cdot}0 \times 10^{-2}$ J.

Q.3

Consider the circuit shown in the figure. The potential difference between points A and B is :

(a) 6 V

(b) 8 V <<

(c) 9 V

(d) 12 V

Explanation:

The circuit (from the figure) has two branches in parallel between A and B: top branch — 12 V EMF with 1 Ω internal resistance;

bottom branch — 6 V EMF with 0·5 Ω internal resistance.

Both batteries drive current from A to B (positive terminals toward B).

Using the parallel-battery formula: V_AB = (E1/r1 + E2/r2) / (1/r1 + 1/r2) = (12/1 + 6/0·5) / (1/1 + 1/0·5) = (12 + 12) / (1 + 2) = 24/3 = 8 V.

The answer is (B) 8 V.

Q.4

A loop carrying a current I clockwise is placed in x–y plane, in a uniform magnetic field directed along z-axis. The tendency of the loop will be to :

(a) move along x-axis

(b) move along y-axis

(c) shrink <<

(d) expand

Explanation:

Clockwise current in the x–y plane with B along +z: at any element, dl × B points radially inward (e.g.

at (R,0), dl = −ŷ, F = I(−ŷ × ẑ)B = −x̂ IB, towards the centre).

Net force on the loop is zero, but every element is pushed inward, so the loop tends to shrink.

Answer (C).

Q.5

A 10 cm long wire lies along y-axis. It carries a current of 1.0 A in positive y-direction. A magnetic field B = (5 mT) ĵ + (8 mT) k̂ exists in the region. The force on the wire is :

(a) (0·8 mN) î <<

(b) −(0·8 mN) î

(c) (80 mN) î

(d) −(80 mN) î

Explanation:

F = I(L × B).

L = 0·10 m ĵ (current in +y direction, length 0·10 m).

B = 5×10⁻³ ĵ + 8×10⁻³ k̂.

F = 1·0 × (0·10 ĵ) × (5×10⁻³ ĵ + 8×10⁻³ k̂) = 0·10 × [5×10⁻³ (ĵ × ĵ) + 8×10⁻³ (ĵ × k̂)].

ĵ × ĵ = 0; ĵ × k̂ = î.

F = 0·10 × 8×10⁻³ î = 8×10⁻⁴ N î = 0·8 mN î.

Q.6

A galvanometer of resistance G is converted into an ammeter of range 0 to I A. If the current through the galvanometer is 0.1% of I A, the resistance of the ammeter is :

(a) G / 999

(b) G / 1000 <<

(c) G / 1001

(d) G / 100·1

Explanation:

Ig = 0·001 I, so the shunt carries 0·999 I.

Ig·G = Is·S → S = G/999.

Ammeter resistance = G ∥ S = G·(G/999)/(G + G/999) = G/1000.

(Equivalently R_A = Ig·G/I = 0·001 G.) → (B) G/1000.

Q.7

The reactance of a capacitor of capacitance C connected to an ac source of frequency v is X. If the capacitance of the capacitor is doubled and the frequency of the source is tripled, the reactance will become :

(a) X / 6 <<

(b) 6X

(c) (2/3)X

(d) (3/2)X

Explanation:

Capacitive reactance $X_C = 1/(2\pi\nu C)$.

Originally $X = 1/(2\pi\nu C)$.

New: $C' = 2C$, $\nu' = 3\nu$.

New reactance $X' = 1/(2\pi \times 3\nu \times 2C) = 1/(6 \times 2\pi\nu C) = X/6$.

Q.8

In the four regions, I, II, III and IV, the electric fields are described as :

Region I : $E_x = E_0 \sin(kz - \omega t)$

Region II : $E_x = E_0$

Region III : $E_x = E_0 \sin kz$

Region IV : $E_x = E_0 \cos kz$

The displacement current will exist in the region :

(a) I <<

(b) IV

(c) II

(d) III

Explanation:

Displacement current exists where $\partial E/\partial t \neq 0$.

Region I: $E_x = E_0 \sin(kz - \omega t)$; $\partial E_x/\partial t = -E_0\omega \cos(kz - \omega t) \neq 0 \rightarrow$ displacement current exists.

Region II: $E_x = E_0$ (constant); $\partial E/\partial t = 0 \rightarrow$ no displacement current.

Region III: $E_x = E_0 \sin kz$ (no t dependence); $\partial E/\partial t = 0$.

Region IV: $E_x = E_0 \cos kz$ (no t dependence); $\partial E/\partial t = 0$.

Only Region I has displacement current.

Q.9

The transition of electron that gives rise to the formation of the second

spectral line of the Balmer series in the spectrum of hydrogen atom corresponds to :

(a) nf = 2 and ni = 3
(b) nf = 3 and ni = 4
(c) nf = 2 and ni = 4 <<
(d) nf = 2 and ni = 5

Explanation:
Balmer series: nf = 2.
The lines are: 1st line ni = 3, 2nd line ni = 4, 3rd line ni = 5, etc.
The second spectral line corresponds to nf = 2 and ni = 4.

Q.10

Ge is doped with As. Due to doping,

(a) the structure of Ge lattice is distorted.
(b) the number of conduction electrons increases. <<
(c) the number of holes increases.
(d) the number of conduction electrons decreases.

Explanation:
As has 5 valence electrons; Ge has 4.
When As replaces a Ge atom, 4 electrons form covalent bonds with neighbouring Ge atoms, and the 5th electron is loosely bound and easily donated to the conduction band.
This creates an n-type semiconductor, increasing the number of conduction electrons.

Q.11

Two beams, A and B whose photon energies are 3·3 eV and 11·3 eV respectively, illuminate a metallic surface (work function 2·3 eV) successively. The ratio of maximum speed of electrons emitted due to beam A to that due to beam B is :

(a) 3
(b) 9

(c) 1/3 <<

(d) 1/9

Explanation:

KE_A = 3·3 − 2·3 = 1·0 eV; KE_B = 11·3 − 2·3 = 9·0 eV.

KE = ½mv².

So v ∝ √(KE).

v_A/v_B = √(KE_A/KE_B) = √(1·0/9·0) = 1/3.

Q.12

The waves associated with a moving electron and a moving proton have the same wavelength λ. It implies that they have the same :

(a) momentum <<

(b) angular momentum

(c) speed

(d) energy

Explanation:

de Broglie wavelength λ = h/p, where p is the momentum.

If both have the same wavelength λ, then p = h/λ is the same for both.

Hence they have the same momentum.

(Speed and energy would differ because the masses of electron and proton are different.)

Q.13

Assertion (A) : In photoelectric effect, the kinetic energy of the emitted photoelectrons increases with increase in the intensity of the incident light.

Reason (R) : Photoelectric current depends on the wavelength of the incident light.

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

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

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

(d) Assertion (A) is false and Reason (R) is also false. <<

Explanation:

Assertion (A) is false: KE of photoelectrons depends on the frequency (not intensity) of incident light;

increasing intensity increases the number of photoelectrons (photocurrent), not their KE.

Reason (R) is also false: Photoelectric current depends on the intensity of incident light (number of photons per second), not on wavelength.

Both A and R are false → option (D).

Q.14

Assertion (A) : The mutual inductance between two coils is maximum when the coils are wound on each other.

Reason (R) : The flux linkage between two coils is maximum when they are wound on each other.

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

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

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

(d) Assertion (A) is false and Reason (R) is also false.

Explanation:

When coils are wound on each other, the coupling coefficient k = 1 (maximum), meaning all flux from one coil links with the other.

$M = k\sqrt{(L_1L_2)}$ is maximum when k = 1.

The reason correctly explains this: the flux linkage is maximum when they are wound on each other.

Both A and R are true, and R correctly explains A.

Q.15

Assertion (A) : Two long parallel wires, freely suspended and connected in

series to a battery, move apart.

Reason (R) : Two wires carrying current in opposite directions repel each other.

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

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

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

(d) Assertion (A) is false and Reason (R) is also false.

Explanation:

When two wires are connected in series to a battery, current flows in opposite directions in them (out along one wire and back along the other in the circuit).

Two parallel wires carrying currents in opposite directions repel each other.

Hence the wires move apart.

Assertion A is true and Reason R correctly explains it.

Q.16

Assertion (A) : Plane and convex mirrors cannot produce real images under any circumstance.

Reason (R) : A virtual image cannot serve as an object to produce a real image.

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

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

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

(d) Assertion (A) is false and Reason (R) is also false. <<

Explanation:

Assertion (A) is false: a plane or convex mirror can form a real image when the object is virtual (a beam converging towards a point behind the mirror).

Reason (R) is false: a virtual image can act as the object for a further lens or mirror,

which can then form a real image.

Hence option (D).

Note: this key is unconfirmed, because the assertion can be read as referring to real objects only.

Q.17

Find the temperature at which the resistance of a wire made of silver will be twice its resistance at 20°C. Take 20°C as the reference temperature and temperature coefficient of resistance of silver at 20°C = $4{\cdot}0 \times 10^{-3}\ K^{-1}$.

Answer: 270°C

Explanation:

$R(T) = R_0[1 + \alpha(T - T_0)]$.

We need $R(T) = 2R_0$.

So $2R_0 = R_0[1 + \alpha(T - 20)]$.

$2 = 1 + 4{\cdot}0 \times 10^{-3} \times (T - 20)$.

$1 = 4{\cdot}0 \times 10^{-3} \times (T - 20)$.

$T - 20 = 1/(4{\cdot}0 \times 10^{-3}) = 250$.

$T = 270°C$.

Q.18

(a) Monochromatic light of frequency $5{\cdot}0 \times 10^{14}$ Hz passes from air into a medium of refractive index 1·5. Find the wavelength of the light (i) reflected, and (ii) refracted at the interface of the two media.

Answer: (i) Reflected wavelength = 6×10^{-7} m = 600 nm; (ii) Refracted wavelength = 4×10^{-7} m = 400 nm

Explanation:

(i) Reflected light remains in air.

$\lambda_{air} = c/v = (3\times10^8)/(5{\cdot}0\times10^{14}) = 6\times10^{-7}$ m = 600 nm.

(ii) Refracted light is in the medium of refractive index 1·5.

Frequency is unchanged on refraction.

Speed in medium $v = c/n = (3\times10^8)/1{\cdot}5 = 2\times10^8$ m/s.

$\lambda_{medium} = v/\nu = (2\times10^{8})/(5\times10^{14}) = 4\times10^{-7}$ m = 400 nm.

OR

Q.18

(b) A plano-convex lens of focal length 16 cm is made of a material of refractive index 1.4. Calculate the radius of the curved surface of the lens.

Answer: R = 6·4 cm

Explanation:

For a plano-convex lens: one surface is plane ($R_1 = \infty$) and one is convex ($R_2 = -R$, using sign convention where R is positive radius).

Lensmaker's equation: $1/f = (n-1)[1/R_1 - 1/R_2] = (1{\cdot}4-1)[1/\infty - 1/(-R)] = 0{\cdot}4 \times (1/R)$.

So $1/16 = 0{\cdot}4/R$.

$R = 0{\cdot}4 \times 16 = 6{\cdot}4$ cm.

Q.19

An object is placed 30 cm in front of a concave mirror of radius of curvature 40 cm. Find the (i) position of the image formed and (ii) magnification of the image.

Answer: (i) v = −60 cm (real image, 60 cm in front of mirror); (ii) m = −2

Explanation:

Focal length f = R/2 = 40/2 = 20 cm.

For concave mirror, f = −20 cm (using sign convention with incident light direction as positive;

u = −30 cm).

Mirror formula: $1/v + 1/u = 1/f$.

$1/v = 1/f - 1/u = 1/(-20) - 1/(-30) = -1/20 + 1/30 = (-3+2)/60 = -1/60$.

v = −60 cm (real image, 60 cm in front of mirror).

Magnification $m = -v/u = -(-60)/(-30) = -2$ (inverted, magnified).

Q.20

Consider a neutron (mass m) of kinetic energy E and a photon of the same energy. Let λn and λp be the de Broglie wavelength of neutron and the

wavelength of photon respectively. Obtain an expression for λn/λp.

Answer: $\lambda_n/\lambda_p = \sqrt{(E/(2mc^2))}$ or equivalently $\lambda_n/\lambda_p = (1/c)\sqrt{(E/(2m))}$

Explanation:

For the neutron: KE = E = $p^2/(2m)$, so $p_n = \sqrt{(2mE)}$.

de Broglie wavelength: $\lambda_n = h/p_n = h/\sqrt{(2mE)}$.

For the photon: E = hc/λp, so λp = hc/E.

Therefore $\lambda_n/\lambda_p = [h/\sqrt{(2mE)}] / [hc/E] = [h/\sqrt{(2mE)}] \times [E/(hc)] = E/(c\sqrt{(2mE)}) = \sqrt{(E)}/(c\sqrt{(2m)}) = \sqrt{(E/(2m))}/c = (1/c)\sqrt{(E/(2m))}$.

Equivalently, $\lambda_n/\lambda_p = \sqrt{(E/(2mc^2))}$.

Q.21

Plot a graph showing the variation of current with voltage for the material GaAs. On the graph, mark the region where :

(a) resistance is negative, and

(b) Ohm's law is obeyed.

Answer: Graph of I vs V for GaAs (Gunn diode characteristic): shows initial ohmic rise, then a region of negative differential resistance (NDR) where current decreases with increasing voltage, then rises again. (a) NDR region: between the threshold voltage and the valley voltage. (b) Ohmic region: low voltage linear portion at the start.

Explanation:

GaAs (used in Gunn diodes) shows a non-linear I–V characteristic.

At low voltages the current increases linearly (Ohm's law obeyed).

Beyond a threshold voltage (~3V), transferred-electron effect causes electrons to move to higher effective-mass valleys, reducing drift velocity and hence current — this is the negative differential resistance (NDR) region where dI/dV < 0, i.e., resistance is negative.

Mark the initial linear portion as the ohmic region and the falling portion as the negative resistance region.

Q.22

A cube of side 0·1 m is placed, as shown in the figure, in a region where electric field E = 500x î exists. Here x is in meters and E in NC^{-1}. Calculate :

(a) the flux passing through the cube, and

(b) the charge within the cube.

Answer: (a) $\Phi = 0{\cdot}5\ Nm^2C^{-1}$; (b) $Q \approx 4{\cdot}43 \times 10^{-12}$ C

Explanation:

From the figure the cube (side 0·1 m) is placed with its left face at x = 0·1 m and right face at x = 0·2 m.

E = 500x î N/C acts along x only; only the two x-faces contribute to flux.

Left face (x = 0·1 m): $E_{left} = 500 \times 0{\cdot}1 = 50$ N/C, flux in $= 50 \times (0{\cdot}1)^2 = 50 \times 0{\cdot}01 = 0{\cdot}5\ Nm^2/C$ (entering).

Right face (x = 0·2 m): $E_{right} = 500 \times 0{\cdot}2 = 100$ N/C, flux out $= 100 \times 0{\cdot}01 = 1{\cdot}0\ Nm^2/C$ (exiting).

Net flux $\Phi = 1{\cdot}0 - 0{\cdot}5 = 0{\cdot}5\ Nm^2C^{-1}$.

Charge: $Q = \varepsilon_0\Phi = 8{\cdot}854 \times 10^{-12} \times 0{\cdot}5 = 4{\cdot}43 \times 10^{-12}$ C.

Q.23

(a) Define current density. Is it a scalar or a vector? An electric field E is maintained in a metallic conductor. If n be the number of electrons (mass m, charge e) per unit volume in the conductor and τ its relaxation time, show that the current density j = σE, where $\sigma = ne^2\tau/m$.

Answer: Derivation: j = σE with $\sigma = ne^2\tau/m$ (see explanation)

Explanation:

Current density j is the current per unit cross-sectional area perpendicular to the direction of flow.

It is a vector quantity, directed along the direction of conventional current flow.

Derivation: Under electric field E, force on electron F = eE (taking magnitude).

Acceleration a = eE/m.

Using drift velocity: $v_d = a\tau = eE\tau/m$.

Current density: $j = nev_d = n \times e \times (eE\tau/m) = (ne^2\tau/m)E$.

Hence $j = \sigma E$ where $\sigma = ne^2\tau/m$.

OR

Q.23

(b) What is a Wheatstone bridge? Obtain the necessary conditions under which the Wheatstone bridge is balanced.

Answer: Balanced condition: $P/Q = R/S$

Explanation:

A Wheatstone bridge is a circuit with four resistors P, Q, R, S arranged in a diamond (bridge) configuration with a galvanometer between the midpoints and a battery across the other diagonal.

Balance condition: the bridge is balanced when no current flows through the galvanometer.

Applying Kirchhoff's laws: at balance, potential at B = potential at D.

Current through P = current through Q (call it I_1), and current through R = current through S (call it I_2).

$V_A - V_B = I_1P$ and $V_A - V_D = I_2R$.

$V_B - V_C = I_1Q$ and $V_D - V_C = I_2S$.

At balance $V_B = V_D$: $I_1P = I_2R$ and $I_1Q = I_2S$.

Dividing: $P/Q = R/S$.

Q.24

A proton with kinetic energy $1{\cdot}3384 \times 10^{-14}$ J moving horizontally from north to south, enters a uniform magnetic field B of 2·0 mT directed eastward. Calculate :

(a) the speed of the proton

(b) the magnitude of acceleration of the proton

(c) the radius of the path traced by the proton

[Take (q/m) for proton = $1{\cdot}0 \times 10^8$ C/kg]

Answer: (a) $v \approx 4 \times 10^6$ m/s; (b) $a = 8 \times 10^{11}$ m/s²; (c) r = 20 m

Explanation:

(a) KE = ½mv², with $m_p = 1{\cdot}67 \times 10^{-27}$ kg:

$v^2 = 2 \times 1{\cdot}3384 \times 10^{-14} / 1{\cdot}67 \times 10^{-27} \approx 1{\cdot}6 \times 10^{13} \rightarrow v \approx 4 \times 10^6$ m/s.

(b) $v \perp B$, so $a = qvB/m = (q/m)vB = 1{\cdot}0 \times 10^8 \times 4 \times 10^6 \times 2{\cdot}0 \times 10^{-3} = 8 \times 10^{11}$ m/s².

(c) $r = mv/(qB) = v/[(q/m)B] = 4 \times 10^6 / (1{\cdot}0 \times 10^8 \times 2{\cdot}0 \times 10^{-3}) = 20$ m.

Q.25

An inductor, a capacitor and a resistor are connected in series with an ac source v = vm sin ωt. Derive an expression for the average power dissipated in the circuit. Also obtain the expression for the resonant frequency of the circuit.

Answer: $P_{avg} = (v_m^2 R)/(2Z^2) = V_{rms} \times I_{rms} \times \cos\varphi$; Resonant frequency $\omega_0 = 1/\sqrt{(LC)}$

Explanation:

In a series LCR circuit: v = vm sinωt.

Current i = im sin(ωt − φ), where im = vm/Z, $Z = \sqrt{(R^2 + (X_L - X_C)^2)}$, $\tan\varphi = (X_L - X_C)/R$.

Instantaneous power p = vi = vm sinωt × im sin(ωt − φ).

Average power: $P_{avg} = ½\ v_m i_m \cos\varphi = V_{rms} I_{rms} \cos\varphi$.

Since $\cos\varphi = R/Z$: $P_{avg} = ½\ v_m i_m (R/Z) = (v_m i_m R)/(2Z) = i_m^2 R/2 = I_{rms}^2 R$.

In terms of vm: $P_{avg} = (v_m^2/2Z^2) \times R = (v_m^2 R)/(2Z^2)$.

Resonant frequency: At resonance XL = XC, so ωL = 1/(ωC), giving $\omega_0 = 1/\sqrt{(LC)}$.

Resonant frequency $f_0 = 1/(2\pi\sqrt{(LC)})$.

Q.26

(a) The wavelength of an electromagnetic wave is related to the characteristic size of the system that produces it. Give two examples to justify this statement.

(b) (i) Long distance radio broadcasts use short-wave bands. Why ?

(ii) Optical and radio telescopes are built on the ground, but X-ray astronomy is possible only from satellites orbiting the Earth. Why ?

Answer: (a) e.g. γ-rays ($\lambda \sim 10^{-14}$ m) come from nuclei ($\sim 10^{-15}$–10^{-14} m) while

visible light (~10^{-7} m) comes from atomic transitions; a radio antenna (~1–100 m) radiates radio waves of comparable wavelength.

(b)(i) Short waves are reflected by the ionosphere, so they reach distant places.

(ii) The atmosphere absorbs X-rays but is transparent to visible and radio waves, so X-ray telescopes must be placed above it.

Explanation:

(a) Wavelength ∝ size of the emitting system: (1) Nuclei, which are tiny (~10^{-15} m), emit γ-rays of very short wavelength, whereas atoms (~10^{-10} m) emit visible/UV light through electron transitions.

(2) A radio-transmitting antenna, of size ~1–100 m, emits radio waves whose wavelength is comparable to the antenna size.

(b)(i) Short-wave signals are reflected back to Earth by the ionosphere (sky-wave propagation), and repeated reflections between the ionosphere and the ground carry them over long distances.

(ii) Visible light and radio waves pass through the Earth's atmosphere, but X-rays are absorbed by it.

So X-ray observation is possible only from satellites above the atmosphere.

Q.27

Write the drawbacks of Rutherford's atomic model. How did Bohr overcome them? Show that the distances between consecutive orbits of the Bohr atom are not equal.

Answer: Drawbacks: an orbiting (accelerating) electron should radiate and spiral into the nucleus (atom unstable), and it predicts a continuous spectrum, not line spectra. Bohr: electrons revolve only in stationary orbits with $mvr = nh/2\pi$ without radiating, and emit/absorb $h\nu = E_i - E_f$ only on jumping between orbits. Since $r_n = n^2a_0$, $r_{(n+1)} - r_n = (2n + 1)a_0$, which increases with n — so the spacings are unequal.

Explanation:

Drawbacks of Rutherford's model: (1) A revolving electron undergoes centripetal acceleration;

classically, an accelerating charge radiates energy continuously, causing the electron to spiral inward and collapse into the nucleus — predicting unstable atoms.

(2) The model predicts a continuous emission spectrum (as the electron spirals in), not the observed discrete line spectrum of hydrogen.

Bohr's overcoming: Bohr postulated (1) electrons move in certain fixed orbits (stationary states) without radiating energy;

(2) radiation is emitted or absorbed only when an electron transitions between orbits;

(3) angular momentum is quantised: $mvr = nh/(2\pi)$.

Orbits not equally spaced: Bohr radius $r_n = n^2 a_0$ where $a_0 = 0{\cdot}529$ Å.

Distance between nth and (n+1)th orbit: $\Delta r_n = r_{(n+1)} - r_n = [(n+1)^2 - n^2]a_0 = (2n+1)a_0$.

Since 2n+1 increases with n, consecutive orbits are progressively farther apart, not equally spaced.

Q.28

(a) State any two properties of a nucleus.

(b) Why is the density of a nucleus much more than that of an atom?

(c) Show that the density of the nuclear matter is the same for all nuclei.

Answer: (a) A nucleus is made of protons and neutrons held by the short-range nuclear force; its radius $R = R_0 A^{(1/3)}$ ($R_0 \approx 1{\cdot}2$ fm).

(b) Nearly all the atom's mass is packed in the nucleus, whose volume is ~10^{-15} of the atom's volume.

(c) $\rho = A{\cdot}m / [(4/3)\pi R_0^3 A] = 3m/(4\pi R_0^3)$, independent of A — so nuclear density is the same for all nuclei.

Explanation:

(a) Properties of a nucleus: (1) The nucleus contains protons and neutrons (collectively called nucleons).

(2) The size (radius) of the nucleus is of the order of 10^{-15} m (femtometres), and follows $R = R_0 A^{(1/3)}$, where $R_0 \approx 1{\cdot}2 \times 10^{-15}$ m and A is the mass number.

(b) In an atom, most of the volume is occupied by the electron cloud, while almost all the mass (protons + neutrons) is concentrated in the tiny nucleus.

Since density = mass/volume, and nuclear volume is extremely small compared to atomic volume, nuclear density is far greater than atomic density.

(c) Nuclear density: mass of nucleus ≈ A × mp (mp = 1·67×10⁻²⁷ kg).
Volume = (4/3)πR³ = (4/3)π(R₀ A^(1/3))³ = (4/3)πR₀³ × A.
Density ρ = (A × mp)/((4/3)πR₀³ × A) = mp/((4/3)πR₀³).
The factor A cancels, so ρ is independent of A — the same for all nuclei.

Q.29(i)

(Case Study: Lenses) A lens is a transparent medium bounded by two surfaces, with one or both surfaces being spherical. The focal length of a lens is determined by the radii of curvature of its two surfaces and the refractive index of its medium with respect to that of the surrounding medium. The power of a lens is reciprocal of its focal length. If a number of lenses are kept in contact, the power of the combination is the algebraic sum of the powers of the individual lenses.

A double-convex lens, with each face having same radius of curvature R, is made of glass of refractive index n. Its power is :

(a) 2(n−1)/R <<
(b) (2n−1)/R
(c) (n−1)/(2R)
(d) (2n−1)/(2R)

Explanation:
Lensmaker's formula: 1/f = (n−1)[1/R₁ − 1/R₂].
For double-convex lens: R₁ = +R (first surface), R₂ = −R (second surface).
1/f = (n−1)[1/R − (−1/R)] = (n−1)(2/R) = 2(n−1)/R.
Power P = 1/f = 2(n−1)/R.

Q.0

(Case Study: Lenses) A double-convex lens of power P, with each face having same radius of curvature, is cut into two equal parts perpendicular to its principal axis. The power of one part of the lens will be :

(a) 2P

(b) P

(c) 4P

(d) P/2 <<

Explanation:

Double-convex lens: P = (n – 1)(1/R + 1/R) = 2(n – 1)/R.

A cut perpendicular to the principal axis gives two plano-convex lenses, each with one curved face of radius R:

P' = (n – 1)(1/R – 1/∞) = (n – 1)/R = P/2 → (D).

(Consistent with part (iii): the two halves in contact give P/2 + P/2 = P.)

Q.0

(Case Study: Lenses) The above two parts are kept in contact with each other as shown in the figure. The power of the combination will be :

(a) P/2

(b) P <<

(c) 2P

(d) P/4

Explanation:

Cutting perpendicular to the axis gives two plano-convex halves, each of power P/2.

In contact, powers add: P/2 + P/2 = P (the original lens is restored).

Answer (B) P.

Q.0

(Case Study: Lenses) (a) A double-convex lens of power P, with each face having same radius of curvature, is cut along its principal axis. The two parts are arranged as shown in the figure. The power of the combination will be :

(a) Zero

(b) P

(c) 2P <<

(d) P/2

Explanation:

Cutting along the principal axis leaves two halves that each keep both faces of radius R, so each has the same focal length and power P (only the aperture is halved).

In the figure the halves sit one behind the other on the same principal axis, in contact, so their powers add: P + P = 2P.

Answer (C) 2P.

Q.0

(Case Study: Lenses) (b) Two convex lenses of focal lengths 60 cm and 20 cm are held coaxially in contact with each other. The power of the combination is :

(a) 6·6 D <<

(b) 15 D

(c) 1/15 D

(d) 1/80 D

Explanation:

P_1 = 100/60 D = 5/3 D; P_2 = 100/20 D = 5 D.

P = P_1 + P_2 = 5/3 + 5 = 20/3 ≈ 6·67 D (f = 15 cm) → (A) 6·6 D.

Q.30(i)

(Case Study: Junction Diode as a Rectifier) The process of conversion of an ac voltage into a dc voltage is called rectification and the device which performs this conversion is called a rectifier. The characteristics of a p-n junction diode reveal that when a p-n junction diode is forward biased, it offers a low resistance and when it is reverse biased, it offers a high resistance. Hence, a p-n junction diode conducts only when it is forward biased. This property of a p-n junction diode makes it suitable for its use as a rectifier.

Thus, when an ac voltage is applied across a p-n junction, it conducts only during those alternate half cycles for which it is forward biased. A rectifier which rectifies only half cycle of an ac voltage is called a half-wave rectifier

and one that rectifies both the half cycles is known as a full-wave rectifier.

The root mean square value of an alternating voltage applied to a full-wave rectifier is $V_0/\sqrt{2}$. Then the root mean square value of the rectified output voltage is :

(a) $V_0/\sqrt{2}$ <<
(b) $V_0^2/2$
(c) $2V_0/\sqrt{2}$
(d) $V_0/(2\sqrt{2})$

Explanation:

In a full-wave rectifier, both half cycles are rectified.
The output is $|V(t)| = |V_0 \sin \omega t|$.
The rms of the rectified output equals the rms of the original sinusoidal signal, because squaring and averaging $|V_0 \sin \omega t|$ gives the same result as for $V_0 \sin \omega t$.
So rms of output = rms of input = $V_0/\sqrt{2}$.

Q.0

(Case Study: Junction Diode as a Rectifier) In a full-wave rectifier, the current in each of the diodes flows for :

(a) Complete cycle of the input signal
(b) Half cycle of the input signal <<
(c) Less than half cycle of the input signal
(d) Only for the positive half cycle of the input signal

Explanation:

In a full-wave rectifier (bridge or centre-tap), each diode conducts for exactly one half cycle of the input.
During the positive half cycle one pair (or one diode in centre-tap) conducts;
during the negative half cycle the other pair (or diode) conducts.
So each diode conducts for half the cycle.

Q.0

(Case Study: Junction Diode as a Rectifier) In a full-wave rectifier :

(a) Both diodes are forward biased at the same time.

(b) Both diodes are reverse biased at the same time.

(c) One is forward biased and the other is reverse biased at the same time. <<

(d) Both are forward biased in the first half of the cycle and reverse biased in the second half of the cycle.

Explanation:

In a full-wave rectifier at any given instant, one diode is forward biased (conducting) and the other is reverse biased (non-conducting).

This alternates each half cycle, ensuring current flows in the same direction through the load for both halves of the input cycle.

Q.0

(Case Study: Junction Diode as a Rectifier) (a) An alternating voltage of frequency of 50 Hz is applied to a half-wave rectifier. Then the ripple frequency of the output will be :

(a) 100 Hz

(b) 50 Hz <<

(c) 25 Hz

(d) 150 Hz

Explanation:

In a half-wave rectifier, only one half cycle (e.g., positive) is passed and the other is blocked.

So the output pulses occur once per input cycle.

Ripple frequency = input frequency = 50 Hz.

Q.0

(Case Study: Junction Diode as a Rectifier) (b) A signal, as shown in the figure, is applied to a p-n junction diode. Identify the output across resistance

RL.

(a) Positive pulse of height 10 V

(b) Negative-going pulse, low level −10 V

(c) Negative pulse of −5 V

(d) Positive pulse of height +5 V (zero otherwise) <<

Explanation:

The diode conducts only when the input is +5 V (forward biased), so across R_L the output is a +5 V pulse and zero when the input is −5 V (reverse biased).

Answer (D): positive pulse of +5 V.

Q.31

(a) (i) Derive an expression for potential energy of an electric dipole p in an external uniform electric field E. When is the potential energy of the dipole (1) maximum, and (2) minimum?

(ii) An electric dipole consists of point charges −1·0 pC and +1·0 pC located at (0, 0) and (3 mm, 4 mm) respectively in x–y plane. An electric field E = (1000 V/m) î is switched on in the region. Find the torque τ acting on the dipole.

Answer: $U = -pE\cos\theta$; maximum (+pE) at θ = 180°, minimum (−pE) at θ = 0°; (ii) $|\tau| = 4\times10^{-12}$ N·m (along −k̂)

Explanation:

(i) Potential energy of dipole: Work done to rotate the dipole from angle θ to dθ: $dW = \tau\, d\theta = pE\sin\theta\, d\theta$.

Integrating from 90° (reference) to θ: $U = -pE\cos\theta$.

(1) Maximum when cosθ = −1, θ = 180°: $U_{max} = +pE$.

(2) Minimum when cosθ = +1, θ = 0°: $U_{min} = -pE$.

(ii) Dipole: −q at (0,0), +q at (3mm, 4mm).

q = 1·0 pC = 1×10^{-12} C.

Dipole vector p = q × d (from −q to +q) = $1\times10^{-12} \times (3\times10^{-3}\,\hat{i} + 4\times10^{-3}\,\hat{j}) = (3\times10^{-15}\,\hat{i} + 4\times10^{-15}\,\hat{j})$ C·m.

E = 1000 î V/m.

$\tau = p \times E = (3\times10^{-15}\,\hat{i} + 4\times10^{-15}\,\hat{j}) \times (1000\,\hat{i}) = 3\times10^{-15}\times1000\,(\hat{i}\times\hat{i}) + 4\times10^{-15}\times1000\,(\hat{j}\times\hat{i})$.

$\hat{i}\times\hat{i} = 0$; $\hat{j}\times\hat{i} = -\hat{k}$.

$\tau = 0 + 4\times10^{-12} \times (-\hat{k}) = -4\times10^{-12}\,\hat{k}$ N·m.

$|\tau| = 4\times10^{-12}$ N·m.

(Note: dipole moment magnitude = $q\times|d| = 10^{-12} \times 5\times10^{-3} = 5\times10^{-15}$ C·m.

Angle of p with E: $p_x = 3\times10^{-15}$, $p_y = 4\times10^{-15}$, so $\sin\theta = 4/5$.

$|\tau| = pE\sin\theta = 5\times10^{-15} \times 1000 \times 4/5 = 4\times10^{-12}$ N·m.)

OR

Q.31

(b) (i) An electric dipole (dipole moment $p = p\,\hat{i}$), consisting of charges $-q$ and q, separated by distance $2a$, is placed along the x-axis, with its centre at the origin. Show that the potential V, due to this dipole, at a point x, ($x >> a$) is equal to $(1/4\pi\varepsilon_0) \times (p\cdot\hat{i}/x^2)$.

(ii) Two isolated metallic spheres S1 and S2 of radii 1 cm and 3 cm respectively are charged such that both have the same charge density $\sigma = (2/\pi) \times 10^{-9}$ C/m². They are placed far away from each other and connected by a thin wire. Calculate the new charge on sphere S1.

Answer: (i) Derivation as shown; (ii) $Q_1' = 2\times10^{-12}$ C = 2 pC

Explanation:

(i) Charges $-q$ at $(-a, 0)$, $+q$ at $(+a, 0)$.

Potential at P(x, 0), $x \gg a$: $V = (q/4\pi\varepsilon_0)[1/(x-a) - 1/(x+a)] = (q/4\pi\varepsilon_0)\cdot2a/(x^2-a^2) \approx (1/4\pi\varepsilon_0)(2qa/x^2) = (1/4\pi\varepsilon_0)(p\cdot\hat{i}/x^2)$, with $p = 2qa$.

(ii) $\sigma = (2/\pi)\times10^{-9}$ C/m².

$Q_1 = \sigma\cdot4\pi r_1^2 = (2/\pi)\times10^{-9} \times 4\pi \times (10^{-2})^2 = 8\times10^{-13}$ C.

$Q_2 = \sigma\cdot4\pi r_2^2 = (2/\pi)\times10^{-9} \times 4\pi \times (3\times10^{-2})^2 = 7.2\times10^{-12}$ C.

Total $Q = 8\times10^{-12}$ C.

After connection the potentials are equal: $Q_1'/r_1 = Q_2'/r_2$, so $Q_2' = 3Q_1'$.

$Q_1' + 3Q_1' = 8\times10^{-12}$ C, hence $Q_1' = 2\times10^{-12}$ C = 2 pC.

Q.32

(a) (i) A resistor and a capacitor are connected in series to an ac source v =

vm sin ωt. Derive an expression for the impedance of the circuit.

(ii) When does an inductor act as a conductor in a circuit? Give reason for it.

(iii) An electric lamp is designed to operate at 110 V dc and 11 A current. If the lamp is operated on 220 V, 50 Hz ac source with a coil in series, then find the inductance of the coil.

Answer: (i) $Z = \sqrt{(R^2 + 1/(\omega^2 C^2))}$; (ii) Inductor acts as a conductor at DC ($\omega \to 0$) because $X_L = \omega L \to 0$, so no back-EMF; (iii) $L \approx 55{\cdot}1$ mH

Explanation:

(i) For series RC: $v = v_m \sin \omega t$.

$V_R = iR$ (in phase), $V_C = q/C$ (lags i by 90°).

Phasor: $Z = \sqrt{(R^2 + X_c^2)} = \sqrt{(R^2 + 1/(\omega C)^2)}$.

(ii) Inductor acts as a conductor at DC (very low/zero frequency): $X_L = \omega L = 0$ at $\omega = 0$, so it offers zero impedance to DC — no changing flux, no back-EMF.

(iii) Rated lamp: V = 110 V, I = 11 A → $R = 110/11 = 10\ \Omega$.

On 220 V, 50 Hz ac with inductor in series: $Z = V_{rms}/I = 220/11 = 20\ \Omega$.

$X_L = \sqrt{(Z^2 - R^2)} = \sqrt{(400 - 100)} = \sqrt{300} = 10\sqrt{3}\ \Omega$.

$L = X_L/\omega = 10\sqrt{3} / (2\pi \times 50) = 10 \times 1{\cdot}732 / 314{\cdot}16 = 17{\cdot}32/314{\cdot}16 \approx 0{\cdot}0551$ H ≈ 55·1 mH.

OR

Q.32

(b) (i) Draw a labelled diagram of a step-up transformer and describe its working principle. Explain any three causes for energy losses in a real transformer.

(ii) A step-up transformer converts a low voltage into high voltage. Does it violate the principle of conservation of energy? Explain.

(iii) A step-up transformer has 200 and 3000 turns in its primary and secondary coils respectively. The input voltage given to the primary coil is 90 V. Calculate :

(1) The output voltage across the secondary coil

(2) The current in the primary coil if the current in the secondary coil is 2·0 A.

Answer: (iii)(1) Vs = 1350 V; (2) Ip = 30 A

Explanation:

(i) A step-up transformer has more turns in the secondary (Ns > Np).

Principle (Faraday's law): A time-varying AC voltage in primary creates a changing flux in the core, which induces an EMF in the secondary: Vs/Vp = Ns/Np.

For step-up Ns > Np so Vs > Vp.

Energy losses: (1) Copper/Joule losses — I^2R heating in coil wires;

minimised by thick low-resistance wires.

(2) Eddy current losses — induced currents in the iron core dissipate heat;

minimised by laminating the core.

(3) Hysteresis losses — energy lost in magnetising/demagnetising the core each cycle;

minimised by using soft iron.

(4) Flux leakage — not all flux from primary links with secondary;

minimised by winding coils over each other.

(ii) No, it does not violate conservation of energy.

While voltage is stepped up (Vs > Vp), the current is correspondingly stepped down (Is < Ip) such that power output = power input (ideal transformer: VsIs = VpIp).

Energy is conserved.

(iii)(1) Vs/Vp = Ns/Np: Vs = Vp × (Ns/Np) = 90 × (3000/200) = 90 × 15 = 1350 V.

(2) For ideal transformer: VpIp = VsIs: Ip = VsIs/Vp = 1350 × 2·0/90 = 30 A.

Q.33

(a) (i) A ray of light passes through a triangular prism. Show graphically, how the angle of deviation varies with the angle of incidence. Hence define the angle of minimum deviation.

(ii) A ray of light is incident normally on a refracting face of a prism of prism angle A and suffers a deviation of angle δ. Prove that the refractive index n of the material of the prism is given by $n = \sin(A + \delta)/\sin A$.

(iii) The refractive index of the material of a prism is $\sqrt{2}$. If the refracting angle of the prism is 60°, find the

(1) Angle of minimum deviation, and

(2) Angle of incidence.

Answer: (iii)(1) $\delta_m = 30°$; (2) Angle of incidence $i = 45°$

Explanation:

(i) The graph of angle of deviation (δ) vs angle of incidence (i) is a U-shaped curve with a minimum.

The minimum point corresponds to the angle of minimum deviation δ_m, where i = e (angle of emergence), and the ray passes through the prism symmetrically.

(ii) Proof: Ray incident normally on first face means angle of refraction at first face = 0.

So the ray travels inside the prism parallel to the base.

At the second face, the angle of incidence inside the prism = A (geometry of the prism).

The ray emerges with angle of refraction r_2.

Deviation $\delta = r_2 - A$ (exterior angle).

So $r_2 = A + \delta$.

Applying Snell's law at second face: $n \sin A = 1 \times \sin r_2 = \sin(A + \delta)$.

Therefore $n = \sin(A + \delta)/\sin A$.

(iii) $n = \sqrt{2}$, $A = 60°$.

Using $n = \sin[(A + \delta_m)/2]/\sin(A/2)$: $\sqrt{2} = \sin[(60° + \delta_m)/2]/\sin 30° = \sin[(60°+\delta_m)/2]/0{\cdot}5$.

$\sin[(60°+\delta_m)/2] = \sqrt{2} \times 0{\cdot}5 = 1/\sqrt{2}$.

$(60°+\delta_m)/2 = 45°$.

$60°+\delta_m = 90°$.

$\delta_m = 30°$.

(2) At minimum deviation i = e and r = A/2 = 30°.

Snell's law: $\sin i = n \sin r = \sqrt{2} \times \sin 30° = \sqrt{2} \times 0{\cdot}5 = 1/\sqrt{2}$.

$i = 45°$.

OR

Q.33

(b) (i) State Huygens principle. A plane wave is incident at an angle i on a reflecting surface. Construct the corresponding reflected wavefront. Using this diagram, prove that the angle of reflection is equal to the angle of incidence.

(ii) What are the coherent sources of light? Can two independent sodium lamps act like coherent sources? Explain.

(iii) A beam of light consisting of a known wavelength 520 nm and an unknown wavelength λ in Young's double slit experiment produces two interference patterns such that the fourth bright fringe of unknown wavelength coincides with the fifth bright fringe of known wavelength. Find the value of λ.

Answer: (iii) λ = 650 nm

Explanation:

(i) Huygens Principle: (1) Every point on a wavefront acts as a source of secondary spherical wavelets.

(2) The new wavefront at a later time is the common tangent (envelope) to all these secondary wavelets.

Proof of law of reflection: Let a plane wavefront AB be incident at angle i on a plane mirror.

When B reaches the mirror at B', A has travelled distance AA' = vt = BB'.

The new wavefront A'B' makes angle r with the mirror.

In triangles ABB' and A'B'B: AB' is common, BB' = AA' = vt, angles at B and A' are 90°.

By RHS congruence, the triangles are congruent, so angle i = angle r.

(ii) Coherent sources are sources that emit light waves of the same frequency, same wavelength, and a constant phase difference.

Two independent sodium lamps cannot be coherent sources because the light emitted from atoms is spontaneous and random;

the phase difference between two independent lamps changes randomly over time (much faster than the eye can detect), resulting in no stable interference pattern.

(iii) For bright fringes: $y_n = n\lambda D/d$.

4th fringe of λ = 5th fringe of 520 nm: $4\lambda = 5 \times 520$ nm.

$\lambda = (5 \times 520)/4 = 2600/4 = 650$ nm.