JEE Advanced / Multidisciplinary PYQs with Answers and Solutions

CHAPTER 22 Electric Charges and Fields

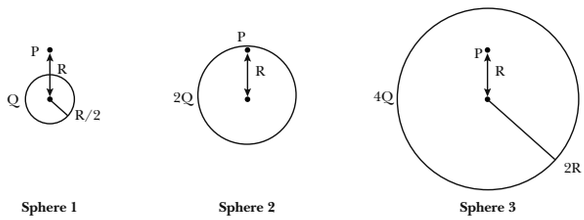
Q1 Let $E_1(r)$, $E_2(r)$ and $E_3(r)$ be the respective electric fields at a distance r from a point charge Q, an infinitely long wire with constant linear charge density λ, and an infinite plane with uniform surface charge density σ. If $E_1(r_0) = E_2(r_0) = E_3(r_0)$ at a given distance r_0, then

(A) $Q = 4\sigma\pi r_0^2$ **(B)** $r_0 = \dfrac{\lambda}{2\pi\sigma}$

(C) $E_1(r_0/2) = 2E_2(r_0/2)$ **(D)** $E_2(r_0/2) = 4E_3(r_0/2)$

(2014, PAPER 1)

Q2 Charges Q, 2Q and 4Q are uniformly distributed in three dielectric solid spheres 1, 2 and 3 of radii R/2, R and 2R respectively, as shown in figure. If magnitudes of the electric fields at point P at a distance R from the centre of spheres 1, 2 and 3 are E_1, E_2 and E_3 respectively, then

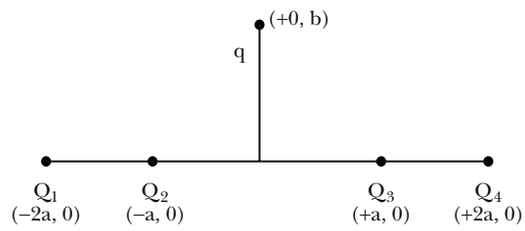


(A) $E_1 > E_2 > E_3$
(B) $E_3 > E_1 > E_2$
(C) $E_2 > E_1 > E_3$
(D) $E_3 > E_2 > E_1$

(2014, PAPER 2)

Q3 Four charges Q_1, Q_2, Q_3 and Q_4 of same magnitude are fixed along the x axis at x = –2a, –a, +a and +2a, respectively. A positive charge q is placed on the positive y axis at a distance b > 0. Four options of the signs of these charges are given in List I. The direction of the forces on the charge q is given in List II. Match List I with List II and select the correct answer using the code given below the lists.

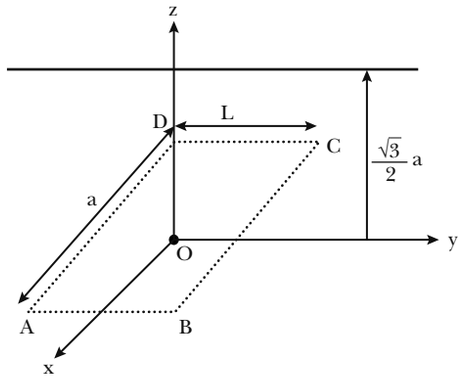
	List I		List II
P.	Q_1, Q_2, Q_3 Q_4 all positive	**1.**	+x
Q.	Q_1, Q_2 positive; Q_3, Q_4 negative	**2.**	–x
R.	Q_1, Q_4 positive; Q_2, Q_3 negative	**3.**	+y
S.	Q_1, Q_3 positive; Q_2, Q_4 negative	**4.**	–y



Code:
(A) P-3, Q-l, R-4, S-2
(B) P-4, Q-2, R-3, S-l
(C) P-3, Q-l, R-2, S-4
(D) P-4, Q-2, R-l, S-3

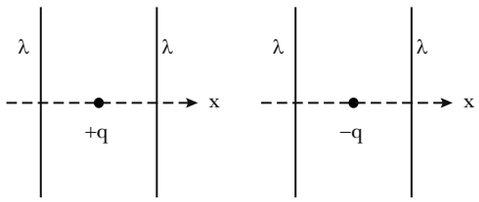
(2014, PAPER 2)

Q4 An infinitely long uniform line charge distribution of charge per unit length λ lies parallel to the y-axis in the y-z plane at $z = \dfrac{\sqrt{3}}{2}a$ (see figure). If the magnitude of the flux of the electric field through the rectangular surface ABCD lying in the x-y plane with its center at the origin is $\dfrac{\lambda L}{n\varepsilon_0}$ (ε_0 = permittivity of free space), then the value of n is _____.



(2015, PAPER 1)

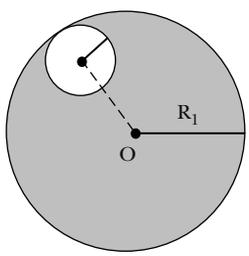
Q5 The figures below depict two situations in which two infinitely long static line charges of constant positive line charge density λ are kept parallel to each other. In their resulting electric field, point charges q and −q are kept in equilibrium between them. The point charges are confined to move in the x direction only. If they are given a small displacement about their equilibrium positions, then the correct statement(s) is(are) _____.



(A) Both charges execute simple harmonic motion.
(B) Both charges will continue moving in the direction of their displacement.
(C) Charge +q executes simple harmonic motion while charge −q continues moving in the direction of its displacement.
(D) Charge −q executes simple harmonic motion while charge +q continues moving in the direction of its displacement.

(2015, PAPER 1)

Q6 Consider a uniform spherical charge distribution of radius R_1 centred at the origin O. In this distribution, a spherical cavity of radius R_2, centred at P with distance OP = a = $R_1 - R_2$ (see figure) is made. If the electric field inside the cavity at position $\vec{r}$ is $\vec{E}(\vec{r})$, then the correct statement(s) is(are) _____.



(A) $\vec{E}$ is uniform, its magnitude is independent of R_2 but its direction depends on $\vec{r}$.
(B) $\vec{E}$ is uniform, its magnitude depends on R_2 and its direction depends on $\vec{r}$.
(C) $\vec{E}$ is uniform, its magnitude is independent of *a* but its direction depends on $\vec{a}$.
(D) $\vec{E}$ is uniform and both its magnitude and direction depend on $\vec{a}$.

(2015, PAPER 2)

Q7 A particle, of mass 10^{-3} kg and charge 1.0 C, is initially at rest. At time t = 0, the particle comes under the influence of an electric field $\vec{E}(t) = E_0 \sin \omega t\ \hat{i}$, where $E_0 = 1.0\ NC^{-1}$ and $\omega = 10^3\ rad\ s^{-1}$. Consider the effect of only the electrical force on the particle. Then the maximum speed, in ms^{-1}, attained by the particle at subsequent times is _____.

(2018, PAPER 2)

Q8 The electric field E is measured at a point P(0, 0, d) generated due to various charge distributions and the dependence of E on d is found to be different for different charge distributions. List-I contains different relations between E and d. List-II describes different electric charge distributions, along with their locations. Match the functions in List-I with the related charge distributions in List-II.

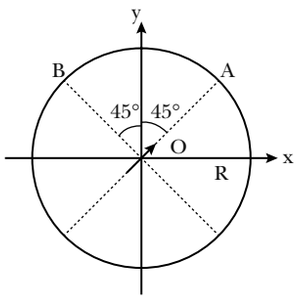
LIST-I	LIST-II
P. E is independent of d	**1.** A point charge Q at the origin
Q. $E \propto \frac{1}{d}$	**2.** A small dipole with point charges Q at (0, 0, ℓ) and −Q at (0, 0, ℓ). Take 2ℓ « d
R. $E \propto \frac{1}{d^2}$	**3.** An infinite line charge coincident with the x-axis. with uniform linear charge density λ
S. $E \propto \frac{1}{d^3}$	**4.** Two infinite wires carrying uniform linear charge density parallel to the x- axis. The one along (y = 0, z = ℓ) has a charge density +λ and the one along (y = 0, z = − ℓ) has a charge density −λ. Take 2ℓ ≪ d
	5. Infinite plane charge coincident with the xy-plane with uniform surface charge density

(A) P → 5; Q → 3, 4; R → 1; S → 2
(B) P → 5; Q → 3; R → 1, 4; S → 2
(C) P → 5; Q → 3; R → 1, 2; S → 4
(D) P → 4; Q → 2, 3; R → 1; S → 5

(2018, PAPER 2)

Q9 An electric dipole with dipole moment $\frac{p_0}{\sqrt{2}}(\hat{i}+\hat{j})$ is held fixed at the origin O in the presence of an uniform electric field of magnitude E_0. If the potential is constant on a circle of radius R centered at the origin as shown in figure, then the correct statement(s) is/are:

($\in_0$ is permittivity of free space. R $\gg$ dipole size)



(A) Total electric field at point A is $\vec{E}_A = \sqrt{2}E_0(\hat{i}+\hat{j})$.

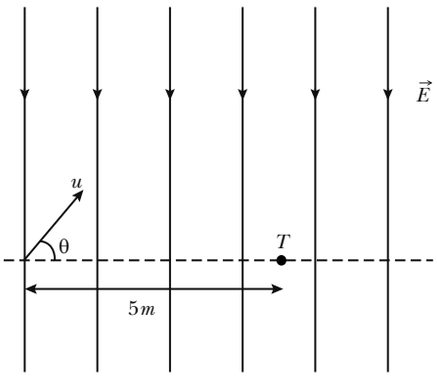
(B) Total electric field at point B is $\vec{E}_B = 0$.

(C) $R = \left(\frac{p_0}{4\pi \in_0 E_0}\right)^{1/3}$.

(D) The magnitude of total electric field on any two points of the circle will be same.

(2019, PAPER 2)

Q10 A uniform electric field, $\vec{E} = -400\sqrt{3}\hat{y}\,NC^{-1}$ is applied in a region. A charged particle of mass m carrying positive charge q is projected in this region with an initial speed of $2\sqrt{10}\times 10^6 ms^{-1}$. This particle is aimed to hit a target T, which is 5 m away from its entry point into the field as shown schematically in the figure. Take $\frac{q}{m} = 10^{10}\,Ckg^{-1}$. Then



(A) the particle will hit T if projected at an angle 45° from the horizontal.

(B) the particle will hit T if projected either at an angle 30° or 60° from the horizontal.

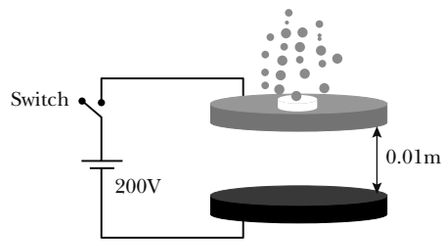
(C) time taken by the particle to hit T could be $\sqrt{\frac{5}{6}}$ μs as well as $\sqrt{\frac{5}{2}}$ μs.

(D) time taken by the particle to hit T is $\sqrt{\frac{5}{3}}$ μs.

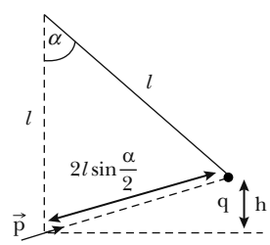
(2020, PAPER 1)

Q11 Two large circular discs separated by a distance of 0.01 m are connected to a battery via a switch as shown in the figure. Charged oil drops of density 900 kg m^{-3} are released through a tiny hole at the center of the top disc. Once some oil drops achieve terminal velocity, the switch is closed to apply a voltage of 200 V across the discs. As a result, an oil drop of radius 8×10^{-7} m stops moving vertically and floats between the discs. The number of electrons present in this oil drop is _____. (neglect the buoyancy force, take acceleration due to gravity = 10 ms^{-2} and charge on an electron (e) = 1.6×10^{-19} C)

(2020, PAPER 2)



Q12 A point charge q of mass m is suspended vertically by a string of length 1. A point dipole of dipole moment $\vec{p}$ is now brought towards q from infinity so that the charge moves away. The final equilibrium position of the system including the direction of the dipole, the angles and distances is shown in the figure below. If the work done in bringing the dipole to this position is N × (mgh), where g is the acceleration due to gravity, then the value of N is _____. (Note that for three coplanar forces keeping a point mass in equilibrium, $\frac{F}{\sin\theta}$ is the same for all forces, where F is any one of the forces and θ is the angle between the other two forces)



(2020, PAPER 2)

Q13 Two identical non-conducting solid spheres of same mass and charge are suspended in air from a common point by two non-conducting, massless strings of same length. At equilibrium, the angle between the strings is α. The spheres are now immersed in a dielectric liquid of density 800 kg m^{-3} and dielectric constant 21. If the angle between the strings remains the same after the immersion, then

(A) electric force between the spheres remains unchanged
(B) electric force between the spheres reduces
(C) mass density of the spheres is 840 kg m^{-3}
(D) the tension in the strings holding the spheres remains unchanged

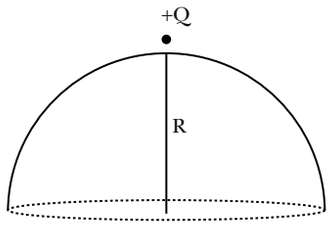
(2020, PAPER 2)

Answer Key

1. (C)	**2.** (C)	**3.** (A)	**4.** (6)	**5.** (C)
6. (D)	**7.** (2)	**8.** (B)	**9.** (B,C)	**10.** (B,C)
11. (6)	**12.** (2)	**13.** (A,C)		

CHAPTER 23 Gauss' Law

Q1 A point charge +Q is placed just outside an imaginary hemispherical surface of radius R as shown in the figure. Which of the following statements is/are correct?



(A) The electric flux passing through the *curved* surface of the hemisphere is $-\frac{Q}{2\varepsilon_0}\left(1-\frac{1}{\sqrt{2}}\right)$.

(B) Total flux through the curved and the flat surfaces is $\frac{Q}{\varepsilon_0}$.

(C) The component of the electric field normal to the flat surface is constant over the surface.

(D) The circumference of the flat surface is an equipotential.

(2017, PAPER 2)

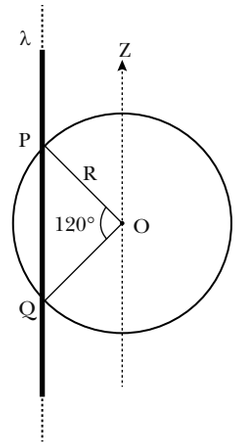
Q2 An infinitely long thin non-conducting wire is parallel to the z-axis and carries a uniform line charge density λ. It pierces a thin non-conducting spherical shell of radius *R* in such a way that the arc *PQ* subtends an angle 120° at the centre *O* of the spherical shell, as shown in the figure. The permittivity of free space is ε_0. Which of the following statements is (are) true?

(A) The electric flux through the shell is $\sqrt{3}R\lambda/\varepsilon_0$.

(B) The z-component of the electric field is zero at all the points on the surface of the shell.

(C) The electric flux through the shell is $\sqrt{2}R\lambda/\varepsilon_0$.

(D) The electric field is normal to the surface of the shell at all points.



(2018, PAPER 2)

Q3 A charged shell of radius R carries a total charge Q. Given ϕ as the flux of electric field through a closed cylindrical surface of height h, radius r and with its center same as that of the shell. Here, center of the cylinder is a point on the axis of the cylinder which is equidistant from its top and bottom surfaces. Which of the following option(s) is/are correct?

[ε_0 is permittivity of free space]

(A) If h < 8R/5 and r = 3R/5 then ϕ = 0
(B) If h > 2R and r > R then $\phi = Q/\varepsilon_0$
(C) If h > 2R and r = 4R/5 then $\phi = Q/5\varepsilon_0$
(D) If h > 2R and r = 3R/5 then $\phi = Q/5\varepsilon_0$

(2019, PAPER 1)

Q4 A circular disc of radius *R* carries surface charge density $\sigma_0(r) = \sigma_0\left(1-\frac{r}{R}\right)$, where σ_0 is a constant and r is the distance from the center of the disc. Electric flux through a large spherical surface that encloses the charged disc completely is ϕ_0. Electric flux through another spherical surface of radius $\frac{R}{4}$ and concentric with the disc is ϕ. Then the ratio $\frac{\phi_0}{\phi}$ is _____.

(2020, PAPER 1)

Answer Key

1. (A,D) **2.** (A,B) **3.** (A,B,D) **4.** (6.40)

CHAPTER 24 Electric Potential

Q1 A particle of unit mass is moving along the x-axis under the influence of a force and its total energy is conserved. Four possible forms of the potential energy of the particle are given in column I (a and U_0 are constants). Match the potential energies in column I to the corresponding statement(s) in column II.

	Column I		Column II
(A)	$U_1(x) = \frac{U_0}{2}\left[1-\left(\frac{x}{a}\right)^2\right]^2$	**(P)**	The force acting on the particle is zero at x = a.
(B)	$U_2(x) = \frac{U_0}{2}\left(\frac{x}{a}\right)^2$	**(Q)**	The force acting on the particle is zero at x = 0.
(C)	$U_3(x) = \frac{U_0}{2}\left(\frac{x}{a}\right)^2 \exp\left[-\left(\frac{x}{a}\right)^2\right]$	**(R)**	The force acting on the particle is zero at x = – a.
(D)	$U_4(x) = \frac{U_0}{2}\left[\frac{x}{a}-\frac{1}{3}\left(\frac{x}{a}\right)^3\right]$	**(S)**	The particle experiences an attractive force towards x = 0 in the region $\lvert x\rvert < a$.
		(T)	The particle with total energy $\frac{U_0}{4}$ can oscillate about the point x = – a.

(A) P Q R S T
(B) P Q R S T
(C) P Q R S T
(D) P Q R S T

(2015, PAPER 1)

Q2 A length-scale (ℓ) depends on the permittivity (ε) of a dielectric material, Boltzmann constant (k_B), the absolute temperature (T), the number per unit volume (n) of certain charged particles, and the charge (q) carried by each of the particles. Which of the following expression(s) for ℓ is(are) dimensionally correct?

(A) $\ell = \sqrt{\left(\frac{nq^2}{\varepsilon k_B T}\right)}$ **(B)** $\ell = \sqrt{\left(\frac{\varepsilon k_B T}{nq^2}\right)}$

(C) $\ell = \sqrt{\left(\frac{q^2}{\varepsilon n^{2/3} k_B T}\right)}$ **(D)** $\ell = \sqrt{\left(\frac{q^2}{\varepsilon n^{1/3} k_B T}\right)}$

(2016, PAPER 1)

Q3 A thin spherical insulating shell of radius R carries a uniformly distributed charge such that the potential at its surface is V_0. A hole with a small area $\alpha 4\pi R^2$ ($\alpha \ll 1$) is made on the shell without affecting the rest of the shell. Which one of the following statements is correct ?

(A) The magnitude of electric field at a point, located on a line passing through the hole and shell's center, on a distance 2R from the center of the spherical shell will be reduced by $\frac{\alpha V_0}{2R}$.

(B) The magnitude of electric field at the center of the shell is reduced by $\frac{\alpha V_0}{2R}$.

(C) The ratio of the potential at the center of the shell to that of the point at $\frac{1}{2}R$ from center towards the hole will be $\frac{1-\alpha}{1-2\alpha}$.

(D) The potential at the center of the shell is reduced by $2\alpha V_0$.

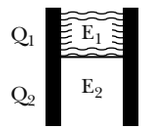
(2019, PAPER 1)

Answer Key

1. (A) → (P, Q, R, T); (B) → (Q, S); (C) → (P, Q, R, S); (D) → (P, R, T) **2.** (B, D) **3.** (A, B, D)

CHAPTER 25 Capacitance

Q1 A parallel plate capacitor has a dielectric slab of dielectric constant K between its plates that covers 1/3 of the area of its plates, as shown in the figure. The total capacitance of the capacitor is C while that of the portion with dielectric in between is C_1. When the capacitor is charged, the plate area covered by the dielectric gets charge Q_1 and the rest of the area gets charge Q_2. The electric field in the dielectric is E_1 and that in the other portion is E_2. Choose the correct option/options, ignoring edge effects.

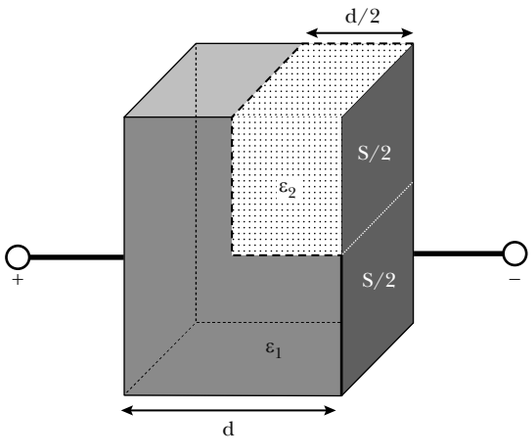


(A) $\frac{E_1}{E_2} = 1$ **(B)** $\frac{E_1}{E_2} = \frac{1}{K}$

(C) $\frac{Q_1}{Q_2} = \frac{3}{K}$ **(D)** $\frac{C}{C_2} = \frac{2+K}{K}$

(2014, PAPER 1)

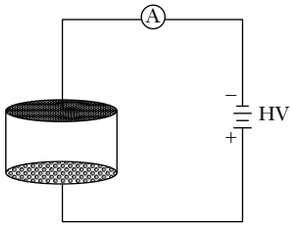
Q2 A parallel plate capacitor having plates of area S and plate separation d, has capacitance C_1 in an. When two dielectrics of different relative permittivities ($\varepsilon_1 = 2$ and $\varepsilon_2 = 4$) are introduced between the two plates as shown in the figure, the capacitance becomes C_2. The ratio $\frac{C_2}{C_1}$ is _____.



(A) 6/5 **(B)** 5/3
(C) 7/5 **(D)** 7/3

(2015, PAPER 2)

Consider an evacuated cylindrical chamber of height h having rigid conducting plates at the ends and an insulating curved surface as shown in the figure. A number of spherical balls made of a light weight and soft material and coated with a conducting material are placed on the bottom plate. The balls have a radius $r \ll h$. Now a high voltage source (HV) is connected across the conducting plates such that the bottom plate is at $+V_0$ and the top plate at $-V_0$. Due to their conducting surface, the balls will get charged, will become equipotential with the plate and are repelled by it. The balls will eventually collide with the top plate, where the coefficient of restitution can be taken to be zero due to the soft nature of the material of the balls. The electric field in the chamber can be considered to be that of a parallel plate capacitor. Assume that there are no collisions between the balls and the interaction between them is negligible. (Ignore gravity)

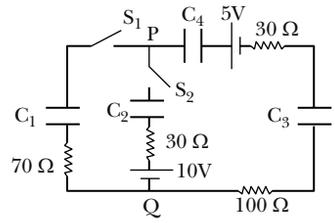


Q3 Which one of the following statements is correct?
(A) The balls will bounce back to the bottom plate carrying the opposite charge they went up with.
(B) The balls will execute simple harmonic motion between the two plates.
(C) The balls will bounce back to the bottom plate carrying the same charge they went up with.
(D) The balls will stick to the top plate and remain there

Q4 The average current in the steady state registered by the ammeter in the circuit will be _____.
(A) proportional to $V_0^{1/2}$
(B) proportional to V_0^2
(C) proportional to the potential V_0
(D) zero

(2016, PAPER 2)

Q5 In the circuit shown, initially there is no charge on capacitors and keys S_1 and S_2 are open. The values of the capacitors are $C_1 = 10\ \mu F$, $C_2 = 30\ \mu F$ and $C_3 = C_4 = 80\ \mu F$. Which of the statement(s) is/are correct?



(A) The key S_1 is kept closed for long time such that capacitors are fully charged. Now key S_2 is closed, at this time, the instantaneous current across 30Ω resistor (between points P and Q) will be 0.2 A (round off to 1st decimal place).
(B) If key S_1 is kept closed for long time such that capacitors are fully charged, the voltage across the capacitor C_1 will be 4V.
(C) At time t = 0, the key S_1 is closed, the instantaneous current in the closed circuit will be 25 mA.
(D) If key S_1 is kept closed for long time such that capacitors are fully charged, the voltage difference between points P and Q will be 10 V.

(2019, PAPER 1)

Q6 A parallel plate capacitor of capacitance C has spacing d between two plates having area A. The region between the plates is filled with N dielectric layers, parallel to its plates, each with thickness $\delta = \frac{d}{N}$. The dielectric constant of the mth layer is $K_m = K\left(1 + \frac{m}{N}\right)$. For a very large N ($>10^3$), the capacitance C is $\alpha\left(\frac{K\varepsilon_0 A}{d\ln 2}\right)$. The value of α will be _____.

[$\in_0$ is the permittivity of free space]

(2019, PAPER 1)

Q7 Two capacitors with capacitance values $C_1 = 2000 \pm 10$ pF and $C_2 = 3000 \pm 15$ pF are connected in series. The voltage applied across this combination is V = 5.00 ± 0.02 V. The percentage error in the calculation of the energy stored in this combination of capacitors is _____.

(2020, PAPER 2)

Answer Key

1. (A,D) **2.** (D) **3.** (A) **4.** (B) **5.** (B,C) **6.** (1) **7.** (1.30)

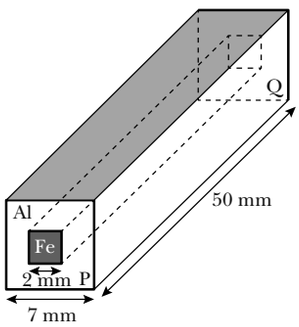
CHAPTER 26 Current and Resistance

Q1 Heater of an electric kettle is made of a wire of length L and diameter d. It takes 4 minutes to raise the temperature of 0.5 kg water by 40 K. This heater is replaced by a new heater having two wires of the same material, each of length L and diameter 2d. The way these wires are connected is given in the options. How much time in minutes will it take to raise the temperature of the same amount of water by 40K?

(A) 4 if wires are in parallel.
(B) 2 if wires are in series.
(C) 1 if wires are in series.
(D) 0.5 if wires are in parallel.

(2014, PAPER 1)

Q2 In an aluminium (Al) bar of square cross section, a square hole is drilled and is filled with iron (Fe) as shown in the figure. The electrical resistivities of Al and Fe are 2.7×10^{-8} Ω m and 1.0×10^{-7} Ω m. respectively. The electrical resistance between the two faces P and Q of the composite bar is _____.

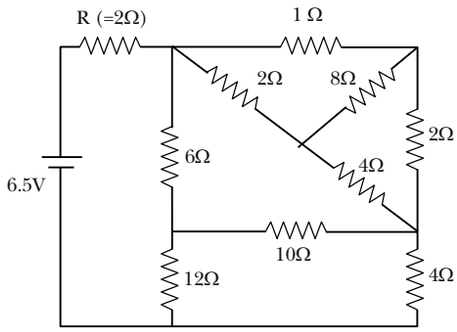


(A) $\frac{2475}{64}\mu\Omega$ **(B)** $\frac{1875}{64}\mu\Omega$

(C) $\frac{1875}{49}\mu\Omega$ **(D)** $\frac{2475}{132}\mu\Omega$

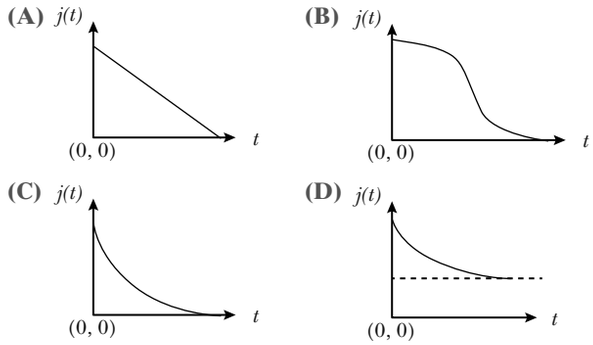
(2015, PAPER 1)

Q3 In the following circuit, the current through the resistor R (= 2Ω) is I Amperes. The value of I is _____.



(2015, PAPER 2)

Q4 An infinite line charge of uniform electric charge density λ lies along the axis of an electrically conducting infinite cylindrical shell of radius R. At time $t = 0$, the space inside the cylinder is filled with a material of permittivity ε and electrical conductivity σ. The electrical conduction in the material follows Ohm's law. Which one of the following graphs best describes the subsequent variation of the magnitude of current density j(t) at any point in the material?



(2016, PAPER 1)

Q5 An incandescent bulb has a thin filament of tungsten that is heated to high temperature by passing an electric current. The hot filament emits black-body radiation. The filament is observed to break up at random locations after a sufficiently long time of operation due to non-uniform evaporation of tungsten from the filament. If the bulb is powered at constant voltage, which of the following statement(s) is (are) true?

(A) The temperature distribution over the filament is uniform.
(B) The resistance over small sections of the filament decreases with time.
(C) The filament emits more light at higher band of frequencies before it breaks up.
(D) The filament consumes less electrical power towards the end of the life of the bulb.

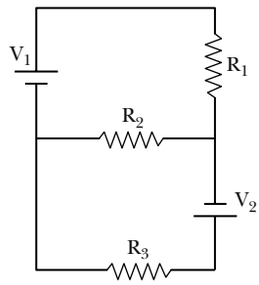
(2016, PAPER 1)

Answer Key

1. (B,D) **2.** (B) **3.** (1) **4.** (C) **5.** (C,D)

CHAPTER 27 Circuits

Q1 Two ideal batteries of emf V_1 and V_2 and three resistances R_1, R_2 and R_3 are connected as shown in the figure. The current in resistance R_2 would be zero if



(A) $V_1 = V_2$ and $R_1 = R_2 = R_3$
(B) $V_1 = V_2$ and $R_1 = 2R_2 = R_3$

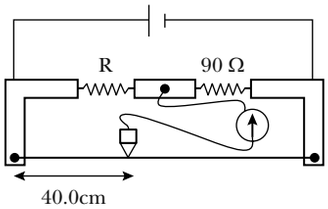
(C) $V_1 = 2V_2$ and $2R_1 = 2R_2 = R_3$
(D) $2V_1 = V_2$ and $2R_1 = R_2 = R_3$

(2014, PAPER 1)

Q2 A galvanometer gives full scale deflection with 0.006 A current. By connecting it to a 4990 Ω resistance, it can be converted into a voltmeter of range 0 – 30 V. If connected to a $\frac{2n}{249}\Omega$ resistance, it becomes an ammeter of range 0 – 1.5 A. The value of n is _____.

(2014, PAPER 1)

Q3 During an experiment with a metre bridge, the galvanometer shows a null point when the jockey is pressed at 40.0 cm using a standard resistance of 90 Ω, as shown in the figure. The least count of the scale used in the metre bridge is 1 mm. The unknown resistance is _____.



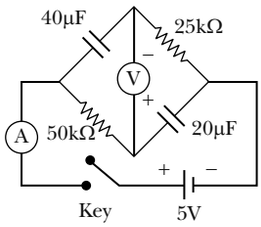
(A) 60 ± 0.15Ω **(B)** 135 ± 0.56Ω
(C) 60 ± 0.25Ω **(D)** 135 ± 0.23Ω

(2014, PAPER 2)

Q4 Consider two identical galvanometers and two identical resistors with resistance R. If the internal resistance of the galvanometers $R_C < R/2$, which of the following statement(s) about any one of the galvanometers is (are) true?
(A) The maximum voltage range is obtained when all the components are connected in series.
(B) The maximum voltage range is obtained when the two resistors and one galvanometer are connected in series, and the second galvanometer is connected in parallel to the first galvanometer.
(C) The maximum current range is obtained when all the components are connected in parallel.
(D) The maximum current range is obtained when the two galvanometers are connected in series and the combination is connected in parallel with both the resistors.

(2016, PAPER 2)

Q5 In rhe circuit shown below, the key is pressed at time t = 0. Which of the following statement(s) is (are) true?



(A) The voltmeter displays –5 V as soon as the key is pressed, and displays +5 V after a long time.
(B) The voltmeter will display 0 V at rime $t = ln\ 2$ seconds.
(C) The current in the ammeter becomes 1/*e* of the initial value after 1 second.
(D) The current in the ammeter becomes zero after a long time.

(2016, PAPER 2)

Consider a simple RC circuit as shown in Figrue 1.
Process 1: In the circuit the switch S is closed at t = 0 and the capacitor is fully charged to voltage V_0 (i.e. charging continues for time T ≫ RC). In the process some dissipation (E_D) occurs across the resistance R. The amount of energy finally stored in the fully charged capacitor is E_c.
Process 2: In a different process the voltage is first set to $\frac{V_0}{3}$ and maintained for a charging time T ≫ RC. Then the voltage is raised to $\frac{2V_0}{3}$ without discharging the capacitor and again maintained for time T ≫ RC. The process is repeated one more time by raising the voltage to V_0 and the capacitor is charged to the same final voltage V_0 as in Process 1.
These two processes are depicted in Figure 2.

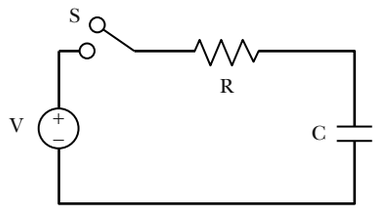


Figure 1

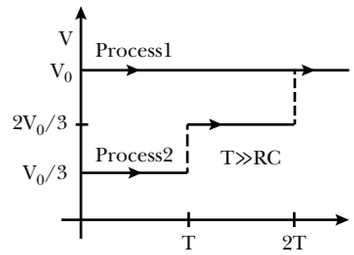


Figure 2

Q6 In Process 1, the energy stored in the capacitor E_c and heat dissipated across resistance E_D are released by:
(A) $E_C = E_D$ **(B)** $E_C = E_D \ln 2$
(C) $E_C = \frac{1}{2} E_D$ **(D)** $E_C = 2E_D$

(2017, PAPER 2)

Q7 In Process 2, Total energy dissipated across the resistance E_D is:
(A) $E_D = \frac{1}{2} C V_0^2$ **(B)** $E_D = 3\left(\frac{1}{2} CV_0^2\right)$
(C) $E_D = \frac{1}{3}\left(\frac{1}{2} CV_0^2\right)$ **(D)** $E_D = 3CV_0^2$

(2017, PAPER 2)

Q8 A moving coil galvanometer has 50 turns and each turn has an area 2×10^{-4} m^2. The magnetic field produced by the magnet inside the galvanometer is 0.02 T. The torsional constant of the suspension wire is 10^{-4} N m rad^{-1}. When a current flows through the galvanometer, a full scale deflection occurs if the coil rotates by 0.2 rad. The resistance of the coil of the galvanometer is 50 Ω. This galvanometer is to be converted into an ammeter capable of measuring current in the range 0 – 1.0 A. For this purpose, a shunt resistance is to be added in parallel to the galvanometer. The value of this shunt resistance, in ohms, is_____.

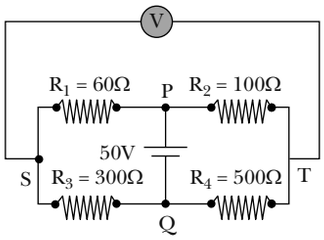
(2018, PAPER 2)

Q9 Two identical moving coil galvanometers have 10 Ω resistance and full scale deflection at 2 μA current. One of them is converted into a voltmeter of 100 mV full scale reading and the other into an Ammeter of 1mA full scale current using appropriate resistors. These are then used to measure the voltage and current in the Ohm's law experiment with R = 1000 Ω resistor by using an ideal cell. Which of the following statement(s) is/are correct?

(A) The measured value of R will be 978 Ω < R < 982 Ω
(B) The resistance of the Voltmeter will be 100 kΩ
(C) If the ideal cell is replaced by a cell having internal resistance of 5Ω then the measured value of R will be more than 1000 Ω
(D) The resistance of the Ammeter will be 0.02Ω (round off to 2nd decimal place)

(2019, PAPER 1)

Q10 In the balanced condition, the values of the resistances of the four arms of a Wheatstone bridge are shown in the figure below. The resistance R_3 has temperature coefficient 0.0004 °C^{-1}. If the temperature of R_3 is increased by 100 °C, the voltage developed between S and T will be _____ volt.



(2020, PAPER 2)

Answer Key

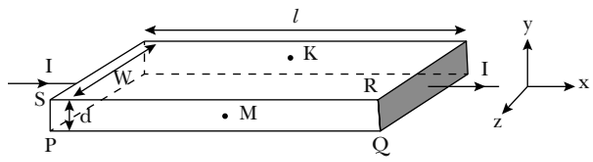
1. (A,B,D)	**2.** (5)	**3.** (C)	**4.** (A,C)
5. (A,B,C,D)	**6.** (A)	**7.** (C)	**8.** (5.56)
9. (A,D)	**10.** (0.27)		

CHAPTER 28 Magnetic Force

Q1 Two parallel wires in the plane of the paper are distance X_0 apart. A point charge is moving with speed u between the wires in the same plane at a distance X_1 from one of the wires. When the wires carry current of magnitude I in the same direction, the radius of curvature of the path of the point charge is R_1. In contrast, if the currents I in the two wires have directions opposite to each other, the radius of curvature of the path is R_2. If $\frac{X_0}{X_1} = 3$, the value of $\frac{R_1}{R_2}$ is _____.

(2014, PAPER 1)

In a thin rectangular metallic strip a constant current I flows along the positive x-direction, as shown in the figure. The length, width and thickness of the strip are ℓ, w and d, respectively. A uniform magnetic field $\vec{B}$ is applied on the strip along the positive y-direction. Due to this, the charge carriers experience a net deflection along the z-direction. This results in accumulation of charge carriers on the surface PQRS and appearance of equal and opposite charges on the face opposite to PQRS. A potential difference along the z-direction is thus developed. Charge accumulation continues until the magnetic force is balanced by the electric force. The current is assumed to be uniformly distributed on the cross section of the strip and carried by electrons.



Q2 Consider two different metallic strips (1 and 2) of the same material. Their lengths are the same, widths are w_1 and w_2 and thicknesses are d_1 and d_2, respectively. Two points K and M are symmetrically located on the opposite faces parallel to the x-y plane (see figure). V_1 and V_2 are the potential differences between K and M in strips 1 and 2, respectively. Then, for a given current I flowing through them in a given magnetic field strength B, the correct statement(s) is(are) _____.

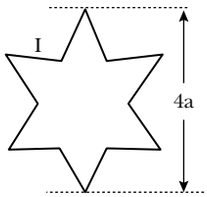
(A) If $w_1 = w_2$ and $d_1 = 2d_2$, then $V_2 = 2V_1$
(B) If $w_1 = w_2$ and $d_1 = 2d_2$, then $V_2 = V_1$
(C) If $w_1 = 2w_2$ and $d_1 = d_2$, then $V_2 = 2V_1$
(D) If $w_1 = 2w_2$ and $d_1 = d_2$, then $V_2 = V_1$

Q3 Consider two different metallic strips (1 and 2) of same dimensions (lengths ℓ, width w and thickness d) with carrier densities n_1 and n_2, respectively. Strip 1 is placed in magnetic field B_1 and strip 2 is placed in magnetic field B_2, both along positive y-directions. Then V_1 and V_2 are the potential differences developed between K and M in strips 1 and 2, respectively. Assuming that the current I is the same for both the strips, the collect option(s) is (are) _____.

(A) If $B_1 = B_2$ and $n_1 = 2n_2$, then $V_2 = 2V_1$
(B) If $B_1 = B_2$ and $n_1 = 2n_2$, then $V_2 = V_1$
(C) If $B_1 = 2B_2$ and $n_1 = n_2$, then $V_2 = 0.5V_1$
(D) If $B_1 = 2B_2$ and $n_1 = n_2$, then $V_2 = V_1$

(2015, PAPER 2)

Q4 A symmetric star conducting wire loop is carrying a steady state current I as shown in figure. The distance between the diametrically opposite vertices of the star is 4a. The magnitude of the magnetic field at the center of the loop is _____.



(A) $\frac{\mu_0 I}{4\pi a} 6[\sqrt{3}-1]$ (B) $\frac{\mu_0 I}{4\pi a} 6[\sqrt{3}+1]$

(C) $\frac{\mu_0 I}{4\pi a} 3[\sqrt{3}-1]$ (D) $\frac{\mu_0 I}{4\pi a} 3[2-\sqrt{3}]$

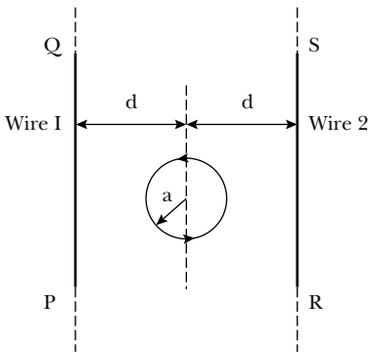
(2017, PAPER 2)

Answer Key

1. (3) **2.** (A,D) **3.** (A,C) **4.** (A)

CHAPTER 29 Magnetic Fields Due to Currents

The figure shows a circular loop of radius *a* with two long parallel wires (numbered 1 and 2) all in the plane of the paper. The distance of each wire from the centre of the loop is *d*. The loop and the wires are carrying the same current I. The current in the loop is in die counterclockwise direction if seen from above.



Q1 When d ≈ a but wires are not touching the loop, it is found that the net magnetic field on the axis of the loop is zero at a height h above the loop. In that case

(A) current in wire 1 and wire 2 is the direction PQ and RS, respectively and h≈ a.

(B) current in wire 1 and wire 2 is the direction PQ and SR, respectively and h≈ a.

(C) current in wire 1 and wire 2 is the direction PQ and SR, respectively and h ≈ 1.2a.

(D) current in wire 1 and wire 2 is the direction PQ and RS. respectively and h ≈ 1.2a.

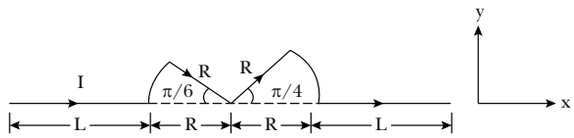
Q2 Consider d ≫ a, and the loop is rotated about its diameter parallel to the wires by 30° from the position shown in the figure. If the currents in the wires are in the opposite directions, the torque on the loop at its new position will be (assume that the net field due to the wires is constant over the loop)

(A) $\frac{\mu_0 I^2 a^2}{d}$ (B) $\frac{\mu_0 I^2 a^2}{2d}$

(C) $\frac{\sqrt{3}\mu_0 I^2 a^2}{d}$ (D) $\frac{\sqrt{3}\mu_0 I^2 a^2}{2d}$

(2014, PAPER 2)

Q3 A conductor (shown in the figure) carrying constant current I is kept in the x-y plane in a uniform magnetic field $\vec{B}$. If F is the magnitude of die total magnetic force acting on the conductor, then the correct statement(s) is (are) _____.



(A) If $\vec{B}$ is along $\hat{z}$, F ∝ (L + R)

(B) If $\vec{B}$ is along $\hat{x}$, F = 0

(C) If $\vec{B}$ is along $\hat{y}$, F ∝ (L+R)

(D) If $\vec{B}$ is along $\hat{z}$, F = 0

A charged particle (electron or proton) is introduced at the origin (x = 0, y = 0, z = 0) with a given initial velocity $\vec{v}$. A uniform electric field $\vec{E}$ and magnetic field $\vec{B}$ are given in columns 1, 2 and 3, respectively. The quantities E_0, B_0 are positive in magnitude.

Column I	Column 2	Column 3
(I) Electron with $\vec{v} = 2\frac{E_0}{B_0}\hat{x}$	**(i)** $\vec{E} = E_0^2\hat{z}$	**(P)** $\vec{B} = -B_0\hat{x}$
(II) Electron with $\vec{v} = \frac{E_0}{B_0}\hat{y}$	**(ii)** $\vec{E} = -E_0\hat{y}$	**(Q)** $\vec{B} = B_0\hat{x}$
(III) Proton with $\vec{v} = 0$	**(iii)** $\vec{E} = -E_0\hat{x}$	**(R)** $\vec{B} = B_0\hat{y}$
(IV) Proton with $\vec{v} = 2\frac{E_0}{B_0}\hat{x}$	**(iv)** $\vec{E} = E_0\hat{x}$	**(S)** $\vec{B} = B_0\hat{z}$

Q4 In which case will the particle move in a straight line with constant velocity?

(A) (II) (iii) (S) **(B)** (IV) (i) (S)

(C) (III)(ii)(R) **(D)** (III) (iii) (P)

Q5 In which case will the particle describe a helical path with axis along the positive z direction?

(A) (II) (ii) (R) **(B)** (IV) (ii) (R)

(C) (IV) (i) (S) **(D)** (III) (iii) (P)

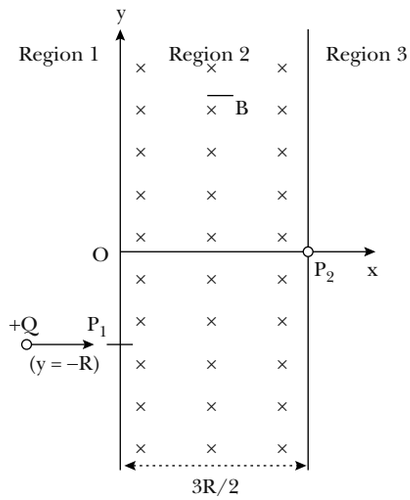
Q6 In which case would be particle move in a straight line along the negative direction of y-axis (i.e., more along- $\hat{y}$)?

(A) (IV) (ii) (S) **(B)** (III) (ii) (P)

(C) (II) (iii) (Q) **(D)** (III) (ii) (R)

(2017, PAPER 1)

Q7 A uniform magnetic field B exists in the region between x = 0 and x = $\frac{3R}{2}$ (region 2 in the figure) pointing normally into the plane of the paper. A particle with charge +Q and momentum p directed along x-axis enters region 2 from region 1 at point P_1 (y = -R). Which of the following option(s) is/are correct?



(A) For $B > \frac{2}{3}\frac{p}{QR}$, the particle will re-enter region 1.

(B) For $B = \frac{8}{13}\frac{p}{QR}$, the particle will enter region 3 through the point P_2 on x-axis.

(C) When the particle re-enters region 1 through the longest possible path in region 2, the magnitude of the change in its linear momentum between point P_1 and the farthest point from y-axis is $p/\sqrt{2}$.

(D) For a fixed B, particles of same charge Q and same velocity v, the distance between the point P_1 and the point of re-entry into region 1 is inversely proportional to the mass of the particle.

(2017, PAPER 2)

Q8 Two infinitely long straight wires lie in the *xy*-plane along the lines $x = \pm R$. The wire located at $x = +R$ carries a constant current I_1 and the wire located at $x = -R$ carries a constant current I_2. A circular loop of radius R is suspended with its centre at $(0, 0, \sqrt{3}R)$ and in a plane parallel to the *xy*-plane. This loop carries a constant current I in the clockwise direction as seen from above the loop. The current in the wire is taken to be positive if it is in the $+\hat{j}$ direction. Which of the following statements regarding the magnetic field $\vec{B}$ is (are) true?

(A) If $I_1 = I_2$, then $\vec{B}$ **cannot** be equal to zero at the origin (0, 0, 0).

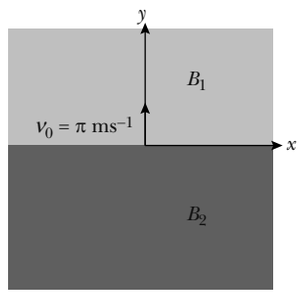
(B) If $I_1 > 0$, and $I_2 < 0$, then $\vec{B}$ can be equal to zero at the origin (0, 0, 0).

(C) If $I_1 < 0$, and $I_2 > 0$, then $\vec{B}$ can be equal to zero at the origin (0, 0, 0).

(D) If $I_1 = I_2$, then the *z*-component of rhe magnetic field at the centre of the loop is $\left(-\frac{\mu_0 I}{2R}\right)$.

(2018, PAPER 1)

Q9 In the *xy*-plane, the region y > 0 has a uniform magnetic field $B_1\hat{k}$ and the region y < 0 has another uniform magnetic field $B_2\hat{k}$. A positively charged particle is projected from the origin along the positive *y*-axis with speed $v_0 = \pi$ ms^{-1} at t = 0, as shown in the figure. Neglect gravity in this problem. Let t = T be the time when the particle crosses the x-axis from below for the first time. If $B_2 = 4B_1$, the average speed of the particle, in ms^{-1}, along the *x*-axis in the time interval *T* is_____.



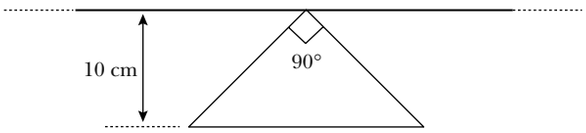
(2018, PAPER 1)

Answer Key

1. (C)	**2.** (B)	**3.** (A, B, C)	**4.** (A)	**5.** (C)
6. (D)	**7.** (A, B)	**8.** (A, B, D)	**9.** (2)	

CHAPTER 31 Electromagnetic Induction

Q1 A conducting loop in the shape of a right angled isosceles triangle of height 10 cm is kept such that the 90° vertex is very close to an infinitely long conducting wire (see the figure). Hie wire is electrically insulated front the loop. The hypotenuse of the triangle is parallel to the wire. The current in the triangular loop is in counterclockwise direction and increased at a constant rate of 10 A s^{-1}. Which of the following statements) is(are) true?



(A) The magnitude of induced *emf* in the wire is $\left(\frac{\mu_0}{\pi}\right)$ volt.

(B) If the loop is rotated at a constant angular speed about the wire, an additional *emf* of $\left(\frac{\mu_0}{\pi}\right)$ volt is induced in the wire.

(C) The induced current in the wire is in opposite direction to the current along the hypotenuse.

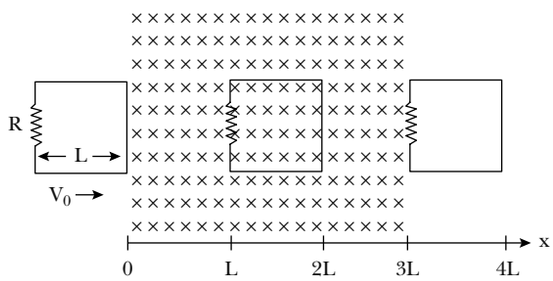
(D) There is a repulsive force between the wire and the loop.

(2016, PAPER 1)

Q2 Two inductors L_1 (inductance 1 mH, internal resistance 3Ω) and L_2 (inductance 2 mH, internal resistance 4Ω), and a resistor R (resistance 12Ω) are all connected in parallel across a 5V battery. The circuit is switched on at time t = 0. The ratio of the maximum to the minimum current (I_{max}/I_{min}) drawn from the battery is _____ .

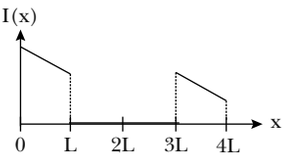
(2016, PAPER 1)

Q3 A rigid wire loop of square shape having side of length L and resistance R is moving along the x-axis with a constant velocity v_0 in the plane of the paper. At t = 0, the right edge of the loop enters a region of length 3L where there is a uniform magnetic field B_0 into the plane of the paper, as shown in the figure. For sufficiently large v_0, the loop eventually crosses the region. Let x be the location of the right edge of the loop. Let v(x), I(x) and F(x) represent the velocity of the loop, current in the loop, and force on the loop, respectively, as a function of x. Counter-clockwise current is taken as positive.

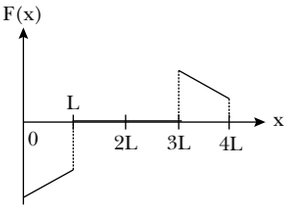


Which of the following schematic plot(s) is(are) correct? (Ignore gravity)

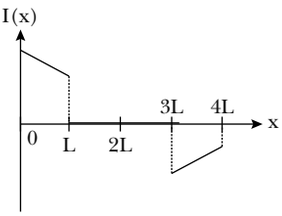
(A)



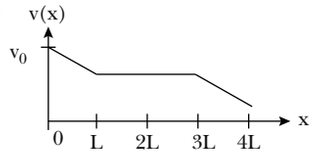
(B)



(C)

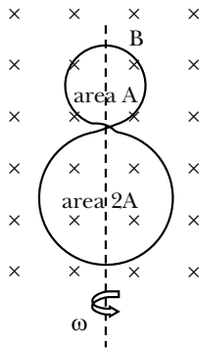


(D)



(2016, PAPER 2)

Q4 A circular insulated copper wire loop is twisted to form two loops of area A and 2A as shown in the figure. At the point of crossing the wires remain electrically insulated from each other. The entire loop lies in the plane (of the paper). A uniform magnetic field $\vec{B}$ points into the plane of the paper. At t = 0, the loop starts rotating about the common diameter as axis with a constant angular velocity ω in the magnetic field. Which of the following options is/are correct?



(A) The rate of change of the flux is maximum when the plane of the loops is perpendicular to plane of the paper.

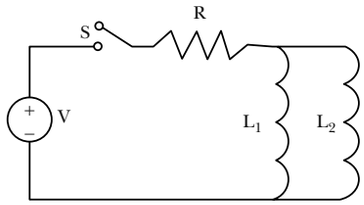
(B) The net emf induced due to both the loops is proportional to cos ωt.

(C) The emf induced in the loop is proportional to the sun of the areas of the two loops.

(D) The amplitude of the maximum net emf induced due to both the loops is equal to the amplitude of maximum emf induced in the smaller loop alone.

(2017, PAPER 1)

Q5 A source of constant voltage V is connected to a resistance R and two ideal inductors L_1 and L_2 through a switch S as shown. There is no mutual inductance between the two inductors. The switch S is initially open. At t = 0, the switch is closed and current begins to flow. Which of the following options is/are correct?



(A) After a long time, the current through L_1 will be $\frac{V}{R}\frac{L_2}{L_1 + L_2}$.

(B) After a long time, the current through L_2 will be $\frac{V}{R}\frac{L_1}{L_1 + L_2}$.

(C) The ratio of the currents through L_1 and L_2 is fixed at all times (t > 0).

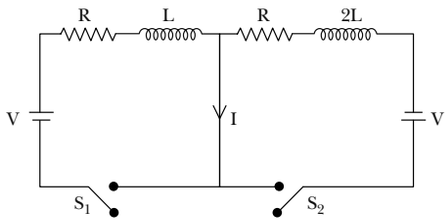
(D) At t = 0, the current through the resistance R is $\frac{V}{R}$.

(2017, PAPER 2)

Q6 In the figure below, the switches S_1 and S_2 are closed simultaneously at $t = 0$ and a current starts to flow in the circuit. Both the batteries have the same magnitude of the electromotive force (emf) and the polarities are as indicated in the figure. Ignore mutual inductance between the inductors. The current I in the middle wire reaches its maximum magnitude I_{max} at time $t = \tau$. Which of the following statements is (are) true?

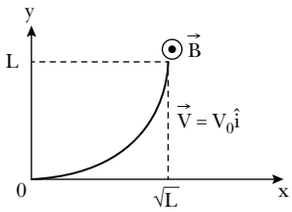
(A) $I_{max} = \frac{V}{2R}$ **(B)** $I_{max} = \frac{V}{4R}$

(C) $\tau = \frac{L}{R}\ln 2$ **(D)** $\tau = \frac{2L}{R}\ln 2$



(2018, PAPER 1)

Q7 A conducting wire of parabolic shape, initially $y = x^2$, is moving with velocity $\vec{V} = V_0\hat{i}$ in a non uniform magnetic field $\vec{B} = B_0\left(1 + \left(\frac{y}{L}\right)^{\beta}\right)\hat{k}$, as shown in figure. If V_0, B_0, L and β are positive constants and Δϕ is the potential difference developed between the ends of the wire, then the correct statement(s) is/are:



(A) $|\Delta\phi|$ is proportional to the length of the wire projected on the y-axis.

(B) $|\Delta\phi|$ remains the same if the parabolic wire is replaced by a straight wire, y = x initially, of length $\sqrt{2}L$.

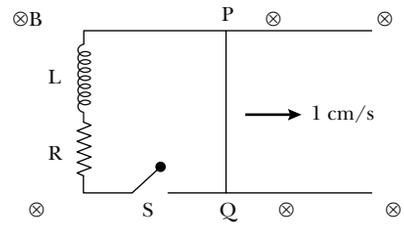
(C) $|\Delta\phi| = \frac{1}{2}B_0V_0L$ for β = 0.

(D) $|\Delta\phi| = \frac{4}{3}B_0V_0L$ for β = 2.

(2019, PAPER 1)

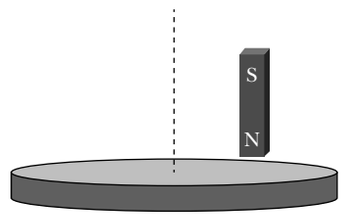
Q8 A 10 cm long perfectly conducting wire PQ is moving with a velocity 1 cm/s on a pair of horizontal rails of zero resistance. One side of the rails is connected to an inductor L = 1 mH and a resistance R = 1 Ω as shown in the figure. The horizontal rails, L and R lie in the same plane with a uniform magnetic field B = 1 T perpendicular to the plane. If the key S is closed at certain instant, the current in the circuit after 1 millisecond is $x \times 10^{-3}$ A, where the value of x is _____.

[Assume the velocity of wire PQ remains constant (1 cm/s) after key S is closed. Given: $e^{-1} = 0.37$, where e is base of the natural logarithm.]



(2019, PAPER 2)

Q9 A light disc made of aluminium (a nonmagnetic material) is kept horizontally and is free to rotate about its axis as shown in the figure. A strong magnet is held vertically at a point above the disc away from its axis. On revolving the magnet about the axis of the disc, the disc will (figure is schematic and not drawn to scale)



(A) rotate in the direction opposite to the direction of magnet's motion

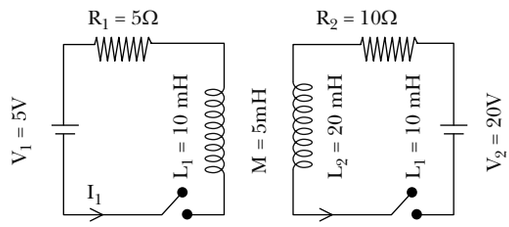
(B) rotate in the same direction as the direction of magnet's motion

(C) not rotate and its temperature will remain unchanged

(D) not rotate but its temperature will slowly rise

(2020, PAPER 1)

Q10 The inductors of two LR circuits are placed next to each other, as shown in the figure. The values of the self-inductance of the inductors, resistances, mutual-inductance and applied voltages are specified in the given circuit. After both the switches are closed simultaneously, the total work done by the batteries against the induced EMF in the inductors by the time the currents reach their steady state values is _____ mJ.



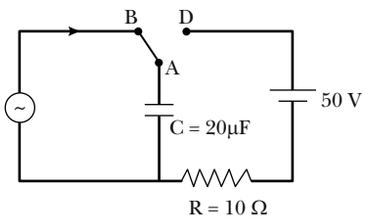
(2020, PAPER 2)

Answer Key

1. (A,D)	**2.** (8)	**3.** (C,D)	**4.** (A,D)	**5.** (A,B,C)
6. (B,D)	**7.** (A,B,D)	**8.** (0.63)	**9.** (B)	**10.** (55)

CHAPTER 32 Electromagnetic Oscillations and Alternating Current

Q1 At time t = 0, terminal A in the circuit shown in the figure is connected to B by a key and an alternating current $I(t) = I_0 \cos(\omega t)$, with I_0 = 1A and ω = 500 rad/s starts flowing in it with the initial direction shown in the figure. At $t = \frac{7\pi}{6\omega}$, the key is switched from B to D. Now onwards only A and D are connected. A total charge Q flows from the battery to charge the capacitor fully. If C = 20 μF, R = 10 Ω and the battery is ideal with emf of 50 V, identify the correct statement(s).



(A) Magnitude of the maximum charge on the capacitor before $t = \frac{7\mu}{6\omega}$ is 1×10^{-3}C.

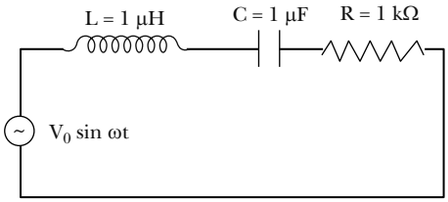
(B) The current in the left part of the circuit just before $t = \frac{7\pi}{6\omega}$ is clockwise.

(C) Immediately after A is connected to D, the current in R is 10 A.

(D) $Q = 2 \times 10^{-3}$C.

(2014, PAPER 1)

Q2 In the circuit shown L = 1 μH, C = 1 μF and R = 1 kΩ. They are connected in series with an a.c. source $V = V_0 \sin \omega t$ as shown. Which of the following options is/are correct?



(A) The frequency at which the current will be in the phase with the voltage is independent of R.

(B) At ω~0 the current flowing through the circuit becomes nearly zero.

(C) At $\omega \gg 10^6$ rad·s^{-1}, the circuit behave like a capacitor.

(D) The current will be in phase with the voltage if $\omega = 10^4$ rad·s^{-1}.

(2017, PAPER 1)

In the circuit, a metal filament lamp is connected in series with a capacitor of capacitance C μF across a 200 V, 50 Hz supply. The power consumed by the lamp is 500 W while the voltage drop across it is 100 V. Assume that there is no inductive load in the circuit. Take *rms* values of the voltages. The magnitude of the phase-angle (in degrees) between the current and supply voltage is ϕ. Assume, $\neq \sqrt{3} \approx 5$.

Answer Key

1. (C,D) **2.** (A,B)

CHAPTER 34 Geometrical Optics: Reflection

Q1 A plano-convex lens is made of a material of refractive index n. When a small object is placed 30 cm away in front of the curved surface of the lens, an image of double the size of the object is produced. Due to reflection from the convex surface of the lens, another faint image is observed at a distance of 10 cm away from the lens. Which of the following statement(s) is (are) true?

(A) The refractive index of the lens is 2.5.

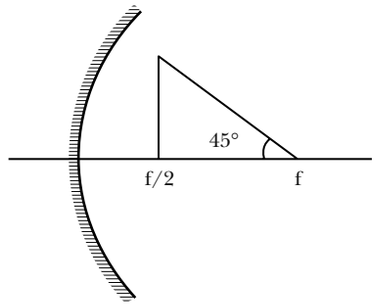
(B) The radius of curvature of the convex surface is 45 cm.

(C) The faint image is erect and real.

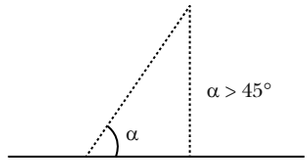
(D) The focal length of the lens is 20 cm.

(2016, PAPER 1)

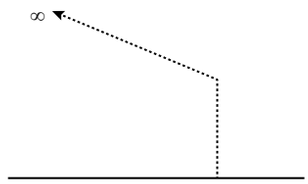
Q2 A wire is bent in the shape of a right angled triangle and is placed in front of a concave mirror of focal length *f*, as shown in the figure. Which of the figures shown in the four options qualitatively represent(s) the shape of the image of the bent wire? (These figures are not to scale.)



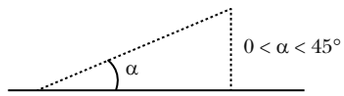
(A)

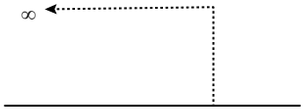


(B)



(C)



(D) 

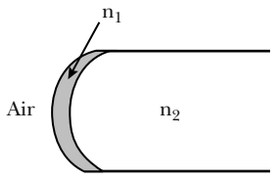
(2018, PAPER 2)

Answer Key

1. (A,D) **2.** (D)

CHAPTER 35 Geometrical Optics: Refraction

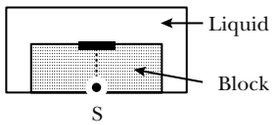
Q1 A transparent thin film of uniform thickness and refractive index $n_1 = 1.4$ is coated on the convex spherical surface of radius R at one end of a long solid glass cylinder of refractive index $n_2 = 1.5$, as shown in the figure. Rays of light parallel to the axis of the cylinder traversing through the film from air to glass get focused at distance f_1 from the film, while rays of light traversing from glass to air get focused at distance f_2 from the film. Then



(A) $|f_1| = 3R$ **(B)** $|f_1| = 2.8$ R
(C) $|f_2| = 2R$ **(D)** $|f_2| = 1.4R$

(2014, PAPER 1)

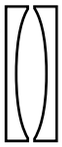
Q2 A point source S is placed at the bottom of a transparent block of height 10 mm and refractive index 2.72. It is immersed in a lower refractive index liquid as shown in the figure. It is found that the light emerging from the block to the liquid forms a circular bright spot of diameter 11.54 mm on the top of the block. The refractive index of the liquid is _____.



(A) 1.21 **(B)** 1.30
(C) 1.36 **(D)** 1.42

(2014, PAPER 2)

Q3 Four combinations of two thin lenses are given in List I. The radius of curvature of all curved surfaces is r and the refractive index of all the lenses is 1.5. Match lens combinations in List I with then focal length in List II and select the correct answer using the code given below the lists.

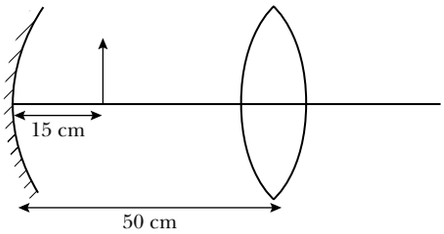
List I	List II
P.	**1.** 2r
Q.	**2.** r/2
R. 	**3.** –r
S.	**4.** r

Code:

(A) P-1, Q-2, R-3, S-4 **(B)** P-2, Q-4, R-3, S-l
(C) P-4, Q-l, R-2, S-3 **(D)** P-2, Q-l, R-3, S-4

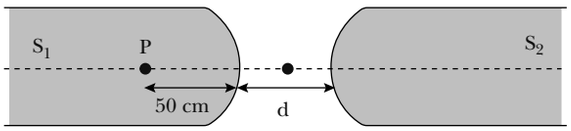
(2014, PAPER 2)

Q4 Consider a concave mirror and a convex lens (refractive index = 1.5) of focal length 10 cm each, separated by a distance of 50 cm in air (refractive index = 1) as shown in the figure. An object is placed at a distance of 15 cm from the mirror. Its erect image formed by this combination has magnification M_1. When the set-up is kept in a medium of refractive index 7/6, the magnification becomes M_2. The magnitude $\left|\frac{M_2}{M_1}\right|$ is _____.



(2015, PAPER 1)

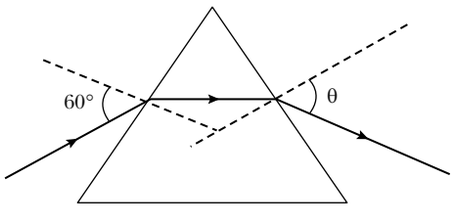
Q5 Two identical glass rods S_1 and S_2 (refractive index = 1.5) have one convex end of radius of curvature 10 cm. They are placed with the curved surfaces at a distance d as shown in the figure, with their axes (shown by the dashed line) aligned. When a point source of light P is placed inside rod S_1 on its axis at a distance of 50 cm from the curved face, the light rays emanating from it are found to be parallel to the axis inside S_2. The distance d is _____.



(A) 60 cm **(B)** 70 cm
(C) 80 cm **(D)** 90 cm

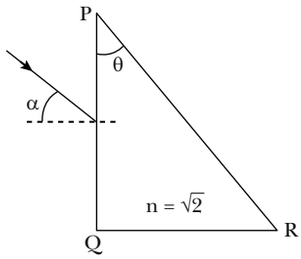
(2015, PAPER 1)

Q6 A monochromatic beam of light is incident at 60° on one face of an equilateral prism of refractive index n and emerges from the opposite face making an angle θ(n) with the normal (see the figure). For $n = \sqrt{3}$ the value of θ is 60° and $\frac{d\theta}{dn} = m$. The value of m is _____.



(2015, PAPER 2)

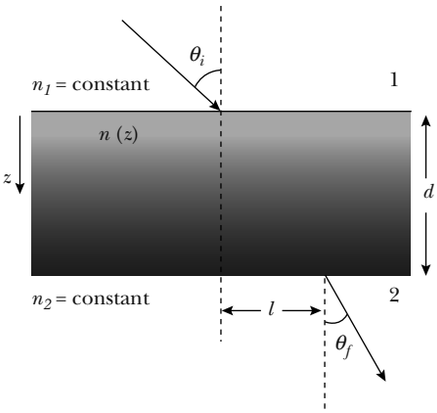
Q7 A parallel beam of light is incident from air at an angle α on the side PQ of a right angled triangular prism of refractive index $n = \sqrt{2}$. Light undergoes total internal reflection in the prism at the face PR when α has a minimum value of 45°. The anele θ of the prism is _____.



(A) 15° **(B)** 22.5°
(C) 30° **(D)** 45°

(2016, PAPER 1)

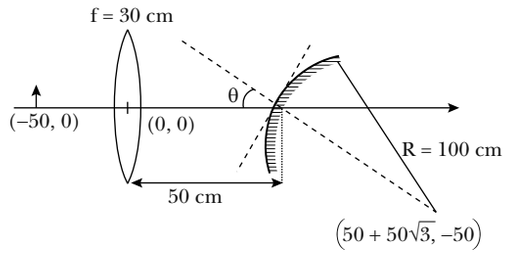
Q8 A transparent slab of thickness d has a refractive index $n(z)$ that increases with z. Here z is the vertical distance inside the slab, measured from the top. The slab is placed between two media with uniform refractive indices n_1 and n_2 ($> n_1$), as shown in the figure. A ray of light is incident with angle θ_i from medium 1 and emerges in medium 2 with refraction angle θ_f with a lateral displacement l.



Which of the following statement (s) is (are) true?
(A) $n_1 \sin\theta_i = n_2 \sin\theta_f$
(B) $n_1 \sin\theta_i = (n_2 - n_1)\sin\theta_f$
(C) l is independent of n_2
(D) l is dependent on $n(z)$

(2016, PAPER 1)

Q9 A small object is placed 50 cm to the left of a thin convex lens of focal length 30 cm. A convex spherical mirror of radius of curvature 100 cm is placed to the right of the lens at a distance of 50 cm. The mirror is tilted such that the axis of the mirror is at an angle θ = 30° to the axis of the lens, as shown in the figure.



If the origin of the coordinate system is taken to be at the centre of the lens, the coordinates (in cm) of the point (x, y) at which the image is formed are _____.

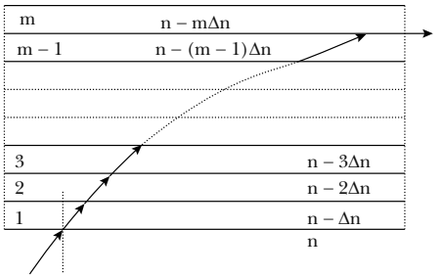
(A) $(25, 25\sqrt{3})$ **(B)** $(125/3, 25/\sqrt{3})$
(C) $(50 - 25\sqrt{3}, 25)$ **(D)** $(0, 0)$

(2016, PAPER 2)

Q10 For an isosceles prism of angle A and refractive index μ, it is found that the angle of minimum deviation $\delta_m = A$. Which of the following options is/are correct?
(A) At minimum deviation, the incident angle i_1 and the refracting angle r_1 at the first refracting surface are related by $r_1 = (i_1/2)$.
(B) For this prism the refractive index μ and the angle of prism A are related as $A = \frac{1}{2}\cos^{-1}(\mu/2)$.
(C) For this prism, the emergent ray at the second surface will be tangential to the surface when the angle of incidence at the first surface is $i_1 = \sin^{-1}\left[\sin A\sqrt{4\cos^2\frac{A}{2} - 1} - \cos A\right]$.
(D) For the angle of incidence $i_1 = A$, the ray inside the prism is parallel to the base of the prism.

(2017, PAPER 1)

Q11 A monochromatic light is travelling in a medium of refractive index n = 1.6. It enters a stack of glass layers from the bottom side at an angle θ = 30°. The interfaces of the glass layers are parallel to each other. The refractive indices of different glass layers are monotonically decreasing as $n_m = n - m\Delta n$, where n_m is the refractive index of the mth slab and Δn = 0.1 (see the figure). The ray is refracted out parallel to the interface between the $(m - 1)^{th}$ and m^{th} slabs from the right side of the stack. What is the value of m?

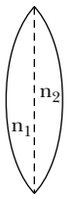


(2017, PAPER 1)

Q12 Sunlight of intensity 1.3 kWm^{-2} is incident normally on a thin convex lens of focal length 20 *cm*. Ignore the energy loss of light due to the lens and assume that the lens aperture size is much smaller than its focal length. The average intensity of light, in $kW\ m^{-2}$, at a distance 22 *cm* from the lens on the other side is _____.

(2018, PAPER 1)

Q13 A thin convex lens is made of two materials with refractive indices n_1 and n_2, as shown in figure. The radius of curvature of the left and right spherical surfaces are equal, f is the focal length of the lens when $n_1 = n_2 = n$. The focal length is $f + \Delta f$ when $n_1 = n$ and $n_2 = n + \Delta n$. Assuming $\Delta n \ll (n - 1)$ and $1 < n < 2$. The correct statement(s) is/are _____.



(A) $\left|\frac{\Delta f}{f}\right| < \left|\frac{\Delta n}{n}\right|$

(B) If $\frac{\Delta n}{n} < 0$ then $\frac{\Delta f}{f} > 0$

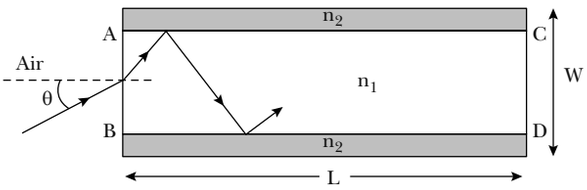
(C) For $n = 1.5$, $\Delta n = 10^{-3}$ and $f = 20$ cm, the value of $|\Delta f|$ will be 0.02 cm (round off to 2nd decimal place).

(D) The relation between $\frac{\Delta f}{f}$ and $\frac{\Delta n}{n}$ remains unchanged if both the convex surfaces are replaced by concave surfaces of the same radius of curvature.

(2019, PAPER 1)

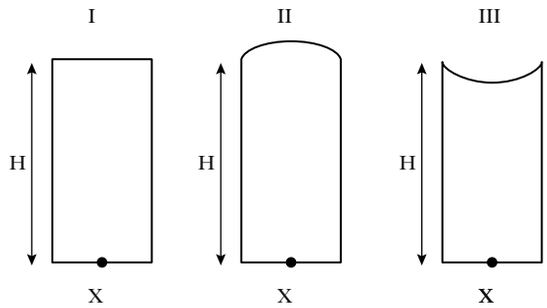
Q14 A planar structure of length L and width W is made of two different optical media of refractive indices $n_1 = 1.5$ and $n_2 = 1.44$ as shown in figure. If $L \gg W$, a ray entering from end AB will emerge from end CD only if the total internal reflection condition is met inside the structure. For L = 9.6 m, if the incident angle θ is varied, the maximum time taken by a ray to exit the plane CD is $t \times 10^{-9}$ s, where t is _____.

[Speed of light $c = 3 \times 10^8$ m/s]



(2019, PAPER 1)

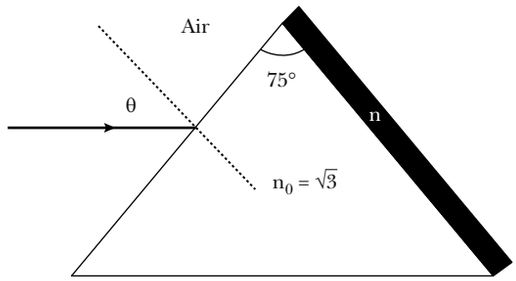
Q15 Three glass cylinders of equal height H = 30 cm and same refractive index n = 1.5 are placed on a horizontal surface as shown in figure. Cylinder I has a flat top, cylinder II has a convex top and cylinder III has a concave top. The radii of curvature of the two curved tops are same (R = 3m). If H_1, H_2 and H_3 are the apparent depths of a point X on the bottom of the three cylinders, respectively, the correct statement(s) is/are:



(A) $H_2 > H_1$
(B) $H_2 > H_3$
(C) $H_3 > H_1$
(D) $0.8\text{ cm} < (H_2 - H_1) < 0.9\text{ cm}$

(2019, PAPER 2)

Q16 A monochromatic light is incident from air on a refracting surface of prism of angle 75° and refractive index $n_0 = \sqrt{3}$. The other refracting surface of the prism is coated by a thin film of material of refractive index n as shown in figure. The light suffers total internal reflection at the coated prism surface for an incidence angle of $\theta \le 60°$. The value of n^2 is _____.

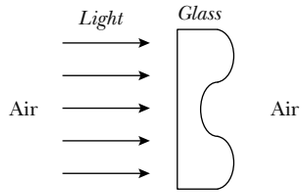


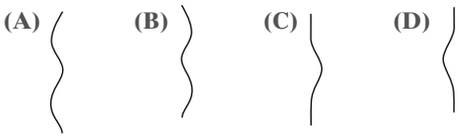
(2019, PAPER 2)

Q17 An optical bench has 1.5 m long scale having four equal divisions in each cm. While measuring the focal length of a convex lens, the lens is kept at 75 cm mark of the scale and the object pin is kept at 45 cm mark. The image of the object pin on the other side of the lens overlaps with image pin that is kept at 135 cm mark. In this experiment, the percentage error in the measurement of the focal length of the lens is _____.

(2019, PAPER 2)

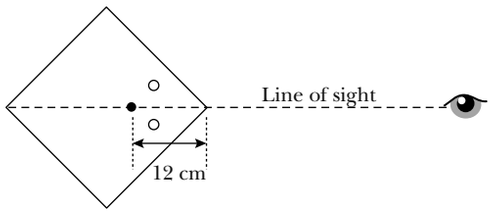
Q18 A parallel beam of light strikes a piece of transparent glass having cross section as shown in the figure below. Correct shape of the emergent wavefront will be (figures are schematic and not drawn to scale)





(2020, PAPER 1)

Q19 A large square container with thin transparent vertical walls and filled with water $\left(\text{refractive index}\,\frac{4}{3}\right)$ is kept on a horizontal table. A student holds a thin straight wire vertically inside the water 12 cm from one of its corners, as shown schematically in the figure. Looking at the wire from this corner, another student sees two images of the wire, located symmetrically on each side of the line of sight as shown. The separation (in cm) between these images is _____.



(2020, PAPER 2)

Answer Key

1. (A,C)	**2.** (C)	**3.** (B)	**4.** (1)
5. (B)	**6.** (2)	**7.** (A)	**8.** (A,C,D)
9. (A)	**10.** (A,C,D)	**11.** (8)	**12.** (130)
13. (B,C,D)	**14.** (50)	**15.** (A,B)	**16.** (1.5)
17. (1.39)	**18.** (A)	**19.** (NONE)	

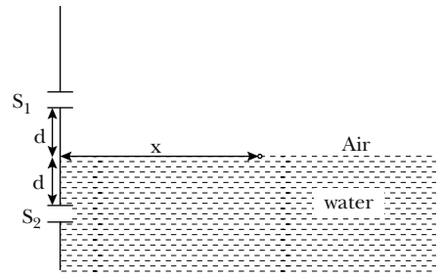
CHAPTER 36 Interference and Diffraction

Q1 A light source, which emits two wavelengths $\lambda_1 = 400$ nm and $\lambda_2 = 600$ nm, is used in a Young's double slit experiment. If recorded fringe widths for λ_1 and λ_2 are β_1 and β_2 and the number of fringes for them within a distance y on one side of the central maximum are m_1 and m_2, respectively, then

(A) $\beta_2 > \beta_1$
(B) $m_1 > m_2$
(C) From the central maximum, 3rd maximum of λ_2 overlaps with 5th minimum of λ_1
(D) The angular separation of fringes for λ_1 is greater than λ_2

(2014, PAPER 1)

Q2 A Young's double slit interference arrangement with slits S_1 and S_2 is immersed in water (refractive index = 4/3) as shown in the figure. The positions of maxima on the surface of water are given by $x^2 = p^2m^2\lambda^2 - d^2$, where λ is the wavelength of light in air (refractive index = 1), 2d is the separation between the slits and m is an integer. The value of p is _____ .

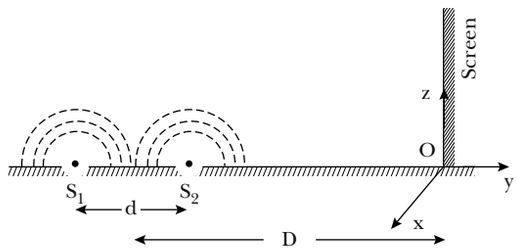


(2015, PAPER 1)

Q3 Four harmonic waves of equal frequencies and equal intensities I_0 have phase angles 0, $\pi/3$, $2\pi/3$ and π. When they are superposed, the intensity of the resulting wave is nI_0. The value of n is _____ .

(2015, PAPER 2)

Q4 While conducting the Young's double slit experiment, a student replaced the two slits with a large opaque plate in the x-y plane containing two small holes that act as two coherent point sources (S_1, S_2) emitting light of wavelength 600 nm. The student mistakenly placed the screen parallel to the x-z plane (for z > 0) at a distance D = 3 m from the mid-point of S_1S_2, as shown schematically in the figure. The distance between the sources d = 0.6003 mm. The origin O is at the intersection of the screen and the line joining S_1S_2, which of the following is(are) true of the intensity pattern on the screen?

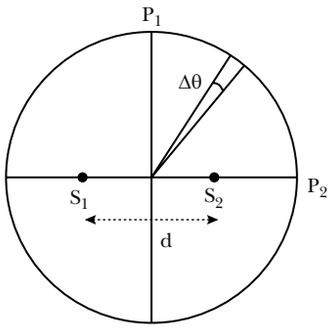


(A) Hyperbolic bright and dark bands with foci symmetrically placed about O in the x-direction.
(B) Semi circular bright and dark bands centred at point O.
(C) The region very close to the point O will be dark.
(D) Straight bright and dark bands parallel to the x-axis.

(2016, PAPER 2)

Q5 Two coherent monochromatic point sources S_1 and S_2 of wavelength λ = 600 nm are placed symmetrically on either side of the centre of the circle as shown. The sources are separated by a distance d = 1.8 mm. This

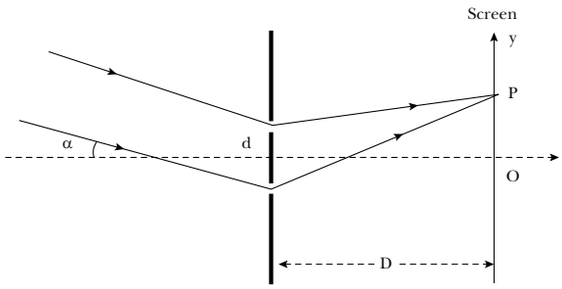
arrangement produces interference fringes visible as alternate bright and dark spots on the circumference of the circle. The angular separation between two consecutive bright spots is $\Delta\theta$. Which of the following options is/are correct?



(A) A dark spot will be formed at the point P_2.
(B) At P_2 the order of the fringe will be maximum.
(C) The total number of fringes produced between P_1 and P_2 in the first quadrant is close to 3000.
(D) The angular separation between two consecutive bright spots decreases as we move from P_1 to P_2 along the first quadrant.

(2017, PAPER 2)

Q6 In a Young's double slit experiment. the slit separation d is 0.3 mm and the screen distance D is 1 m. A parallel beam of light of wavelength 600 nm is incident on the slits at angle α as shown in figure. On the screen, the point O is equidistant from the slits and distance PO is 11.0 mm. Which of the following statements(s) is/are correct?



(A) For $\alpha = \dfrac{0.36}{\pi}$ degree, there will be destructive interference at point O.
(B) Fringe spacing depends on α.
(C) For $\alpha = \dfrac{0.36}{\pi}$ degree, there will be destructive interference at point P.
(D) For $\alpha = 0$, there will be constructive interference at point P.

(2019, PAPER 2)

Answer Key

1. (A,B,C) **2.** (3) **3.** (3) **4.** (B,C) **5.** (B,C)
6. (C)

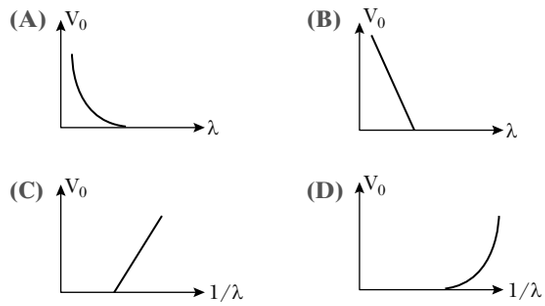
CHAPTER 38 Photons and Matter Waves

Q1 A metal surface is illuminated by light of two different wavelengths 248 nm and 310 nm. The maximum speeds of the photoelectrons corresponding to these wavelengths are u_1 and u_2, respectively. If the ratio $u_1 : u_2 = 2 : 1$ and hc = 1240 eV nm, the work function of the metal is nearly

(A) 3.7 eV **(B)** 3.2 eV
(C) 2.8 eV **(D)** 2.5 eV

(2014, PAPER 2)

Q2 For photo-electric effect with incident photon wavelength λ, the stopping potential is V_0. Identify the correct variation(s) of V_0 with λ and $1/\lambda$.



(2015, PAPER 1)

Q3 In a historical experiment to determine Planck's constant, a metal surface was irradiated with light of different wavelengths. The emitted photoelectron energies were measured by applying a stopping potential. The relevant data for the wavelength (λ) of incident light and the corresponding stopping potential (V_0) are given below:

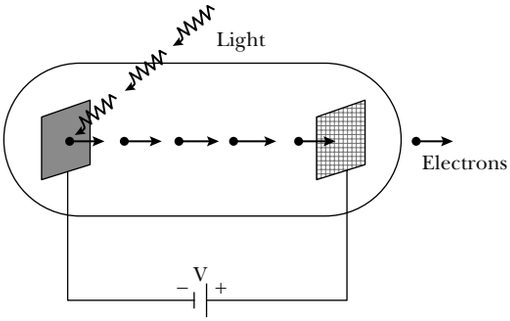
λ (μm)	V_0 (Volt)
0.3	2.0
0.4	1.0
0.5	0.4

Given that $c = 3 \times 10^8$ ms^{-1} and $e = 1.6 \times 10^{-19}$ C. Planck's constant (in units of J s) found from such an experiment is _____.

(A) 6.0×10^{-34}
(B) 6.4×10^{-34}
(C) 6.6×10^{-34}
(D) 6.8×10^{-34}

(2016, PAPER 1)

Q4 Light of wavelength λ_{ph} falls on a cathode plate inside a vacuum tube as shown in the figure. The work function of the cathode surface is ϕ and the anode is a wire mesh of conducting material kept at a distance d from the cathode. A potential difference V is maintained between the electrodes. If the minimum de Broglie wavelength of the electrons passing through the anode is λ_e, which of the following statement(s) is(are) true?



(A) For large potential difference ($V \gg \phi/e$), λ_e is approximately halved if V is made four times
(B) λ_e increases at the same rate as λ_{ph} for $\lambda_{ph} < hc/\phi$
(C) λ_e is approximately halved, if d is doubled
(D) λ_e decreases with increase in ϕ and λ_{ph}

(2016, PAPER 2)

Q5 A photoelectric material having work-function ϕ_0 is illuminated with light of wavelength λ $\left(\lambda < \frac{hc}{\phi_0}\right)$. The fastest photoelectron has a de Broglie wavelength λ_d. A change in wavelength of the incident light by $\Delta\lambda$ results in change $\Delta\lambda_d$ in λ_d. then the ratio $\Delta\lambda_d/\Delta\lambda$ is proportional to _____.

(A) λ_d/λ **(B)** λ_d^2/λ
(C) λ_d^3/λ **(D)** λ_d^3/λ^2

(2017, PAPER 2)

Q6 In a photoelectric experiment a parallel beam of monochromatic light with power of 200 W is incident on a perfectly absorbing cathode of work function 6.25 eV. The frequency of light is just above the threshold frequency so that the photoelectrons are emitted with negligible kinetic energy. Assume that the photoelectron emission efficiency is 100%. A potential difference of 500 V is applied between the cathode and the anode. All the emitted elections are incident normally on the anode and are absorbed. The anode experiences a force $F = n \times 10^{-4}$ N due to the impact of the elections. The value of n is_____.

Mass of the electron $m_e = 9 \times 10^{-31}$ kg and 1.0 eV = 1.6×10^{-19} J.

(2018, PAPER 2)

Q7 A free hydrogen atom after absorbing a photon of wavelength λ_a gets excited from the state n = 1 to the state n = 4. Immediately after that the electron jumps to n = m state by emitting a photon of wavelength λ_e, Let the change in momentum of atom due to the absorption and the emission are Δp_a and Δp_e, respectively. If $\frac{\lambda_a}{\lambda_e} = \frac{1}{5}$, which of the option(s) is/are correct?

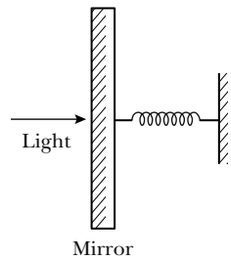
[Use hc = 1242 eV nm; 1 nm = 10^{-9}m, h and c are Planck's constant and speed of light, respectively.]

(A) $\frac{\Delta p_a}{\Delta p_e} = \frac{1}{2}$
(B) The ratio of kinetic energy of the electron in the state n = m to the state n = 1 is $\frac{1}{4}$
(C) $\lambda_e = 418$ nm
(D) m = 2

(2019, PAPER 2)

Q8 A perfectly reflecting mirror of mass M mounted on a spring constitutes a spring-mass system of angular frequency Ω such that $\frac{4\pi M\Omega}{h} = 10^{24}$ m^{-2} with h as Planck's constant. N photons of wavelength $\lambda = 8\pi \times 10^{-6}$ m strike the mirror simultaneously at normal incidence such that the minor gets displaced by 1 μm. If the value of N is $x \times 10^{12}$, then the value of x is _____.

[Consider the spring as massless]



(2019, PAPER 2)

Answer Key

1. (A) **2.** (A,C) **3.** (B) **4.** (A) **5.** (D) **6.** (24) **7.** (B,D) **8.** (1)

CHAPTER 39 Hydrogen Atom

Q1 Consider a hydrogen atom with its electron in the nth orbital. An electromagnetic radiation of wavelength 90 nm is used to ionize the atom. If the kinetic energy of the ejected electron is 10.4 eV, then the value of n is _____ . (hc = 1242 eV nm)

(2015, PAPER 1)

Q2 An electron in an excited state of Li^{2+} ion has angular momentum $3h/2\pi$. The de Broglie wavelength of the electron in this state is $\rho\pi a_0$ (where a_0 is the Bohr radius). The value of p is _____ .

(2015, PAPER 2)

Q3 Highly excited states for hydrogen-like atoms (also called Rydberg states) with nuclear charge Ze are defined by their principal quantum number n, where $n \gg 1$. Which of the following statement(s) is (are) true?
(A) Relative change in the radii of two consecutive orbitals does not depend on Z.
(B) Relative change in the radii of two consecutive orbitals varies as $1/n$.
(C) Relative change in the energy of two consecutive orbitals varies as $1/n^3$.
(D) Relative change in the angular momenta of two consecutive orbitals varies as $1/n$.

(2016, PAPER 1)

Q4 Ahydrogen atom in its ground state is irradiated by light of wavelength 970 Å. Taking $hc/e = 1.237 \times 10^{-6}$ eV m and the ground state energy of hydrogen atom as –13.6 eV, the number of lines present in the emission spectrum is _____.

(2016, PAPER 1)

Q5 An electron in a hydrogen atom undergoes a transition from an orbit with quantum number n_i, to another with quantum number n_f, V_i and V_f are respectively the initial and final potential energies of the electon. If $\frac{V_i}{V_f} = 6.25$, then the *smallest possible n_f is* _____.

(2017, PAPER 1)

Q6 Consider a hydrogen-like ionized atom with atomic number Z with a single electron, In the emission spectrum of this atom, the photon emitted in the n = 2 to n = 1 transition has energy 74.8 eV higher than the photon emitted in the n = 3 to n = 2 transition. The ionization energy of the hydrogen atom is 13.6 eV.

The value of Z is _____.

(2018, PAPER 2)

Q7 A particle of mass m moves in circular orbits with potential energy V(r) = Fr, where F is a positive constant and r is its distance from the origin. Its energies are calculated using the Bohr model. If the radius of the particle's orbit is denoted by R and its speed and energy are denoted by v and E, respectively, then for the nth orbit (here h is the Planck's constant)

(A) $R \propto n^{1/3}$ and $v \propto n^{2/3}$

(B) $R \propto n^{2/3}$ and $v \propto n^{1/3}$

(C) $E = \frac{3}{2}\left(\frac{n^2h^2F^2}{4\pi^2 m}\right)^{1/3}$

(D) $E = 2\left(\frac{n^2h^2F^2}{4\pi^2 m}\right)^{1/3}$

(2020, PAPER 1)

Answer Key

1. (2) **2.** (2) **3.** (A,B,D) **4.** (6) **5.** (5)
6. (3) **7.** (B,C)

CHAPTER 40 All About Atoms

Q1 If λ_{cu} is the wavelength of K_α X-ray line of copper (atomic number 29) and λ_{Mo} is the wavelength of the X-ray line of molybdenum (atomic number 42). then the ratio $\lambda_{cu}/\lambda_{Mo}$ is close to _____.

(A) 1.99 **(B)** 2.14
(C) 0.50 **(D)** 0.48

(2014, PAPER 2)

Q2 In an X-ray tube, electrons emitted from a filament (cathode) carrying current I hit a target (anode) at a distance d from the cathode. The target is kept at a potential V higher than the cathode resulting in emission of continuous and characteristic X-rays. If the filament current I is decreased to $\frac{I}{2}$, the potential difference v is increased to 2V, and the separation distance d is reduced to $\frac{d}{2}$, then

(A) the cut-off wavelength will reduce to half, and the wavelengths of the characteristic X-rays will remain the same.

(B) the cut-off wavelength as well as the wavelengths of the characteristic X-rays will remain the same.

(C) the cut-off wavelength will reduce to half, and the intensities of all the X-rays will decrease.

(D) the cut-off wavelength will become two times larger, and the intensity of all the X-rays will decrease.

(2020, PAPER 2)

Answer Key

1. (B) **2.** (A,C)

CHAPTER 41 The Nucleus

Q1 A nuclear power plant supplying electrical power to a village uses a radioactive material of half life T years as the fuel. The amount of fuel at the beginning is such that the total power requirement of the village is 12.5 % of the electrical power available form the plant at that time. If the plant is able to meet the total power needs of the village for a maximum period of nT years, then the value of n is _____.

(2015, PAPER 1)

Q2 Match the nuclear processes given in column I with the appropriate option(s) in column II

	Column I		Column II
(A)	Nuclear fusion	**(P)**	Absorption of thermal neutrons by $^{235}_{92}U$
(B)	Fission in a nuclear reactor	**(Q)**	$^{60}_{27}Co$ nucleus
(C)	β-decay	**(R)**	Energy production in stars via hydrogen conversion to helium
(D)	γ-ray emission	**(S)**	Heavy water
		(T)	Neutrino emission

(2015, PAPER 1)

Q3 For a radioactive material, its activity A and rate of change of its activity R are defined as $A = -\frac{dN}{dt}$ and $R = -\frac{dA}{dt}$, where N(t) is the number of nuclei at time t. Two radioactive sources P (mean life τ) and Q(mean life 2τ) have the same activity at t = 0. Their rates of change of activities at

$t = 2\tau$ are R_P and R_Q, respectively. If $\frac{R_P}{R_Q} = \frac{n}{e}$, then the value of n is _____.

(2015, PAPER 2)

Q4 A fission reaction is given by ${}^{236}_{92}U \rightarrow {}^{140}_{54}Xe + {}^{94}_{38}Sr + x + y$, where x and y are two particles. Considering ${}^{236}_{92}U$ to be at rest, the kinetic energies of the products are denoted by K_{xe}, K_{Sr}, K_x(2MeV) and K_y(2MeV), respectively. Let the binding energies per nucleon of ${}^{236}_{92}U$, ${}^{140}_{54}Xe$ and ${}^{94}_{38}Sr$ be 7.5 MeV, 8.5 MeV and 8.5 MeV respectively. Considering different conservation laws, the correct option(s) is(are) _____.

(A) x = n, y = n, K_{Sr} = 129MeV, K_{Xe} = 86 MeV
(B) x = p, y = e^-, K_{Sr} = 129 MeV, K_{Xe} = 86 MeV
(C) x = p, y = n, K_{Sr} = 129 MeV, K_{xe} = 86 MeV
(D) x = n, y = n, K_{Sr} = 86 MeV, K_{xe} = 129 MeV

(2015, PAPER 2)

Q5 The isotope ${}^{12}_{5}B$ having a mass 12.014 u undergoes β-decay to ${}^{12}_{6}C$. ${}^{12}_{6}C$ has an excited state of the nucleus (${}^{12}_{6}C^*$) at 4.041 MeV above its ground state. If ${}^{12}_{5}B$ decays to ${}^{12}_{6}C^*$, the maximum kinetic energy of the β-particle in units of MeV is _____.

(1 u = 931.5 MeV/c^2, where c is the speed of light in vacuum).

(2016, PAPER 1)

Q6 The electrostatic energy of Z protons uniformly distributed throughout a spherical nucleus of radius R is given by

$$E = \frac{3}{5}\frac{Z(Z-1)e^2}{4\pi\varepsilon_0 R}$$

The measured masses of the neutron, ${}^{1}_{1}H$, ${}^{15}_{7}N$ and ${}^{15}_{8}O$ are 1.008665 u, 1.007825 u, 15.000109 u and 15.003065u, respectively. Given that the radii of both the ${}^{15}_{7}N$ and ${}^{15}_{8}O$ nuclei are same, 1 u = 931.5 MeV/c^2 (c is the speed of light) and $e^2/(4\pi\varepsilon_0)$ = 1.44 MeV fm. Assuming that the difference between the binding energies of ${}^{15}_{7}N$ and ${}^{15}_{8}O$ is purely due to the electrostatic energy, the radius of either of the nuclei is _____.

(1 fm = 10^{-15}m)

(A) 2.85 fm **(B)** 3.03 fm
(C) 3.42 fm **(D)** 3.80 fm

(2016, PAPER 2)

Q7 An accident in a nuclear laboratory resulted in deposition of a certain amount of radioactive material of half-life 18 days inside the laboratory. Tests revealed that the radiation was 64 times more than the permissible level required for safe operation of the laboratory. What is the minimum number of days after which the laboratory can be considered safe for use?

(A) 64 **(B)** 90
(C) 108 **(D)** 120

(2016, PAPER 2)

Q8 ${}^{131}I$ is an isotope of Iodine that β decays to an isotope of Xenon with a half-life of 8 days. A small amount of a serum labelled with ${}^{131}I$ is injected into the blood of a person. The activity of the amount of ${}^{131}I$ injected was 2.4×10^5 Becquerel (Bq). It is known that the injected serum will get distributed uniformly in the blood stream in less than half an hour. After 11.5 hours, 2.5 ml of blood is drawn from the person's body, and gives an activity of 115 Bq. The total volume of blood in the person's body, in liters is approximately _____ (you may use $e^x \approx 1 + x$ for $|x| \ll 1$ and ln 2 ≈ 0.7).

(2017, PAPER 1)

Q9 In a radioactive decay chain, ${}^{232}_{90}Th$ nucleus decays to ${}^{212}_{82}Pb$ nucleus. Let N_α and N_β be the number of α and β^- particles, respectively, emitted in this decay process. Which of the following statements is (are) true?

(A) $N_\alpha = 5$ **(B)** $N_\alpha = 6$
(C) $N_\beta = 2$ **(D)** $N_\beta = 4$

(2018, PAPER 2)

Q10 In a radioactive sample ${}^{40}_{19}K$ nuclei either decay into stable ${}^{40}_{20}Ca$ nuclei with decay constant 4.5×10^{-10} per year or into stable ${}^{40}_{18}Ar$ nuclei with decay constant 0.5×10^{-10} per year. Given that in this sample all the stable ${}^{40}_{20}Ca$ and ${}^{40}_{18}Ar$ nuclei are produced by the ${}^{40}_{19}K$ nuclei only. In time $t \times 10^9$ years, if the ratio of the sum of stable ${}^{40}_{20}Ca$ and ${}^{40}_{18}Ar$ nuclei to the radioactive ${}^{40}_{19}K$ nuclei is 99, the value of t will be _____.

[Given: ln10 = 2.3]

(A) 1.15 **(B)** 4.6
(C) 9.2 **(D)** 2.3

(2019, PAPER 1)

Q11 Suppose a ${}^{226}_{88}Ra$ nucleus at rest and in ground state undergoes α-decay to a ${}^{222}_{86}Rn$ nucleus in its excited state. The kinetic energy of the emitted α particle is found to be 4.44 MeV. ${}^{222}_{86}Rn$ nucleus then goes to its ground state by γ-decay. The energy of the emitted γ photon is _____ keV.

[Given: atomic mass of ${}^{226}_{88}Ra$ = 226.005 u, atomic mass of ${}^{222}_{86}Rn$ = 226.000 u, atomic mass of α particle = 4.000 u. 1 u = 931 MeV/c^2, c is speed of the light]

(2019, PAPER 2)

Answer Key

1. (3)	**2.** ((A) → (R, T); (B) → (P, S); (C) → (P, Q, R, T); (D) → (P, Q, R, T))	**3.** (2)	**4.** (A)
5. (9)	**6.** (C)	**7.** (C)	**8.** (5)
9. (A,C)	**10.** (C)	**11.** (135)	

ANSWERS WITH EXPLANATION

CHAPTER 22 Electric Charges and Fields

1. The electric field formulas are

Point charge: $E_1(r) = \frac{Q}{4\pi \epsilon_0 r^2}$

Infinite Wire: $E_2(r) = \frac{\lambda}{2\pi \epsilon_0 r}$

Infinite Plane: $E_3(r) = \frac{\sigma}{2\epsilon_0}$ (independent of r)

Given $E_1(r_0) = E_2(r_0) = E_3(r_0)$

$$E_2(r_0) = E_3(r_0) \Rightarrow \frac{\lambda}{2\pi \epsilon_0 r_0} = \frac{\sigma}{2\epsilon_0} \Rightarrow r_0 = \frac{\lambda}{\pi\sigma}$$

2. We calculate the field E at distance R from the center for each sphere

Sphere 1 (Radius R/2): Point P is outside

$$E_1 = \frac{1}{4\pi \epsilon_0} = \frac{Q}{R^2}$$

Sphere 2 (Radius R): Point P is on the surface

$$E_2 = \frac{1}{4\pi \epsilon_0} = \frac{2Q}{R^2}$$

Sphere 3 (Radius 2R): Point P is inside. For a Uniform sphere

$$E_{in} = \frac{1}{4\pi \epsilon_0} = \frac{Q_{total} \cdot R}{R^3_{max}}$$

$$E_3 = \frac{1}{4\pi \epsilon_0} \frac{4Q \cdot R}{(2R)^3} = \frac{1}{4\pi \epsilon_0} \frac{4QR}{8R^3}$$

$$= \frac{1}{4\pi \epsilon_0} \frac{Q}{2R^2}$$

Comparing magnitudes $E_2 > E_1 > E_3$

3. The charge q is at (0, b)

P: All positive, Horizontal components cancel due to symmetry (Q_1 vs Q_2 and Q_3 vs Q_4) Vertical component add up. Direction: +y(3) Q: Q_1, Q_2 (+x side) are positive; Q_3, Q_4 (–x side) are negative. Positive charges push q left, negative charges pull q left. Vertical components cancel Direction: –x(2) R: Q_1 and Q_4 (2a, –2a) positive: Q_2, Q_3 (a, –a) negative. Q_2, Q_3 are closer and pull q down Q_1, Q_4 are further and push q up. Net force is –y(4)

S: Q_1, Q_3 positive; Q_2, Q_4 negative. Summing the vectors based on positions results in a net +x(1) direction.

4. Geometry: The line charge is paralle to the y-axis at a distance of z = 3a/2. The rectangular surface ABCD lies in the x – y plane, with sides along the y-direction. (length l) and x direction (width a from –a/2 to a/2)

flux Calculation: The total flux passing through the rectangular plane is equivalent to the flux through a segment of a cylindrical surface surrounding the line change. The solid angle subtended by the rectangle at the line charge dictates the fraction of total flux $\frac{\lambda L}{\epsilon_0}$ passing through it.

The flux is calculated to be $\phi = \frac{\lambda L}{6\epsilon_0}$

Comparing $\phi = \frac{\lambda L}{6\epsilon_0}$

$\boxed{n = 6}$

5. Charge +q executes simple harmonic motion while charge –q continues moving in the direction of its displacement.

At the equilibrium position (center) the +q charge is in stable equilibrium (restoring force α – x), resulting in SHM while the –q charge is in unstable equilibrium, experiencing a net force in the direction of its displacement.

6. The expression $\vec{E} = \frac{\rho}{3\epsilon_0}\vec{a}$ shows that the field is uniform (constant throughout the cavity), and its magnitude and direction depend solely on the vector $\vec{a}$.

7. F(t) = qE(t) = (1.0 C) (1.0 Sin (10^3t)

= Sin (10^3t)N

$$a(t) = \frac{F(t)}{m} = \frac{\text{Sin}(10^3 t)}{10^{-3}} = 10^3 \text{Sin}(10^3 t) \text{m/s}^2$$

v(t) = ∫a(t) dt = ∫10^3 Sin(10^3t) dt

= –Cos(10^3t) + C

Since v(0) = 0, C = 1, So, v(t) = 1 – Cos (10^3t)

The maximum speed occurs when cos(10^3t) = –1

yielding v_{max} = 1 – (–1)

= 2.0 m/s

8. P → 5; Q → 3; R → 1, 4; S → 2

P: E independent of d → 5 (Infinite plane charge $E = \frac{\sigma}{2\epsilon_0}$

Q: $E \propto 1/d \rightarrow 3$ $\left(\text{Infinite line charge, } E = \frac{2k\lambda}{d}\right)$

R: $E \propto 1/d^2 \rightarrow 1$ (point charge), 4 (Two infinite wires, dipole-like at distance)

S: $E \propto 1/d^3 \rightarrow 2$ (Small dipole)

9. The dipole moment is $\vec{P} = \frac{p_0}{\sqrt{2}}(\hat{i} + \hat{j})$ making a 45° angle with the x-axis. For the potential to be constant on a circle of radius R, the external electric field $\vec{E}_0$ must exactly cancel the tangential component of the dipole's potential.

Point B lies on the perpendicular bisector (equatorial line) of the dipole. At this point, the electric field from the dipole and the uniform field $\vec{E}_0$ are equal and opposite, resulting in a total electric field $\vec{F}_B = 0$.

Using the condition for an equipotential circle, the relation is

$$E_0 = \frac{1}{4\pi \epsilon_0}\frac{P_0}{R^3}$$

$$R = \left(\frac{P_0}{4\pi \epsilon_0 E_0}\right)^{1/3}$$

10. Determine Acceleration: The electric field $\vec{E} = -400\sqrt{3}\,\hat{j}$ N/C is downward. The acceleration

$$a = \frac{qE}{m} = (10^{10}) \times 400\sqrt{3} = 4\sqrt{3} \times 10^{12}\,\text{m/s}^2$$

Projectile Motion: This is a projectile motion problem where gravity is replaced by electric aceleration.

Range $R = \dfrac{U^2 \operatorname{Sin}(2\theta)}{a}$

Placing R = 5m, u = 2×10^6 m/s and a = $4\sqrt{3} \times 10^{12}$ m/s^2 we solve for

$$\operatorname{Sin}(2\theta) = \frac{\sqrt{3}}{2}$$

$2\theta = 60°$ or $120°$

$\theta = 30°$ or $60°$

11. Equilibrium Condition: The electric force must balance the weight of the drop

$qE = mg$

$$E = \frac{V}{d} = \frac{200}{0.1} = 2 \times 10^4\,\text{V/m}$$

$$m = \text{Density} \times \text{Volume} = 900 \times \frac{4}{3}\pi(8 \times 10^{-7})^3$$

$$q = \frac{mg}{E} = \frac{(900 \times \frac{4}{3}\pi \times (8 \times 10^{-7})^3) \times 10}{2 \times 10^4}$$

$n = \dfrac{q}{e}$ Plugging in $e = 1.6 \times 10^{-19}$ C

$\boxed{n = 6}$.

12. The work done in bringing the dipole from infinity to its final position is equal to the change in potential energy of the system

$$W = \Delta U = U_{\text{final}} - U_{\text{initial}}$$

Using the geometry provided ($h = l - l \cos \alpha$) and the potential energy of the change in the dipole's field, the calculation yields w = 2mgh.

13. Let $\theta = \alpha/2$ The equilibrium equation are

$T \cos\theta = mg$

$T \sin\theta = Fe$

Dividing these gives: $\tan\theta = \dfrac{Fe}{mg}$

when immersed in a dielectric liquid the electrostatic force is reduced by the dielectric constant $k\left(F'_e = \dfrac{F_e}{k}\right)$ and the weight is reduced by buoyancy ($mg' = mg - V\rho_1 g$)

$$\tan\theta = \frac{F'_e}{mg} = \frac{F_e/k}{mg - V\rho_1 g}$$

$k(mg - V\rho_1 g) = mg$

$k(V\rho_s g - V\rho_1 g) = V\rho_s g$

$k(\rho_s - \rho_1) = \rho_s$

$$\rho_s = \frac{k\rho_1}{k-1}$$

$k = 21$ and $\rho_1 = 800$ kg/m^3

$$\rho_s = \frac{21 \times 800}{21 - 1} = \frac{16800}{20} = 840\ \text{kg/m}^3.$$

CHAPTER 23 Gauss' Law

1. Solid angle subtended by the flat surface at the position of the charge.

$$\Omega = 2\pi(1 - \cos\theta)$$

Since $\theta = 45°$

$$\Omega = 2\pi(1 - \cos 45°)$$

$$= 2\pi\left(1 - \frac{1}{\sqrt{2}}\right)$$

flux entering through the curved surface is equal to the flux leaving through the flat surface

ϕcurved = ϕflat

$$\phi\text{curved} = \frac{Q}{4\pi\varepsilon_0} \times 2\pi\left(1 - \frac{1}{\sqrt{2}}\right)$$

$$= \frac{Q}{2\epsilon_0}\left(1 - \frac{1}{\sqrt{2}}\right)$$

2. A $\rightarrow$ True $\rightarrow$ Flux through the shell: $\dfrac{3R\lambda}{\epsilon_0}$ (Gauss's law)

B $\rightarrow$ True $\rightarrow$ $E_z = 0$ everywhere on the shell due to symmetry.

3. A $\rightarrow$ True $\rightarrow$ If the cylinder is inside the shells,

flux $\phi = 0$

B $\rightarrow$ True $\rightarrow$ If the cylinder fully encloses the shells,

flux $\phi = Q/\epsilon_0$

D $\rightarrow$ True $\rightarrow$ $\phi = Q/5\epsilon_0$

4. Total charge on the disc $\rightarrow Q = \dfrac{\pi\sigma_0 R^2}{3}$

Total flux through enclosing sphere $\rightarrow \phi_0 = \dfrac{Q}{\epsilon_0}$

Flux through sphere of radius $\dfrac{4R}{5} \rightarrow \phi = \dfrac{112}{375}\phi_0$

Ratio $\dfrac{\phi_0}{\phi} = \dfrac{375}{112} \approx 6.40$

CHAPTER 24 Electric Potential

1. **(A)** $U_1 = \frac{U_0}{2}\left[1-\left(\frac{x}{a}\right)^2\right]$

   U_{min} at $1-\left(\frac{x}{a}\right)^2 = 0$

   $x = \pm a$, $f = 0$ at $x = \pm a$

   (B) $U_2 = \frac{U_0}{2}\left(\frac{x^2}{A^2}\right)$

   (C) $U_3 = \frac{U_0}{2}\left(\frac{x}{a}\right)^2 \frac{x^2}{e^{a2}}$

   (D) $U_4 = \frac{U_0}{2}\left[\frac{x}{a}-\frac{1}{3}\left(\frac{x}{a}\right)^3\right] = \frac{U}{3}$

   At $x = -a$

   $U_4 = \frac{4}{3}\frac{U_0}{2} = -\frac{U_0}{3}$

   At $x = a$

   $U_4 = \frac{2}{3}\frac{U_0}{2} = \frac{U_0}{3}$

   $\frac{1}{a} - \frac{x^3}{a^3} = 0$

   $\frac{1}{a} - \frac{x^3}{a^3} = x = \pm a$

2. $k_BT \approx FL$, $\varepsilon \approx \frac{Q^2}{FL^2}$ and $n \approx L^{-3}$

   where F is force, Q is charge and L is length.

3. $V_0 = \frac{\sigma 4\pi R^2}{4\pi\varepsilon_0 R} \Rightarrow \sigma = \frac{V_0\varepsilon_0}{R}$

   So V at R/2

   $= V_0 - \frac{1}{4\pi\varepsilon_0}\frac{2}{R}\frac{V_0\varepsilon_0}{R}\alpha 4\pi R^2 = V_0(1-2\alpha)$

   and V at center $V_0 - \frac{1}{4\pi\varepsilon_0}\frac{1}{R}\frac{V_0\varepsilon_0\alpha 4\pi R^2}{R}$

   $V_0(1-\alpha)$

CHAPTER 25 Capacitance

1. Split into two parallel capacitors

   dielectric 1/3 area, $C_1 = K_{\epsilon_0} A/3d$

   air 2/3 area, $C_2 = \epsilon_0 2A/3d$

   Total $C = C_1 + C_2$

   So $C/C_1 = (2 + K)/K$

   Charge $Q_1/Q_2 = C_1/C_2 = K/2$, field $E_1/E_2 = 1/K$

2. Initial energy $U = Q_2/2C$, Dielectric (K) inserted, battery off : $C' = KC$, Q same, so

   $U' = \frac{Q^2}{2KC} = \frac{U}{K}$

3. Series $\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$

   If $C_1 = C_2 = C$, $C_{eq} = C/2$

   Voltage splits equally.

4. Dielectric (K = 2) in half area

   $C_1 = 2_{\epsilon_0}(A/2)/d$, $C^2 = \epsilon_0(A/2)/d$, $C_{eq} = C_1 + C_2$

   $= 1.5_{\epsilon_0} A/d$

5. Dielectric (K) inserted, battery off

   $C' = KC$, Q constant, $V' = V/K$

   energy $U' = \frac{Q^2}{2KC}$

6. Dielectric over 1/2 area

   $C_1 = K_{\epsilon_0} A/2d$, $C_2 = \epsilon_0 A/2d$

   Ctotal $= (K + 1)_{\epsilon_0} A/2d$

7. Dielectric (K = 1.5) over 2/3 area

   $C1 = 1.5_{\epsilon_0}(2A/3)/d$, $C_2 = \epsilon_0(A/3)/d$

   $C_{total}/C_0 = (1.5 \times 2/3 \times 1/3) = 1.30$

CHAPTER 26 Current and Resistance

1. Wire in Series

   Each wire has resistance R/4

   Since two wires are in series, the total resistance is R/2

   Power is inversely proportional to resistance

   Pnew = P/2

   Since power is half, heating time is

   $t = 4 \times \frac{1}{2} = 2$ min

   Wire in parallel

   $R_{parallel} = R/8$

   Pnew = 8P

   since power is 8 time greater, heating is

   $t = \frac{4}{8} = 0.5$ min.

2. For Iron

   $R_{Fe} = \frac{\rho_{Fe} \times 50 \times 10^{-3}}{(2 \times 10^{-3})^2} = 1250\mu\Omega$

   for Aluminum

   $R_{Al} = \frac{\rho_{Al} \times 50 \times 10^{-3}}{(49+4) \times 10^{-6}} = 30\mu\Omega$

   $R_{eq} = \frac{1250 \times 30}{1280} = \frac{1875}{64}\mu\Omega$

3. $R_{eq} = 13/2\Omega$

   current supplied by cell = 1A

4. The graph should start at j0 at t = 0

   the graph should show an exponential decay, approaching zero asymptotically as time increases.

   option C is correct as it represents an exponentially decreasing function starting from a maximum at t = 0

5. As the filament breaks, its temperature increases, shifting emitted light to higher frequencies (Wien's law)

   since resistance R increases with temperature and voltage remains constant power consumption $P = V^2/R$ decreases towards the end of the bulb's life.

CHAPTER 27 Circuits

1. Use Kirchhoff's Laws: loop rule ($\sum V = 0$) and junction rule ($\sum I = 0$). For two loops with resistors and EMFs, solve for current.
2. Single loop:
   $I = \mathcal{E}/Req$
   If $\mathcal{E} = 10V$, $Req = 2\Omega$
   then $I = 10/2 = 5A$
3. Use Kirchhoff's loop rule to find $V_A - V_B$, for a loop with $\mathcal{E} = 6V$, $R = 2\Omega$
   $I = 2A$, $V_{drop} = IR$
4. RC circuit time constant $\tau = RC$. Charging
   $V_C = \mathcal{E}(1 - e^{-t/\tau})$
5. Ammeter (low resistance) in series voltmeter (high resistance) in parallel
6. Work done by battery
   $W = q\mathcal{E}$
   If $\mathcal{E} = 12V$, Power, $P = \mathcal{E}I$
7. Discharging $Q = Q_0 e^{-t/RC}$
   If $t = RC$, then $Q = Q_{0/e}$
8. Two loops: $\mathcal{E}_1 = 10V$, $R_1 = 2\Omega$, $R_2 = 1\Omega$
   Solve using Kirchhoff's: $I_1 = 5.56A$
9. Use node method or Kirchhoff's to find $V_A - V_B$ for resistors in series / parallel
   Calculate drops.
10. Charging
    $V_C = \mathcal{E}(1 - e^{-t/RC})$
    For $t = 0.5$ RC
    $V_{c/\varepsilon} = 1 - e^{-0.5}$
    ≈ 0.27

CHAPTER 28 Magnetic Force

1. $R_1 = \dfrac{mv}{qB_1} R_2 = \dfrac{mv}{qB_2}$

   ratio $\dfrac{R_1}{R_2} = \dfrac{B_2}{B_1} = \dfrac{1/3}{1/9} = 3$

2. Given that $I_1 = I_2$
   $ne\,A_1V_1 = ne\,A_2V_2$
   substituting area as $A = d'w$
   $d_1w_1v_1 = d_2w_2v_2$
   The potential difference across MK is given by
   $V = Bvw$

   So $\dfrac{V_1}{V_2} = \dfrac{v_1w_1d_1}{v_2w_2d_2}$

3. Since $I_1 = I_2$
   $n_1w_1d_1v_1 = n_2w_2d_2v_2$
   The potential difference is given by
   $V = Bvw$
   Taking the ratio

   $\dfrac{V_1}{V_2} = \dfrac{B_1v_1w_1}{B_2v_2w_2}$

   Using the current relation

   $\dfrac{V_1}{V_2} = \dfrac{B_1n_1}{B_2n_2}$

4. From the Biot-Savart law, the total magnetic field at the center due to a symmetric current – carrying star shaped loop can be expressed as

   $$B = \frac{\mu_0 I}{4\pi a} \times 6(\sqrt{3} + 1)$$

CHAPTER 29 Magnetic Fields Due to Currents

1. $\left|\vec{B}_{wires}\right| = \left|\vec{B}_{loop}\right|$

   $2 = \dfrac{\mu_0 I}{2\pi\sqrt{a^2 + h^2}} \times \dfrac{a}{\sqrt{a^2 + h^2}} = \dfrac{\mu_0 I a^2}{2\left(a^2 + h^2\right)^{3/2}}$

   $h \approx 1.2a$

2. $\tau = MB \sin\theta = I\pi a^2 \times 2 \times \dfrac{\mu_0 I}{2\pi d} \sin 30°$

   $= \dfrac{\mu_0 I^2 a^2}{2d}$

3. lorentz force
   $F = q(E + V \times B)$
   Consider electric and magnetic contributions apply vector analysis
4. Ampere's Force Law

   $$F \frac{\mu_0 I_1 I_2 L}{2\pi d}$$

   Parallel currents attract, anti-parallel currents repel, Use Ampere's force law Determine force direction.
5. Ampere's Circuital Law

   $$\oint B \cdot dl = \mu_0 I_{enc} v$$

   Used to compute magnetic fields in symmetric setups. Integrate field Contribution.
6. Magnetic Field in a Solenoid
   $B = \mu_0 nI$
7. $R' = \dfrac{p}{qB}$

   $(R' - R)^2 + R^2 = R'$

   $R' = \dfrac{13}{8} R$

8. Magnetic force on a current
   $F = BIL$
   Use right hand rule.

9. Arrange speed along x- axis

$$= \frac{\text{total distance}}{\text{total time}}$$

$$= \frac{2R + 2r}{\frac{\mu R}{V_0} + \frac{\pi v}{V_0}} = \frac{2V_0}{\pi} = 2 \text{ m/s}$$

CHAPTER 31 Electromagnetic Induction

1. Faraday's law : $\varepsilon = -d\phi/dt$

   where $\phi = B \cdot A$

   If B changes or loop area changes $\varepsilon \neq 0$

   A → EMF induced if B varies

   D → Current depends on dB/dt

2. Motional EMF $\varepsilon = Blv$

   For B = 2T, l = 2m, v = 2m/s, $\varepsilon = 2 \times 2 \times 2 = 8V$

3. Lenz's laws : Induced current oppose change in flux

   If magnet approaches, flux increases current flows to oppose.

   C → current direction opposes motion

   D → flux change causes EMF

4. RL circuit growth $I = (V/R)(1 - e^{-t/\tau}), \tau = L/R$

   A → current increases exponentially

   D → time constant depends on L/R.

5. $\varepsilon = Blv$, direction by right hand rule

   A → EMF depends on r

   B → current flows in loop

   C → force oppose motion

6. Energy in inductor $U = \frac{1}{2}LI^2$

   B → energy stored in magnetic field

   D → power P = IE

7. Induced E-field : $\oint E \cdot dl = \frac{-d\phi}{dt}$

   A → non-conservative field

   B → depends on dB/dt

   D → induces current

8. RL decay : $J = I_0 e^{-t/\tau}, \tau = L/R$

   At $t = \tau$, $I/I_0 = e^{-1} \approx 0.63$

9. $\varepsilon = -d\phi/dt$, If B increases linearly ε is constant

   B → EMF is constant

10. Mutual inductance $\varepsilon_2 = MdI_1/dt$

    For M = 5H, $dI_1/dt = 11A/S$

    $\varepsilon_2 = 5 \times 11 = 55V$

CHAPTER 32 Electromagnetic Oscillations and Alternating Current

1. Voltage $v = v_0 \sin wt$

   Charge $q = Q \sin wt$ where $Q = 2 \times 10^{-3}$ C

   At $t = \frac{7\pi}{6w}$ Current $I - \frac{3}{2} I_0$ (anticlockwise)

   Immediate current after $t = \frac{7\pi}{6w}$: $\iota = 10A$

   charge flow $= 2 \times 10^{-6}$ C

2. $$I = \frac{V_0}{\sqrt{\left[Lw - \frac{1}{Cw}\right] + R^2}}$$

   $f_R = \frac{1}{\sqrt{LC}}$ Resonance frequency

   If $w \gg 10^6$ rad/s then circuit behaves as inductive circuit.

CHAPTER 34 Geometrical Optics: Reflection

1. For refraction through the lens

   $1/v - 1/30 = 1/f$

   $2/v = 1/u$

   $v = -2u = 60cm$

   $f = +20cm$

   for reflection

   $1/10 + 1/30 = 2/R$

   R = 30cm

   Refractive index

   $n - 1 = 1/Rf = 1/20$

   $n = 5/2$

   Thus the faint image is exact and virtual.

2. $\tan\theta = \frac{x_0}{f + x_0}$

   $$\frac{h}{x + 2f} = \frac{x_0}{f + x_0}$$

   $$\frac{h}{x_0}(f + x_0) = x + 2f$$

   $$\frac{h}{x_0}(f + x_0) = \frac{h}{x_0}(f - x_0) + 2f$$

   $2hx_0 = 2fx_0$

   $\therefore h = f$

CHAPTER 35 Geometrical Optics: Refraction

1. Use Snell's law
   $n_1 \text{Sin}\theta_1 = n_2 \text{Sin}\theta_2$
   For air ($n_1 = 1$) to glass ($n_2 = 1.5$), $\theta_2 < \theta_1$
   A → refraction bends toward normal → true
   C → refractive index ratio affects angle → true
2. Critical angle $\theta_C = \text{Sin}^{-1}\left(\frac{n_2}{n_1}\right)$
   for glass ($n_1 = 1.5$) to air ($n_2 = 1$), $\theta_C = \text{Sin}^{-1}\left(\frac{1}{1.5}\right) \approx 41.8$
   TIR occurs if incidence > θ_C
   light reflects if angle > 41.8°
3. lens formula
   $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$
   for convex lens ($f > 0$) object beyond $2f$ gives real image
   Calculate v with typical $u = -2f$, $v = 2f$
4. Minimum deviation $\delta_m = 2i - A$ where $A = 60'$
   $n = \sqrt{2}$.
   $\text{Sin}(A + \delta_m)/2 = n\text{Sin}\left(A/2\right)$, So $\delta_m = 30'$
5. Refraction $n_2/v - n_1/u = (n_2 - n_1)/R$
   for air ($n_1 = 1$) to glass ($n_2 = 1.5$), R > 0
   Solve for v with typical u, R
6. Convex lens (f = 10cm), object at $2f$, image at $2f$ plane mirror reflects back, image retraces. Number of passes or foci is 2.
7. $n_1 \text{Sin}\theta_1 = n_2 \text{Sin}\theta_2$
   for slab, apparent depth = real depth/n
   If $n = 4/3$, shift occurs
8. For $n = \sqrt{2}$, $\theta_C = 45°$, TIR if $\theta > 45°$
   A → TIR at 45°
   C → ray emerges perpendicular
   D → depends on n hold.
9. Microscope magnification $M = \left(2/f_o\right)\left(D/f_e\right)$ for f_o, f_e given, calculate M.
10. $1/f = 1/v - 1/u$, for $u > f$, real image,
    A → real image
    C → inverted.
    D → magnification varies
11. $n\text{Sin}\theta = (n - m\Delta n) \times \text{Sin}90°$
    $m = \frac{n}{2\Delta n}$
    m = 8.
12. The area of A over which the light falls $\frac{A}{A_{lens}} = \left(\frac{2}{20}\right)^2 = \frac{1}{100}$
    So intensity at A = 100 × 1.3 = 130 kw/m²
13. $\text{Sin}\theta_C = \frac{n_2}{n_1}$, for $n_1 = 1.5$, $\theta_C = 41.8°$
    B → angle > 45° reflect
    C → depends on n
    D → no refraction
14. $1.5\ \text{Sin}\theta_C = 1.44\ \text{Sin}90°$
    $\text{Sin}\theta_C = \frac{24}{25}$
    $1 = \frac{x}{\text{Sin}\theta_C} = \frac{25}{4}x$
    total length for light to travel
    $l' = \frac{25}{4} \times 9.6 = 10\text{ m}$
    $\therefore$ time $= \frac{l'}{c/1.5} = 5 \times 10^{-8}$ Sec => 50×10^{-9} Sec
    t = 50
15. $n_2/v - n_1/u = (n_2 - n_1)/R$, for convex R, real image
    A → real image B → depends on u are true.
16. Apparent depth = real depth/n. If real = 3m apparent = 3m,
    $n = 3/2 = 1.5$.
17. $n_1 \text{Sin}\theta_1 = n_2 \text{Sin}\theta_2$
    for $\theta_1 = 45°$, $\theta_2 = 32°$, $n_2 = \text{Sin}45°/\text{Sin}32° \approx 1.39$
18. $n = \text{Sin}((A + \delta m)/2)/\text{Sin}\left(A/2\right)$
    for A = 60°, δm = 30°, $n = \sqrt{2}$
19. If mirror misaligned or no interference no valid option.

CHAPTER 36 Interference and Diffraction

1. A → $\beta_2 > \beta_1$ (fringe width $\beta \alpha \lambda$, and $\lambda_2 > \lambda_1$)
   B → $m_1 > m_2$ (more fringes for smaller β, so $m_1 > m_2$)
   C → 3rd max of λ_2 overlaps with 5th min of λ_1
2. In young's double slit experiment, the fringe positions in air are given by
   $x = m\frac{\lambda L}{d}$
   When immersed in water (n = 4/3) the wavelength change to $\lambda' = \frac{\lambda}{n} = \frac{3\lambda}{4}$
   new fringe position are
   $\chi^1 = \frac{m\lambda' L}{d} = m\frac{\left(3\lambda/4\right)L}{d} = m\frac{3\lambda L}{4d}$

Given in the problem

$x^2 = p^2 m^2 \lambda^2 - d^2$

By comparing with

$x^2 = m^2(9\lambda^2 L^2/16d^2)$

$P^2 = 9 \Rightarrow P = 3$

3. The I and IV waves interfere destructively so, considering only the interference of the second and third wave

$$I_{net} = I_0\left(\frac{1}{3}+\frac{1}{3}+2+\frac{1}{3}\times\cos\frac{2\pi}{3}\right)$$

Since $\cos\frac{2\pi}{3} = -\frac{1}{2}$ we get

$$I_{net} = I_0\left(\frac{1}{3}+\frac{1}{3}+2\times\frac{1}{3}\times\left(-\frac{1}{2}\right)\right)$$

$$I_{net} = I_0\left(\frac{2}{3}-\frac{1}{3}\right) = \frac{3I_0}{3} = I_0$$

The number of contributing waves is n =3.

4. Since the S_1 S_2 line is perpendicular to the screen, the interference pattern consist of concentric semicircles.

At point O, the path difference is given by

$$\frac{3}{2}(s_1O - s_2O) = \frac{9\pi}{2}$$

Substituting value

$$\frac{9\pi}{2} = \frac{600\times3\times10^{-9}\times200\times1}{600\times10^{-9}}$$

$$\frac{9\pi}{2} = \pi$$

Since this corresponds to a path difference of an odd multiple of $\frac{\lambda}{2}$, destructive interference occurs leading to darkness near O.

5. Path difference at point P

$\Delta x = d\cos\theta$

At P_1, $\theta = 90° \Rightarrow \Delta x = o \rightarrow$ maxima

At P_2, $\theta = 90° \Rightarrow \Delta x = d = n\lambda$

$$n = \frac{1.8\times10^{-3}}{600\times10^{-9}} = 3000 \rightarrow \text{maxima}$$

For maxima at P, $d\cos\theta = n\lambda$

Or $d[-\sin\theta]d\theta = (dn)\lambda$

Angular fringe width $\left|\frac{d\theta}{dn}\right| = \frac{\lambda}{d\sin\theta}$

6. Given

$$\alpha = 0.36° = \frac{1}{500} \text{ radian}$$

Path difference at O

$$d\sin\alpha = 0.3\times10^{-3}\times\frac{1}{500} = 6\times10^{-7} = \lambda$$

Path difference at P

$$d(\sin\alpha + \sin\theta) = d\left(\frac{1}{500}+\frac{1}{1000}\right)$$

Path difference at P is $5{\cdot}5\lambda$

CHAPTER 38 Photons and Matter Waves

1. A photon is a quantum particle of light with energy $E = h\nu$

It has no rest mass but has momentum $P = \frac{h}{\lambda}$

2. Einstein's photoelectric equation

$K_{max} = h\nu - \phi$

where K_{max} is the maximum kinetic energy of the ejected electron ϕ is the work function and $h\nu$ is the incident photon energy.

Threshold frequency (ν_0)

$$\nu_0 = \frac{\phi}{h}$$

If $\nu < \nu_0$ no photoelectron is emitted

3. Stopping potential V_s

$eV_s = k_{max}$

This equation determines the voltage needed to stop all photoelectrons.

4. Work function ϕ is the minimum energy required to eject an electron

$\phi = h\nu_o$

5. Increasing intensity increases the number of photoelectrons but does not affect their kinetic energy.

The kinetic energy depends only on frequency.

6. Find wavelength using de Broglie's equation:

$$\lambda = \frac{6.626\times10^{-34}}{(9.11\times10^{-31})\times V}$$

assume $V = 3\times10^6$ m/s

$$\lambda = \frac{6.626\times10^{-34}}{(9.11\times10^{-31})\times(3\times10^6)}$$

$$\lambda = \frac{6.626\times10^{-34}}{2.733\times10^{-24}}$$

$\lambda = 2.42\times10^{-10}\,m \approx 24\text{Å}$

7. Photon momentum formula h

$$p = \frac{h}{\lambda}$$

Compton Effect

Scattering of photons leads to a shift in wavelength.

8. Substituting values (assumed $v = 1.5 \times 10^7$ m/s for electron)

$$\lambda = \frac{6.626 \times 10^{-34}}{(9.11 \times 10^{-31}) \times (1.5 \times 10^7)}$$

$$\lambda = \frac{6.626 \times 10^{-34}}{1.3665 \times 10^{-23}}$$

$\lambda = 4.85 \times 10^{-11}$ m ≈ 0.485Å ≈ 1

CHAPTER 39 Hydrogen Atom

1. Energy of the electromagnetic radiation Eph.

$$\text{Eph} = \frac{hc}{\lambda} = \frac{1242\text{eVnm}}{90\text{nm}} = 13.8 \text{ eV}$$

Binding Energy by photoelectric effect equation

$\text{Eph} = |E_n| + KE_{ejected}$

$13.8 \text{ eV} = |E_n| + 10.4 \text{ eV}$

$|E_n| = 3.4$ eV

Principal Quantum Number n

$$E_n = \frac{-13.6}{n^2}\text{eV} \qquad \text{(Hydrogen)}$$

$$3.4 = \frac{13.6}{n^2} = n^2 = \frac{13.6}{3.4} = 4$$

$\boxed{n = 2}$.

2. Angular momentom $L = \frac{nh}{2\pi}$

Given $L = \frac{3h}{2\pi}$ we find $\boxed{n = 3}$

The de Broglie wavelength in a stable orbit satisfies $2\pi r_n = nh$

For a hydrogen-like ion

($Z = 3$ for Li^{2+}), the radius is $r_n = \frac{a_0 n^2}{Z}$

Substituting values

$$r_3 = \frac{a_0(3)^2}{3} = 3a_0$$

$$\lambda = \frac{2\pi r_3}{3} = \frac{2\pi(3a_0)}{3} = 2\pi a_0$$

Comparing with $P\pi a_0$ we get $\boxed{P = 2}$

3. A → True → Relative change in radii

$$\frac{\Delta r}{r} = \frac{r_{n+1} - r_n}{r_n} = \frac{(n+1)^2 - n^2}{n^2} \approx \frac{2n}{n^2} = \frac{2}{n}$$

This is independent of Z.

$$B \rightarrow \text{True} \rightarrow \frac{\Delta r}{r} \alpha \frac{1}{n}$$

D → True → Angular momentum $L = \frac{nh}{2\pi}$

Relative change $\frac{\Delta L}{L} = \frac{\frac{(n+1)h}{2\pi} - \frac{nh}{2\pi}}{\frac{nh}{2\pi}} = \frac{1}{n}$

4. Energy absorbed:

$$\Delta E = \frac{hc}{\lambda} = \frac{1.237 \times 10^{-6}\text{eVm}}{970 \times 10^{-10}\text{m}} \approx 12.75 \text{ eV}$$

The electron reaches energy level

$$E_n = -13.6 + 12.75 = -0.85 \text{ eV}$$

Using $E_n = \frac{-13.6}{n^2}$

$$n = \sqrt{\frac{13.6}{0.85}} = 4.$$

Number of emission lines

$$= \frac{n(n+1)}{2} = \frac{4(3)}{2} = 6$$

5. Potential energy $V \propto -\frac{1}{n^2}$

$$\frac{V_i}{V_f} = \frac{n_f^2}{n_i^2}$$

Given

$$\frac{V_i}{V_f} = 6.25 \Rightarrow \left(\frac{n_f}{n_i}\right)^2 = 6.25$$

$$\frac{n_f}{n_i} = 2.5 = \frac{25}{10} = \frac{5}{2}$$

To keep n_i and n_f as integers the simplest ratio is $n_i = 2$ and $n_f = 5$.

6. Photon energy

$$E_{n_1 \rightarrow n_2} = 13.6 \cdot Z^2 \left(\frac{1}{n_2^2} - \frac{1}{n_1^2}\right)$$

$$E_{2\rightarrow 1} = 13.6\, Z^2 \left(1 - \frac{1}{4}\right) = 13.6\, Z^2 (0.75)$$

$$E_{3\rightarrow 2} = 13.6\, Z^2 \left(\frac{1}{4} - \frac{1}{9}\right) = 13.6\, Z^2 \left(\frac{5}{36}\right)$$

Solving Z

$E_{2\rightarrow 1} - E_{3\rightarrow 2} = 74.8$

$$13.6\, Z^2 \left(\frac{3}{4} - \frac{5}{36}\right) = 74.8$$

$$13.6\, Z^2 \left(\frac{22}{36}\right) = 74.8 \Rightarrow 13.6\, Z^2 (0.611)$$

$$Z^2 \approx \frac{74.8}{8.31} \approx 9 \Rightarrow \boxed{Z = 3}$$

7. Central force

$$F_C = \frac{-dV(r)}{dr} = -F$$

$$\frac{mv^2}{R} = F \Rightarrow v^2 = \frac{FR}{m} \qquad \text{(A)}$$

Bohr's Quantization condition

$$mvR = \frac{nh}{2\pi} \Rightarrow v = \frac{nh}{2\pi mR} \qquad \text{(B)}$$

Radius and velocity Proportionalities Substitute v from equation B into A

$$\left(\frac{nh}{2\pi mR}\right)^2 = \frac{FR}{m}$$

$$\frac{n^2h^2}{4\pi^2m^2R^2} = \frac{FR}{m}$$

$$R^3 = \frac{n^2h^2}{4\pi^2mF} \Rightarrow R = \left(\frac{n^2h^2}{4\pi^2mF}\right)^{1/3}$$

$R \propto n^{2/3}$

$$v \propto \frac{n}{n^{2/3}} \Rightarrow \boxed{v \propto n^{1/3}}$$

Kinetic Energy

$k = \frac{1}{2}mv^2$ from equation A $mv^2 = FR$

So $k = \frac{FR}{2}$

Potential energy $V = FR$

Total Energy

$$E = k + V = \frac{FR}{2} + FR = \frac{3}{2}FR$$

Substitute the value of R

$$E = \frac{3}{2}F\left(\frac{n^2h^2}{4\pi^2mF}\right)^{1/3}$$

$$E = \frac{3}{2}\left(\frac{n^2h^2F^3}{4\pi^2mF}\right)^{1/3} = \frac{3}{2}\left(\frac{n^2h^2F^2}{4\pi^2m}\right)^{1/3}$$

$$\boxed{E = \frac{3}{2}\left(\frac{n^2h^2F^2}{4\pi^2m}\right)^{1/3}}$$

CHAPTER 40 All About Atoms

1. Using Moseley's law

$$\lambda \alpha \frac{1}{(z-1)^2}$$

The ratio is $\frac{\lambda Cu}{\lambda MO} = \frac{(41)^2}{(28)^2} = \frac{1681}{784} \approx 2.14$

2. Both A and C state that the cut off wavelength reduces to half, which is correct. However they differ in their statements about the characteristics X-ray wavelength.

CHAPTER 41 The Nucleus

1. For radioactive decay $N = N_0e^{-\lambda t}$

   If $t = 2\frac{T_1}{2}, N/N_0 = \left(1/2\right)^2 = 1/4$

   Number of half-lives or decay left is 3
2. Match properties (e.g. A: mass, B: charge) to isotopes (P: ^1H, Q: ^2H, R: ^3H, S: ^4He, T: neutron).
   A (mass) links to R, T
   B(charge) to P, S
3. Alpha decay : $A \to A - 4$, beta $Z \to Z + 1$
   For $^{238}U \to {}^{234}Th$, 2 alpha decays needed
4. Gamma decay releases energy without changing A or Z.
   If excited, $^{60}C_0$ decays
5. Fission of ^{235}U yield ~ 2.5 neutrons per event.
6. Beta decay: $n \to p + e^- + \bar{v}$
   If $^{14}C \to {}^{14}N$
7. $t = \left(1/\lambda\right)\ln\left(N_0/N\right)$

   For $^{14}{}_C$ half life = 5730 years

   if $N/N_0 = 1/2$ $t = T_{1/2}$.
8. Decay series (e.g. $238_U \to 206_{pb}$) involves α (2per) and β decays.
9. Fission releases neutron and energy.
10. Alpha decay: $A \to A - 4, Z \to Z - 2$
    If $226_{Rq} \to 222_{Rn}$
11. Binding energy = Δm·931 MeV
    For 56_{Fe}, $\Delta m \approx 0.145$ u
    $0.145 \times 931 \approx 135$ MeV

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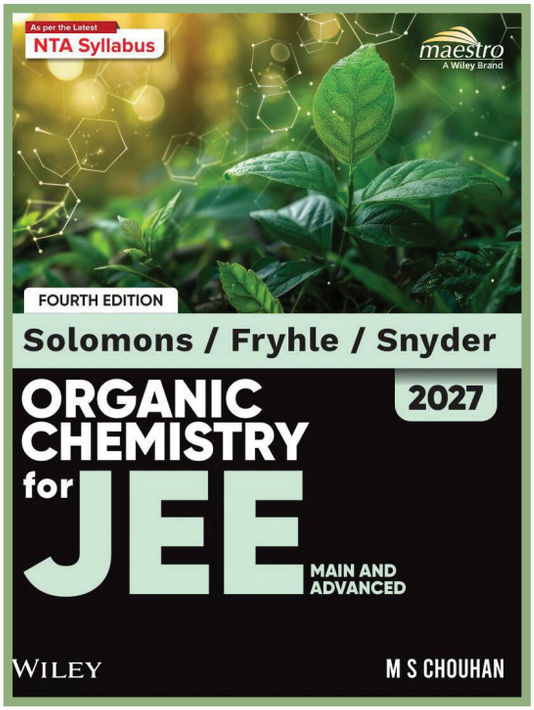

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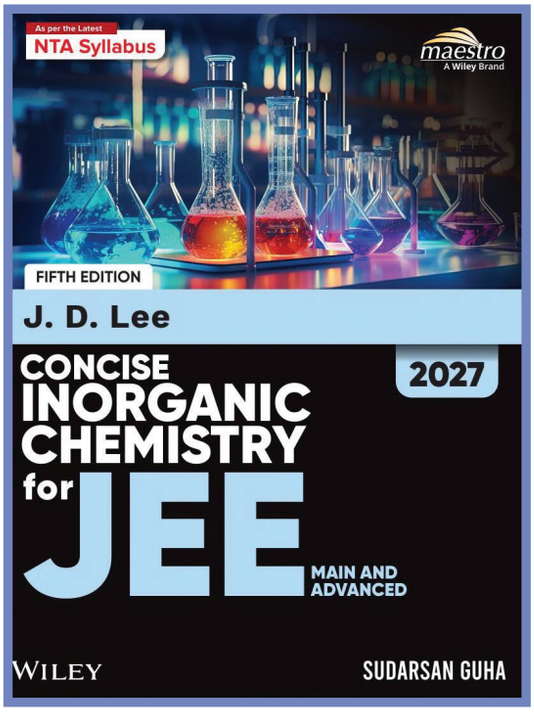

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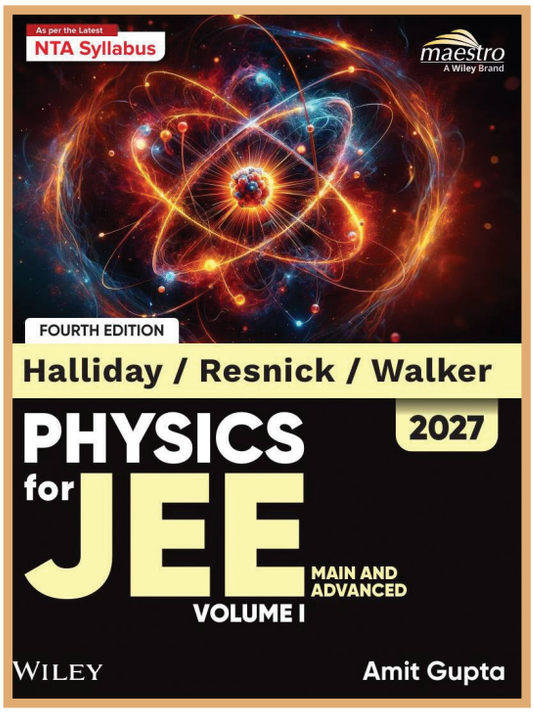

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