CBSE Class 12 Physics 2026 — Set 2 — 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

Three point charges 2q, –2q and q are kept at the vertices of an equilateral triangle of side l. The potential energy of the system is

(a) zero

(b) $-2q^2 / (\varepsilon_0 l)$

(c) $q^2 / (2\varepsilon_0 l)$

(d) $-q^2 / (\pi\varepsilon_0 l)$ <<

Explanation:

Potential energy U = $(1/4\pi\varepsilon_0) \times$ [sum of pairwise products / separation].

Pairs: $(2q)(-2q)/l + (2q)(q)/l + (-2q)(q)/l = (-4q^2 + 2q^2 - 2q^2)/l = -4q^2/l$.

So $U = (1/4\pi\varepsilon_0)(-4q^2/l) = -q^2/(\pi\varepsilon_0 l)$.

Q.2

Two metal spheres of radii r1 and r2 (> r1) having charges q1 and q2 respectively kept in air, are brought in contact. Which of the following statements is not correct?

(a) The total charge of the two spheres is conserved.

(b) Both spheres attain the same potential.

(c) The final potential of the system equals $(1/4\pi\varepsilon_0) \times (q1 + q2)/(r1 + r2)$.

(d) The final potential of the system equals $(1/4\pi\varepsilon_0) \times (q1 + q2)(r1 + r2)/(r1\ r2)$. <<

Explanation:

After contact both spheres reach the same potential V and the total charge q1 + q2 is conserved.

The spheres are connected, so $V = (1/4\pi\varepsilon_0)(q1 + q2)/(r1 + r2)$, which is statement (C) and is correct.

Statement (D) multiplies by (r1 + r2)/(r1 r2) instead, which is wrong.

The statement that is not correct is (D).

Q.3

The maximum kinetic energy of the electrons emitted from a photosensitive

surface depends on

(a) work function of the surface φ_0 only.

(b) frequency of the incident radiation v only.

(c) intensity of the incident radiation I only.

(d) Both φ_0 and v. <<

Explanation:

By Einstein's photoelectric equation: $KE_{max} = hv - \varphi_0$.

The maximum kinetic energy depends on both the frequency v of incident radiation and the work function φ_0 of the surface.

Intensity affects the number of emitted electrons (photocurrent) but not their maximum kinetic energy.

Q.4

In Bohr model of hydrogen atom, for large values of n, the distance between the consecutive orbits is proportional to

(a) $\sqrt{n}$

(b) n <<

(c) n^2

(d) n^3

Explanation:

In Bohr model, $r_n = n^2 a_0$.

The difference between consecutive orbits: $r_{n+1} - r_n = a_0[(n+1)^2 - n^2] = a_0[2n + 1] \approx 2na_0$ for large n.

Therefore the distance between consecutive orbits is proportional to n.

Q.5

A straight long wire lying along y-axis, carries a current of 1 A along –y direction. The magnetic field due to the conductor at a point (50 cm, 0, 0) will point along.

(a) z-axis <<

(b) –z-axis

(c) x-axis

(d) –x-axis

Explanation:

$B \propto I\, dl \times \hat{r}$.

Current direction: $-\hat{y}$.

Point (0.5 m, 0, 0) lies along $+\hat{x}$ from the wire.

$(-\hat{y}) \times \hat{x} = -(\hat{y} \times \hat{x}) = -(-\hat{z}) = +\hat{z}$.

Check by right-hand rule: thumb along –y, fingers curl towards +z at a point on the +x axis.

So B points along the z-axis → (A).

Q.6

Which of the following materials has positive and small value of magnetic susceptibility?

(a) Cu

(b) Al <<

(c) Bi

(d) Ni

Explanation:

Materials with small positive magnetic susceptibility are paramagnetic.

Aluminium (Al) is a paramagnetic material with a small positive susceptibility.

Copper (Cu) and Bismuth (Bi) are diamagnetic (small negative χ), and Nickel (Ni) is ferromagnetic (large positive χ).

Q.7

A galvanometer of resistance 27 Ω is converted into an ammeter of range (0 – 10 mA) using a resistance of 3 Ω. The galvanometer will show full scale deflection for a current of about –

(a) 10 mA

(b) 100 mA

(c) 1 mA <<

(d) 3 mA

Explanation:

For an ammeter: $I_g \times G = (I - I_g) \times S$, where $G = 27\ \Omega$, $S = 3\ \Omega$, $I = 10$ mA.

$I_g \times 27 = (10 - I_g) \times 3 \rightarrow 27I_g = 30 - 3I_g \rightarrow 30I_g = 30 \rightarrow I_g = 1$ mA.

The galvanometer shows full-scale deflection for 1 mA.

Q.8

The magnetic flux Φ (in Wb) linked with a coil is related to time t (in s) as $\Phi = 5At^2 + Bt - 2C$. The SI units of A and B are respectively

(a) Wb s^2, Wb s

(b) Wb s^{-1}, Wb

(c) Wb s^{-2}, Wb s^{-1} <<

(d) Wb s^{-1}, Wb s^{-2}

Explanation:

= Wb.

For $[5At^2]$ = Wb: $[A]$ = Wb/s^2 = Wb s^{-2}.

For $[Bt]$ = Wb: $[B]$ = Wb/s = Wb s^{-1}.

So A has unit Wb s^{-2} and B has unit Wb s^{-1}.

Answer: (C).

Q.9

The figure shows the variation of capacitive reactance (XC) of two ideal capacitors of capacitances C1 and C2 with the reciprocal of angular frequency (1/ω) of ac source. The value of C1/C2 is

(a) 2

(b) √2

(c) √3

(d) 1/√3 <<

Explanation:

$X_C = (1/C)(1/\omega)$, so the slope of the XC vs (1/ω) graph equals 1/C.

From the figure, the C_1 line is steeper at 45° (slope = tan 45° = 1) and the C_2 line is

less steep at 30° (slope = tan 30° = 1/√3).

Therefore: $1/C_1 = 1$ and $1/C_2 = 1/\sqrt{3}$, which gives $C_1 = 1$ and $C_2 = \sqrt{3}$.

So $C_1/C_2 = 1/\sqrt{3}$.

Answer: (D) $1/\sqrt{3}$.

Q.10

A magnet held vertically, with its north pole down is dropped along the axis of a closed solenoid placed vertically on a table. If the observer looks down from the top,

(a) the induced current will flow in the anticlockwise direction. <<

(b) the induced current will flow in the clockwise direction.

(c) no induced current will flow in the solenoid.

(d) the magnet will fall with a constant velocity.

Explanation:

As the north pole (facing down) approaches the top of the solenoid, the flux through the solenoid increases downward.

By Lenz's law, the induced current opposes this increase, so it creates a north pole at the top of the solenoid to repel the approaching north pole.

Using the right-hand rule for a north pole at the top, current must flow anticlockwise when viewed from the top.

Q.11

An electromagnetic wave is propagating along x-axis. At any instant, the phase difference (in radian) between the electric field (E) and the magnetic field (B) associated with the wave is

(a) zero <<

(b) $\pi/4$

(c) $\pi/2$

(d) π

Explanation:

In an electromagnetic wave, the electric field E and magnetic field B oscillate in phase

with each other (both reach maximum, minimum and zero at the same instant).
The phase difference between E and B is zero.

Q.12

In Bohr model of hydrogen atom, the electron makes a transition from n = 5 to n = 1 state. As a result, a photon of wavelength λ is emitted in the process. The wavelength of the photon emitted when an electron makes a transition from energy level n = 5 to n = 2 will be

(a) 8λ/7
(b) 24λ/7
(c) 16λ/7
(d) 32λ/7 <<

Explanation:
Using Rydberg formula: $1/\lambda = R[1/n1^2 – 1/n2^2]$.
For n=5→n=1: $1/\lambda = R[1/1 – 1/25] = R \times 24/25$.
For n=5→n=2: $1/\lambda' = R[1/4 – 1/25] = R[(25–4)/100] = R \times 21/100$.
$\lambda'/\lambda = (24/25)/(21/100) = (24/25) \times (100/21) = 2400/525 = 32/7$.
So $\lambda' = 32\lambda/7$.

Q.13

Assertion (A): On increasing the intensity of incident light of frequency v (> v_o) on a photosensitive surface, the photocurrent increases.
Reason (R): The stopping potential for a photosensitive surface increases with increase of frequency v (> v_o) of incident light.

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

Explanation:

Assertion A is true: increasing intensity means more photons per second, so more electrons are emitted per second, increasing photocurrent.

Reason R is also true: stopping potential = $(h\nu - \varphi_0)/e$, which increases with frequency.

However, R explains why KE_max increases with frequency, not why photocurrent increases with intensity.

So both are true but R does not explain A.

Answer: (B).

Q.14

Assertion (A): On forward biasing a p-n junction diode, the height of the barrier potential increases.

Reason (R): In forward biasing of a p-n junction diode, the direction of the applied voltage is in the same direction as the built-in potential.

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

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

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

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

Explanation:

Assertion A is false: forward biasing reduces the height of the barrier potential (depletion width decreases).

Reason R is also false: in forward biasing, the applied voltage opposes the built-in potential (p-side connected to +ve terminal reduces the barrier).

Both A and R are false.

Answer: (D).

Q.15

Assertion (A): Light added to light can produce darkness.

Reason (R): When two coherent light waves interfere, there is darkness at position of destructive interference.

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

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

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

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

Explanation:

Assertion A is true: when two coherent light waves meet in destructive interference, the resulting intensity is zero (darkness).

Reason R is true and it correctly explains A — at the dark fringes in Young's double-slit experiment, two light beams meet and produce zero intensity due to destructive interference.

Answer: (A).

Q.16

Assertion (A): Two electric heaters of power P1 and P2 (> P1) are joined in series across a dc source of voltage V. The power consumed by the combination will be less than that consumed by P1 when connected across the same source.

Reason (R): The power consumed by an electric device when connected to a dc source of voltage V is proportional to its resistance.

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

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

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

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

Explanation:

Assertion A is true: P1 alone across V consumes power P1.

In series, $R_{series} = R1 + R2 > R1$.

Power in series = $V^2/R_{series} < V^2/R1 = P1$.

So series combination consumes less than P1 — correct.
Reason R is false: $P = V^2/R$, so power is INVERSELY proportional to resistance (not directly proportional).
Answer: (C).

Q.17

Write two points of difference between intrinsic and extrinsic semiconductors.

Answer: 1. Intrinsic: pure semiconductor (e.g. pure Si or Ge); extrinsic: doped with trivalent or pentavalent impurity. 2. Intrinsic: ne = nh (equal electron and hole concentration); extrinsic: ne ≠ nh (one type dominates).

Explanation:
Intrinsic semiconductors are pure materials where electron-hole pairs are thermally generated (ne = nh = ni).
Extrinsic semiconductors are doped: n-type has ne >> nh (pentavalent dopant);
p-type has nh >> ne (trivalent dopant).
Other differences: conductivity of extrinsic is much higher and controllable;
Fermi level position differs.

Q.18

Find ratio ($\lambda_\alpha / \lambda_p$) of the de Broglie wavelength λ_α and λ_p associated respectively with an alpha particle and a proton, (i) if they are moving with the same kinetic energy. (ii) just after they are accelerated through the same potential difference.

Answer: (i) $\lambda_\alpha/\lambda_p = 1/2$; (ii) $\lambda_\alpha/\lambda_p = 1/(2\sqrt{2}) \approx 0.354$

Explanation:
$\lambda = h/p$. $m_\alpha = 4m_p$ and $q_\alpha = 2q_p$.
(i) Same kinetic energy K: $p = \sqrt{(2mK)}$, so $\lambda_\alpha/\lambda_p = \sqrt{(m_p/m_\alpha)} = \sqrt{(1/4)} = 1/2$.
(ii) Same potential difference V: $K = qV$, so $p = \sqrt{(2mqV)}$ and $\lambda_\alpha/\lambda_p = \sqrt{(m_p q_p/(m_\alpha q_\alpha))} = \sqrt{(1/(4 \times 2))} = 1/(2\sqrt{2}) \approx 0.354$.

Q.19

A ray of light in air is incident at angle i on a face of an equilateral glass prism and is refracted through the prism. As i is varied, it is observed that the ray undergoes minimum deviation, when the i is three-fourth of the angle of the prism. Calculate the speed of light in the prism.

Answer: 2.12×10^8 m/s

Explanation:

For equilateral prism, A = 60°.

Angle of incidence at minimum deviation: i = (3/4)A = (3/4)(60°) = 45°.

At minimum deviation, angle of refraction r = A/2 = 30°.

Applying Snell's law at the first face: sin i = n sin r →

sin 45° = n sin 30° →

(√2/2) = n × (1/2) →

n = √2.

Speed of light in prism: v = c/n = $(3 \times 10^8)/\sqrt{2} = 3 \times 10^8/1.414 \approx 2.12 \times 10^8$ m/s.

Q.20

A heating element using nichrome is connected to a 220 V supply. Initially it draws a current of 2.9 A. After some time, the current attains a steady value of 2.5 A. Find the steady temperature of the heating element if the room temperature is 27°C. The temperature coefficient of resistance of nichrome is 1.7×10^{-4} °C^{-1}.

Answer: ≈ 968°C

Explanation:

Initial resistance (at 27°C): $R_o = V/I_o = 220/2.9$ Ω.

Steady resistance: $R_T = 220/2.5$ Ω.

Using $R_T = R_o[1 + \alpha(T - T_o)]$: $(220/2.5) = (220/2.9)[1 + 1.7\times10^{-4}(T - 27)]$.

Dividing: $2.9/2.5 = 1 + 1.7\times10^{-4}(T - 27)$.

$1.16 = 1 + 1.7\times10^{-4}(T - 27)$.

$0.16 = 1.7\times10^{-4}(T - 27)$.

$T - 27 = 0.16/(1.7\times10^{-4}) = 941.2$.

T = 941.2 + 27 ≈ 968°C.

Q.21

A 5 cm long pencil is placed along the principal axis of a concave mirror of focal length 20 cm such that its nearest end is at a distance of 25 cm from the mirror. Calculate the length of the image of the pencil.

Answer: 40 cm

Explanation:

Pencil: nearest end at $u_1 = -25$ cm, farthest end at $u_2 = -30$ cm.

$f = -20$ cm (concave mirror).

For nearest end: $1/v_1 + 1/u_1 = 1/f \rightarrow$

$1/v_1 = 1/(-20) - 1/(-25) = -1/20 + 1/25 = (-5+4)/100 = -1/100 \rightarrow$

$v_1 = -100$ cm.

For farthest end: $1/v_2 = 1/(-20) - 1/(-30) = -1/20 + 1/30 = (-3+2)/60 = -1/60 \rightarrow$

$v_2 = -60$ cm.

Length of image = $|v_1 - v_2| = |-100 - (-60)| = 40$ cm.

OR

Q.21

In a Young's double-slit experiment, a beam of light consisting of two wavelengths 500 nm and 600 nm is used. The interference fringes are observed at a screen placed 1.8 m away from the plane of slits (slit separation 0.3 mm). Calculate the least distance from the central maximum where the bright fringes due to both the wavelengths coincide.

Answer: 1.8 cm

Explanation:

Fringe width: $\beta = \lambda D/d$.

$\beta_1 = (500\times10^{-9} \times 1.8)/(0.3\times10^{-3}) = 900\times10^{-9}/3\times10^{-4} = 3\times10^{-3}$ m = 3 mm.

$\beta_2 = (600\times10^{-9} \times 1.8)/(0.3\times10^{-3}) = 1080\times10^{-9}/3\times10^{-4} = 3.6\times10^{-3}$ m = 3.6 mm.

Coincidence condition: $n_1\beta_1 = n_2\beta_2 \rightarrow n_1 \times 3 = n_2 \times 3.6 \rightarrow n_1/n_2 = 3.6/3 = 6/5$.

Minimum integers: $n_1 = 6$, $n_2 = 5$.

Least distance = $n_1\beta_1$ = 6 × 3 mm = 18 mm = 1.8 cm.

Q.22

(a) Consider the following nuclides: $^{12}_{6}C$, $^{198}_{80}Hg$, $^{14}_{6}C$, $^{197}_{79}Au$. Group them into isotopes and isotones.

(b) How does the size of a nucleus depend on its mass number A? Hence prove that the density of nucleus is a constant, independent of A, for all nuclei.

Answer: (a) Isotopes: $^{12}_{6}C$ and $^{14}_{6}C$ (same Z=6, different A). Isotones: $^{198}_{80}Hg$ and $^{197}_{79}Au$ (same N=118, different Z). (b) R = R_0A^(1/3); density ρ = $3m/(4\pi R_0^3)$ ≈ constant ≈ 2.3×10^{17} kg/m³.

Explanation:

(a) Isotopes have same atomic number Z: ^{12}C and ^{14}C both have Z=6.

Isotones have same neutron number N: ^{198}Hg has N=198–80=118; ^{197}Au has N=197–79=118.

Same N → isotones.

(b) Nuclear radius: R = R_0A^(1/3), where R_0 ≈ 1.2 fm.

Nuclear volume: $V = (4/3)\pi R^3 = (4/3)\pi R_0^3 A$.

Mass of nucleus ≈ A × m_nucleon.

Density ρ = mass/volume = $(A \times m_{nucleon})/[(4/3)\pi R_0^3 A] = 3m_{nucleon}/(4\pi R_0^3)$.

The factor A cancels, so ρ is independent of A.

With m_nucleon ≈ 1.67×10^{-27} kg and R_0 = 1.2×10^{-15} m: ρ ≈ $3\times1.67\times10^{-27}/(4\pi\times(1.2\times10^{-15})^3) \approx 2.3\times10^{17}$ kg/m³.

Q.23

(a) An electric field E = E_0 î exists in a region of space. Draw three equipotential surfaces in the region.

(b) Two point charges –q and +q are located at points (–a, 0, 0) and (a, 0, 0) respectively. Find the electrostatic potential at point (x, 0, 0) where x >> a.

Answer: (a) Three equally spaced planes perpendicular to the x-axis (y-z planes).

(b) $V = qa/(2\pi\varepsilon_0 x^2)$ [= $2kqa/x^2$], positive

Explanation:

(a) For a uniform field $E = E_0\hat{i}$ (along x-axis), equipotential surfaces are planes perpendicular to the x-axis (i.e., planes of constant x, which are y-z planes).

Three such parallel planes at equal intervals along x.

(b) Potential at (x, 0, 0): r_+ = distance from +q at (a,0,0) = x – a;

r_- = distance from –q at (–a,0,0) = x + a.

$V = (1/4\pi\varepsilon_0)[(+q)/(x–a) + (–q)/(x+a)] = (q/4\pi\varepsilon_0)[(1/(x–a)) – (1/(x+a))] = (q/4\pi\varepsilon_0)[2a/(x^2–a^2)]$.

For $x >> a$: $x^2–a^2 \approx x^2$. So $V \approx (q/4\pi\varepsilon_0)(2a/x^2) = qa/(2\pi\varepsilon_0x^2)$.

Note: Using the dipole formula, $p = q(2a)$ along +x, $V = (1/4\pi\varepsilon_0)(p\cdot\hat{r}/r^2) = (1/4\pi\varepsilon_0)(2qa/x^2)$ for point on the dipole axis in the direction of p.

Q.24

Name the electromagnetic waves which are used for (i) detection of fractures in bones (ii) physiotherapy (iii) radar systems. Also write their wavelength range.

Answer: (i) X-rays: about 10^{-13} m to 10^{-8} m. (ii) Infrared waves: about 7×10^{-7} m to 10^{-3} m. (iii) Microwaves: about 10^{-3} m to 0.1 m.

Explanation:

(i) X-rays detect bone fractures because bone absorbs them much more than soft tissue;

wavelength about 10^{-13} m to 10^{-8} m.

(ii) Infrared (heat) waves are used in physiotherapy for muscle relaxation;

wavelength about 7×10^{-7} m to 10^{-3} m.

(iii) Microwaves are used in radar; wavelength about 10^{-3} m to 0.1 m (1 mm to 10 cm).

Q.25

(i) Define mutual inductance of a pair of coils. Write its SI unit.

(ii) A long solenoid of radius R and length L has n turns per unit length. A circular loop of radius r (< R) is placed inside at the centre of the solenoid such that its axis coincides with the axis of the solenoid. Obtain the mutual inductance of the solenoid and the loop.

Answer: (i) M is defined by: EMF in secondary = –M (dI/dt); or flux linkage in secondary = M × current in primary. SI unit: Henry (H). (ii) M = $\mu_0 n \pi r^2$.

Explanation:

(i) Mutual inductance M of a pair of coils is the ratio of the EMF induced in one coil to the rate of change of current in the other: M = $N_2\Phi_{21}/I_1$.

SI unit: Henry (H) = Wb/A = V·s/A.

(ii) Magnetic field inside solenoid: B = $\mu_0 nI$ (uniform inside).

Flux through the circular loop of radius r: $\Phi = B \times \pi r^2 = \mu_0 nI \times \pi r^2$.

Mutual inductance: $M = \Phi/I = \mu_0 n \pi r^2$.

OR

Q.25

Two long straight parallel conductors A and B carrying steady currents Ia and Ib in the same direction are separated by a distance d. Deduce the expressions for the force acting on length L of conductor B due to conductor A and show it in figure. Write the expression for the force acting on length L of conductor A due to conductor B and show that it follows Newton's third law.

Answer: $F = \mu_0 I_a I_b L/(2\pi d)$ (attractive). Force on B due to A = Force on A due to B in magnitude, opposite in direction → Newton's third law.

Explanation:

Magnetic field due to conductor A at position of B: $B_A = \mu_0 I_a/(2\pi d)$.

Force on length L of conductor B: $F_B = I_b L B_A = \mu_0 I_a I_b L/(2\pi d)$.

Direction: since currents are in same direction, wires attract each other.

By symmetry, force on length L of conductor A due to B: $F_A = \mu_0 I_a I_b L/(2\pi d)$, directed towards B (attractive).

$|F_A| = |F_B|$ in magnitude but opposite in direction.

This satisfies Newton's third law: $F_{AB} = -F_{BA}$.

Q.26

(a) State Bohr's second postulate and mention its significance.

(b) Prove that, in Bohr model of hydrogen atom as principal quantum number n becomes large, the energy levels get closer and closer.

Answer: (a) The electron can revolve only in those orbits where its angular momentum is an integral multiple of h/(2π): mvr = nh/(2π). Significance: quantises energy levels. (b) $E_n = -13.6/n^2$ eV; $E_{n+1} - E_n \to 0$ as $n \to \infty$.

Explanation:

(a) Bohr's second postulate (quantisation of angular momentum): An electron revolves around the nucleus only in those orbits for which the angular momentum is an integral multiple of h/(2π): $L = mvr = nh/(2\pi)$, where n = 1, 2, 3, ...

Significance: This postulate explains the discrete energy levels and the stability of electron orbits.

(b) Energy levels: $E_n = -13.6/n^2$ eV.

$E_{n+1} - E_n = -13.6[(1/(n+1)^2 - 1/n^2)] = -13.6[n^2 - (n+1)^2]/[n^2(n+1)^2] = 13.6(2n+1)/[n^2(n+1)^2]$.

For large n: $(2n+1)/[n^2(n+1)^2] \approx 2n/n^4 = 2/n^3 \to 0$ as $n \to \infty$.

Therefore, the energy difference between consecutive levels decreases as n increases, meaning energy levels get closer and closer for large n.

Q.27

(a) Explain the statement: "Current is a scalar although we represent current with an arrow".

(b) Use Kirchhoff's rules to find the current through 3 Ω resistor in the circuit shown in the figure.

Answer: (a) Current is a scalar: it does not obey the vector law of addition; currents add algebraically at a junction, and the arrow only shows the sense of flow. (b) Current through the 3 Ω resistor = 7/13 A ≈ 0.54 A (from E to B)

Explanation:

(a) Current is a scalar because currents add algebraically (Kirchhoff's junction rule), not by the parallelogram law.

The arrow only shows the sense of conventional flow.

(b) Polarities read from the figure: 3 V cell has + at A; 5 V cell has + at C.

Let I_1 circulate A→B→E→F→A through the 3 V cell and 4 Ω, and I_2 circulate B→C→D→E→B through the 5 V cell and 2 Ω.

Then the 3 Ω carries $I_1 - I_2$ from B to E.

Loop ABEFA: $3 - 3(I_1 - I_2) - 4I_1 = 0 \rightarrow 7I_1 - 3I_2 = 3$.

Loop BCDEB: $5 - 2I_2 - 3(I_2 - I_1) = 0 \rightarrow 3I_1 - 5I_2 = -5$.

Solving: $I_1 = 15/13$ A, $I_2 = 22/13$ A.

$I(3\ \Omega) = I_1 - I_2 = -7/13$ A, so the current through 3 Ω is 7/13 A ≈ 0.54 A, flowing from E to B.

Check by node B ($V_E = 0$): $V_B/3 + (V_B + 5)/2 + (V_B - 3)/4 = 0 \rightarrow$

$V_B = -21/13$ V, so I = 7/13 A upward.

Q.28

Derive an expression for the magnetic field B, due to a circular coil of N turns, each of radius r carrying current I, at a distance 'x' from the centre along its axis.

Answer: $B = \mu_0 NIr^2/[2(r^2 + x^2)^{(3/2)}]$

Explanation:

Consider an element dl of the circular coil.

By Biot-Savart law, the magnetic field due to dl at a point P on the axis at distance x from centre: $dB = (\mu_0 I/4\pi)(dl/s^2)$, where $s = \sqrt{(r^2 + x^2)}$ is the distance from the element to P.

The component of dB along the axis: $dB_x = dB \times (r/s) = (\mu_0 I/4\pi)(dl \cdot r/s^3)$.

Integrating over the entire coil ($dl = 2\pi r$ for N turns): $B = (\mu_0 I/4\pi)(2\pi rN \cdot r/s^3) = \mu_0 NIr^2/[2(r^2 + x^2)^{(3/2)}]$.

At centre (x=0): $B = \mu_0 NI/(2r)$.

At large distances ($x >> r$): $B \approx \mu_0 NIr^2/(2x^3) = \mu_0 NIA/(2\pi x^3)$ where $A = \pi r^2$ is the area.

Q.29(a)

(Case Study: p-n Junction) A p-type or n-type semiconductor can be converted into a p-n junction by doping it with suitable impurity. The motion of majority charge carriers causes diffusion current across the junction while the barrier electric field causes motion of minority carriers for drift current. In

case of unbiased diode, the diffusion and drift currents are equal. This equilibrium is disturbed by the biasing batteries. Diodes, therefore, allow currents in one direction. This property of diode is used in making rectifiers.

Silicon is doped with which of the following to obtain p-type semiconductor?

(a) Phosphorus
(b) Arsenic
(c) Boron <<
(d) Antimony

Explanation:
To obtain a p-type semiconductor, silicon (tetravalent) must be doped with a trivalent impurity (Group 13 elements) that creates holes.
Boron (B) is a trivalent element.
Phosphorus, Arsenic, and Antimony are pentavalent (Group 15) elements that give n-type semiconductors.

Q.29(b)

(Case Study: p-n Junction) A semiconductor has an electron concentration of 5×10^{22} m^{-3}. The concentration of holes is (given ni = 1.5×10^{16} m^{-3})

(a) 5×10^{22} m^{-3}
(b) 1.5×10^{6} m^{-3}
(c) 9×10^{8} m^{-3}
(d) 4.5×10^{9} m^{-3} <<

Explanation:
Using the mass action law: $ne \times nh = ni^2$.
$nh = ni^2/ne = (1.5 \times 10^{16})^2/(5 \times 10^{22}) = 2.25 \times 10^{32}/(5 \times 10^{22}) = 4.5 \times 10^{9}$ m^{-3}.
Answer: (D).

Q.29(c)

(Case Study: p-n Junction) During forward biasing of a p-n junction diode, the

(a) current is mainly due to drifting of majority carriers. <<
(b) current is mainly due to drifting of minority carriers.
(c) diffusion and drift currents are equal.
(d) current is of the order of 1 A.

Explanation:
In forward biasing, the external voltage reduces the barrier potential and allows the majority carriers (holes in p-region, electrons in n-region) to diffuse across the junction.
The current is mainly due to the diffusion of majority carriers.
Option (A) is the closest, reading 'drifting' as the flow of majority carriers.
In reverse bias, minority carriers drift.
The current in forward bias is typically in mA range, not 1 A.

Q.29(d)
(Case Study: p-n Junction) The threshold voltage for silicon diode is about

(a) 0.2 V
(b) 0.5 V
(c) 0.7 V <<
(d) 1.5 V

Explanation:
The threshold (knee) voltage for a silicon diode is approximately 0.7 V.
For germanium it is about 0.3 V.
Below this threshold voltage, the diode offers very high resistance and negligible current flows.

OR

Q.29(d)
(Case Study: p-n Junction — OR) When we dope Ge with a pentavalent element, four of its electrons bond with four germanium neighbours but fifth electron remains weakly bound. The ionisation energy for this electron is about

(a) 0.01 eV <<

(b) 0.05 eV

(c) 0.1 eV

(d) 0.15 eV

Explanation:

When a pentavalent impurity (like Phosphorus or Arsenic) is doped into Germanium, four of the five valence electrons form covalent bonds with the Ge neighbours.

The fifth electron is loosely bound to the impurity atom (donor level) and requires very little energy to break free.

This ionisation energy is very small, approximately 0.01 eV for Ge (compared to ~0.05 eV for Si), which is much less than the bandgap energy (~0.67 eV for Ge).

Q.30(a)

(Case Study: Convex Lens — Two Positions) In an experiment with a convex lens of focal length f, the screen is fixed at a distance D from the object. A student slowly moves the lens away from the object towards the screen and finds she is able to form sharp images for two positions of the lens. The distance between these two positions is d. The value of d is

(a) $\sqrt{[D(D - 4f)]}$ <<

(b) $\sqrt{[D(D - 2f)]}$

(c) $2\sqrt{(Df)}$

(d) $\sqrt{[D(D - f)]}$

Explanation:

For two positions of the lens giving sharp images, if the lens is at distance u from object, then image distance v = D – u.

Using lens formula: $1/f = 1/(D–u) – 1/(–u) = 1/(D–u) + 1/u$.

This gives $u^2 – Du + Df = 0$ (a quadratic in u).

The two solutions u_1 and u_2: $u_1 + u_2 = D$; $u_1u_2 = Df$.

Distance between two positions: $d = |u_1 – u_2| = \sqrt{[(u_1+u_2)^2 – 4u_1u_2]} = \sqrt{[D^2 – 4Df]} = \sqrt{[D(D–4f)]}$.

Answer: (A).

Q.30(b)

(Case Study: Convex Lens — Two Positions) Compared to the size of the object, the images formed in the two positions of the lens are respectively

(a) reduced, enlarged
(b) reduced, reduced
(c) enlarged, enlarged
(d) enlarged, reduced <<

Explanation:

For two positions giving sharp images (lens moving from object towards screen): at position 1 (lens closer to object, u < D/2), image distance v > D/2, so magnification m = v/u > 1 →
enlarged image.
At position 2 (lens closer to screen, u > D/2), image distance v < D/2, m < 1 →
reduced image.
So the two images are enlarged then reduced.
Answer: (D) enlarged, reduced.

Q.30(c)

(Case Study: Convex Lens — Two Positions) If the distance between object and screen is 80.00 cm and the lens forms sharp images at two positions separated by 20.00 cm, the focal length of convex lens is

(a) 15.50 cm
(b) 18.75 cm <<
(c) 20.50 cm
(d) 22.75 cm

Explanation:

Using the displacement method formula: $f = (D^2 – d^2)/(4D)$.
With D = 80 cm and d = 20 cm: $f = (80^2 – 20^2)/(4 \times 80) = (6400 – 400)/320 = 6000/320 = 18.75$ cm.
Answer: (B).

Q.30(d)

(Case Study: Convex Lens — Two Positions) Consider a convex lens of focal length 15 cm. For which of the following values of object-screen distance, two positions of the lens can be found to obtain sharp image on the screen?

(a) 45 cm
(b) 50 cm
(c) 55 cm
(d) 65 cm <<

Explanation:

For two positions of the lens to exist, we need D > 4f.
Here f = 15 cm, so D > 60 cm.
Among the options: 45 cm (< 60, no), 50 cm (< 60, no), 55 cm (< 60, no), 65 cm (> 60, yes).
Answer: (D) 65 cm.

OR

Q.30(d)

(Case Study: Convex Lens — Two Positions — OR) A thin convex lens of focal length 10 cm and another thin lens of focal length 'f' are placed coaxially in contact. If the power of their combination is 10/3 D, the value of 'f' is

(a) –15 cm <<
(b) –10 cm
(c) –20 cm
(d) –30 cm

Explanation:

$P_1 = 1/0.10$ m = 10 D.
$P = P_1 + P_2 \rightarrow 10/3 = 10 + P_2 \rightarrow P_2 = -20/3$ D.
$f = 1/P_2 = -3/20$ m = –15 cm → (A) –15 cm.

Q.31

(a) What are coherent sources? Why are they necessary for observing a stable interference pattern? Draw a graph showing the variation of intensity of light with the position on the screen in Young's double-slit experiment.

(b) Find the intensity of light at a point on the screen when two interfering waves of the same intensity (I_o) have a path difference of (i) $\lambda/4$ and (ii) $\lambda/3$.

Answer: (b)(i) $I = 2I_o$; (b)(ii) $I = I_o$

Explanation:

(a) Coherent sources are sources that emit light waves of the same frequency, same amplitude, and have a constant phase difference between them.

They are necessary for a stable interference pattern because: (1) if sources have different frequencies, phase difference changes continuously →
fringe pattern shifts rapidly →
no stable bright/dark fringes observed; (2) with constant phase difference, bright and dark fringes remain fixed in position.

The intensity graph shows a sinusoidal/cosine² variation: $I = 4I_o\cos^2(\delta/2)$, alternating between $4I_o$ (bright fringes) and 0 (dark fringes).

(b) $I = 4I_o\cos^2(\delta/2)$, where path difference = $\lambda\delta/(2\pi)$ →
phase difference $\delta = (2\pi/\lambda) \times$ path difference.

(i) Path difference = $\lambda/4$: $\delta = (2\pi/\lambda)(\lambda/4) = \pi/2$.

$I = 4I_o\cos^2(\pi/4) = 4I_o \times (1/\sqrt{2})^2 = 4I_o \times 1/2 = 2I_o$.

(ii) Path difference = $\lambda/3$: $\delta = (2\pi/\lambda)(\lambda/3) = 2\pi/3$.

$I = 4I_o\cos^2(\pi/3) = 4I_o \times (1/2)^2 = 4I_o \times 1/4 = I_o$.

OR

Q.31

(a) Draw a labelled ray diagram of a refracting telescope when it forms image of a distant object at infinity. Derive expression for its magnifying power.

(b) (i) In a telescope the objective has much larger aperture than the eye piece. Why?

(ii) Write two advantages of reflecting telescope over refracting telescope.

Answer: (a) m = fo/fe (for image at infinity). (b)(i) To gather more light and resolve fine details. (ii) No chromatic aberration; easier to make large mirrors.

Explanation:

(a) A refracting telescope has two convex lenses: objective (large focal length fo) and eyepiece (small focal length fe).

For a distant object at infinity, the objective forms a real, inverted, diminished image at its focal plane.

The eyepiece is adjusted so this image lies at its focal plane (for relaxed eye, image at infinity).

Magnifying power m = angle subtended at eye / angle subtended by object = (h/fe)/(h/fo) = fo/fe, where h is the size of the intermediate image.

(b)(i) A larger aperture of the objective collects more light (light gathering power $\propto$ area $\propto D^2$), allowing observation of dim and distant objects.

Also, resolving power $\propto$ D, so larger aperture resolves finer angular details.

(ii) Advantages of reflecting telescope: (1) No chromatic aberration (mirrors reflect all wavelengths equally, no dispersion);

(2) Mirrors are easier to manufacture and support in large sizes compared to lenses (only one surface needs to be shaped, and mirrors can be supported from behind);

(3) No spherical aberration with parabolic mirrors.

Q.32

(a) Derive an expression for the capacitance of a parallel plate capacitor of plate area A and plate separation d with air present between the plates.

(b) Two air-filled capacitors of capacitances C1 and C2 are connected in parallel with a dc battery. After the capacitors are fully charged, a slab of dielectric constant K is inserted between the plates of each capacitor. How will the (i) charge on each capacitor and (ii) energy stored in the capacitor be affected after the slab is introduced?

Answer: (a) $C = \varepsilon_0 A/d$. (b)(i) Charge increases by factor K: Q' = KCV. (ii) Energy increases by factor K: U' = KU.

Explanation:

(a) A parallel plate capacitor has plates of area A separated by distance d.

Surface charge density $\sigma = Q/A$.

Electric field between plates (from Gauss's law): $E = \sigma/\varepsilon_o = Q/(\varepsilon_o A)$.

Potential difference: $V = E \times d = Qd/(\varepsilon_o A)$.

Capacitance: $C = Q/V = \varepsilon_o A/d$.

(b) Capacitors are connected to battery (constant voltage V).

With dielectric K inserted:

(i) New capacitance $C' = KC$ (since $C' = K\varepsilon_o A/d$).

Since voltage is fixed by battery: $Q' = C'V = KCV = KQ$.

Charge increases by factor K for each capacitor.

(ii) Energy stored: $U' = (1/2)C'V^2 = (1/2)(KC)V^2 = K \times (1/2)CV^2 = KU$.

Energy increases by factor K.

The extra energy (K–1)U comes from the battery, which also delivers energy to pull in the dielectric slab.

OR

Q.32

(a) An electric field E is established across the ends of a cylindrical conductor of length L and area of cross-section A. Discuss how electrons attain an average velocity, independent of time. Hence, obtain a relation between current in the conductor and this 'average velocity' of electrons.

(b) (i) This 'average velocity' is found to be few mm/s for currents in range of a few amperes. How then is current established almost the instant a circuit is closed?

(ii) Two copper wires having their radii in the ratio of 3 : 2 are connected in series across a battery. Find the ratio of the drift velocities of the electrons in the wires.

Answer: (a) $I = nAev_d$ (drift velocity relation). (b)(i) Due to electric field propagating at speed of light. (ii) $v_{d1}/v_{d2} = 4/9$.

Explanation:

(a) When electric field E is applied, each electron experiences force F = eE, giving acceleration a = eE/m.

Between collisions (mean free path), electrons accelerate.

At each collision, velocity is randomised.

The average drift velocity gained between collisions: $v_d = a\tau = eE\tau/m$, where τ is the relaxation time (average time between collisions).

Since τ and m are material constants, v_d is constant (not growing with time) — independent of time.

Relation for current: In time dt, electrons in a cylinder of length $v_d \cdot dt$ pass through area A.

Number of electrons = $n \times A \times v_d \times dt$ (n = electron number density).

Charge = $n \times A \times v_d \times dt \times e$.

Current I = charge/dt = $nAev_d$.

(b)(i) Although individual electrons drift slowly (mm/s), the electric field (and hence the 'signal' to start drifting) propagates through the conductor at nearly the speed of light ($\sim 3\times10^8$ m/s).

So all electrons throughout the circuit start drifting almost simultaneously, establishing current instantly.

(ii) For same current I (series connection): $I = nAev_d \rightarrow v_d = I/(nAe) \propto 1/A \propto 1/r^2$.

Ratio of drift velocities: $v_{d1}/v_{d2} = r_2^2/r_1^2 = 2^2/3^2 = 4/9$.

Q.33

(a) A series combination of L, C and R is connected to an a.c. source. Using a phasor diagram, derive an expression for the impedance of the circuit and phase difference between V and I.

(b) Under what conditions the (i) impedance of the circuit is minimum? (ii) Wattless current flows in the circuit?

Answer: (a) $Z = \sqrt{[R^2 + (X_L - X_C)^2]}$; $\tan\varphi = (X_L - X_C)/R$. (b)(i) At resonance: $\omega = 1/\sqrt{(LC)}$, $Z_{min} = R$. (ii) When R = 0 (pure L or pure C circuit).

Explanation:

(a) Phasor diagram for series LCR: Current I is reference phasor.

Voltage across R: $V_R = IR$ (in phase with I).

Voltage across L: $V_L = IX_L$ (leading I by $\pi/2$).

Voltage across C: $V_C = IX_C$ (lagging I by $\pi/2$).

Net voltage phasor: $V = \sqrt{(V_R^2 + (V_L - V_C)^2)} = I\sqrt{(R^2 + (X_L - X_C)^2)}$.

Impedance: $Z = V/I = \sqrt{[R^2 + (X_L - X_C)^2]}$, where $X_L = \omega L$, $X_C = 1/(\omega C)$.

Phase difference: $\tan \varphi = (V_L - V_C)/V_R = (X_L - X_C)/R$.

(b)(i) $Z = \sqrt{[R^2 + (X_L - X_C)^2]}$ is minimum when $X_L = X_C \rightarrow$

$\omega L = 1/(\omega C) \rightarrow$

$\omega = 1/\sqrt{(LC)}$ (resonance condition).

At resonance, $Z_{min} = R$.

(ii) Wattless current (no power dissipation) flows when the phase angle $\varphi = 90°$, i.e., power factor $\cos \varphi = 0$.

This occurs when $R = 0$ (purely reactive circuit — pure inductor or pure capacitor or when $X_L \neq X_C$ with $R = 0$).

In practice, wattless current is the reactive component of current: $I_{wattless} = I \sin \varphi$.

OR

Q.33

(i) With the help of a labelled diagram, explain the principle, construction and working of an a.c. generator.

(ii) Deduce an expression for the induced emf in the coil of the generator.

(iii) If T is the time period of the rotation of the coil, at what values of t (in a cycle) is the emf of the generator maximum?

Answer: (ii) $\varepsilon = NBA\omega \sin(\omega t) = \varepsilon_o \sin(\omega t)$, where $\varepsilon_o = NBA\omega$. (iii) emf is maximum at $t = T/4$ and $t = 3T/4$.

Explanation:

(i) Principle: Electromagnetic induction — when a coil rotates in a magnetic field, the flux through it changes, inducing an emf (Faraday's law).

Construction: Armature coil (N turns, area A) mounted on an axle between poles of a strong magnet (field B).

Two slip rings connected to the two ends of the coil.

Carbon brushes press against slip rings to collect current.

External load connected via brushes.

(ii) At time t, angle θ = ωt (ω = angular frequency).

Flux through coil: Φ = NBA cos(ωt).

Induced emf: ε = –dΦ/dt = –NBA × (–ω sin(ωt)) = NBAω sin(ωt) = ε_o sin(ωt), where ε_o = NBAω is the peak emf.

(iii) ε = ε_o sin(ωt) is maximum when sin(ωt) = ±1 →

ωt = π/2 or 3π/2 →

t = π/(2ω) = T/4 or t = 3π/(2ω) = 3T/4.

So emf is maximum at t = T/4 and t = 3T/4 in each cycle.