CBSE Class 12 Physics 2024 — Set 3 — 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

Consider a group of charges q1, q2, q3 ... such that $\Sigma q \neq 0$. Then equipotentials at a large distance, due to this group are approximately :

(a) Plane

(b) Spherical surface <<

(c) Paraboloidal surface

(d) Ellipsoidal surface

Explanation:

At large distances, any charge distribution whose total charge is non-zero behaves like a point charge.

The equipotential surfaces of a point charge are concentric spheres, so the equipotentials are approximately spherical surfaces.

Q.2

A proton is taken from point P1 to point P2, both located in an electric field. The potentials at points P1 and P2 are −5 V and +5 V respectively. Assuming that kinetic energies of the proton at points P1 and P2 are zero, the work done on the proton is :

(a) $-1{\cdot}6 \times 10^{-18}$ J

(b) $1{\cdot}6 \times 10^{-18}$ J <<

(c) Zero

(d) $0{\cdot}8 \times 10^{-18}$ J

Explanation:

Work done on the proton by the external agent = $q(V_2 - V_1) = (1.6 \times 10^{-19}\ C)(+5\ V - (-5\ V)) = 1.6 \times 10^{-18}$ J.

The kinetic energy is zero at both points, so the field's own work is -1.6×10^{-18} J and the work done on the proton by the agent is $+1.6 \times 10^{-18}$ J.

Answer: (B).

Q.3

A 2.0 cm segment of wire, carrying 5.0 A current in positive y-direction lies

along y-axis, as shown in the figure. The magnetic field at a point (3 m, 4 m, 0) due to this segment (part of a circuit) is :

(a) $(0.12\ \text{nT})\ \hat{j}$

(b) $-(0.10\ \text{nT})\ \hat{j}$

(c) $-(0.24\ \text{nT})\ \hat{k}$ <<

(d) $(0.24\ \text{nT})\ \hat{k}$

Explanation:

Using Biot-Savart law for a short element: $dB = (\mu_0/4\pi)(I\ dl \times \hat{r})/r^2$.

The element is along $\hat{y}$, position vector to (3,4,0) from origin is $r = 3\hat{x} + 4\hat{y}$, $|r| = 5$ m.

$dl \times \hat{r} = (dl\ \hat{y}) \times (3\hat{x} + 4\hat{y})/5 = (dl/5)(3(\hat{y} \times \hat{x}) + 4(\hat{y} \times \hat{y})) = (dl/5)(-3\hat{k} + 0) = -(3dl/5)\hat{k}$.

$B = (10^{-7})(5)(0.02)(-3/5)/25 = (10^{-7} \times 5 \times 0.02 \times 0.6)/25 = (10^{-7} \times 0.06)/25 = 2.4 \times 10^{-10}$ T, direction $-\hat{k}$.

So $B = -(0.24\ \text{nT})\ \hat{k}$.

Q.4

A circular loop of wire, carrying a current, is placed in the xy-plane with its centre coinciding with the origin. It is subjected to a uniform magnetic field pointing along +z-axis. The loop will :

(a) move along x-axis

(b) move along −y-axis

(c) move along z-axis

(d) remain stationary <<

Explanation:

The magnetic moment of the circular loop is along ±z-axis (perpendicular to the plane of the loop).

Since the external magnetic field B is also along +z-axis, the torque $\tau = M \times B = 0$.

Also, since the field is uniform, the net force on the loop is zero.

Therefore the loop remains stationary.

Q.5

A current carrying circular loop of magnetic moment M is suspended in a

vertical plane in an external magnetic field B such that its plane is normal to B. The work done in rotating this loop by 45° about an axis perpendicular to B is closest to :

(a) −0.3 MB

(b) 0.3 MB <<

(c) −1.7 MB

(d) 1.7 MB

Explanation:

Initially the plane of the loop is normal to B, so M is parallel to B ($\theta_1 = 0°$).

After rotating 45° about an axis perpendicular to B, $\theta_2 = 45°$.

Work done = $U_2 - U_1 = -MB\cos45° - (-MB\cos0°) = MB(1 - \cos45°) = MB(1 - 1/\sqrt{2})$ $= MB(1 - 0.707) \approx 0.293\ MB \approx 0.3\ MB$.

Q.6

The current in a coil of 15 mH increases uniformly from zero to 4 A in 0.004 s. The emf induced in the coil will be :

(a) 22·5 V

(b) 17·5 V

(c) 15·0 V <<

(d) 12·5 V

Explanation:

Induced emf = $L(dI/dt) = (15 \times 10^{-3}\ H)(4\ A / 0.004\ s) = (15 \times 10^{-3})(1000) = 15.0\ V$.

Q.7

Consider a solenoid of length l and area of cross-section A with fixed number of turns. The self-inductance of the solenoid will increase if :

(a) both l and A are increased

(b) l is decreased and A is increased <<

(c) l is increased and A is decreased

(d) both l and A are decreased

Explanation:

For a solenoid with fixed turns N, $L = \mu_0 N^2 A/l$, so $L \propto A/l$.

L increases when A increases and l decreases, which is option (B).

In (A) and (D) the change in A/l depends on the relative changes, and in (C) A/l falls.

Q.8

Which one of the following has the highest frequency ?

(a) Infrared rays

(b) Gamma rays <<

(c) Radio waves

(d) Microwaves

Explanation:

The electromagnetic spectrum in order of increasing frequency: Radio waves < Microwaves < Infrared < Visible < UV < X-rays < Gamma rays.

Gamma rays have the highest frequency ($> 10^{18}$ Hz).

Q.9

A proton and an alpha particle having equal velocities approach a target nucleus. They come momentarily to rest and then reverse their directions. The ratio of the distance of closest approach of the proton to that of the alpha particle will be :

(a) 1/2

(b) 2 <<

(c) 1/4

(d) 4

Explanation:

At closest approach all KE converts to PE: $(1/2)mv^2 = (1/4\pi\varepsilon_0)\cdot(q_{proj}\cdot Ze)/r_{min}$, so $r_{min} = (1/4\pi\varepsilon_0)\cdot 2\cdot q_{proj}\cdot Ze/(mv^2)$.

For equal velocities v and the same target nucleus, $r \propto q_{proj}/m$.

Therefore $r_p/r_\alpha = (q_p/m_p)/(q_\alpha/m_\alpha) = (e/m)/(2e/4m) = (e/m)/(e/2m) = 2$.

Answer: 2 (option B).

Q.10

Which one of the following is the correct graph between the maximum kinetic energy (Km) of the emitted photoelectrons and the frequency of incident radiation (v) for a given photosensitive surface ?

(a) Graph A
(b) Graph B
(c) Graph C <<
(d) Graph D

Explanation:

Einstein's relation is Km = h(v − v0): a straight line of slope h that meets the v-axis at the threshold frequency v0, with Km = 0 below it.
Graph (A) has a negative slope, so it is wrong.
Graph (B) has a positive Km-intercept at v = 0, which is impossible because Km is 0 below v0.
Graph (D) starts from the origin with no threshold, so it is wrong.
Graph (C) rises in a straight line from a point v0 on the positive v-axis, so it is correct.
Option (C).

Q.11

An electron makes a transition from n = 2 level to n = 1 level in the Bohr model of a hydrogen atom. Its period of revolution :

(a) increases by 87·5%
(b) decreases by 87·5% <<
(c) increases by 43·75%
(d) decreases by 43·75%

Explanation:

In Bohr model, period $T \propto n^3$.
$T_2/T_1 = (n_2/n_1)^3 = (2/1)^3 = 8$.
So T_n=2 = 8T_n=1.
Transition from n=2 to n=1: initial period $T_i = 8T_1$, final period $T_f = T_1$.
Change = $T_f - T_i = T_1 - 8T_1 = -7T_1$.

Percentage change = $(-7T_1)/(8T_1) \times 100 = -87.5\%$.

Period decreases by 87.5%.

Q.12

Si is doped with a pentavalent element. The energy required to set the additional electron free is about :

(a) 0·01 eV

(b) 0·05 eV <<

(c) 0·72 eV

(d) 1·1 eV

Explanation:

In n-type semiconductor (Si doped with pentavalent element), the donor energy level lies just below the conduction band.

The energy required to ionise the donor (free the extra electron) is the donor ionisation energy, typically ~0.045–0.05 eV for Si.

This is much less than the band gap (1.1 eV).

The closest answer is 0.05 eV.

Q.13

Assertion (A) : In a semiconductor, the electrons in the conduction band have lesser energy than those in the valence band.

Reason (R) : Donor energy level is just above the valence band in a semiconductor.

(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: electrons in the conduction band have HIGHER energy than

those in the valence band — they gained energy to jump across the band gap.
Reason (R) is also FALSE: in an n-type semiconductor, the donor energy level is just BELOW the conduction band (not above the valence band).
Both are false → option (D).

Q.14

Assertion (A) : Photoelectric effect demonstrates the particle nature of light.
Reason (R) : Photoelectric current is proportional to frequency of incident radiation.

(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 TRUE: photoelectric effect shows that light consists of photons (particles), as the effect depends on frequency not intensity.
Reason (R) is FALSE: photoelectric current is proportional to the INTENSITY (number of photons) of incident radiation, not to frequency.
Frequency determines whether emission occurs and the maximum KE of emitted electrons.
So A is true, R is false → option (C).

Q.15

Assertion (A) : A proton and an electron enter a uniform magnetic field B with the same momentum p such that p is perpendicular to B. They describe circular paths of the same radius.
Reason (R) : In a magnetic field, orbital radius r is equal to p/(qB).

(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 TRUE: r = mv/(qB) = p/(qB).

If p is the same for proton and electron but q differs (|e| same for both), then r_proton = p/(eB) = r_electron.

So same radius.

Reason (R) is TRUE and it correctly explains why: r = p/(qB), so for equal p and equal |q| = e, radius is the same.

Both true, R explains A → option (A).

Q.16

Assertion (A) : A convex lens, when immersed in a liquid, disappears.

Reason (R) : The refractive indices of material of the lens and the liquid are equal.

(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 TRUE: when the refractive index of the lens equals that of the liquid, by lens maker's formula 1/f = (n_lens/n_liquid − 1)(1/R1 − 1/R2) = 0, so focal length becomes infinite and the lens has no converging/diverging power — it disappears optically.

Reason (R) is TRUE and correctly explains this.

Both true, R explains A → option (A).

Q.17

(a) What is meant by 'relaxation time' of free electrons in a conductor? Show

that the resistance of a conductor can be expressed by R = ml/(ne²τA), where symbols have their usual meanings.

Answer: Relaxation time (τ) is the average time between two successive collisions of a free electron with the lattice ions/atoms of the conductor. Derivation: Drift velocity v_d = eEτ/m. Current I = nAev_d = nAe(eEτ/m) = nAe²τE/m. Since E = V/l and I = V/R: V/R = nAe²τ(V/l)/m → R = ml/(nAe²τ). Here m = mass of electron, l = length, n = number density, A = cross-sectional area, e = charge of electron, τ = relaxation time.

Explanation:

Relaxation time τ is defined as the mean free time between successive collisions.
Using Drude model: a = eE/m, so v_d = aτ = eEτ/m.
Current density J = nev_d = ne²Eτ/m.
Resistivity ρ = E/J = m/(ne²τ).
Resistance R = ρl/A = ml/(ne²τA).

OR

Q.17

(b) OR: Draw the circuit diagram of a Wheatstone bridge. Obtain the condition when no current flows through the galvanometer in it.

Answer: Wheatstone bridge has four resistors P, Q, R, S in a diamond configuration with a battery across one diagonal and galvanometer across the other. Balanced condition: P/Q = R/S (or PS = QR). Derivation using Kirchhoff's laws: when galvanometer current Ig = 0, I1P = I2R and I1Q = I2S. Dividing: P/Q = R/S.

Explanation:

Circuit: Battery E connected between nodes A and C;
galvanometer G between nodes B and D;
P between A-B, Q between B-C, R between A-D, S between D-C.
At balance (Ig=0): potential at B = potential at D.
V_A − V_B = I1P; V_B − V_C = I1Q; V_A − V_D = I2R; V_D − V_C = I2S.
From V_B = V_D: I1P/I1Q = I2R/I2S → P/Q = R/S.

Q.18

The magnifying power of an astronomical telescope is 24. In normal adjustment, distance between its two lenses is 150 cm. Find the focal length of the objective lens.

Answer: 144 cm

Explanation:

In normal adjustment: magnifying power $m = f_o/f_e = 24$ and tube length $L = f_o + f_e = 150$ cm.

From $m = f_o/f_e$: $f_o = 24f_e$.

Substituting: $24f_e + f_e = 150 \rightarrow 25f_e = 150 \rightarrow f_e = 6$ cm.

Therefore $f_o = 24 \times 6 = 144$ cm.

Q.19

Explain the following :

(a) For a simple microscope, the angular size of the object equals the angular size of the image. Yet it offers magnification.

(b) Both plane and convex mirrors produce virtual images of objects. Can they produce real images under some circumstances ?

Answer: (a) A simple microscope is a convex lens used with the object inside its focal length, giving a virtual, erect, magnified image. The angular size of the image equals the angular size of the object as seen through the lens, but the lens lets the object be placed much closer to the eye than the near point D = 25 cm. Without the lens the object can be viewed clearly only from 25 cm, where it subtends a smaller angle. The magnification is the ratio of the angle with the lens to the angle at 25 cm without it, $m = 1 + D/f > 1$. (b) Normally no. A plane or convex mirror forms a real image only when the incident rays are converging towards a point behind the mirror (a virtual object). The reflected rays then actually meet in front of the mirror and form a real image.

Explanation:

(a) The magnification compares the angle the object subtends when it is held close to the eye through the lens with the angle it would subtend at the near point (25 cm) without the lens;

the lens makes the first angle larger even though the image and the object subtend the same angle at the eye.

(b) Plane and convex mirrors give real images only for a virtual object, i.e.

converging incident rays.

Q.20

The minimum intensity of white light that our eyes can perceive is about 0.1 nWm^{-2}. Calculate the number of photons of this light entering our pupil (area 0.4 cm^2) per second.

(Average wavelength of white light = 500 nm and Planck's constant = 6.6×10^{-34} Js)

Answer: $\approx 1 \times 10^4$ photons per second

Explanation:

Energy of one photon: $E = hc/\lambda = (6.6 \times 10^{-34} \times 3 \times 10^8)/(500 \times 10^{-9}) = 3.96 \times 10^{-19}$ J $\approx 4 \times 10^{-19}$ J.

Power entering the pupil = intensity × area = $(0.1 \times 10^{-9}$ W $m^{-2})(0.4 \times 10^{-4}$ $m^2) = 4 \times 10^{-15}$ W.

Number of photons per second = $(4 \times 10^{-15})/(3.96 \times 10^{-19}) \approx 1 \times 10^4$.

Q.21

Suppose a pure Si crystal has 5×10^{28} atoms m^{-3}. It is doped by 1 ppm concentration of boron. Calculate the concentration of holes and electrons, given that ni = $1{\cdot}5 \times 10^{16}$ m^{-3}. Is the doped crystal n-type or p-type ?

Answer: Hole concentration (p) $\approx 5 \times 10^{22}$ m^{-3}; electron concentration (n) $\approx 4.5 \times 10^9$ m^{-3}; p-type semiconductor.

Explanation:

Boron is trivalent (acceptor impurity).

Concentration of boron atoms = 1 ppm × 5×10^{28} = $(1/10^6) \times 5 \times 10^{28} = 5 \times 10^{22}$ m^{-3}.
Since boron >> ni, p ≈ N_A = 5×10^{22} m^{-3}.
Using mass action law: $np = ni^2 = (1.5 \times 10^{16})^2 = 2.25 \times 10^{32}$ m^{-6}.
Electron concentration $n = ni^2/p = 2.25 \times 10^{32} / 5 \times 10^{22} = 4.5 \times 10^9$ m^{-3}.
Since holes >> electrons, it is p-type.

Q.22

Determine the current in branches AB, AC and BC of the network shown in figure.

Answer: I(AB) = 0.625 A (= 5/8 A), I(AC) = 2.5 A (= 5/2 A, through the 10 V / 1 ohm branch), I(BC) = 2.5 A (= 5/2 A). (Also I(AD) = 1.875 A, I(CD) = 0, I(DB) = 1.875 A through the 5 V branch.) All currents flow in the directions indicated by the arrows in the figure.

Explanation:
From the figure: nodes A(left), B(top), C(centre), D(bottom), F(right).
AB = 4 ohm, BC = 2 ohm, AD = 4 ohm, CD = 2 ohm;
a 10 V battery with 1 ohm internal resistance in branch A-C (arrow C->A);
and an ideal 5 V source (epsilon at F) in branch D-F-B (arrow D->B).
Applying Kirchhoff's laws with the figure's assumed positive directions (i_AB: A->B, i_AD: A->D, i_BC: B->C, i_CD: C->D, i_CA: C->A, i_DB: D->B): KCL at A,B,C + KVL on loops ABCA, ADCA, BCDB.
Loop BCDB: 2 i_BC + 2 i_CD - 5 = 0.
Solving the system exactly gives i_AB = 5/8 A = 0.625 A, i_AD = 15/8 A = 1.875 A, i_BC = 5/2 A = 2.5 A, i_CD = 0, i_CA = 5/2 A = 2.5 A, i_DB = 15/8 A = 1.875 A.
Sanity: I through the 10 V branch = 10 V / (1 + (6 || 6)) = 10/4 = 2.5 A, matching i_CA; the 5 V source makes the A-side split asymmetric (0.625 / 1.875 instead of 1.25 / 1.25).
KCL verified at every node.

Q.23

Two long straight parallel conductors carrying currents, exert a force on each other. Why ? Derive an expression for the force per unit length between two

long straight parallel conductors carrying currents in opposite directions. Explain the nature of the force between these conductors.

Answer: $F/l = \mu_0 I_1 I_2/(2\pi d)$. For opposite currents, the force is repulsive.

Explanation:

Two parallel conductors carrying currents exert force because each conductor creates a magnetic field that acts on the current in the other conductor.

Derivation: Conductor 1 (current I_1) creates magnetic field $B_1 = \mu_0 I_1/(2\pi d)$ at the location of conductor 2.

Force on length l of conductor 2: $F = I_2 l B_1 = I_2 l \times \mu_0 I_1/(2\pi d)$.

Force per unit length: $F/l = \mu_0 I_1 I_2/(2\pi d)$.

For currents in opposite directions, by right-hand rule, the force on each conductor is directed away from the other →

repulsive force.

Q.24

A sinusoidal voltage is applied to an electric circuit containing a circuit element in which current leads voltage by π/2.

(a) Identify the circuit element.

(b) Write the formula for its reactance.

(c) Show graphically the variation of this reactance with frequency of ac voltage.

(d) Explain the behaviour of this element when it is used in (i) an ac circuit, and (ii) a dc circuit.

Answer: (a) Capacitor. (b) Capacitive reactance $X_C = 1/(\omega C) = 1/(2\pi f C)$. (c) X_C vs f is a hyperbola (X_C decreases as f increases, $X_C \to \infty$ as $f \to 0$, $X_C \to 0$ as $f \to \infty$). (d)(i) In ac circuit: capacitor allows ac to pass, offers reactance $X_C = 1/(\omega C)$ which decreases with frequency. (ii) In dc circuit: capacitor blocks steady dc ($f = 0$, $X_C = \infty$) after initial charging; steady-state current = zero.

Explanation:

Current leads voltage by π/2 → capacitor.

$X_C = 1/(2\pi fC)$.

Graph: rectangular hyperbola with X_C on y-axis and f on x-axis.

For ac: capacitor continuously charges and discharges, allowing alternating current to flow.

For dc: after charging to supply voltage, current stops flowing (acts as open circuit).

Q.25

The electric field in an electromagnetic wave in vacuum is given by :

$E = (6{\cdot}3\ N/C)\ [\cos(1{\cdot}5\ rad/m)\ y + (4{\cdot}5 \times 10^8\ rad/s)\ t]\ \hat{i}$

(a) Find the wavelength and frequency of the wave.

(b) What is the amplitude of the magnetic field of the wave ?

(c) Write an expression for the magnetic field of this wave.

Answer: (a) Wavelength $\lambda = 2\pi/k = 2\pi/1.5 \approx 4.19$ m; Frequency $f = \omega/(2\pi) = 4.5\times10^8/(2\pi) \approx 7.16 \times 10^7$ Hz. (b) $B_o = E_o/c = 6.3/(3\times10^8) = 2.1 \times 10^{-8}$ T. (c) $B = (2.1 \times 10^{-8}\ T)\cos[(1.5\ rad/m)y + (4.5 \times 10^8\ rad/s)t]\ \hat{k}$

Explanation:

(a) Wave number $k = 1.5$ rad/m $\rightarrow \lambda = 2\pi/1.5 = 4\pi/3 \approx 4.19$ m.

Angular frequency $\omega = 4.5 \times 10^8$ rad/s $\rightarrow f = \omega/(2\pi) = 4.5\times10^8/6.28 \approx 7.16 \times 10^7$ Hz.

(b) $E_o = 6.3$ N/C; $B_o = E_o/c = 6.3/(3\times10^8) = 2.1 \times 10^{-8}$ T.

(c) The wave travels in $-y$ direction (since $ky + \omega t$ form).

E is along $\hat{i}$, wave travels along $-\hat{y}$, and E × B must point along the direction of propagation.

Since $\hat{i} \times \hat{k} = -\hat{j}$, B is along $+\hat{k}$.

$B = (2.1 \times 10^{-8}\ T)\cos[(1.5)y + (4.5\times10^8)t]\ \hat{k}$.

Q.26

State Bohr's first and second postulates. Use them to derive an expression for the radius of the nth orbit in a hydrogen atom.

Answer: $r_n = n^2a_o = n^2 \times 0.529$ Å, where $a_o = \varepsilon_o h^2/(\pi m e^2) = 0.529 \times 10^{-10}$ m is the Bohr radius.

Explanation:

First postulate: Electrons revolve in certain stable orbits without radiating energy.

Second postulate: The angular momentum of the electron is quantised: $mvr = nh/(2\pi)$.

From force balance: Coulomb force = centripetal force → $ke^2/r^2 = mv^2/r \rightarrow v^2 = ke^2/(mr)$.

From quantisation: $v = nh/(2\pi mr)$.

Squaring and equating: $n^2h^2/(4\pi^2m^2r^2) = ke^2/(mr) \rightarrow r = n^2h^2/(4\pi^2mke^2) = n^2\varepsilon_0h^2/(\pi me^2)$.

For n=1: $r_1 = a_0 \approx 0.529$ Å.

General: $r_n = n^2a_0$.

Q.27

(a) Define atomic mass unit (u).

(b) Calculate the energy required to separate a deuteron into its constituent parts (a proton and a neutron). Given :

m(D) = 2.014102 u

mH = 1.007825 u

mn = 1.008665 u

Answer: (a) Atomic mass unit (u) is defined as 1/12 of the mass of a carbon-12 atom. 1 u = 1.66054×10^{-27} kg. (b) Mass defect Δm = mH + mn − m(D) = 1.007825 + 1.008665 − 2.014102 = 0.002388 u. Binding energy = $\Delta m \times 931.5$ MeV/u = $0.002388 \times 931.5 \approx 2.224$ MeV.

Explanation:

(a) 1 u = (mass of ^{12}C atom)/12.

(b) $\Delta m = (1.007825 + 1.008665) - 2.014102 = 2.016490 - 2.014102 = 0.002388$ u.

BE = $0.002388 \times 931.5 = 2.224$ MeV.

This energy (≈ 2.22 MeV) is required to separate the deuteron into a free proton and a free neutron.

Q.28

(a) Draw the circuit diagrams for obtaining the V−I characteristics of a p-n junction diode. Explain briefly the salient features of the V−I characteristics in (i) forward biasing, and (ii) reverse biasing.

Answer: (a) Forward bias: p-side to +ve terminal, n-side to −ve terminal. Forward

V-I: current is nearly zero until threshold/knee voltage (~0.7V for Si), then rises steeply. Reverse bias: p-side to −ve terminal, n-side to +ve terminal. Reverse V-I: very small reverse saturation current (due to minority carriers) until breakdown voltage, then current rises sharply.

Explanation:

Forward bias reduces the depletion layer width and barrier potential.
Beyond knee voltage (~0.3V for Ge, ~0.7V for Si), exponential increase in current.
Reverse bias increases the depletion layer.
Only a tiny reverse saturation current (few μA) flows due to minority carriers.
At breakdown voltage (Zener/avalanche), reverse current increases suddenly.

OR

Q.28

(b) OR: On the basis of energy band diagrams, distinguish between (i) an insulator, (ii) a semiconductor, and (iii) a conductor.

Answer: (i) Insulator: very large band gap (Eg > 3 eV, e.g. diamond ~5.4 eV); valence band completely filled, conduction band empty, electrons cannot jump at room temperature. (ii) Semiconductor: moderate band gap (Eg ~ 1 eV, e.g. Si ~1.1 eV, Ge ~0.72 eV); at room temperature some electrons can be thermally excited to conduction band, leaving holes. (iii) Conductor: overlapping conduction and valence bands (or partially filled conduction band, Eg = 0); large number of free electrons available at room temperature.

Explanation:

The key distinction is the magnitude of the band gap and the occupancy of bands at room temperature.
Insulators: Eg large, no conduction.
Semiconductors: Eg small, partial conduction.
Conductors: Eg = 0 (overlapping bands), abundant free electrons.

Q.29(i)

Case Study Q29: The figure shows four pairs of parallel identical conducting

plates, separated by the same distance 2.0 cm and arranged perpendicular to x-axis. The electric potential of each plate is mentioned. The electric field between a pair of plates is uniform and normal to the plates.

(i) For which pair of the plates is the electric field E along î ?

(a) I
(b) II
(c) III
(d) IV <<

Explanation:
E = −dV/dx, so E points along +î only where the potential falls from left to right.
Pair I: −70 V → −50 V (rises).
Pair II: −50 V → +150 V (rises).
Pair III: −20 V → +200 V (rises).
Pair IV: −100 V → −400 V (falls).
So E is along +î only for pair IV.
Answer: (D).

Q.0

Case Study Q29: (ii) An electron is released midway between the plates of pair IV. It will :

(a) move along î at constant speed
(b) move along −î at constant speed
(c) accelerate along î
(d) accelerate along −î <<

Explanation:
In pair IV the potential falls from −100 V (left) to −400 V (right), so E is along +î.
The force on an electron is F = −eE, along −î, and it is constant, so the electron accelerates along −î.
Answer: (D).

Q.0

Case Study Q29: (iii) Let V0 be the potential at the left plate of any set, taken to be at x = 0 m. Then potential V at any point (0 ≤ x ≤ 2 cm) between the plates of that set can be expressed as :

(a) V = V0 + αx <<

(b) V = V0 + αx²

(c) V = V0 + αx^(1/2)

(d) V = V0 + αx^(3/2)

Explanation:

Between parallel plates, the electric field is uniform (E = constant).

The potential varies linearly with distance: V(x) = V0 − Ex = V0 + αx, where α = −E (a positive or negative constant).

This is a linear relationship, so V = V0 + αx.

Q.0

Case Study Q29: (iv)(a) Let E1, E2, E3 and E4 be the magnitudes of the electric field between the pairs of plates I, II, III and IV respectively. Then :

(a) E1 > E2 > E3 > E4

(b) E3 > E4 > E1 > E2

(c) E4 > E3 > E2 > E1 <<

(d) E2 > E3 > E4 > E1

Explanation:

All pairs are 2.0 cm apart, so E = |ΔV|/d ∝ |ΔV|.

|ΔV|: I = 20 V, II = 200 V, III = 220 V, IV = 300 V.

Hence $E_4 > E_3 > E_2 > E_1$.

Answer: (C).

Q.0

Case Study Q29: (iv)(b) OR: An electron is projected from the right plate of set I directly towards its left plate. It just comes to rest at the plate. The speed with which it was projected is about : (Take e/m = 1.76 × 10^{11} C/kg)

(a) 1.3×10^5 m/s

(b) 2.6×10^6 m/s <<

(c) 6.5×10^5 m/s

(d) 5.2×10^7 m/s

Explanation:

Set I has $|\Delta V| = 20$ V.

By energy conservation, $\frac{1}{2}mv^2 = e \cdot \Delta V$, so $v = \sqrt{(2(e/m)\Delta V)} = \sqrt{(2 \times 1.76 \times 10^{11} \times 20)} = \sqrt{(7.04 \times 10^{12})} \approx 2.6 \times 10^6$ m/s.

Answer: (B).

Q.30(i)

Case Study Q30: Diffraction and interference are closely related phenomena that occur together. Two slits of width 2 μm each in an opaque material are separated by a distance of 6 μm. Monochromatic light of wavelength 450 nm is incident normally on the slits. One finds a combined interference and diffraction pattern on the screen.

(i) The number of peaks of the interference fringes formed within the central peak of the envelope of the diffraction pattern will be :

(a) 2

(b) 3

(c) 4

(d) 6 <<

Explanation:

Slit width $a = 2$ μm and separation $d = 6$ μm.

The central diffraction envelope lies between the first minima at $\sin\theta = \pm\lambda/a$, and interference maxima occur at $\sin\theta = n\lambda/d$.

The number of interference peaks within the central envelope is taken as $2d/a = 2 \times 6/2 = 6$, option (D).

Note: the fringes at $n = \pm 3$ fall exactly on the diffraction minima, so strictly only 5 bright peaks are visible;

5 is not among the options.

Q.0

Case Study Q30: (ii) The number of peaks of the interference formed if the slit width is doubled while keeping the distance between the slits same will be :

(a) 1
(b) 2
(c) 3 <<
(d) 4

Explanation:

If slit width a is doubled: new a = 4 μm, d = 6 μm remains.
New d/a = 6/4 = 3/2.
The first diffraction minimum: sin θ = λ/a_new.
Interference maxima missing when n = d/a_new = 3/2 (non-integer, so no missing maximum).
Number of interference maxima in central diffraction peak: from n = −1 to +1 (since d/a = 1.5, n = ±1 is within, n = ±2 would be outside or at boundary).
Peaks: n = 0, ±1 → 3 peaks.
Answer: 3.

Q.0

Case Study Q30: (iii)(a) If instead of 450 nm light, another light of wavelength 680 nm is used, number of peaks of the interference formed in the central peak of the envelope of the diffraction pattern will be :

(a) 2
(b) 4
(c) 6 <<
(d) 9

Explanation:

The ratio d/a does not depend on wavelength, so using 680 nm light leaves the count

unchanged: 2d/a = 2 × 6/2 = 6, option (C).

Note: the fringes at n = ±3 fall exactly on the diffraction minima, so strictly only 5 bright peaks are visible;

5 is not among the options.

Q.0

Case Study Q30: (iii)(b) OR: Consider the diffraction of light by a single slit described in this case study. The first minimum falls at an angle equal to :

(a) $\sin^{-1}(0.12)$

(b) $\sin^{-1}(0.225)$ <<

(c) $\sin^{-1}(0.32)$

(d) $\sin^{-1}(0.45)$

Explanation:

For single-slit diffraction, first minimum: $\sin\theta = \lambda/a = 450\text{ nm} / 2\ \mu\text{m} = 450 \times 10^{-9} / 2 \times 10^{-6} = 0.225$.

So $\theta = \sin^{-1}(0.225)$.

Q.0

Case Study Q30: (iv) The number of bright fringes formed due to interference on 1 m of screen placed at 4/3 m away from the slits is :

(a) 2

(b) 3

(c) 6

(d) 10 <<

Explanation:

Fringe width $\beta = \lambda D/d = (450 \times 10^{-9} \times 4/3) / (6 \times 10^{-6}) = (600 \times 10^{-9})/(6 \times 10^{-6}) = 0.1$ m.

Number of fringes on 1 m of screen = 1 m / 0.1 m = 10 fringes.

Q.31

(a)(i) Obtain the expression for the capacitance of a parallel plate capacitor with a dielectric medium between its plates.

(a)(ii) A charge of 6 μC is given to a hollow metallic sphere of radius 0.2 m.

Find the potential at (i) the surface and (ii) the centre of the sphere.

Answer: (i) $C = \varepsilon_0\varepsilon_r A/d = K\varepsilon_0 A/d$, where $K = \varepsilon_r$ is the dielectric constant. (ii) Potential at surface = Potential at centre = $kQ/R = (9\times10^9 \times 6\times10^{-6})/0.2 = 2.7 \times 10^5$ V = 270 kV.

Explanation:

(i) With dielectric of constant K between plates of area A separated by d: $E = \sigma/(K\varepsilon_0) = Q/(KA\varepsilon_0)$.

$V = Ed = Q/(KA\varepsilon_0) \times d$.

$C = Q/V = K\varepsilon_0 A/d$.

(ii) For a hollow metallic sphere, all charge resides on the surface.

Outside and on the surface: $V = kQ/r$.

At surface ($r = R = 0.2$ m): $V = (9\times10^9)(6\times10^{-6})/0.2 = 54000/0.2 = 270000$ V $= 2.7\times10^5$ V.

Inside a conductor, potential is constant and equal to the surface potential, so $V_{centre} = V_{surface} = 2.7\times10^5$ V.

OR

Q.31

(b) OR: (i) A charge +Q is placed on a thin conducting spherical shell of radius R. Using Gauss's theorem, derive an expression for the electric field at a point lying (i) inside and (ii) outside the shell.

(ii) Show that the electric field for same charge density (σ) is twice in case of a conducting plate or surface than in a nonconducting sheet.

Answer: (i) Inside ($r < R$): $E = 0$ (no enclosed charge). Outside ($r > R$): $E = Q/(4\pi\varepsilon_0 r^2)$, radially outward. (ii) For conducting surface: $E = \sigma/\varepsilon_0$. For nonconducting sheet: $E = \sigma/(2\varepsilon_0)$ on each side. So $E_{conductor} = 2 \times E_{nonconductor}$.

Explanation:

(i) Inside: Gaussian surface (sphere of radius $r < R$) encloses no charge →

$E\times4\pi r^2 = 0$ →

$E = 0$.

Outside: Gaussian surface (sphere of radius r > R) encloses Q →
$E \times 4\pi r^2 = Q/\varepsilon_0$ →
$E = Q/(4\pi\varepsilon_0 r^2)$.
(ii) Nonconducting infinite sheet: $E = \sigma/(2\varepsilon_0)$ on each side (field lines go both ways).
Conducting plate: by Gauss's law over a pillbox, $E \times A = \sigma A/\varepsilon_0$ (field only on one side, other side E=0) →
$E = \sigma/\varepsilon_0 = 2 \times \sigma/(2\varepsilon_0)$.

Q.32

(a)(i)(1) What is meant by current sensitivity of a galvanometer? Mention the factors on which it depends.

(a)(i)(2) A galvanometer of resistance G is converted into a voltmeter of range (0 to V) by using a resistance R. Find the resistance, in terms of R and G, required to convert it into a voltmeter of range (0 to V/2).

(a)(ii) The magnetic flux through a coil of resistance 5 Ω increases with time as : $\Phi = (2.0\ t^3 + 5.0\ t^2 + 6.0\ t)$ mWb. Find the magnitude of induced current through the coil at t = 2 s.

Answer: (i)(1) Current sensitivity = deflection per unit current = NBA/(k) [rad/A or div/μA]; depends on N, B, A (coil dimensions) and k (restoring constant). (i)(2) For range V: $R + G = V/I_g \rightarrow R = V/I_g - G$. For range V/2: $R' + G = (V/2)/I_g = (R+G)/2 \rightarrow R' = (R+G)/2 - G = R/2 - G/2 = (R-G)/2$. (ii) $e = d\Phi/dt = (6t^2 + 10t + 6)$ mV. At t = 2s: $e = (6\times4 + 10\times2 + 6) = (24 + 20 + 6) = 50$ mV = 0.05 V. $I = e/R_{coil} = 0.05/5 = 0.01$ A = 10 mA.

Explanation:
(i)(1) Current sensitivity $S_i = \theta/I = NBA/k$.
Depends on: number of turns N, magnetic field B, area A, spring constant k.
(i)(2) $I_g = V/(R+G)$.
For new range V/2: $R' = (V/2)/I_g - G = (V/2)(R+G)/V - G = (R+G)/2 - G = (R-G)/2$.
(ii) Φ in mWb, so $d\Phi/dt = d/dt(2t^3+5t^2+6t)$ mWb/s = $(6t^2+10t+6)$ mV.
At t=2: 6(4)+10(2)+6 = 24+20+6 = 50 mV.
$I = 50\times10^{-3}/5 = 10\times10^{-3}$ A = 10 mA.

OR

Q.32

(b) OR: (i) A rectangular coil of N turns and area of cross-section A is rotated at a steady angular speed ω in a uniform magnetic field. Obtain an expression for the emf induced in the coil at any instant of time.

(ii) Two coplanar and concentric circular loops L1 and L2 are placed coaxially with their centres coinciding. The radii of L1 and L2 are 1 cm and 100 cm respectively. Calculate the mutual inductance of the loops. (Take $\pi^2 = 10$)

Answer: (i) $e = NBA\omega \sin(\omega t) = e_0 \sin(\omega t)$, where $e_0 = NBA\omega$ is the peak emf. (ii) $M = \mu_0 \pi r_1^2/(2r_2) = (4\pi \times 10^{-7} \times \pi \times (0.01)^2)/(2 \times 1) = (4\pi^2 \times 10^{-7} \times 10^{-4})/2 = (4 \times 10 \times 10^{-11})/2 = 2 \times 10^{-10}$ H = 0.2 nH.

Explanation:

(i) Flux through coil: $\Phi = NBA\cos(\omega t)$.

Induced emf $e = -d\Phi/dt = NBA\omega \sin(\omega t)$.

Peak emf $e_0 = NBA\omega$.

(ii) Since $r_1 << r_2$, the field of L2 is approximately uniform over L1.

B at centre due to L2 carrying current I: $B_2 = \mu_0 I/(2r_2)$.

Flux through L1: $\Phi_1 = B_2 \times \pi r_1^2 = \mu_0 I \pi r_1^2/(2r_2)$.

$M = \Phi_1/I = \mu_0 \pi r_1^2/(2r_2) = (4\pi \times 10^{-7} \times \pi \times (10^{-2})^2)/(2 \times 1) = (4\pi^2 \times 10^{-7} \times 10^{-4})/2 = (4 \times 10 \times 10^{-11})/2 = 2 \times 10^{-10}$ H.

Q.33

(a)(i) Trace the path of a ray of light showing refraction through a triangular prism and hence obtain an expression for angle of deviation (δ) in terms of A, i and e, where symbols have their usual meanings. Draw a graph showing the variation of angle of deviation with the angle of incidence.

(a)(ii) In the figure, a ray of light is incident on a transparent liquid contained in a thin glass box at an angle of 45° with its one face. The emergent ray passes along the face AB. Find the refractive index of the liquid.

Answer: (i) $\delta = i + e - A$, where i = angle of incidence, e = angle of emergence, A

= prism angle. At minimum deviation i = e and $r_1 = r_2 = A/2$. Graph: δ vs i is a U-shaped curve with its minimum δ_m at i = e. (ii) Refractive index $n = \sqrt{(3/2)} = \sqrt{6}/2 \approx 1.22$.

Explanation:

(i) At first surface: $r_1 + r_2 = A$ (from geometry of prism).

$\delta = (i - r_1) + (e - r_2) = i + e - (r_1 + r_2) = i + e - A$.

Graph shows δ decreasing from high i, reaching minimum δ_m when i = e, then increasing.

(ii) Ray incident at 45° on the face.

If emergent ray is along face AB, the angle of refraction at AB = 90°.

Inside the liquid the angle at AB = critical angle C.

By Snell's law at entry face: $\sin 45° = n \times \sin r$.

At face AB: $n \times \sin C = 1 \times \sin 90° \rightarrow \sin C = 1/n$.

Geometry: $r + C = 90° \rightarrow r = 90° - C$.

So $\sin 45° = n \times \sin(90° - C) = n \cos C$.

And $\sin C = 1/n \rightarrow \cos C = \sqrt{(1 - 1/n^2)}$.

$\sin 45° = n \times \sqrt{(1 - 1/n^2)} \rightarrow$

$1/\sqrt{2} = \sqrt{(n^2 - 1)} \rightarrow$

$n^2 - 1 = 1/2 \rightarrow$

$n^2 = 3/2 \rightarrow$

$n = \sqrt{(3/2)} = \sqrt{6}/2 \approx 1.22$.

OR

Q.33

(b) OR: (i) The displacement of two light waves, each of amplitude a and frequency ω, emanating from two coherent sources of light, are given by $y1 = a \cos \omega t$ and $y2 = a \cos(\omega t + \varphi)$. φ is the phase difference between the two waves. These light waves superpose at a point. Obtain the expression for the resultant intensity at that point.

(ii) In Young's double slit experiment, find the ratio of intensities at two points on a screen when waves emanating from two slits reaching these points have path differences (i) λ/6 and (ii) λ/12.

Answer: (i) $I = 4I_0 \cos^2(\varphi/2)$, where $I_0 = ka^2$ is the intensity due to one source. (ii) For path difference $\lambda/6$: $\varphi = 2\pi/6 = \pi/3$; $I_1 = 4I_0 \cos^2(\pi/6) = 4I_0 \times (3/4) = 3I_0$. For path difference $\lambda/12$: $\varphi = 2\pi/12 = \pi/6$; $I_2 = 4I_0 \cos^2(\pi/12) = 4I_0 \times \cos^2(15°) = 4I_0 \times ((\sqrt{6}+\sqrt{2})/4)^2 = 4I_0 \times (8+4\sqrt{3})/16 = I_0(2+\sqrt{3})$. Ratio $I_1/I_2 = 3I_0/[I_0(2+\sqrt{3})] = 3/(2+\sqrt{3}) = 3(2-\sqrt{3})/((4-3)) = 3(2-\sqrt{3}) = (6-3\sqrt{3})$.

Explanation:

(i) Resultant displacement: $y = y1+y2 = a \cos \omega t + a \cos(\omega t+\varphi) = 2a \cos(\varphi/2) \cos(\omega t+\varphi/2)$.

Amplitude $A = 2a \cos(\varphi/2)$.

Intensity $I = kA^2 = k \times 4a^2 \cos^2(\varphi/2) = 4I_0 \cos^2(\varphi/2)$.

(ii) Phase difference $\varphi = (2\pi/\lambda) \times$ path difference.

For $\Delta = \lambda/6$: $\varphi = \pi/3$; $I_1 = 4I_0 \cos^2(\pi/6) = 4I_0 \times 3/4 = 3I_0$.

For $\Delta = \lambda/12$: $\varphi = \pi/6$; $I_2 = 4I_0 \cos^2(\pi/12)$.

$\cos(15°) = \cos(45°-30°) = (\sqrt{6}+\sqrt{2})/4$; $\cos^2(15°) = (8+4\sqrt{3})/16 = (2+\sqrt{3})/4$.

$I_2 = 4I_0 \times (2+\sqrt{3})/4 = I_0(2+\sqrt{3})$.

Ratio $I_1:I_2 = 3:(2+\sqrt{3}) = 3(2-\sqrt{3}):1$ after rationalising.