CBSE Class 12 Physics 2026 — 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

A particle of mass m and charge q starts from rest and moves in an electric field $E = E_0 \hat{i}$. After travelling a distance x in the field along x-axis, the kinetic energy of the particle will be :

(a) $q E_0 x^2$

(b) $q E_0 x$ <<

(c) $q^2 E_0 x$

(d) $q^2 E_0^2 x$

Explanation:

Work done by the electric field on the particle = Force × displacement = $qE_0 \times x = qE_0x$.

By work-energy theorem, kinetic energy gained = qE_0x (since it starts from rest).

So KE = qE_0x.

Q.2

A square loop of side 50 cm is placed in a uniform magnetic field of 3·0 T acting perpendicular to the plane of the loop. If the loop is rotated through an angle of 90° in 0·3 s, the value of emf induced in the loop would be :

Answer: 2·5 V (none of the printed options)

Explanation:

$A = (0{\cdot}5)^2 = 0{\cdot}25\ m^2$.

$\Phi_1 = BA = 3{\cdot}0 \times 0{\cdot}25 = 0{\cdot}75$ Wb (field $\perp$ plane);

after a 90° turn the plane is parallel to B, so $\Phi_2 = 0$.

$|\Delta\Phi| = 0{\cdot}75$ Wb $\rightarrow \varepsilon = \Delta\Phi/\Delta t = 0{\cdot}75/0{\cdot}3 = 2{\cdot}5$ V.

2·5 V is not among the printed options (0·25, 0·50, 0·75, 1·0 V) — a misprint in the paper.

Q.3

A plane electromagnetic wave travels through a medium and the magnetic field associated with it is given by $B = 5 \times 10^{-8} \sin(3 \times 10^{10}\ t - 150\ x)$ T, where x is in metres and t is in seconds. The velocity of the wave is :

(a) $2{\cdot}0 \times 10^{8}\ ms^{-1}$ <<

(b) $4{\cdot}5 \times 10^{7}\ ms^{-1}$

(c) $3{\cdot}5 \times 10^{7}\ ms^{-1}$

(d) $2{\cdot}5 \times 10^{8}\ ms^{-1}$

Explanation:

The wave equation is $B = B_0 \sin(\omega t - kx)$, where $\omega = 3 \times 10^{10}$ rad/s and $k = 150$ rad/m.

Velocity $v = \omega/k = (3 \times 10^{10})/(150) = 2 \times 10^{8}\ ms^{-1}$.

Answer: (A) $2{\cdot}0 \times 10^{8}\ ms^{-1}$.

Q.4

A thin plano-convex lens and a thin equi-concave lens are kept coaxially in contact as shown in the figure. Assuming both the lenses are made of glass of refractive index μ, and R is the radius of curvature of each curved surface, the focal length of the combination is :

(a) $R / (\mu - 1)$

(b) $-R / (\mu - 1)$ <<

(c) $2R / (\mu - 1)$

(d) $-2R / (\mu - 1)$

Explanation:

From the figure: the upper lens has a flat top and a convex lower surface (plano-convex, $R_1 = \infty$, $R_2 = -R$), so $1/f_1 = (\mu-1)/R$.

The lower lens is equi-concave with both surfaces of radius R, so $1/f_2 = (\mu-1)(-1/R - 1/R) = -2(\mu-1)/R$.

Combination: $1/f = 1/f_1 + 1/f_2 = (\mu-1)/R - 2(\mu-1)/R = -(\mu-1)/R$, so $f = -R/(\mu-1)$.

Answer: (B).

Q.5

The phase difference between the two superimposing waves that give rise to a bright spot in a Young's double-slit experiment is (n is an integer) :

(a) $2n\pi$ <<

(b) $2n\pi + \pi/4$

(c) $2n\pi + \pi/2$

(d) $2n\pi + \pi$

Explanation:

For constructive interference (bright fringe) in Young's double-slit experiment, the path difference must be an integer multiple of wavelength: $\Delta = n\lambda$.

The corresponding phase difference is $\delta = (2\pi/\lambda) \times n\lambda = 2n\pi$.

Answer: (A) $2n\pi$.

Q.6

A telescope has an objective lens of focal length 144 cm and an eyepiece of focal length 6·0 cm. The magnifying power and the length of telescope tube will be respectively :

(a) 24, 150 cm <<

(b) 42, 138 cm

(c) 24, 138 cm

(d) 42, 150 cm

Explanation:

For a telescope in normal adjustment (image at infinity): Magnifying power $M = f_o/fe = 144/6 = 24$.

Length of tube $L = f_o + fe = 144 + 6 = 150$ cm.

Answer: (A) 24, 150 cm.

Q.7

In which of the following, total internal reflection does not occur ?

(a) Twinkling of stars <<

(b) Brilliance of diamonds

(c) Optical fibre

(d) Reflecting prism

Explanation:

Twinkling of stars is caused by atmospheric refraction — the random variation of the refractive index of the atmosphere causes starlight to bend slightly by different

amounts, making the star appear to twinkle.
It does NOT involve total internal reflection.
Brilliance of diamonds, optical fibres, and reflecting prisms all use total internal reflection.
Answer: (A) Twinkling of stars.

Q.8

Radiation of wavelength 200 nm is incident on a photosensitive surface of work function 4·2 eV. The kinetic energy of fastest photoelectrons emitted from this surface will be close to :

(a) 3·5 eV
(b) 3·0 eV
(c) 2·5 eV
(d) 2·0 eV <<

Explanation:
Photon energy E = hc/λ = 1240 eV·nm / 200 nm = 6.2 eV.
KE_max = E − φ = 6.2 − 4.2 = 2.0 eV → option (D).

Q.9

A proton and an alpha particle have equal momentum. The ratio of their kinetic energies (Ep/Ea) and de Broglie wavelengths associated with them (λp/λa) respectively are :

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

Explanation:
Given equal momentum p: KE = $p^2/(2m)$.
So Ep/Ea = $(p^2/2mp)/(p^2/2ma)$ = ma/mp.
Mass of alpha particle = 4mp (approximately).
So Ep/Ea = 4mp/mp = 4.

de Broglie wavelength λ = h/p.

Since momenta are equal, λp/λa = h/p ÷ h/p = 1.

So the ratios are 4 and 1.

Answer: (C) 4, 1.

Q.10

If r_1 and r_2 are the radii of atomic nuclei of mass numbers 64 and 27 respectively, then the value of (r_1/r_2) is :

(a) 1

(b) 4/3 <<

(c) 3/4

(d) 27/64

Explanation:

Nuclear radius r = r_0 A^(1/3), where A is the mass number.

$r_1/r_2 = (A_1/A_2)^{(1/3)} = (64/27)^{(1/3)} = (4^3/3^3)^{(1/3)} = 4/3$.

Answer: (B) 4/3.

Q.11

When the forward bias voltage in a semiconductor diode is changed from 0·8 V to 1·0 V, the forward current changes by 2·0 mA. The forward bias resistance of the diode will be :

(a) 200 Ω

(b) 175 Ω

(c) 100 Ω <<

(d) 125 Ω

Explanation:

Dynamic/AC forward resistance = $\Delta V/\Delta I = (1.0 - 0.8)V / (2.0 \times 10^{-3}\ A) = 0.2/0.002 = 100\ \Omega$.

Answer: (C) 100 Ω.

Q.12

The process named 'minority carrier injection' in a p-n junction diode occurs

during :

(a) forward biasing <<

(b) reverse biasing

(c) no biasing at low temperature

(d) no biasing at high temperature

Explanation:

Minority carrier injection occurs during forward biasing of a p-n junction.

When forward biased, the potential barrier decreases, allowing majority carriers from each side to cross the junction into the other side where they become minority carriers — this is minority carrier injection.

Answer: (A) forward biasing.

Q.13

Assertion (A) : In a Wheatstone bridge circuit, if we interchange the position of the cell and the galvanometer, the balance condition P/Q = R/S remains unchanged.

Reason (R) : P/Q = R/S => Q/S = P/R, so balance condition remains same.

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

Explanation:

Assertion (A) is true: swapping cell and galvanometer in a balanced Wheatstone bridge does not change the balance condition P/Q = R/S.

Reason (R) is also true and provides the correct mathematical justification: if P/Q = R/S, this implies Q/S = P/R (cross-multiplying: PS = QR, which is the same condition).

This is the correct explanation of why interchanging the cell and galvanometer positions does not change the balance condition.

Answer: (A).

Q.14

Assertion (A) : The cylindrical soft iron core in a moving coil galvanometer only makes the magnetic field radial and does not affect the strength of the magnetic field.

Reason (R) : In a moving coil galvanometer, the plane of the coil is always perpendicular to the magnetic field.

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

Explanation:

Assertion is false: the soft iron core makes the field radial AND increases its strength (high permeability concentrates the field lines).
Reason is false: in the radial field the plane of the coil is always PARALLEL to the magnetic field (its normal is perpendicular to B), so torque = NIAB at all positions.
Both Assertion (A) and Reason (R) are false → option (D).

Q.15

Assertion (A) : Photoelectric current depends upon the intensity of the incident radiation.

Reason (R) : Stopping potential is independent of the intensity of the 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) Both Assertion (A) and Reason (R) are false.

Explanation:

Assertion (A) is true: photoelectric current (number of photoelectrons per second) is directly proportional to the intensity of incident radiation.

Reason (R) is also true: stopping potential depends only on the frequency of incident radiation, not on its intensity.

However, Reason (R) does not explain why photoelectric current depends on intensity — these are two separate observations about the photoelectric effect.

Answer: (B).

Q.16

Assertion (A) : Nuclear forces are always attractive.

Reason (R) : The nuclear force between protons and neutrons in a nucleus is a weak force.

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

Explanation:

Assertion (A) is false: nuclear forces are not always attractive.

At very short distances (less than about 0.7 fm), nuclear forces become strongly repulsive, preventing nucleons from merging.

Reason (R) is also false: nuclear forces are the STRONG force (not the weak force).

The strong nuclear force is approximately 100 times stronger than the electromagnetic force.

Answer: (D) Both Assertion and Reason are false.

Q.17

In the given figure, a steady current I flows through the circuit when points A and C are connected by a wire of negligible resistance. Find the potential difference between points B and C.

Answer: I = 0.5 A; $V_B - V_C = -5.5$ V (C is 5.5 V higher than B)

Explanation:

Figure: for E_1 (6 V, 1 Ω) the + plate is on the A side;
for E_2 (4 V, 3 Ω) the + plate is on the C side.
Both – terminals face B, so the cells oppose each other in the loop A–B–C–A (A and C joined by a wire).
Net emf = 6 – 4 = 2 V, total resistance = 1 + 3 = 4 Ω, so I = 2/4 = 0.5 A, in the direction of the arrows (C→B→A).
Going C→B through E_2 the current enters its + terminal, so $V_C - V_B = E_2 + I \times 3 = 4 + 1.5 = 5.5$ V.
Check via A: $V_A - V_B = E_1 - I \times 1 = 6 - 0.5 = 5.5$ V, and $V_A = V_C$.
Hence $V_{BC} = V_B - V_C = -5.5$ V.

OR

Q.17

A battery of emf 21 V and internal resistance 3 Ω is connected to a resistor. If the current in the circuit is 3 A, find : (i) the resistance of the resistor, (ii) the terminal voltage of the battery.

Answer: (i) R = 4 Ω, (ii) Terminal voltage = 12 V

Explanation:

(i) Using Kirchhoff's voltage law: emf = I(R + r), where r = 3 Ω and I = 3 A.
$21 = 3(R + 3) \rightarrow R + 3 = 7 \rightarrow R = 4$ Ω.
(ii) Terminal voltage V = emf − I×r = 21 − 3×3 = 21 − 9 = 12 V.
Alternatively, V = I×R = 3 × 4 = 12 V.
✓

Q.18

Explain why diffraction of sound is more common in daily experience than that of light.

Answer: Diffraction is significant when the wavelength is comparable to the size of the obstacle/opening. Sound has wavelengths in the range 1 cm to 10 m, comparable to everyday objects, while light has wavelengths ~400–700 nm, much smaller than everyday obstacles.

Explanation:

Diffraction is pronounced when the wavelength (λ) is of the same order as the size of the obstacle or aperture (d), i.e., λ/d ≈ 1.

Sound waves have wavelengths ranging from about 1 cm to 10 m, which are comparable to the size of common obstacles like doors, buildings, and furniture.

Therefore, sound diffracts easily around corners and through openings in daily life.

Light has wavelengths of approximately 400–700 nm (4×10^{-7} to 7×10^{-7} m), which are much smaller than everyday objects.

Hence, diffraction effects of light are negligible with ordinary objects and are only noticeable with very small apertures or obstacles (like a hair or a narrow slit).

Q.19

Explain the terms mass defect and binding energy. How are they related ?

Answer: Mass defect Δm = [Zmp + (A−Z)mn − M_nucleus]. Binding energy BE = Δm × c². They are related by BE = Δm × c².

Explanation:

Mass defect (Δm): The actual mass of a nucleus is always less than the sum of the masses of its constituent protons and neutrons (nucleons).

This difference in mass is called mass defect.

Δm = [Z × mp + (A − Z) × mn] − M_nucleus, where Z = atomic number, A = mass number, mp = mass of proton, mn = mass of neutron, M_nucleus = actual mass of nucleus.

Binding energy (BE): The energy equivalent of the mass defect is called the binding energy of the nucleus.

It represents the energy required to completely separate the nucleus into its

constituent nucleons.

BE = Δm × c², where c = speed of light.

Relation: Binding energy = Mass defect × (speed of light)².

BE = Δm × c².

A larger binding energy per nucleon indicates a more stable nucleus.

Q.20

A particle of mass M at rest splits up into two particles of masses m_1 and m_2 having non-zero velocities. Calculate the ratio of the de Broglie wavelengths associated with the two particles.

Answer: $\lambda_1/\lambda_2 = 1$ (the de Broglie wavelengths are equal)

Explanation:

Since the parent particle is at rest, by conservation of momentum: $m_1v_1 + m_2v_2 = 0$, so $m_1v_1 = -m_2v_2$.

The magnitudes of momenta are equal: $|p_1| = m_1|v_1| = m_2|v_2| = |p_2|$.

Therefore $p_1 = p_2$ (in magnitude).

de Broglie wavelength $\lambda = h/p$.

So $\lambda_1/\lambda_2 = (h/p_1)/(h/p_2) = p_2/p_1 = 1$.

The de Broglie wavelengths of the two particles are equal ($\lambda_1 = \lambda_2$), and their ratio is 1.

Q.21

How are charge carriers created in an intrinsic semiconductor ? Explain.

Answer: Charge carriers in an intrinsic semiconductor are created by thermal excitation: valence electrons absorb thermal energy and break covalent bonds, jumping to the conduction band, creating electron-hole pairs.

Explanation:

In an intrinsic (pure) semiconductor like silicon or germanium, charge carriers are created by thermal excitation: (1) At absolute zero temperature, all valence electrons are locked in covalent bonds and no free carriers exist.

(2) At room temperature, thermal energy (kT ≈ 0.026 eV) is sufficient to break some covalent bonds.

Electrons in the valence band absorb this thermal energy and gain enough energy to

jump across the forbidden energy gap (band gap) into the conduction band.

(3) When an electron leaves the valence band, it leaves behind a vacancy called a 'hole', which behaves as a positive charge carrier.

(4) Thus, electron-hole pairs are created.

For every free electron in the conduction band, there is one hole in the valence band: n = p = n_i (intrinsic carrier concentration).

(5) These thermally generated electron-hole pairs are the charge carriers responsible for electrical conduction in intrinsic semiconductors.

Q.22

(a) Establish the relation between drift velocity of electrons (vd) and electric current (I) in a conductor. (b) How is vd affected when the length of the conductor is doubled, keeping the voltage applied across the conductor constant ?

Answer: (a) I = nAevd, where n = number density of electrons, A = cross-sectional area, e = electron charge. (b) vd becomes half.

Explanation:

(a) Let a conductor of cross-section A have n free electrons per unit volume with drift velocity v_d.

In time dt the electrons within length $v_d \cdot dt$ cross a section: volume = A v_d dt, number = n A v_d dt, charge dQ = n A v_d e dt.

Current I = dQ/dt = n e A v_d.

(b) With V constant and L doubled, E = V/L halves.

Since $v_d = eE\tau/m \propto E$, v_d also halves.

(Equivalently R doubles, I halves, and v_d = I/(nAe) halves.)

Q.23

(a) A circular coil of 30 turns and radius 8·0 cm carrying a current of 6 A is suspended vertically in a uniform horizontal magnetic field of 1·0 T. The field lines make an angle of 30° with the plane of the coil. Calculate the magnitude of the external torque that must be applied to prevent the coil from turning. What would happen if the circular coil is replaced by a planar

coil of irregular shape that encloses the same area, keeping other parameters unchanged ?

Answer: τ ≈ 3.1 N·m; the torque stays the same for an irregular planar coil of the same area

Explanation:

N = 30, I = 6 A, r = 0.08 m, B = 1.0 T.

m = NIA = 30 × 6 × π(0.08)² = 3.62 A·m².

B makes 30° with the plane, so the angle between the normal (m) and B is 60°.

τ = mB sin 60° = 3.62 × 1.0 × 0.866 = 3.13 N·m ≈ 3.1 N·m.

τ = NIAB sinθ depends only on the area, not the shape, so an irregular planar coil enclosing the same area experiences the same torque.

OR

Q.23

(b) An alpha particle (mass 6·4 × 10^{-27} kg and charge 3·2 × 10^{-19} C) having 8·0 MeV energy, enters a region of a uniform magnetic field of 0·5 T. If the field is directed perpendicular to the velocity of the particle, find the radius of the circular path described by the particle. Mention the condition under which the particle in this region (i) describes a helical path, and (ii) goes straight undeviated.

Answer: r = 0.8 m; (i) helical path: velocity has a component along B (angle with B is neither 0°/180° nor 90°); (ii) undeviated: velocity parallel or anti-parallel to B

Explanation:

KE = 8.0 MeV = 8.0 × 10^{6} × 1.6 × 10^{-19} J = 12.8 × 10^{-13} J.

KE = ½mv² →

v² = 2KE/m = (2 × 12.8 × 10^{-13})/(6.4 × 10^{-27}) = (25.6 × 10^{-13})/(6.4 × 10^{-27}) = 4 × 10^{14} m²/s².

v = 2 × 10^{7} m/s.

For circular motion in magnetic field: qvB = mv²/r →

r = mv/(qB) = (6.4 × 10^{-27} × 2 × 10^{7})/(3.2 × 10^{-19} × 0.5) = (12.8 × 10^{-20})/(1.6 × 10^{-19}) = 12.8/16 = 0.8 m.

So r = 0.8 m.

Conditions: (i) Helical path: when the velocity of the alpha particle has a component along the direction of B (i.e., the angle between velocity and B is neither 0° nor 90°).

In this case, the component along B remains unchanged (no force on it) while the perpendicular component causes circular motion, resulting in a helical path.

(ii) Straight undeviated path: when the velocity of the alpha particle is parallel or anti-parallel to B (angle = 0° or 180°).

The magnetic force F = qv × B = 0, so the particle moves in a straight line without deflection.

Q.24

(a) Discuss the behaviour of an inductor connected to (i) a dc source, and (ii) a high frequency ac source. (b) What is the phase relation between current and voltage in an ideal inductor connected to an ac source ? Draw a phasor diagram for the circuit.

Answer: (a)(i) Acts as low resistance; (ii) Acts as high impedance. (b) Current lags voltage by 90° (π/2).

Explanation:

(a)(i) DC source (ω = 0): Inductive reactance XL = ωL = 0.

The inductor acts as a pure resistor with only its wire resistance.

It allows steady dc to flow (after the initial transient where it opposes the change).

In the steady state, it behaves like a short circuit (if wire resistance is negligible).

(ii) High frequency ac source (ω → large): XL = ωL is very large.

The inductor offers very high impedance to high-frequency ac.

Very little current flows.

The inductor essentially blocks high-frequency ac — acts as an open circuit at very high frequencies.

(b) For an ideal inductor connected to ac source $V = V_0 \sin\omega t$: The induced emf = $L(dI/dt) = V$, giving $I = -(V_0/\omega L)\cos\omega t = (V_0/\omega L)\sin(\omega t - \pi/2)$.

So current lags voltage by π/2 (90°).

Phasor diagram: V phasor is drawn along the reference direction;

I phasor is drawn at 90° clockwise (lagging) from V.

The voltage phasor leads the current phasor by 90°.

Q.25

(a) Depict the variation of electric field (E) and magnetic field (B) with respect to the direction of propagation of an electromagnetic wave. Write their two important characteristics. (b) Show that $1/\sqrt{(\mu_o\varepsilon_o)}$ gives the velocity of an electromagnetic wave in free space.

Answer: (a) E and B oscillate perpendicular to each other and to the direction of propagation; they are in phase. (b) From Maxwell's equations, $v = 1/\sqrt{(\mu_o\varepsilon_o)} = c = 3 \times 10^8$ m/s.

Explanation:

(a) In an electromagnetic wave travelling in the z-direction: E oscillates along x-direction, B oscillates along y-direction, both perpendicular to each other and to the direction of propagation (z).

The wave is transverse.

Two important characteristics: (1) E and B are always perpendicular to each other and to the direction of propagation.

(2) E and B oscillate in phase (they reach their maxima and minima at the same time and place), and E/B = c (the speed of light).

(b) From Maxwell's equations, for a plane electromagnetic wave in free space: $\partial^2E/\partial x^2 = \mu_o\varepsilon_o\, \partial^2E/\partial t^2$.

This is a wave equation of the form $\partial^2E/\partial x^2 = (1/v^2)\, \partial^2E/\partial t^2$, which gives $1/v^2 = \mu_o\varepsilon_o$, so $v = 1/\sqrt{(\mu_o\varepsilon_o)}$.

Substituting values: $\mu_o = 4\pi \times 10^{-7}$ T·m/A, $\varepsilon_o = 8.854 \times 10^{-12}$ $C^2N^{-1}m^{-2}$.

$\mu_o\varepsilon_o = 4\pi \times 10^{-7} \times 8.854 \times 10^{-12} = 111.265 \times 10^{-19} \approx 1.113 \times 10^{-17}$.

$1/\sqrt{(\mu_o\varepsilon_o)} = 1/\sqrt{(1.113 \times 10^{-17})} = 1/(3.336 \times 10^{-9}) \approx 3 \times 10^8$ m/s = c.

This equals the measured speed of light, confirming that light is an electromagnetic wave.

Q.26

A ray of light is travelling through a rectangular glass slab (refractive index 3/2) and is incident on the horizontal glass-air surface at the critical angle for

the two media. The slab is then brought in contact with water (refractive index 4/3) such that a thin horizontal layer of water is formed on the surface of the slab. Find the angle at which the ray will emerge into air from the water-air surface.

Answer: The ray emerges grazing the water–air surface, i.e. at 90° to the normal (angle of incidence in water 48.6° equals the critical angle for water–air)

Explanation:

Critical angle at glass–air: sin C = 1/(3/2) = 2/3, so the ray meets the glass–water surface at i with sin i = 2/3.

Snell's law at glass–water: (3/2)(2/3) = (4/3) sin r → sin r = 3/4, r ≈ 48.6°.

The water layer has parallel faces, so the ray meets the water–air surface at 48.6°.

The critical angle for water–air is sin C' = 1/(4/3) = 3/4, so C' ≈ 48.6° as well.

The incidence equals the critical angle, so the ray just emerges, grazing along the water–air surface at 90° to the normal.

Q.27

Differentiate between nuclear fission and nuclear fusion. Give one example for each with nuclear reaction.

Answer: Fission: heavy nucleus splits into lighter nuclei releasing energy. Fusion: light nuclei combine to form a heavier nucleus releasing energy.

Explanation:

Nuclear Fission: (1) A heavy nucleus (like uranium-235) splits into two or more lighter nuclei when bombarded by a neutron.

(2) Large amount of energy is released.

(3) It requires only a slow neutron to initiate.

(4) Products are radioactive.

(5) It is the basis of nuclear reactors and atomic bombs.

Example: $^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3\,{}^{1}_{0}n$ + energy.

Nuclear Fusion: (1) Two or more light nuclei combine (fuse) to form a heavier nucleus.

(2) Even larger amount of energy per nucleon is released than in fission.

(3) It requires extremely high temperature (~10^7 K) and pressure to overcome the

Coulomb repulsion between nuclei.

(4) Products are generally stable (not radioactive).

(5) It is the source of energy in the Sun and stars; basis of hydrogen bomb.

Example: $^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n + 17.6$ MeV.

Q.28

With the help of circuit diagrams, briefly explain the forward biasing and the reverse biasing of a p-n junction diode.

Answer: Forward bias: p-side to +ve terminal, n-side to −ve terminal; depletion layer narrows, current flows. Reverse bias: p-side to −ve terminal, n-side to +ve terminal; depletion layer widens, negligible current.

Explanation:

Forward Biasing: Circuit diagram: Connect the positive terminal of the battery to the p-side and the negative terminal to the n-side of the p-n junction.

Effect: The external voltage opposes the built-in potential barrier.

The depletion layer width decreases.

Majority carriers (holes in p-region, electrons in n-region) are pushed towards the junction, reducing the potential barrier.

For silicon, when forward bias voltage exceeds ~0.7 V (threshold/knee voltage), a significant forward current flows through the circuit.

The diode offers very low resistance in forward bias.

Reverse Biasing: Circuit diagram: Connect the positive terminal of the battery to the n-side and the negative terminal to the p-side.

Effect: The external voltage adds to the built-in potential barrier.

The depletion layer width increases.

Majority carriers are pulled away from the junction, increasing the potential barrier.

Only a very small reverse saturation current (due to minority carriers) flows.

The diode offers very high resistance in reverse bias.

If the reverse voltage exceeds the breakdown voltage, sudden large current flows (Zener breakdown or avalanche breakdown).

Q.0

(Case Study — Capacitors in Series/Parallel) Capacitors are manufactured

with certain standard capacitances and working voltages. However, these standard values may not be the ones that are actually needed in a particular application. Two or more capacitors can be grouped in series or in parallel to achieve desired capacitance and voltage. When connected in series, the total capacitance decreases while the voltage rating increases, whereas in parallel connections, the total capacitance increases and maintains the same voltage rating. A capacitor stores energy in the electric field between its plates and stored energy is proportional to the square of the voltage and capacitance $U = \frac{1}{2}CV^2$, where symbols have their usual meanings.

Two capacitors, one of 3 μF and the other of 6 μF, are connected in series in the circuit as shown in the figure, for a long time. (i) The total capacitance of the circuit is :

(a) 6 μF
(b) 3 μF
(c) 9 μF
(d) 2 μF <<

Explanation:

For capacitors in series: $1/C_{total} = 1/C_1 + 1/C_2 = 1/3 + 1/6 = 2/6 + 1/6 = 3/6 = 1/2$.
So $C_{total} = 2$ μF.
Answer: (D) 2 μF.

Q.0

(Case Study — Capacitors in Series/Parallel) Two capacitors, one of 3 μF and the other of 6 μF, are connected in series in the circuit as shown in the figure, for a long time. (ii) The current in the 10 Ω resistor is :

(a) 0·3 A
(b) 0·6 A
(c) 0·2 A <<
(d) 0

Explanation:

After a long time the capacitors are fully charged and carry no current.

The current flows only through the 3 V source, the 5 Ω and the 10 Ω resistor in series: I = 3/(5 + 10) = 0.2 A.

Answer: (C).

Q.0

(Case Study — Capacitors in Series/Parallel) Two capacitors, one of 3 μF and the other of 6 μF, are connected in series in the circuit as shown in the figure, for a long time. (iii) The potential difference between point A and B is :

(a) 2 V <<

(b) 0·3 V

(c) 0·2 V

(d) 3 V

Explanation:

The capacitor branch (6 μF + 3 μF in series) is between A and B in parallel with the 10 Ω resistor and carries no steady current.

So V_{AB} equals the voltage across the 10 Ω resistor: $V_{AB} = 0.2 \times 10 = 2$ V.

Answer: (A).

Q.0

(Case Study — Capacitors in Series/Parallel) Two capacitors, one of 3 μF and the other of 6 μF, are connected in series in the circuit as shown in the figure, for a long time. (iv)(a) The value of charge on the plates of the 6 μF capacitor is :

(a) 6 μC

(b) 4 μC <<

(c) 12 μC

(d) 8 μC

Explanation:

The series capacitors (6 μF and 3 μF) are across A and B, so the voltage across them

is V_AB = 2 V.

C_eq = 2 μF, so each capacitor carries Q = C_eq V = 2 μF × 2 V = 4 μC.

The charge on the plates of the 6 μF capacitor is 4 μC.

Answer: (B).

Q.0

(Case Study — Capacitors in Series/Parallel) Two capacitors, one of 3 μF and the other of 6 μF, are connected in series in the circuit as shown in the figure, for a long time. (iv)(b) The wire between two capacitors is cut at point P. The current in the circuit will :

(a) increase

(b) decrease

(c) remain the same <<

(d) first increase then become stable

Explanation:

In steady state the capacitor branch already carries no current;

the current flows only through the 3 V source, 5 Ω and 10 Ω (I = 0.2 A).

Cutting the wire at P only opens the capacitor branch, which carried no current, so the current in the circuit remains the same.

Answer: (C).

Q.0

(Case Study — Charged particles in E and B fields) Consider two charged particles 1 and 2 of masses m and m/2 having charges −q and +2q respectively. They are accelerated from rest through the same potential difference V and acquire kinetic energy K_1 and K_2. Then they enter in a region of uniform magnetic field B perpendicular to their velocities. The ratio of their kinetic energies (K_1/K_2) is :

(a) 1/2 <<

(b) 1/4

(c) 4

(d) 1

Explanation:

Kinetic energy gained by a charge accelerated through potential difference V: K = qV.

Particle 1: charge magnitude $|q_1| = q$, $K_1 = qV$.

Particle 2: charge magnitude $|q_2| = 2q$, $K_2 = 2qV$.

$K_1/K_2 = qV/(2qV) = 1/2$.

Answer: (A) 1/2.

Q.0

(Case Study — Charged particles in E and B fields) Consider two charged particles 1 and 2 of masses m and m/2 having charges −q and +2q respectively, accelerated through potential difference V and entering magnetic field B perpendicular to velocities. The ratio of the radii of the circular paths described by them (r_1/r_2) is :

(a) $1/\sqrt{2}$

(b) $\sqrt{2}$

(c) 1/2

(d) 2 <<

Explanation:

$r = p/(|q|B) = \sqrt{(2mK)}/(|q|B)$, with $K = |q|V$.

Particle 1: m, q, $K_1 = qV \rightarrow r_1 = \sqrt{(2mqV)}/(qB)$.

Particle 2: m/2, 2q, $K_2 = 2qV \rightarrow r_2 = \sqrt{(2 \cdot (m/2) \cdot 2qV)}/(2qB) = \sqrt{(2mqV)}/(2qB)$.

$r_1/r_2 = 2 \rightarrow$ option (D).

Q.0

(Case Study — Charged particles in E and B fields) Suppose particles 1 and 2 enter the magnetic field $B = B_0 \hat{k}$ with velocities $v_1 = v_1 \hat{i}$ and $v_2 = v_2 \hat{i}$. Then :

(a) both particles revolve clockwise

(b) both particles revolve anticlockwise

(c) particle 1 revolves clockwise while particle 2 revolves anticlockwise

(d) particle 1 revolves anticlockwise while particle 2 revolves clockwise <<

Explanation:

Magnetic force $F = qv \times B$.

For particle 1 (charge $-q$): $F_1 = (-q)(v_1\,\hat{i}) \times (B_0\,\hat{k}) = -qv_1B_0\,(\hat{i} \times \hat{k}) = -qv_1B_0\,(-\hat{j}) = qv_1B_0\,\hat{j}$.

Force is in +y direction.

A positive force in $+\hat{j}$ when moving in $+\hat{i}$ direction means the particle curves upward initially →

anticlockwise revolution (when viewed from +z axis).

For particle 2 (charge $+2q$): $F_2 = (2q)(v_2\,\hat{i}) \times (B_0\,\hat{k}) = 2qv_2B_0\,(\hat{i} \times \hat{k}) = 2qv_2B_0\,(-\hat{j}) = -2qv_2B_0\,\hat{j}$.

Force is in $-\hat{j}$ direction.

Moving in $+\hat{i}$ with force in $-\hat{j}$ → curves downward → clockwise revolution.

So particle 1 revolves anticlockwise, particle 2 revolves clockwise.

Answer: (D).

Q.0

(Case Study — Charged particles in E and B fields) Particles 1 and 2 of masses m and m/2, charges −q and +2q. If period of revolution for particle 1 is 4 μs, then for particle 2, the period will be :

(a) 1 μs <<

(b) 2 μs

(c) 4 μs

(d) 8 μs

Explanation:

Period of revolution in magnetic field: $T = 2\pi m/(|q|B)$.

For particle 1: $T_1 = 2\pi m/(qB) = 4$ μs.

For particle 2: $T_2 = 2\pi(m/2)/(2qB) = 2\pi m/(4qB) = (1/4) \times 2\pi m/(qB) = T_1/4 = 4/4 = 1$ μs.

Answer: (A) 1 μs.

Q.0

(Case Study — Charged particles in E and B fields) Particles 1 and 2 of

masses m and m/2, charges −q and +2q, accelerated through same potential difference V. If the value of momentum for particles 1 and 2 are p_1 and p_2, then :

(a) $p_1 = p_2/2$

(b) $p_1 = p_2$ <<

(c) $p_1 = 2p_2$

(d) $p_1 = 4p_2$

Explanation:

Momentum $p = \sqrt{(2mK)} = \sqrt{(2m|q|V)}$.

For particle 1: $p_1 = \sqrt{(2m \cdot qV)} = \sqrt{(2mqV)}$.

For particle 2: $m_2 = m/2$, $|q_2| = 2q$.

$p_2 = \sqrt{(2 \cdot (m/2) \cdot 2qV)} = \sqrt{(2mqV)}$.

Therefore $p_1 = p_2$.

Answer: (B) $p_1 = p_2$.

Q.31

(a)(i) In the figure, OA and OB show the variation of electric potential V at a point due to two point charges Q_1 and Q_2 with 1/r respectively. Here r represents the distance of the point from the two point charges. (I) Identify the nature of the two charges Q_1 and Q_2. (II) What is the value of $|Q_1/Q_2|$? Justify your answer.

(a)(ii) Two point charges −2 μC and 5 μC are placed at (−30 cm, 0) and (30 cm, 0) respectively in an external electric field $E = (A/x^2)\,\hat{i}$, where $A = 9 \times 10^5$ $N \cdot m^2 C^{-1}$. Find the electrostatic potential energy of this configuration.

Answer: (i)(I) Q_1 is positive (OA has positive slope), Q_2 is negative (OB has negative slope). (II) $|Q_1/Q_2| = 3$. (ii) U_total = 20.85 J

Explanation:

(i) The figure shows line OA at 60° above the 1/r axis (positive slope) and line OB at 30° below (negative slope).

Since V = kQ/r, slope of V vs 1/r line = kQ.

Positive slope for OA → Q_1 is positive.

Negative slope for OB → Q_2 is negative.

(II) Slope of OA = tan(60°) = √3 = kQ_1.

Slope of OB magnitude = tan(30°) = 1/√3 = $k|Q_2|$.

$|Q_1/Q_2|$ = tan(60°)/tan(30°) = √3 ÷ (1/√3) = 3.

(ii) External field $E = A/x^2$ î with $A = 9\times10^5$ N·m²C⁻¹.

Potential due to external field: φ(x) = A/x.

At x = −0.30 m: $\varphi_1 = 9\times10^5/(-0.30) = -3\times10^6$ V.

$U_1 = q_1\varphi_1 = (-2\times10^{-6})(-3\times10^6) = 6$ J.

At x = +0.30 m: $\varphi_2 = 9\times10^5/0.30 = 3\times10^6$ V.

$U_2 = q_2\varphi_2 = (5\times10^{-6})(3\times10^6) = 15$ J.

Interaction PE: $U_{12} = k(q_1)(q_2)/r_{12} = (9\times10^9)(-2\times10^{-6})(5\times10^{-6})/0.60 = -9\times10^{-2}/0.60 = -0.15$ J.

Total U = 6 + 15 − 0.15 = 20.85 J.

OR

Q.31

(b)(i) Two infinitely long straight wires having linear charge densities −λ and 3λ are held vertically parallel to each other, distance r apart in free space. Find the nature and magnitude of the force/length exerted by one wire on the other.

(b)(ii) A small hollow conducting sphere of radius r_1 is given a charge Q. It is surrounded by a concentric conducting spherical shell of inner radius r_2 and outer radius r_3, having charge −3q. If a point charge 2q were kept at the centre, find : (I) the electric flux through a concentric spherical Gaussian surface of radius x for (1) $x < r_1$, and (2) $r_1 < x < r_2$. (II) electric field at a point distant x from the centre for (1) $x > r_3$, and (2) $r_1 < x < r_2$. (III) surface charge density on the inner surface of (1) sphere, and (2) shell.

Answer: (i) $3\lambda^2/(2\pi\varepsilon_0 r)$ per unit length, attractive. (ii) $\Phi = 2q/\varepsilon_0$ ($x < r_1$), $(Q + 2q)/\varepsilon_0$ ($r_1 < x < r_2$); $E = (Q - q)/(4\pi\varepsilon_0 x^2)$ ($x > r_3$), $(Q + 2q)/(4\pi\varepsilon_0 x^2)$ ($r_1 < x < r_2$); σ =

$-2q/(4\pi r_1^2)$ on sphere's inner surface, $-(Q + 2q)/(4\pi r_2^2)$ on shell's inner surface

Explanation:

(b)(i) Field of wire with $-\lambda$ at distance r: $E = \lambda/(2\pi\varepsilon_0 r)$.

Force per unit length on the 3λ wire = $3\lambda \times \lambda/(2\pi\varepsilon_0 r) = 3\lambda^2/(2\pi\varepsilon_0 r)$.

Charges are opposite → attractive.

(b)(ii) Charge distribution: point charge 2q at centre induces $-2q$ on the inner surface of the sphere, so its outer surface carries $Q + 2q$.

The shell's inner surface carries $-(Q + 2q)$;

its outer surface carries $-3q + (Q + 2q) = Q - q$.

(I) (1) $x < r_1$: $q_{enc} = 2q \rightarrow \Phi = 2q/\varepsilon_0$.

(2) $r_1 < x < r_2$: $q_{enc} = Q + 2q \rightarrow \Phi = (Q + 2q)/\varepsilon_0$.

(II) (1) $x > r_3$: $q_{enc} = 2q + Q - 3q = Q - q \rightarrow E = (Q - q)/(4\pi\varepsilon_0 x^2)$, radial.

(2) $r_1 < x < r_2$: $E = (Q + 2q)/(4\pi\varepsilon_0 x^2)$, radial.

(III) (1) Inner surface of sphere: $\sigma = -2q/(4\pi r_1^2)$.

(2) Inner surface of shell: $\sigma = -(Q + 2q)/(4\pi r_2^2)$.

Q.32

(a)(i) A light bulb and an open coil inductor are connected in series across an ac source of variable frequency. How will the glow of the bulb be affected when : (I) an iron bar is inserted inside the coil, and (II) the frequency of the source is decreased ? Justify your answers. Assume that in each above case other factors remain unchanged.

(a)(ii) An ac voltage $V = 280 \sin(100\pi t)$ volt is connected across a series LCR circuit in which R = 400 Ω, L = 5/π H and C = 50/π μF. Taking $\sqrt{2} = 1{\cdot}4$, calculate : (I) impedance of the circuit. (II) rms value of current that flows in the circuit. (III) power factor of the circuit.

Answer: (a)(i)(I) Glow decreases; (II) Glow increases. (a)(ii)(I) Z = 500 Ω; (II) I_{rms} = 0.4 A; (III) $\cos\varphi = 0.8$

Explanation:

(a)(i)(I) Inserting an iron bar increases L, so $X_L = \omega L$ increases, Z increases, current decreases and the bulb glows less.

(II) Decreasing the frequency decreases $X_L = 2\pi fL$, so Z decreases, current increases and the bulb glows brighter.

(a)(ii) $\omega = 100\pi$ rad/s.

$X_L = \omega L = 100\pi \times 5/\pi = 500\ \Omega$.

$X_C = 1/(\omega C) = 1/(100\pi \times 50\times10^{-6}/\pi) = 200\ \Omega$.

(I) $Z = \sqrt{(R^2 + (X_L - X_C)^2)} = \sqrt{(400^2 + 300^2)} = 500\ \Omega$.

(II) $V_{rms} = 280/\sqrt{2} = 280/1.4 = 200$ V, so $I_{rms} = 200/500 = 0.4$ A.

(III) $\cos\varphi = R/Z = 400/500 = 0.8$.

OR

Q.32

(b)(i) State Lenz's law and explain that it follows the law of conservation of energy. (b)(ii) Write the dimensional formula for self-inductance. The current in a coil changes from 8·0 A to 2·0 A in 0·6 s. If an average emf induced in the coil is 50 V, calculate the self-inductance of the coil.

Answer: (b)(i) Lenz's law: induced emf opposes the change in flux; follows energy conservation. (b)(ii) Dimensional formula: $[ML^2T^{-2}A^{-2}]$; L = 5 H.

Explanation:

(b)(i) Lenz's Law: The direction of the induced current is such that it opposes the cause that produces it (i.e., it opposes the change in magnetic flux).

Connection to energy conservation: When an external agent changes the magnetic flux through a coil, an induced current flows.

By Lenz's law, this induced current creates a magnetic field that opposes the change.

Therefore, the external agent must do work against this opposing force to maintain the change in flux.

The mechanical work done by the external agent is converted into electrical energy of the induced current, which is then dissipated as heat.

Energy is conserved — mechanical energy → electrical energy → thermal energy.

If Lenz's law were violated (induced emf aiding the cause), the current would increase without any external energy input, violating conservation of energy.

(b)(ii) Dimensional formula for self-inductance L: From $emf = L(dI/dt)$, $L = emf/(dI/dt)$.

$[L] = [V]/[A/s] = [V\cdot s/A] = [ML^2T^{-3}A^{-1} \times T \times A^{-1}] = [ML^2T^{-2}A^{-2}]$.

Calculation: Average emf = $L\,|\Delta I/\Delta t|$.

$|\Delta I| = |2.0 - 8.0| = 6.0$ A.

$\Delta t = 0.6$ s.

$50 = L \times (6.0/0.6) = L \times 10$.

$L = 50/10 = 5$ H.

Q.33

(a)(i) A point object is kept in front of a convex spherical surface of radius of curvature R. Draw the ray diagram to show the formation of image and derive the relation between the object and image distance (u and v) in terms of refractive index n of the medium and R. (ii) A convex lens of focal length 20 cm is used to form the image of an object placed 30 cm away from the lens. Find the position and nature of the image formed.

Answer: (i) Refraction formula: $n_2/v - n_1/u = (n_2 - n_1)/R$. (ii) v = 60 cm on the same side as refracted light; real, inverted, magnified image.

Explanation:

(a)(i) Derivation of refraction at a convex spherical surface separating medium of refractive index n_1 (object side) from n_2 (image side): Using Snell's law and small angle approximation for paraxial rays: $n_1 \sin\alpha_1 \approx n_1 \alpha_1 = n_2 \sin\alpha_2 \approx n_2 \alpha_2$.

For a ray from object O at distance u, incident at point P on the convex surface with centre of curvature C at distance R: Using the geometry and Snell's law at the surface, the standard derivation gives: $n_2/v - n_1/u = (n_2 - n_1)/R$.

This is the refraction formula for a single spherical refracting surface.

(a)(ii) Using the thin lens formula: $1/v - 1/u = 1/f$.

f = +20 cm (convex lens), u = −30 cm (object on left, negative sign by convention).

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

v = +60 cm.

The positive sign indicates the image is on the other side of the lens from the object (real image).

Nature: The image is real (v is positive), inverted, and magnified.

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

The image is 2 times magnified and inverted.

Position: 60 cm from the lens on the other side of the object.

OR

Q.33

(b)(i) Two thin converging lenses of focal length f_1 and f_2 are placed coaxially in contact. Derive expression for the focal length of the combination. (b)(ii) A beam of coherent light of wavelength 550 nm is incident normal to the plane of a pair of two slits S_1 and S_2 each of width $1{\cdot}2 \times 10^{-6}$ m separated by 1·1 mm. Dark and bright fringes are observed on a screen 2·2 m away from the plane of the slits. Calculate : (I) fringe width. (II) distance of the second dark fringe from the central maximum. (III) what will happen when the entire apparatus is immersed in water.

Answer: (i) $1/f = 1/f_1 + 1/f_2$. (ii) (I) $\beta = 1.1$ mm; (II) 1.65 mm; (III) fringe width decreases to $\beta/n \approx 0.825$ mm in water

Explanation:

(b)(i) Lens 1: $1/v_1 - 1/u = 1/f_1$.

The image I_1 acts as the object for lens 2 (in contact): $1/v - 1/v_1 = 1/f_2$.

Adding: $1/v - 1/u = 1/f_1 + 1/f_2$.

For the equivalent lens $1/v - 1/u = 1/f$, so $1/f = 1/f_1 + 1/f_2$.

(b)(ii) $\lambda = 550 \times 10^{-9}$ m, $d = 1.1 \times 10^{-3}$ m, $D = 2.2$ m.

(I) $\beta = \lambda D/d = (550 \times 10^{-9} \times 2.2)/(1.1 \times 10^{-3}) = 1.1 \times 10^{-3}$ m = 1.1 mm.

(II) nth dark fringe: $y = (2n - 1)\lambda D/(2d)$. For $n = 2$: $y = 3\beta/2 = 1.65$ mm.

(III) In water ($n = 4/3$) the wavelength becomes λ/n, so $\beta' = \beta/n = 1.1 \times 3/4 = 0.825$ mm — fringes come closer (fringe width decreases).