Physics by
Nayan Jha

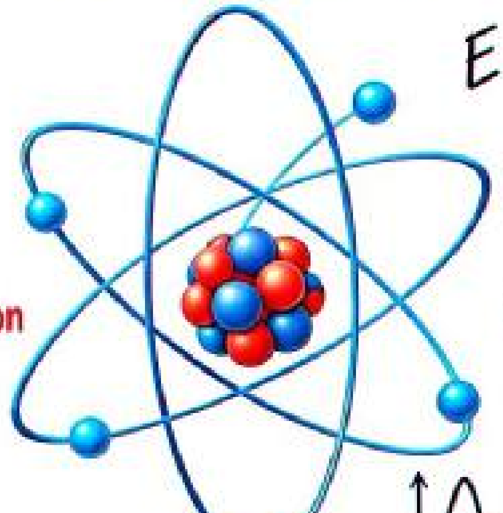
Concepts + Practice = Success

PHYSICS OBJECTIVE

FOR CLASS 12th BOARD EXAMINATION

PART-1

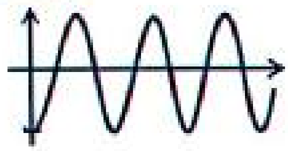
- MULTIPLE CHOICE QUESTIONS (MCQs) with Solution
- ASSERTION-REASON QUESTIONS with Solution
- CASE STUDY BASED QUESTIONS with Solution
- CHAPTER-WISE PRACTICE QUESTIONS



$E = mc^2$

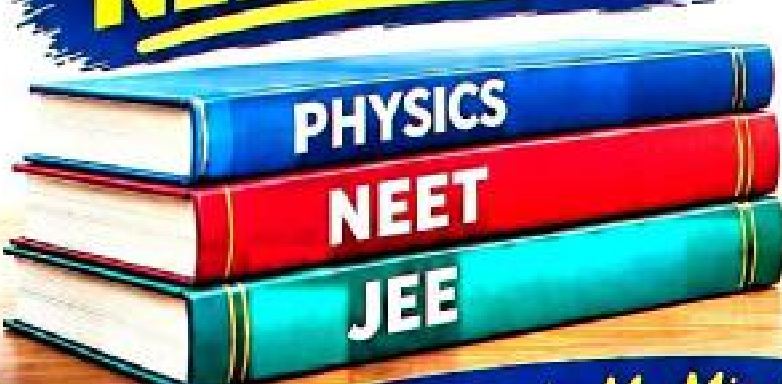
$F = ma$

$V = IR$



Also Useful for NEET and JEE

Better Preparation Brighter Future



- Concepts Clear
- Exam Oriented
- Detailed Solutions
- Score High

Your Success is My Mission

Introduction to Objective Physics for Class 12

"Objective Physics" by Nayan Jha meets the demand for objective questions in Class 12 Physics exams.

Key Features of This Book:

Comprehensive Question Types:

Multiple Choice Questions (MCQs)

Assertion–Reason Questions

Case Study Based Questions

Focus on Conceptual Understanding: Each question enhances students' conceptual understanding of Physics.

Problem-Solving Skill Development: The book strengthens students' ability to solve various Physics problems.

Detailed Solutions:

Every question includes a detailed solution.

Solutions explain the correct answer and underlying Physics principles.

Target Audience and Benefits:

This book is for:

Class 12th Board Examination Preparation: It offers effective preparation for board exams.

NEET and JEE Aspirants: Concept-based questions benefit students preparing for NEET and JEE.

How This Book Helps Students:

Chapter-wise Practice: Chapter-organized questions allow students to assess preparation and identify improvement areas.

Beyond Memorization: The aim is to foster deeper understanding, helping students understand concepts, learn applications, and build confidence in solving objective questions.

Author's Philosophy:

"Concepts + Practice = Success — Your Success is My Mission."

— Nayan Jha

Physics by Nayan Jha

CHAPTER

Electric Charges and Fields

Recap Notes

- **Charge :** Electric charge is an intrinsic property of elementary particles of matter which gives rise to electric force between various objects.
  - **Quantization :** Charge is always in the form of an integral multiple of electronic charge and never its fraction.
    $q = \pm ne$
    where n is an integer and $e = 1.6 \times 10^{-19}$ C.
  - Millikan's oil drop experiment showed the discrete nature of charge. Charge cannot be fractional multiple of e.
  - **Conservation of charge :** Net charge of an isolated physical system always remains constant. Charge can neither be created nor destroyed. It can be transferred from one body to another.
  - Electric charge is additive, *i.e.*, total charge is the algebraic sum of the individual charges.
  - Electric charge is invariant as it does not depend upon the motion of the charged body or the observer.
- **Coulomb's inverse square law :** It states that the electrostatic force of attraction or repulsion acting between two stationary point charges is given by

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

where F denotes the force between two charges q_1 and q_2 separated by a distance r in free space. ε_0 is a constant known as permittivity of free space. Free space is vacuum and may be taken to be air practically.

$$\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9 \ \frac{\text{N m}^2}{\text{C}^2}$$

  - If free space is replaced by a medium, then ε_0 is replaced by $(\varepsilon_0 K)$ or $(\varepsilon_0 \varepsilon_r)$ where K is known as dielectric constant or relative permittivity.

$$F = \frac{1}{4\pi\varepsilon}\frac{q_1 q_2}{r^2} = \frac{1}{4\pi\varepsilon_0 K}\frac{q_1 q_2}{r^2} = \frac{1}{4\pi\varepsilon_0 \varepsilon_r}\frac{q_1 q_2}{r^2}$$

$$K = \frac{\varepsilon}{\varepsilon_0} \text{ or } \varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$$

$K = 1$ for vacuum (or air) and $K = \infty$ for conductor/metal.

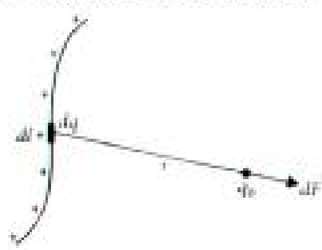
$\varepsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2\text{N}^{-1}\text{m}^{-2}$ and its dimensional formula is $[\text{M}^{-1}\text{L}^{-3}\text{T}^4\text{A}^2]$.

Vector form of the law (q_1 and q_2 are like charges)

(i) $\vec{F}_{12} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{|\vec{r}_1 - \vec{r}_2|^3}(\vec{r}_1 - \vec{r}_2) = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{21}^3}\vec{r}_{21}$

(ii) $\vec{F}_{21} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{|\vec{r}_2 - \vec{r}_1|^3}(\vec{r}_2 - \vec{r}_1) = \frac{q_1 q_2}{4\pi\varepsilon_0}\frac{1}{r_{12}^3}\vec{r}_{12}$

- **Electrostatic force due to continuous charge distribution**
  The region in which charges are closely spaced is said to have continuous distribution of charge. It is of three types :
  - **Linear charge distribution**



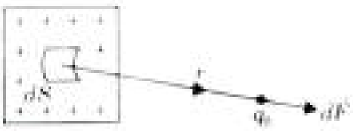
$dq = \lambda\, dl$

where, λ = linear charge density

$$d\vec{F} = \frac{1}{4\pi\varepsilon_0}\frac{q_0(dq)}{|r|^2}\hat{r} \rightarrow d\vec{F} = \frac{1}{4\pi\varepsilon_0}\frac{q_0(\lambda\, dl)}{|r|^2}\hat{r}$$

Net force on charge q_0, $\vec{F} = \frac{q_0}{4\pi\varepsilon_0}\int_l \frac{\lambda\, dl}{|r|^2}\hat{r}$

- **Surface charge distribution**

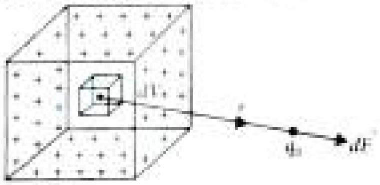


$dq = \sigma\, dS$

where, σ = surface charge density

Net force on charge q_0, $\vec{F} = \frac{q_0}{4\pi\varepsilon_0}\int_S \frac{\sigma dS}{|r|^2}\hat{r}$

- **Volume charge distribution**



$dq = \rho\, dV$

where, ρ = volume charge density

Net force on charge q_0, $\vec{F} = \frac{q_0}{4\pi\varepsilon_0}\int_V \frac{\rho dV}{|r|^2}\hat{r}$

- **Electric field intensity :** The electric field intensity at any point due to source charge is defined as the force experienced per unit positive test charge placed at that point without disturbing the source charge. It is expressed as

$$\vec{E} = \lim_{q_0 \to 0} \frac{\vec{F}}{q_0}$$

Here, $q_0 \to 0$, *i.e.*, the test charge q_0 must be small, so that it does not produce its own electric field.

SI unit of electric field intensity (E) is N/C and it is a vector quantity.

- **Electric field intensity due to a point charge**

Electric field intensity at P is,

$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{q}{|r|^2}\hat{r}$$

The magnitude of the electric field at a point P is given by

$$|\vec{E}| = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$$

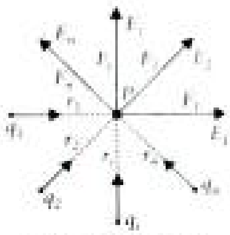
If $q > 0$, *i.e.*, positive charge, then E is directed away from source charge. On the other hand if $q < 0$, *i.e.*, negative charge, then E is directed towards the source charge.

$E \propto \frac{1}{r^2}$.

- **Electric field due to a system of charges or superposition principle**

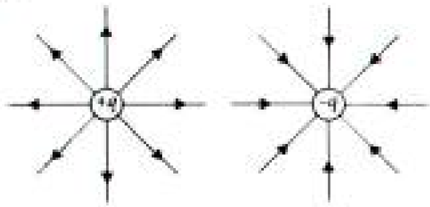
$$\vec{E} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \ldots\ldots + \vec{E}_n$$

$$\Rightarrow \vec{E} = \frac{1}{4\pi\varepsilon_0}\sum_{i=1}^{n}\frac{q_i}{|r|^2}\hat{r}_i$$

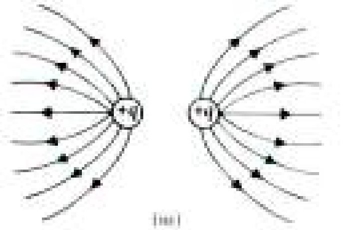


A system of charges

- The electric field lines due to positive and negative charges and their combinations are :



(i) (ii)



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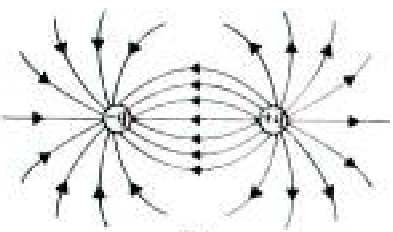


(iv)

- **Electric dipole :** Two equal and opposite charges (q) each, separated by a small distance ($2l$) constitute an electric dipole. Many of the atoms/molecules are dipoles.

(i) Electric dipole moment, $\vec{p} = 2q\vec{l}$.

(ii) Dipole moment is a vector quantity and is directed from negative to positive charge.

(iii) Unit of dipole moment is coulomb metre (C m).

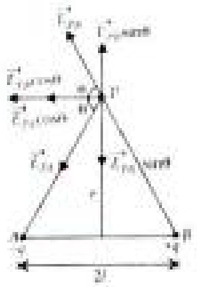
(iv) Dimension of dipole moment = [ATL]

- **Intensity of electric field due to a dipole**
  - Along axis at distance r from centre of dipole $\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{2\vec{p}}{r^3}$

Direction of E is along the direction of dipole moment.

  - Along equator of dipole at distance r from centre $\vec{E} = \frac{-1}{4\pi\varepsilon_0}\frac{\vec{p}}{r^3}$

Direction of $\vec{E}$ is antiparallel to direction of $\vec{p}$.

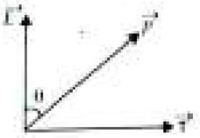


  - At any point along direction θ
$E = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3}\sqrt{1+3\cos^2\theta}$

The direction of $\vec{E}$ makes an angle β with the line joining the point with centre of dipole where $\tan\beta = \frac{1}{2}\tan\theta$.

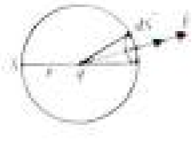
- **Electric dipole in a uniform electric field**

- The resultant electric force on dipole $= qE - qE = 0$
- Two forces [qE and ($-qE$)] equal and opposite, separated by a distance constitute a couple (torque).
- Torque on a dipole $= pE\sin\theta$ numerically.
Vectorially,
Torque $(\vec{\tau}) = \vec{p}\times\vec{E}$



- The direction of τ is perpendicular to the plane containing $\vec{p}$ and $\vec{E}$.
- The torque tends to align the dipole in the direction of field.
- Torque is maximum when $\theta = 90°$ *i.e.*, dipole is perpendicular to E.
$\therefore$ Maximum torque $= pE$.
When $\theta = 0°$ or $180°$ then $\tau_{min} = 0$.
- When dipole is parallel to electric field, it is in stable equilibrium. When it is antiparallel to electric field, it is in unstable equilibrium.

- **Gauss's law :** For a closed surface enclosing a net charge q, the net electric flux ϕ emerging out is given by $\phi = \oint_S \vec{E}\cdot d\vec{S} = \frac{q}{\varepsilon_0}$



- If a dipole is enclosed by a closed surface, flux ϕ is equal to zero.
Here the algebraic sum of charges $(+q - q = 0)$ is zero.
- Flux from a cube
(i) If q is at the centre of cube, total flux $(\phi) = \frac{q}{\varepsilon_0}$
(ii) From each face of cube, flux $= \frac{q}{6\varepsilon_0}$
- Electric field due to a thin, infinitely long straight wire of uniform linear charge density λ,
$E = \frac{\lambda}{2\pi\varepsilon_0 r}$, where r is the perpendicular distance of the observation point from the wire.
- Electric field due to a thin non conducting infinite sheet of charge with uniform surface charge density σ is $E = \frac{\sigma}{2\varepsilon_0}$
- Electric field between two infinite thin plane parallel sheets of uniform surface charge density σ and $-\sigma$ is $E = \sigma/\varepsilon_0$.

Practice Time

Multiple Choice Questions (MCQs)

1. A cup contains 250 g of water. Find the number of positive charges present in the cup of water.

(a) 1.34×10^{19} C (b) 1.34×10^{7} C
(c) 2.43×10^{19} C (d) 2.43×10^{7} C

2. The number of electrons present in -1 C of charge is

(a) 6×10^{18} (b) 1.6×10^{19}
(c) 6×10^{19} (d) 1.6×10^{18}

3. Consider the charges q, q and $-q$ placed at the vertices of an equilateral triangle of each side l. The force on each charge is

(a) $F = \frac{q^2}{4\pi\varepsilon_0 l}$ (b) $F = \frac{q^2}{4\pi\varepsilon_0 l}$

(c) $F = \frac{q^2}{4\pi\varepsilon_0 l^2}$ (d) zero

4. Which of the following statements is not true about electric field lines?

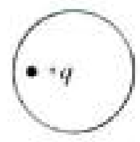
(a) Electric field lines start from positive charge and end at negative charge.
(b) Two electric field lines can never cross each other.
(c) Electrostatic field lines do not form any closed loops.
(d) Electric field lines cannot be taken as continuous curve.

5. The electric field at a point is

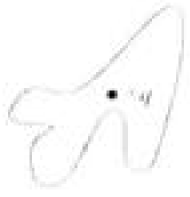
(a) always continuous
(b) continuous if there is no charge at that point
(c) discontinuous if there is a charge at that point
(d) both (b) and (c) are correct.

6. The electric flux through the surface

I. 

II. 

III. 

IV. 

(a) in figure (IV) is largest
(b) in figure (III) is the least
(c) in figure (II) is same as in figure (III) but is smaller than figure (IV)
(d) is the same for all figures.

7. Which of the following statements about dipole moment is not true?

(a) The dimensions of dipole moment is [LTA].
(b) The unit of dipole moment is cm.
(c) Dipole moment is vector quantity and directed from negative to positive charge.
(d) Dipole moment is a vector quantity has magnitude (charge) $q \times$ (separation between charge) a.

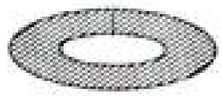
8. The SI unit of electric flux is

(a) N C^{-1} m^2 (b) N C m^{-2}
(c) N C^{-2} m^2 (d) N C^{-1} m^{-2}

9. The electrostatic force on a small sphere of charge 0.2 μC due to another small sphere of charge -0.4 μC in air is 0.4 N. The distance between the two spheres is

(a) 4.2×10^{-6} m (b) 4.2×10^{-3} m
(c) 1.8×10^{-3} m (d) 1.8×10^{-6} m

10. A thin disc of radius $b = 2a$ has a concentric hole of radius a in it (see figure). It carries uniform surface charge σ on it. If the electric field on its axis at height h ($h << a$) from its centre is given as Ch then value of C is



(a) $\frac{\sigma}{a\varepsilon_0}$ (b) $\frac{\sigma}{2a\varepsilon_0}$ (c) $\frac{\sigma}{4a\varepsilon_0}$ (d) $\frac{\sigma}{8a\varepsilon_0}$

11. The force between two small charged spheres having charges of 1×10^{-7} C and 2×10^{-7} C placed 20 cm apart in air is

(a) 4.5×10^{-2} N (b) 4.5×10^{-3} N
(c) 5.4×10^{-2} N (d) 5.4×10^{-3} N

12. An electric dipole with dipole moment 2×10^{-19} cm is aligned at 30 with the direction of a uniform electric field of magnitude 4 10^4 N C^{-1}. The magnitude of the torque acting on the dipole is
(a) 2×10^{-5} N m (b) 2×10^{-4} N m
(c) 4×10^{-4} N m (d) 4×10^{-5} N m

13. A charge 10 μC is placed at the centre of a hemisphere of radius R = 10 cm as shown. The electric flux through the hemisphere (in MKS units) is

(a) 20×10^5
(b) 10×10^5
(c) 6×10^5
(d) 2×10^5

14. A point charge $+q$, is placed at a distance d from an isolated conducting plane. The field at a point P on the other side of the plane is
(a) directed perpendicular to the plane and away from the plane
(b) directed perpendicular to the plane but towards the plane
(c) directed radially away from the point charge
(d) directed radially towards the point charge.

15. If there were only one type of charge in the universe, then
(a) $\oint_s \vec{E}.d\vec{s} \neq 0$ on any surface
(b) $\oint_s \vec{E}.d\vec{s} = 0$ if the charge is outside the surface
(c) $\oint_s \vec{E}.d\vec{s} = \frac{q}{\varepsilon_0}$ if charges of magnitude q were inside the surface
(d) both (b) and (c) are correct.

16. What will happen when we rub a glass rod with silk cloth?
(a) Some of the electrons from the glass rod are transferred to the silk cloth.
(b) The glass rod gets positively charged and silk cloth gets negatively charged.
(c) New charge is created in the process of rubbing.
(d) both (a) and (b) are correct.

17. Three charges 1 μC, 1 μC and 2 μC are kept at vertices of A, B and C of an equilateral triangle ABC of side 10 cm respectively. The resultant force on the charge at C is
(a) 0.9 N (b) 1.8 N (c) 2.72 N (d) 3.12 N

18. Consider a region inside which there are various types of charges but the total charge is zero. At points outside the region
(a) the electric field is necessarily zero
(b) the electric field is due to the dipole moment of the charge distribution only
(c) the dominant electric field is inversely proportional to r^3, for large r (distance from origin)
(d) the work done to move a charged particle along a closed path, away from the region will not be zero.

19. An electron initially at rest falls a distance of 1.5 cm in a uniform electric field of magnitude 2×10^4 N/C. The time taken by the electron to fall this distance is
(a) 1.3×10^2 s (b) 2.1×10^{-12} s
(c) 1.6×10^{-10} s (d) 2.9×10^{-9} s

20. If $\oint_s \vec{E}.d\vec{s} = 0$ over a surface, then
(a) the electric field inside the surface and on it is zero
(b) the electric field inside the surface is necessarily uniform
(c) all charges must necessarily be outside the surface
(d) all of these.

21. The electric field in a region is given by
$\vec{E} = \frac{A}{x^3}\hat{i} + By\,\hat{j} + Cz^2\hat{k}$.
The SI units of A, B and C are, respectively
(a) $\frac{\text{Nm}^3}{\text{C}}, \text{V/m}^2, \frac{\text{N}}{\text{m}^2\text{C}}$ (b) $\text{Vm}^2, \text{V/m}, \frac{\text{N}}{\text{m}^2\text{C}}$
(c) $\text{V/m}^2, \text{V/m}, \frac{\text{NC}}{\text{m}^2}$ (d) $\text{V/m}, \frac{\text{Nm}^3}{\text{C}}, \frac{\text{NC}}{\text{m}}$

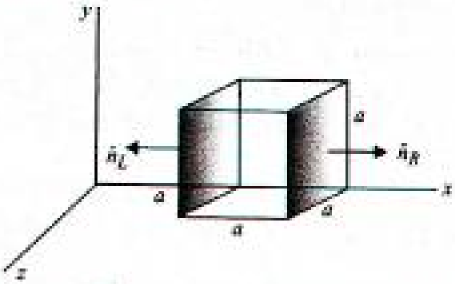
22. An electric dipole with dipole moment 1×10^{-19} cm is aligned at 30° with the direction of a uniform electric field of magnitude 3×10^4 N C^{-1}. The magnitude of the torque acting on the dipole is
(a) 7×10^{-5} N m (b) 2×10^{-5} N m
(c) 6×10^{-5} N m (d) 3×10^{-5} N m

23. If $\vec{E}_{ax}$ and $\vec{E}_{eq}$ represents electric field at a point on the axial and equatorial line of a dipole. If points are at a distance r from the centre of the dipole, for $r >> a$
(a) $\vec{E}_{ax} = \vec{E}_{eq}$ (b) $\vec{E}_{ax} = -\vec{E}_{eq}$
(c) $\vec{E}_{ax} = -2\vec{E}_{eq}$ (d) $\vec{E}_{eq} = 2\vec{E}_{ax}$

24. A polythene piece rubbed with wool is found to have a negative charge of 6×10^{-7} C. The number of electrons transferred to polythene from wool is

(a) 3.75×10^{10} (b) 9.6×10^{10}
(c) 9.6×10^{12} (d) 3.75×10^{12}

25. The electric field components in the given figure are $E_x = \alpha x^{1/2}$, $E_y = E_z = 0$ in which $\alpha = 800$ N C^{-1} m$^{-1/2}$. The charge within the cube is if net flux through the cube is 1.05 N m^2 C^{-1} (assume $a = 0.1$ m)

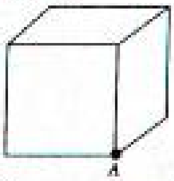


(a) 9.30×10^{-12} C (b) 9.27×10^{12} C
(c) 6.97×10^{-12} C (d) 6.97×10^{12} C

26. The dipole moment of a dipole in a uniform external field $\vec{E}$ is $\vec{P}$. Then the torque $\vec{\tau}$ acting on the dipole is

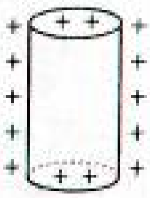
(a) $\vec{\tau} = \vec{P} \times \vec{E}$ (b) $\vec{\tau} = \vec{P} \cdot \vec{E}$
(c) $\vec{\tau} = 2(\vec{P} + \vec{E})$ (d) $\vec{\tau} = (\vec{P} + \vec{E})$

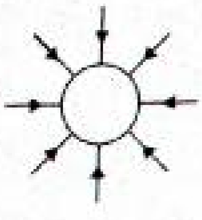
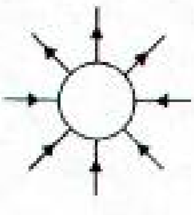
27. The total flux through the faces of the cube with side of length 'a' if a charge q is placed at corner A of the cube is

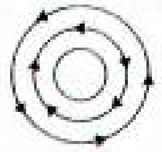
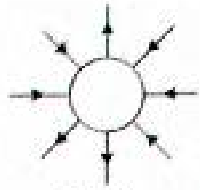


(a) $\frac{q}{8\varepsilon_0}$ (b) $\frac{q}{4\varepsilon_0}$ (c) $\frac{q}{2\varepsilon_0}$ (d) $\frac{q}{\varepsilon_0}$

28. Which of the following figures correctly shows the top view sketch of the electric field lines for a uniformly charged hollow cylinder as shown is figure?



(a)  (b) 

(c)  (d) 

29. The number of electrons that must be removed from an electrically neutral silver dollar to give it a charge of + 2.4 C is

(a) 2.5×10^{19} (b) 1.5×10^{19}
(c) 1.5×10^{-19} (d) 2.5×10^{-19}

30. Two large, thin metal plates are parallel and close to each other. On their inner faces, the plates have surface charge densities of opposite signs and of magnitude 16×10^{-22} C m^{-2}. The electric field between the plates is

(a) 1.8×10^{-10} N C^{-1} (b) 1.9×10^{-10} N C^{-1}
(c) 1.6×10^{-10} N C^{-1} (d) 1.5×10^{-10} N C^{-1}

31. The force per unit charge is known as

(a) electric flux (b) electric field
(c) electric potential (d) electric current.

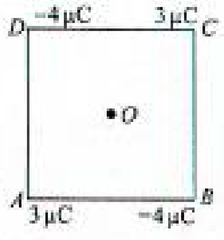
32. Object may acquire an excess or deficiency of charge by

(a) electric force (b) heating
(c) shaking (d) by rubbing.

33. Electric field lines provide information about

(a) field strength (b) direction
(c) nature of charge (d) all of these.

34. Four point charges are placed at the corners of a square $ABCD$ of side 10 cm, as shown in figure. The force on a charge of 1 μC placed at the centre of square is



(a) 7 N (b) 8 N (c) 2 N (d) zero

35. Two infinite plane parallel sheets, separated by a distance d have equal and opposite uniform charge densities σ. Electric field at a point between the sheets is

(a) $\frac{\sigma}{2\varepsilon_0}$ (b) $\frac{\sigma}{\varepsilon_0}$
(c) zero
(d) depends on the location of the point.

36. Two insulated charged metallic spheres P and Q have their centres separated by a distance

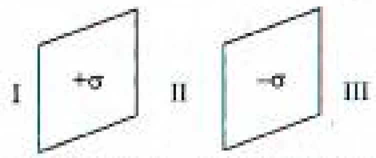
of 60 cm. The radii of P and Q are negligible compared to the distance of separation. The mutual force of electrostatic repulsion if the charge on each is 3.2×10^{-7} C is

(a) 5.2×10^{-4} N (b) 2.5×10^{-3} N
(c) 1.5×10^{-3} N (d) 3.5×10^{-4} N

37. Three charges of equal magnitude q is placed at the vertices of an equilateral triangle of side l. The force on a charge Q placed at the centroid of the triangle is

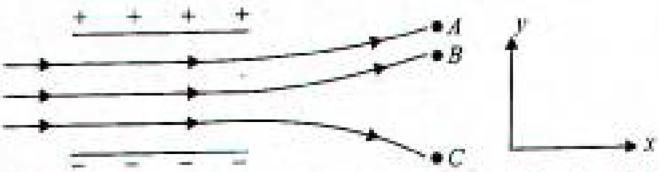
(a) $\frac{3Qq}{4\pi\varepsilon_0 l^2}$ (b) $\frac{2Qq}{4\pi\varepsilon_0 l^2}$ (c) $\frac{Qq}{2\pi\varepsilon_0 l^2}$ (d) zero

38. Two large thin metal plates are parallel and close to each other. On their inner faces, the plates have surface charge densities of opposite signs and magnitude 27×10^{-22} C m^{-2}. The electric field $\vec{E}$ in region II in between the plates is



(a) 4.25×10^{-8} N C^{-1} (b) 6.28×10^{-10} N C^{-1}
(c) 3.05×10^{-10} N C^{-1} (d) 5.03×10^{-10} N C^{-1}

39. The tracks of three charged particles in a uniform electrostatic field as shown in the figure. Which particle has the highest charge to mass ratio ?



(a) A (b) B (c) C (d) A and B

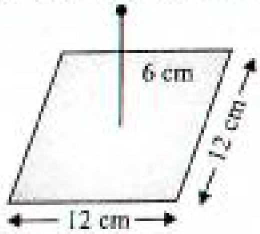
40. Which of the following statement is true about electrical forces?

(a) Electrical forces are produced by electrical charges.
(b) Like charges attract, unlike charges repel.
(c) Electric forces are weaker than gravitational forces.
(d) Positive and negative charges can combine to produce a third type of charge.

41. The dimensional formula of electric intensity is

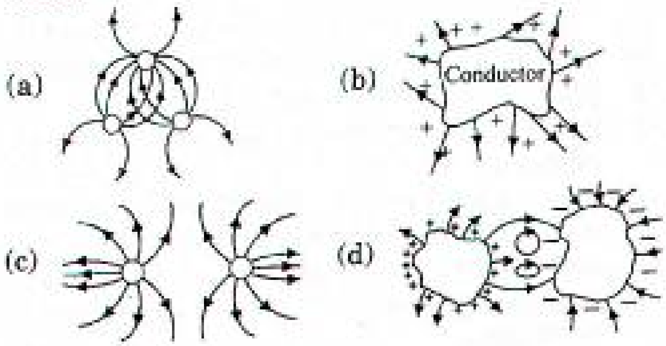
(a) $[M^1L^1T^3A^{-1}]$ (b) $[ML^{-1}T^{-3}A^1]$
(c) $[M^1L^1T^{-3}A^{-1}]$ (d) $[M^1L^2T^1A^1]$

42. A point charge +20 μC is at a distance 6 cm directly above the centre of a square of side 12 cm as shown in figure. The magnitude of electric flux through the square is



(a) 2.5×10^6 N m^2 C^{-1} (b) 3.8×10^5 N m^2 C^{-1}
(c) 4.2×10^5 N m^2 C^{-1} (d) 2.9×10^6 N m^2 C^{-1}

43. Which of the following curves shown here cannot possibly represent electrostatic field lines?



44. The unit of electric dipole moment is

(a) Newton (b) Coulomb
(c) Farad (d) Debye.

45. An electric dipole is placed at an angle of 30° with an electric field of intensity 2×10^5 N C^{-1}. It experiences a torque equal to 4 N m. The charge on the dipole if the dipole length is 2 cm is

(a) 8 mC (b) 4 mC (c) 6 mC (d) 2 mC

46. The constant k in Coulomb's law depends on

(a) nature of medium (b) system of units
(c) intensity of charge (d) both (a) and (b).

47. A coin is made up of Al and weighs 0.75 g. It has a square shape and its diagonal measures 17 mm. It is electrically neutral and contains equal amounts of positive and negative charges. The magnitude of these charges is (Atomic mass of Al = 26.98 g)

(a) 3.47×10^4 C (b) 3.47×10^2 C
(c) 1.67×10^{20} C (d) 1.67×10^{22} C

48. If an object of mass 1 kg contains 4×10^{20} atoms. If one electron is removed from every atom of the solid, the charge gained by the solid in 1 g is

(a) 2.8 C (b) 6.4×10^{-2} C
(c) 3.6×10^{-3} C (d) 9.2×10^{-4} C

49. A force of 2.25 N acts on a charge of 15×10^{-4} C. The intensity of electric field at that point is
(a) 150 N C^{-1} (b) 15 N C^{-1}
(c) 1500 N C^{-1} (d) 1.5 N C^{-1}

50. Electrical as well as gravitational affects can be thought to be caused by fields. Which of the following is true of an electrical or gravitational field ?
(a) The field concept is often used to describe contact forces.
(b) Gravitational or electric field does not always exist in the space around an object.
(c) Fields are useful for understanding forces acting through a distance.
(d) There is no way to verify the existence of a force field since it is just a concept.

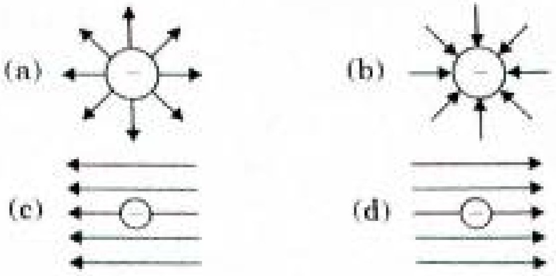
51. Coulomb's law relates two charges and distance between them describing the electric force as being
(a) proportional to the sum of the charges
(b) inversely proportional to the distance between charges
(c) proportional to the product of the charges and inversely proportional to the distance
(d) proportional to the product of the charges and inversely proportional to the square of distance.

52. When a person combs his hair, static electricity is sometimes generated by what process?
(a) Contact between the comb and hair results is charge.
(b) Friction between the comb and hair result is the transfer of electrons.
(c) Deduction between the comb and hair.
(d) Induction between the comb and hair.

53. The acceleration for electron and proton due to electrical force of their mutual attraction when they are 1 Å apart is
(a) 3.1×10^{22} m s^{-2}, 1.3×10^{19} m s^{-2}
(b) 3.3×10^{18} m s^{-2}, 3.2×10^{16} m s^{-2}
(c) 2.5×10^{22} m s^{-2}, 1.3×10^{19} m s^{-2}
(d) 2.5×10^{18} m s^{-2}, 1.3×10^{16} m s^{-2}

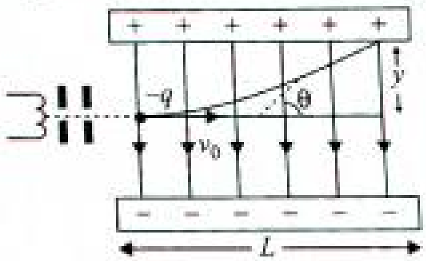
54. A dipole of electric dipole moment p is placed in a uniform electric field of strength E. If θ is the angle between positive directions of p and E, then the potential energy of the electric dipole is largest when θ is
(a) $\frac{\pi}{4}$ (b) $\frac{\pi}{2}$ (c) π (d) zero

55. Which of the following figure represents the electric field lines due to a single negative charge?



56. Which of the following statements is not true about Gauss's law?
(a) Gauss's law is true for any closed surface.
(b) The term q on the right side of Gauss's law includes the sum of all charges enclosed by the surface.
(c) Gauss's law is not much useful in calculating electrostatic field when the system has some symmetry.
(d) Gauss's law is based on the inverse square dependence on distance contained in the coulomb's law.

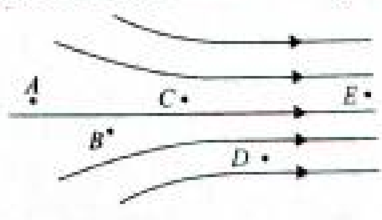
57. A particle of mass m and charge $-q$ enters the region between the two charged plates initially moving along x-axis with speed v_x as shown is figure. The length of plate is L and a uniform electric field E is maintained between the plates. The vertical deflection of the particle at the far edge of the plate is .



(a) $\frac{qEL^2}{2mv_x^2}$ (b) $\frac{qEL^2}{2mv_x}$ (c) $\frac{2mv_x^2}{qEL^2}$ (d) $\frac{2mv_x}{qE^2L}$

58. Electric flux emanating through a surface element $d\vec{S} = 5\hat{i}$ placed in an electric field $\vec{E} = 4\hat{i} + 4\hat{j} + 4\hat{k}$ is
(a) 10 units (b) 20 units
(c) 4 units (d) 16 units

59. A non-uniform electric field is represented by the diagram. At which of the following points the electric field is greatest in magnitude?



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

60. Two charges q and $-3q$ are placed fixed on x-axis separated by distance d. Where should a third charge $2q$ be placed such that it will not experience any force?

(a) $\frac{d-\sqrt{3}d}{2}$ (b) $\frac{d+\sqrt{3}d}{2}$ (c) $\frac{d+3d}{2}$ (d) $\frac{d-3d}{2}$

Case Based MCQs

Case I : Read the passage given below and answer the following questions from 61 to 65.

Quantization of Electric Charge

Smallest charge that can exist in nature is the charge of an electron. During friction it is only the transfer of electrons which makes the body charged. Hence net charge on any body is an integral multiple of charge of an electron [1.6×10^{-19} C] *i.e.*,

$q = \pm ne$

where $n = 1, 2, 3, 4, ...$

Hence no body can have a charge represented as $1.1e$, $2.7e$, $\frac{3}{5}e$, etc.

Recently, it has been discovered that elementary particles such as protons or neutrons are composed of more elemental units called quarks.

61. Which of the following properties is not satisfied by an electric charge?
(a) Total charge conservation.
(b) Quantization of charge.
(c) Two types of charge.
(d) Circular line of force.

62. Which one of the following charges is possible?
(a) 5.8×10^{-18} C (b) 3.2×10^{-18} C
(c) 4.5×10^{-19} C (d) 8.6×10^{-19} C

63. If a charge on a body is 1 nC, then how many electrons are present on the body ?
(a) 6.25×10^{27} (b) 1.6×10^{19}
(c) 6.25×10^{28} (d) 6.25×10^{9}

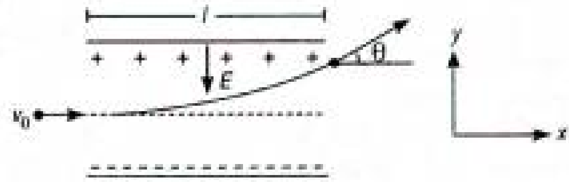
64. If a body gives out 10^9 electrons every second, how much time is required to get a total charge of 1 C from it?
(a) 190.19 years (b) 150.12 years
(c) 198.19 years (d) 188.21 years

65. A polythene piece rubbed with wool is found to have a negative charge of 3.2×10^{-7}C. Calculate the number of electrons transferred.
(a) 2×10^{12} (b) 3×10^{12}
(c) 2×10^{14} (d) 3×10^{14}

Case II : Read the passage given below and answer the following questions from 66 to 70.

Motion of Charged Particle in Uniform Electric Field

When a charged particle is placed in an electric field, it experiences an electrical force. If this is the only force on the particle, it must be the net force. The net force will cause the particle to accelerate according to Newton's second law. So $\vec{F}_e = q\vec{E} = m\vec{a}$



If $\vec{E}$ is uniform, then $\vec{a}$ is constant and $\vec{a} = q\vec{E}/m$. If the particle has a positive charge, its acceleration is in the direction of the field. If the particle has a negative charge, its acceleration is in the direction opposite to the electric field. Since the acceleration is constant, the kinematic equations can be used.

66. An electron of mass m, charge e falls through a distance h metre in a uniform electric field E. Then time of fall,
(a) $t = \sqrt{\frac{2hm}{eE}}$ (b) $t = \frac{2hm}{eE}$
(c) $t = \sqrt{\frac{2eE}{hm}}$ (d) $t = \frac{2eE}{hm}$

67. An electron moving with a constant velocity v along X-axis enters a uniform electric field applied along Y-axis. Then the electron moves
(a) with uniform acceleration along Y-axis
(b) without any acceleration along Y-axis
(c) in a trajectory represented as $y = ax^2$
(d) in a trajectory represented as $y = ax$.

68. Two equal and opposite charges of masses m_1 and m_2 are accelerated in an uniform electric field through the same distance. What is the ratio of their accelerations if their ratio of masses is $\frac{m_1}{m_2} = 0.5$?

(a) $\frac{a_1}{a_2} = 2$ (b) $\frac{a_1}{a_2} = 0.5$

(c) $\frac{a_1}{a_2} = 3$ (d) $\frac{a_1}{a_2} = 1$

69. A particle of mass m carrying charge q is kept at rest in a uniform electric field E and then released. The kinetic energy gained by the particle, when it moves through a distance y is

(a) $\frac{1}{2}qEy^2$ (b) qEy (c) qEy^2 (d) qE^2y

70. A charged particle is free to move in an electric field. It will travel

(a) always along a line of force

(b) along a line of force, if its initial velocity is zero

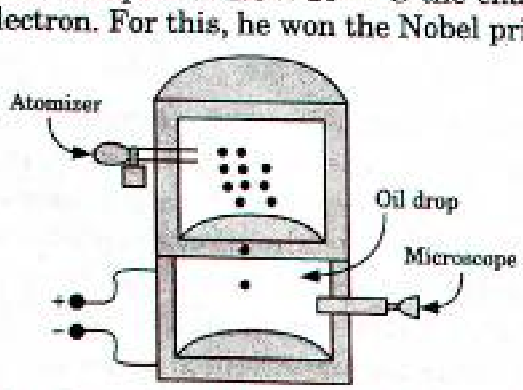
(c) along a line of force, if it has some initial velocity in the direction of an acute angle with the line of force

(d) none of these.

Case III : Read the passage given below and answer the following questions from 71 to 75.

Millikan's Oil-drop Experiment

In 1909, Robert Millikan was the first to find the charge of an electron in his now-famous oil-drop experiment. In that experiment, tiny oil drops were sprayed into a uniform electric field between a horizontal pair of oppositely charged plates. The drops were observed with a magnifying eyepiece, and the electric field was adjusted so that the upward force on some negatively charged oil drops was just sufficient to balance the downward force of gravity. That is, when suspended, upward force qE just equaled Mg. Millikan accurately measured the charges on many oil drops and found the values to be whole number multiples of 1.6×10^{-19} C the charge of the electron. For this, he won the Nobel prize.



71. If a drop of mass 1.08×10^{-14} kg remains stationary in an electric field of 1.68×10^5 N C^{-1}, then the charge of this drop is

(a) 6.40×10^{-19} C (b) 3.2×10^{-19} C

(c) 1.6×10^{-19} C (d) 4.8×10^{-19} C

72. Extra electrons on this particular oil drop (given the presently known charge of the electron) are

(a) 4 (b) 3 (c) 5 (d) 8

73. A negatively charged oil drop is prevented from falling under gravity by applying a vertical electric field 100 V m^{-1}. If the mass of the drop is 1.6×10^{-3} g, the number of electrons carried by the drop is ($g = 10$ m s^{-2})

(a) 10^{18} (b) 10^{15} (c) 10^{12} (d) 10^{9}

74. The important conclusion given by Millikan's experiment about the charge is

(a) charge is never quantized

(b) charge has no definite value

(c) charge is quantized

(d) charge on oil drop always increases.

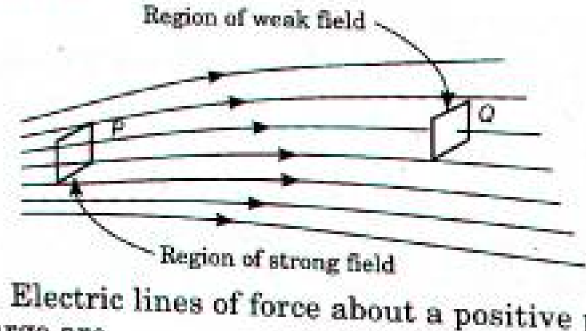
75. If in Millikan's oil drop experiment, charges on drops are found to be 8μC, 12μC, 20μC, then quanta of charge is

(a) 8μC (b) 20μC (c) 12μC (d) 4μC

Case IV : Read the passage given below and answer the following questions from 76 to 80.

Relation between Strength of Electric Field and Density of Lines of Force

Electric field strength is proportional to the density of lines of force *i.e.*, electric field strength at a point is proportional to the number of lines of force cutting a unit area element placed normal to the field at that point. As illustrated in the given figure, the electric field at P is stronger that at Q.



76. Electric lines of force about a positive point charge are

(a) radially outwards (b) circular clockwise

(c) radially inwards

(d) parallel straight lines.

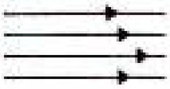
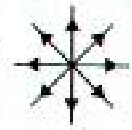
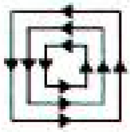
77. Which of the following is false for electric lines of force?

(a) They always start from positive charges and terminate on negative charges.

(b) They are always perpendicular to the surface of a charged conductor.

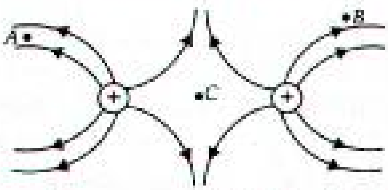
(c) They always form closed loops.
(d) They are parallel and equally spaced in a region of uniform electric field.

78. Which one of the following pattern of electric line of force in not possible in filed due to stationary charges ?

(a) 
(b) 
(c) 
(d) 

79. Electric lines of force are curved
(a) in the field of a single positive or negative charge
(b) in the field of two equal and opposite charges
(c) in the field of two like charges
(d) both (b) and (c).

80. The figure below shows the electric field lines due to two positive charges. The magnitudes E_A, E_B and E_C of the electric fields at points *A*, *B* and *C* respectively are related as



(a) $E_A > E_B > E_C$ (b) $E_B > E_A > E_C$
(c) $E_A = E_B > E_C$ (d) $E_A > E_B = E_C$

Case V : Read the passage given below and answer the following questions from 81 to 85.

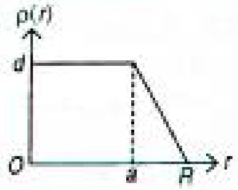
Continuous Charge Distribution
In practice, we deal with charges much greater in magnitude than the charge on an electron, so we can ignore the quantum nature of charges and imagine that the charge is spread in a region in a continuous manner. Such a charge distribution is known as continuous charge distribution. There are three types of continuous charge distribution : (i) Line charge distribution (ii) Surface charge distribution (iii) Volume charge distribution as shown in figure.

Line charge $\Delta Q = \lambda \Delta l$ Surface charge $\Delta Q = \sigma \Delta S$ Volume charge $\Delta Q = \rho \Delta V$

81. Statement 1 : Gauss's law can't be used to calculate electric field near an electric dipole.
Statement 2 : Electric dipole don't have symmetrical charge distribution.
(a) Statement 1 and statement 2 are true
(b) Statement 1 is false but statement 2 is true.
(c) Statement 1 is true but statement 2 is false.
(d) Both statements are false.

82. An electric charge of 8.85×10^{-13} C is placed at the centre of a sphere of radius 1 m. The electric flux through the sphere is
(a) $0.2\ N\ C^{-1}\ m^2$ (b) $0.1\ N\ C^{-1}\ m^2$
(c) $0.3\ N\ C^{-1}\ m^2$ (d) $0.01\ N\ C^{-1}\ m^2$

83. The electric field within the nucleus is generally observed to be linearly dependent on *r*. So,



(a) $a = 0$
(b) $a = \frac{R}{2}$
(c) $a = R$
(d) $a = \frac{2R}{3}$

84. What charge would be required to electrify a sphere of radius 25 cm so as to get a surface charge density of $\frac{3}{\pi}\ C\ m^{-2}$?
(a) 0.75 C (b) 7.5 C (c) 75 C (d) zero

85. The SI unit of linear charge density is
(a) C m (b) $C\ m^{-1}$ (c) $C\ m^{-2}$ (d) $C\ m^{-3}$

Assertion & Reasoning Based MCQs

For question numbers 86-100, two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is NOT the correct explanation of A
(c) A is true but R is false
(d) A is false and R is also false

86. Assertion (A) : If a conducting medium is placed between two charges, then electric force between them becomes zero.
Reason (R) : Reduction in a force due to introduced material is inversely proportional to its dielectric constant.

87. Assertion (A) : In electrostatics, electric lines of force can never be closed loops, as a line can never start and end on the same charge.
Reason (R) : The number of electric lines of force originating or terminating on a charge is proportional to the magnitude of charge.

88. Assertion (A) : The electric field due to a discrete charge configuration is not defined at the locations of the discrete charges.
Reason (R) : For a surface charge distribution, electric field is discontinuous across the surface.

89. Assertion (A) : Charge is quantized.
Reason (R) : Charge which is less than 1 C is not possible.

90. Assertion (A) : The electric flux emanating out and entering a closed surface are 8×10^3 and 2×10^3 V m respectively. The charge enclosed by the surface is 0.053 μC.
Reason (R) : Gauss's theorem in electrostatics may be applied to verify.

91. Assertion (A) : Total flux through a closed surface is zero if no charge is enclosed by the surface.
Reason (R) : Gauss law is true for any closed surface, no matter what its shape or size is.

92. Assertion (A) : The surface densities of two spherical conductors of different radii are equal. Then the electric field intensities near their surface are also equal.
Reason (R) : Surface density is equal to charge per unit area.

93. Assertion (A) : Three equal charges are situated on a circle of radius r such that they form on equilateral triangle, then the electric field intensity at the centre is zero.
Reason (R) : The force on unit positive charge at the centre, due to the three equal charges are represented by the three sides of a triangle taken in the same order. Therefore, electric field intensity at centre is zero.

94. Assertion (A) : The electric lines of forces diverges from a positive charge and converge at a negative charge.
Reason (A) : A charged particle free to move in an electric field always move along an electric line of force.

95. Assertion (A) : Charging is due to transfer of electrons.
Reason (R) : Mass of a body decreases slightly when it is negatively charged.

96. Assertion (A) : Range of Coulomb force is infinite.
Reason (R) : Coulomb force acts between two charged particles.

97. Assertion (A) : If a point charge be rotated in a circle around a charge, the work done will be zero.
Reason (R) : Work done is equal to dot product of force and distance.

98. Assertion (A) : A point charge is lying at the centre of a cube of each side. The electric flux emanating from each surface of the cube is $\frac{1}{6}^{th}$ of total flux.
Reason (R) : According to Gauss theorem, total electric flux through a closed surface enclosing a charge is equal to $1/\varepsilon_0$ times the magnitude of the charge enclosed.

99. Assertion (A) : A point charge is brought in an electric field. The field at a nearby point is increase, whatever be the nature of the charge.
Reason (R) : The electric field is independent of the nature of charge.

100. Assertion (A) : For charge to be in equilibrium, sum of the forces on charge due to rest of the two charges must be zero.
Reason (R) : A charge is lying at the centre of the line joining two similar charges each which are fixed. The system will be in equilibrium if that charge is one fourth of the similar charges.

ANSWERS

1. **(b) :** Mass of water = 250 g
Molecular mass of water = 18 g
Number of molecules in 18 g of water
(Avogadro's Number) = 6.02×10^{23}
∴ Number of molecules in one cup of water

$$= \frac{250}{18} \times 6.02 \times 10^{23}$$

Each molecule of water contains two hydrogen atoms and one oxygen atom, *i.e.*, 10 electrons and 10 protons.
∴ Total positive and negative charge has the same magnitude and is

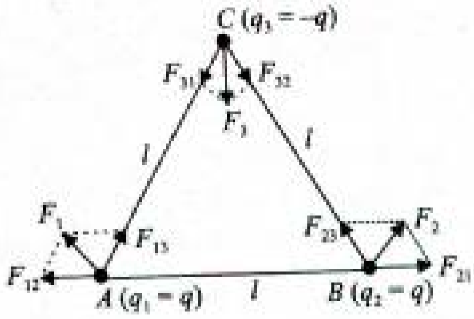
$$= \frac{250}{18} \times 6.02 \times 10^{23} \times 10 \times 1.6 \times 10^{-19}\ C = 1.34 \times 10^7\ C$$

2. **(a)** : By quantisation of charge,

$q = ne$

or $n = \frac{q}{e} = \frac{-1C}{-(1.6\times10^{-19})} = 6\times10^{18}$ electrons

3. **(d)** : From diagram, force on $q_1(=q)$ at A,



$\vec{F}_1 = \vec{F}_{12} + \vec{F}_{13} = F\hat{r}_1$

Here $F = \frac{q^2}{4\pi\varepsilon_0 l^2}$ and $\hat{r}_1$ is the unit vector along BC

Force on $q_2(=q)$ at B,

$\vec{F}_2 = \vec{F}_{21} + \vec{F}_{23} = F\hat{r}_2$ (here $\hat{r}_2$, is the unit vector along AC)

Force on $q_3(=-q)$ at C

$\vec{F}_3 = \vec{F}_{31} + \vec{F}_{32} = \left(\sqrt{F_1^2 + F_2^2 + 2F_1F_2\cos60^\circ}\right)\hat{n} = \sqrt{3}F\hat{n}$

Here $\hat{n}$ = unit vector along the direction bisecting $\angle BCA$

or $\vec{F}_1 + \vec{F}_2 + \vec{F}_3 = 0$

4. **(d)** : In a charge-free region, electric field lines can be taken to be continuous curves without any breaks.

5. **(d)** : Electric field at a point is continuous if there is no charge at that point. And the field is discontinuous if there is charge at that point.

6. **(d)** : As per Gauss's theorem in electrostatics, the electric flux through a surface depends only on the amount of charge enclosed by the surface. It does not depend on size and shape of the surface. Therefore, electric flux through the surface is the same for all figures.

7. **(d)** : Dipole moment is a vector quantity and has magnitude of $2qa$ and it is in the direction of the dipole axis from $-q$ to q.

8. **(a)** : As electric flux, $\phi = E.\Delta s$

$\therefore$ unit of ϕ is N C^{-1} m^2

9. **(b)** : Here, $q_1 = 0.2\ \mu C = 0.2\times10^{-6}$ C

$q_2 = -0.4\ \mu C = 0.4\times10^{-6}$ C

$F = 0.4$ N

As $F = \frac{q_1q_2}{4\pi\varepsilon_0 r^2}$

$\therefore\ r^2 = \frac{q_1q_2}{4\pi\varepsilon_0 F} = \frac{0.2\times10^{-6}\times0.4\times10^{-6}\times9\times10^9}{0.4}$

$= 1.8\times10^{-3} = 0.18\times10^{-4}$

$\therefore\ r = (0.18\times10^{-4})^{1/2} = 0.42\times10^{-2}$ m $= 4.2\times10^{-3}$ m

10. **(c)** : Electric field due to complete disc ($R = 2a$),

$$E_1 = \frac{\sigma}{2\varepsilon_0}\left[1 - \frac{x}{\sqrt{R^2+x^2}}\right] = \frac{\sigma}{2\varepsilon_0}\left[1 - \frac{h}{\sqrt{4a^2+h^2}}\right]$$

$$= \frac{\sigma}{2\varepsilon_0}\left[1 - \frac{h}{2a}\right] \quad (\because h << a)$$

Electric field due to disc ($R = a$),

$$E_2 = \frac{\sigma}{2\varepsilon_0}\left[1 - \frac{h}{a}\right]$$

Hence, electric field due to given disc,

$$E = E_1 - E_2 = \frac{\sigma h}{4\varepsilon_0 a}$$

$$\therefore\ C = \frac{\sigma}{4a\varepsilon_0}$$

11. **(b)** : Here, $q_1 = 1\times10^{-7}$ C, $q_2 = 2\times10^{-7}$ C,

$r = 20$ cm $= 20\times10^{-2}$ m

As $F = \frac{q_1q_2}{4\pi\varepsilon_0 r^2}$

$= \frac{9\times10^9\times1\times10^{-7}\times2\times10^{-7}}{(20\times10^{-2})^2} = 4.5\times10^{-3}$ N

12. **(d)** : Here, $p = 2\times10^{-9}$ cm, $\theta = 30^\circ$

$E = 4\times10^4$ N C^{-1}

As $\tau = pE\sin\theta$

$= 2\times10^{-9}\times4\times10^4\sin30^\circ = 4\times10^{-5}$ N m

13. **(c)** : According to Gauss's theorem,

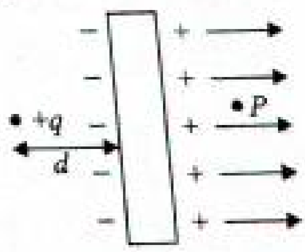
Electric flux through the sphere $= \frac{q}{\varepsilon_0}$

$\therefore$ Electric flux through the hemisphere $= \frac{1}{2}\frac{q}{\varepsilon_0}$

$= \frac{10\times10^{-6}}{2\times8.854\times10^{-12}} = 0.56\times10^6$ Nm^2 C^{-1}

$= 0.6\times10^6$ Nm^2 C^{-1} $= 6\times10^5$ Nm^2 C^{-1}

14. **(a)** : When a point charge $+q$ is placed at a distance d from an isolated conducting plane, some negative charge develops on the surface of the plane towards the charge and an equal positive charge develops on opposite side of the plane. Hence, the field at a point P on the other side of the plane is directed perpendicular to the plane and away from the plane as shown in figure.



15. **(d)** : According to Gauss's theorem in electrostatics

$$\oint \vec{E}.d\vec{s} = \frac{q}{\varepsilon_0}$$

Here q is charge enclosed by the surface.

If the charge is outside the surface, therefore $q_{inside} = 0$

Also, $\oint \vec{E}.d\vec{s} = 0$.

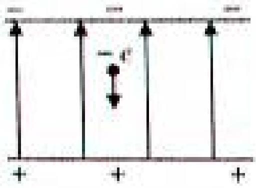
So both (b) and (c) are correct.

16. (d) : When a glass rod is rubbed with silk cloth then some of the electrons from the glass rod get transferred to silk cloth and thus the glass rod gets positively charged and the silk get negatively charged. No new charge is created in the process of rubbing.

17. (d)

18. (c) : When there are various types of charges in a region, but the total charge is zero, the region can be supposed to contain a number of electric dipoles. Therefore, at points outside the region, the dominant electric field $\propto \frac{1}{r^3}$ for large r.

19. (d) : In figure, the field is upward.



So the negatively charged electron experiences a downward force.

$\therefore$ The acceleration of electron is

$$a_e = \frac{eE}{m_e} \quad ...(i)$$

The time required by the electron to fall through a distance h is

$$t_e = \sqrt{\left(\frac{2h}{a_e}\right)} = \sqrt{\frac{2hm_e}{eE}} \quad \text{(using (i))}$$

$$= \left[\frac{2\times1.5\times10^{-2}\ \text{m}\times9.11\times10^{-31}}{1.6\times10^{-19}\text{C}\times2\times10^4}\right]^{1/2} = 2.9 \times 10^{-9}\ \text{s}$$

20. (c) : As $\oint \vec{E}.d\vec{s} = \frac{q}{\varepsilon_0}$

where q is charge enclosed by the surface.

when $\oint \vec{E}.d\vec{s} = 0, q = 0$

i.e. net charge enclosed by the surface must be zero. Therefore, all other charges must be outside the surface. This is because charges outside the surface do not contribute to the electric flux.

21. (a) : The electric field in a region is given by

$$\vec{E} = \frac{A}{x^3}\hat{i} + By\hat{j} + Cz^2\hat{k}$$

Compare it with $\vec{E} = E_x\hat{i} + E_y\hat{j} + E_z\hat{k}$

we get

$$E_x = \frac{A}{x^3},\ E_y = By,\ E_z = Cz^2$$

$$\therefore \quad A = E_x x^3 = \text{N C}^{-1}\ \text{m}^3 = \frac{\text{N m}^3}{\text{C}}$$

$$B = \frac{E_y}{y} = \frac{\text{N C}^{-1}}{\text{m}} = \frac{\text{N}}{\text{C m}} = \frac{\text{N m}}{\text{C m}^2} = \frac{\text{V}}{\text{m}^2}$$

$$C = \frac{E_z}{z^2} = \frac{\text{N C}^{-1}}{\text{m}^2} = \frac{\text{N}}{\text{C m}^2}$$

22. (d) : Here, $p = 1 \times 10^{-9}$ cm, $\theta = 30°$

$E = 6 \times 10^4$ N C^{-1}

As $\tau = pE \sin\theta$

$= 1 \times 10^{-9} \times 6 \times 10^4 \sin 30°$

$= 3 \times 10^{-5}$ N m

23. (c) : $\vec{E}_{ax} = \frac{1}{4\pi\varepsilon_0}\frac{2\vec{p}}{r^3}$; $\vec{E}_{eq} = -\frac{1}{4\pi\varepsilon_0}\frac{\vec{p}}{r^3} = -\frac{\vec{E}_{ax}}{2}$

$\therefore \quad \vec{E}_{ax} = -2\vec{E}_{eq}$

24. (d) : Here, $q = -6 \times 10^{-7}$ C

Charge on one electron, $e = -1.6 \times 10^{-19}$ C

$\therefore$ Number of electrons transferred from wood to polythene,

$$n = \frac{q}{e} = \frac{-6\times10^{-7}}{-1.6\times10^{-19}} = 3.75 \times 10^{12}$$

25. (a) : By Gauss's law,

$$\phi = \frac{q}{\varepsilon_0}$$

or $q = \phi\varepsilon_0$

$= 1.05 \times 8.854 \times 10^{-12}$ C $= 9.30 \times 10^{-12}$ C

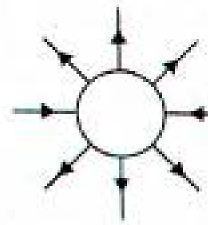
26. (a) : The torque acting on a dipole in a uniform external field $\vec{E}$ is $\vec{\tau} = \vec{P} \times \vec{E}$ or $PE \sin\theta$ and its direction is perpendicular to $\vec{E}$ and also $\vec{P}$.

27. (a) : In the figure, when a charge q is placed at corner A of the cube, it is being shared equally by 8 cubes.

$\therefore$ The total flux through the faces of the given cube

$$= \frac{q}{8\varepsilon_0}$$

28. (b) : For a uniformly charged hollow cylinder, the electric field lines are as shown in figure (b).



29. (b) : Charge on single electron is $e = 1.6 \times 10^{-19}$ C

Total charge, $q = +2.4$ C

Then by quantization of charge

$q = ne$

$\therefore$ number of electrons, $n = \frac{q}{e}$

$$= \frac{2.4\,\text{C}}{1.6\times10^{-19}\,\text{C}} = 1.5 \times 10^{19}$$

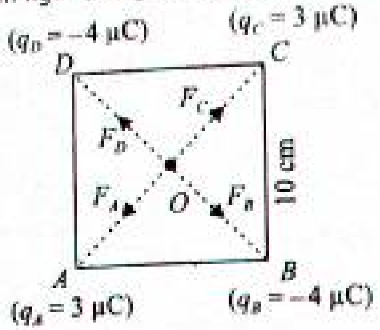
30. (a) : Here, $E = \frac{\sigma}{\varepsilon_0} = \frac{16\times10^{-22}}{8.854\times10^{-12}} = 1.8 \times 10^{-10}$ N C^{-1}

31. (b)

32. (d) : Object can be charged by rubbing. During rubbing some of the free electrons may get transferred from one object to other.

33. (d)

34. (d) : From figure, length of diagonal of the square



$= AC = BD = \sqrt{10^2 + 10^2} = 10\sqrt{2}$ cm

$OA = OB = OC = OD = \dfrac{10\sqrt{2}}{2} = \dfrac{10}{\sqrt{2}}$ cm

Forces of repulsion on 1 μC charge at O due to 3 μC charge, at A and C are equal and opposite. So they cancel each other. Similarly, forces of attraction of 1 μC charge at O due to –4 μC charges at B and D are also equal and opposite. So they also cancel each other.

Hence the net force on the charge of 1 μC at O is zero.

35. (b) : Electric field, $E = \dfrac{\sigma}{\varepsilon_0}$.

36. (b) : Here, $q_1 = q_2 = 3.2 \times 10^{-7}$ C, $r = 60$ cm $= 0.6$ m

Electrostatic force, $F = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q_1 q_2}{r^2}$

$= \dfrac{9\times10^9\,(3.2\times10^{-7})^2}{(0.6)^2}$

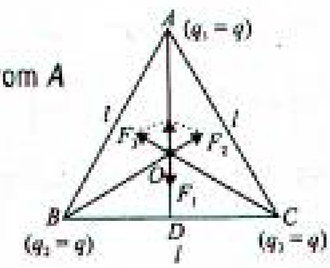
$= 2.56 \times 10^{-3}$ N

37. (d) : As shown in figure draw $AD \perp BC$.

$\therefore \quad AD = AB\cos30° = \dfrac{l\sqrt{3}}{2}$

Distance AO of the centroid O from A

$= \dfrac{2}{3}AD = \dfrac{2l}{3}\dfrac{\sqrt{3}}{2} = \dfrac{l}{\sqrt{3}}$



$\therefore$ Force on Q at O due to charge $q_1 = q$ at A

$F_1 = \dfrac{1}{4\pi\varepsilon_0}\dfrac{Qq}{(l/\sqrt{3})^2} = \dfrac{3Qq}{4\pi\varepsilon_0 l^2}$, along AO

Similarly, force on O due to charge $q_2 = q$ at B

$F_2 = \dfrac{3Qq}{4\pi\varepsilon_0 l^2}$ along BO

and force on Q due to charge $q_3 = q$ at C

$F_3 = \dfrac{3Qq}{4\pi\varepsilon_0 l^2}$, along CO

Angle between forces F_2 and $F_3 = 120°$

By parallelogram law, resultant of F_2 and $F_3 = \dfrac{3Qq}{4\pi\varepsilon_0 l^2}$ along OA

$\therefore \quad$ Total force on $Q = \dfrac{3Qq}{4\pi\varepsilon_0 l^2} - \dfrac{3Qq}{4\pi\varepsilon_0 l^2} = 0$

38. (c) : The value of $\vec{E}$ in the region II, in between the plates,

$= \dfrac{\sigma}{\varepsilon_0} = \dfrac{27\times10^{-22}}{8.85\times10^{-12}} = 3.05\times10^{-10}$ N C^{-1}

39. (c) : Particles A and B have negative charges because they are being deflected towards the positive plate of the electrostatic field. Particle C has positive charge because it is being deflected towards the negative plate.

$\therefore \quad$ deflection of charged particle in time t in y-direction

$h = 0\times t + \dfrac{1}{2}at^2 = \dfrac{1}{2}\dfrac{qE}{m}t^2$

i.e. $\ h \propto q/m$

As the particle C suffers maximum deflection in y-direction, so it has highest charge to mass q/m ratio.

40. (a)

41. (c) : From $E = \dfrac{F}{q}$

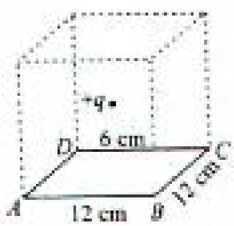
$= \dfrac{[M^1L^1T^{-2}]}{[AT]} = [M^1L^1T^{-3}A^{-1}]$

42. (b) : Here, take the square as one face of the cube with edge 12 cm.

The point charge +20 μC is at a distance 6 cm directly above the centre of $ABCD$

From figure, it is clear that square $ABCD$ is one of the six faces of a cube of side 12 cm.

By Gauss's theorem, total electric flux through all the six faces of the cube $= \dfrac{q}{\varepsilon_0}$



$\therefore \quad$ Electric flux through the square

$\phi = \dfrac{1}{6}\dfrac{q}{\varepsilon_0}$

$= \dfrac{1}{6}\times\dfrac{20\times10^{-6}}{8.85\times10^{-12}}$

$= 3.8 \times 10^5$ N m^2 C^{-1}

43. (b) : Electrostatic field lines start or end only at 90° to the surface of the conductor. So curve (b) cannot represent electrostatic field lines.

44. (d)

45. (d) : Here, $E = 2 \times 10^5$ N C^{-1}

$l = 2$ cm, $\tau = 4$ N m

Torque, $\vec{\tau} = \vec{p}\times\vec{E} = pE\sin\theta$

$\therefore \quad 4 = p \times 2 \times 10^5 \times \sin 30°$ or $p = 4 \times 10^{-5}$ C m

As $\ p = ql$

$\therefore$ Charge, $q = \frac{p}{l} = \frac{4 \times 10^{-5} \text{ C m}}{0.02 \text{ m}}$

$= 2 \times 10^{-3}$ C = 2 mC

46. (a) : The value of $k = \frac{1}{4\pi\varepsilon_0}$

where ε_0 is permittivity of free space

$= 8.854 \times 10^{-12}$ C^2 N^{-1} m^{-2}

47. (a) : Mass of the coin = 0.75 g,

Atomic number, $Z_{Al} = 13$

Atomic mass of aluminium = 26.98 g

Avogadro's number = 6.02×10^{23}

Number of Al atoms in the coin,

$N = \frac{6.02 \times 10^{23}}{26.98} \times 0.75 = 1.67 \times 10^{22}$

As charge number of Al is 13, each atom of Al contain 13 protons and 13 electrons.

Magnitude of positive and negative charges is one paisa coin

$= NZe$

$= 1.67 \times 10^{22} \times 13 \times 1.6 \times 10^{-19}$ C

$= 3.47 \times 10^4$ C

48. (b) : Here, number of electrons removed = number of atoms in 1 g

or $n = \frac{4 \times 10^{20}}{10^3} = 4 \times 10^{17}$

$\therefore$ charge, $q = ne = 4 \times 10^{17} \times 1.6 \times 10^{-19}$ C

$= 6.4 \times 10^{-2}$ C

49. (c) : Electric field,

$E = \frac{F}{q} = \frac{2.25 \text{ N}}{15 \times 10^{-4} \text{ C}} = 1500$ N C^{-1}

50. (c)

51. (d)

52. (b) : While combing hair, friction between the comb and the hair results is the transfer of electrons.

53. (c) : Force of mutual attraction between an electron and a proton

$F = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2}$

$= \frac{9 \times 10^9 (1.6 \times 10^{-19})^2}{(10^{-10})^2} = 2.3 \times 10^{-8}$ N

Acceleration of electron $= \frac{F}{m_e}$

$= \frac{2.3 \times 10^{-8}}{9 \times 10^{-31}}$

$= 2.5 \times 10^{22}$ m s^{-2}

Acceleration of proton $= \frac{F}{m_p}$

$= \frac{2.3 \times 10^{-8}}{1.66 \times 10^{-27}}$

$= 1.3 \times 10^{19}$ m s^{-2}

54. (c) : The potential energy of an electric dipole in a uniform electric field is

$U = -\vec{p} \cdot \vec{E}$

$U = -pE\cos\theta$

For U to be maximum

$\cos\theta = -1 \Rightarrow \theta = \pi$

55. (b) : The field lines of single negative charge are radially inward.

56. (c) : Gauss's law is often useful towards a much easier calculation of electrostatic field when the system has some symmetry. This is facilitated by the choice of a suitable Gaussian surface.

57. (a) : Here, in the vertical direction,

initial velocity, $v = 0$

acceleration, $a = \frac{F}{m} = \frac{qE}{m}$ ...(i) $(\because F = qE)$

Time taken to cross the field,

$t = \frac{\text{distance}}{\text{velocity}} = \frac{L}{v_x}$ ...(ii)

($\because$ velocity along the horizontal direction is constant)

or $s = vt + \frac{1}{2}at^2$

$\therefore$ deflection, $y = 0 + \frac{1}{2}\left(\frac{qE}{m}\right)\left(\frac{L}{v_x}\right)^2$ [Using (i) and (ii)]

$\therefore$ $y = \frac{qEL^2}{2mv_x^2}$

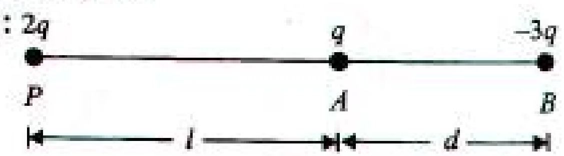
58. (b) : Here, $\vec{E} = 4\hat{i} + 4\hat{j} + 4\hat{k}$, $d\vec{S} = 5\hat{i}$

Electric flux, $d\phi = \vec{E} \cdot d\vec{S}$

$= \left(4\hat{i} + 4\hat{j} + 4\hat{k}\right) \cdot \left(5\hat{i}\right) = 20$ units

59. (d) : Electric field strength is maximum where the electric field lines are closer.

60. (b) :



Let a charge $2q$ be placed at P, at a distance l from A where charge q is placed, as shown in figure.

The charge $2q$ will not experience any force, when force of repulsion on it due to q is balanced by force of attraction on it due to $-3q$ at B where $AB = d$

or $\frac{(2q)(q)}{4\pi\varepsilon_0 l^2} = \frac{(2q)(-3q)}{4\pi\varepsilon_0 (l+d)^2}$

$(l+d)^2 = 3l^2$

or $2l^2 - 2ld - d^2 = 0$

$\therefore \quad l = \frac{2d \pm \sqrt{4d^2 + 8d^2}}{4} = \frac{d}{2} \pm \frac{\sqrt{3}d}{2}$

$l = \frac{d + \sqrt{3}d}{2}$

61. (d)

62. (b) : From, $q = ne$, $n = \frac{q}{e} = \frac{3.2 \times 10^{-18}}{1.6 \times 10^{-19}} = 20$

As n is an integer, hence this value of charge is possible.

63. (d) : Charge on the body is $q = ne$

$\therefore$ No. of electrons present on the body is

$n = \frac{q}{e} = \frac{1 \times 10^{-9}\text{C}}{1.6 \times 10^{-19}\text{C}} = 6.25 \times 10^9$

64. (c) : Here, $n = 10^9$ electrons per second

Charge given per second,

$q = ne = 10^9 \times 1.6 \times 10^{-19}$ C

$q = 1.6 \times 10^{-10}$ C

Total charge, $Q = 1$ C (given)

$\therefore$ Time required $= \frac{Q}{q} = \frac{1}{1.6 \times 10^{-10}}$ s $= 6.25 \times 10^9$s

$\therefore \quad \frac{6.25 \times 10^9}{3600 \times 24 \times 365}$ year = 198.19 years.

65. (a) : As $q = ne$, $n = \frac{3.2 \times 10^{-7}}{1.6 \times 10^{-19}}$

$\Rightarrow n = 2 \times 10^{12}$ electrons.

66. (a) : From Newton's law

$F = m\vec{a}$ or $qE = m\vec{a} \Rightarrow a = \frac{qE}{m} = \frac{eE}{m}$

Using, $s = ut + \frac{1}{2}at^2$

$\therefore \quad h = 0 + \frac{1}{2} \times \frac{eE}{m}t^2 \Rightarrow t = \sqrt{\frac{2hm}{eE}}$

67. (c)

68. (b) : Force is same in magnitude for both.

$\therefore \quad m_1a_1 = m_2a_2$;

$\frac{a_1}{a_2} = \frac{m_2}{m_1} = \frac{1}{0.5} = 2$

69. (b) : Here, $u = 0$; $a = \frac{qE}{m}$; $s = y$

Using, $v^2 - u^2 = 2as \Rightarrow v^2 = 2\frac{qE}{m}y$

$\therefore$ K.E. $= \frac{1}{2}mv^2 = qEy$

70. (b) : If charge particle is put at rest in electric field, then it will move along line of force.

71. (a) : As, $qE = mg \Rightarrow q = \frac{1.08 \times 10^{-14} \times 9.8}{1.68 \times 10^5}$

$= 6.4 \times 10^{-19}$ C

72. (a) : $q = ne$ or $\Rightarrow n = \frac{6.4 \times 10^{-19}}{1.6 \times 10^{-19}} = 4$

73. (c) : For the drop to be stationary.

Force on the drop due to electric field = Weight of the drop

$qE = mg$

$q = \frac{mg}{E} = \frac{1.6 \times 10^{-6} \times 10}{100} = 1.6 \times 10^{-7}$ C

Number of electrons carried by the drop is

$n = \frac{q}{e} = \frac{1.6 \times 10^{-7}\text{ C}}{1.6 \times 10^{-19}\text{ C}} = 10^{12}$

74. (c)

75. (d) : Millikan's experiment confirmed that the charges are quantized, *i.e.*, charges are small integer multiples of the base value which is charge on electron. The charges on the drops are found to be multiple of 4. Hence, the quanta of charge is 4 μC.

76. (a)

77. (c) : Electric lines of force do not form any closed loops.

78. (c) : Electric field lines can't be closed.

79. (d)

80. (a)

81. (a) : Gauss's law is applicable for any closed surface. Gauss's law is most useful in situation where the charge distribution has spherical or cylindrical symmetry or is distributed uniformly over the plane. Whereas electric dipole is a system of two equal and opposite point charges separated by a very small and finite distance.

So both statements are correct.

82. (b) : According to Gauss's law, the electric flux through the sphere is

$\phi = \frac{q_{in}}{\varepsilon_0} = \frac{8.85 \times 10^{-13}\text{C}}{8.85 \times 10^{-12}\text{ C}^2\text{ N}^{-1}\text{ m}^{-2}} = 0.1 \text{ N C}^{-1}\text{ m}^2$

83. (c) : For uniformly volume charge density, $E = \frac{\rho r}{3\varepsilon_0}$

$E \propto r$

84. (a) : $r = 25$ cm $= 0.25$ m, $\sigma = \frac{3}{\pi}$ C/m^2

As, $\sigma = \frac{q}{4\pi r^2} \Rightarrow q = 4\pi \times (0.25)^2 \times \frac{3}{\pi} = 0.75$ C

85. (b) : The line charge density at a point on a line is the charge per unit length of the line at that point

$\lambda = \frac{dq}{dL}$

Thus, the SI unit for λ is C m^{-1}.

86. (a) : The dielectric constant of any material is $K = \frac{E_0}{E} = \frac{F_0/q}{F/q} = \frac{F_0}{F} \Rightarrow F = \frac{F_0}{K}$, where F_0 is force when conductor is not present between the charge. F is a force after introduction of conductor between charges. Since dielectric constant of a conducting medium is infinity therefore $F = 0$.

87. (b) : Electrostatic field lines of force can never form any closed loop. Because electric field originate from positive charge and terminates on negative charge.

88. (b)

89. (c) : The charge q on a body is given as $q = ne$ where n is any integer positive or negative.
The charge on the electron is $q = 1.6 \times 10^{-19}$ C which is less than 1 C.

90. (a) : According to Gauss's theorem in electrostatics,

$\phi = q/\varepsilon_0$

$q = \varepsilon_0\phi = 8.85 \times 10^{-12}\,[8 \times 10^3 - 2 \times 10^3]$

$= 53.10 \times 10^{-9}$ C $= 0.053\ \mu$C.

91. (b) : Gauss law implies that the total electric flux through a closed surface is zero if no charge is enclosed by the surface and it is true for any closed surface, independent of its shape and size.

92. (b) : As $\sigma_1 = \sigma_2$ (Given)

$$\therefore\ \frac{q_1}{4\pi r_1^2} = \frac{q_2}{4\pi r_2^2},\ \text{or},\ \frac{q_1}{q_2} = \frac{r_1^2}{r_2^2}$$

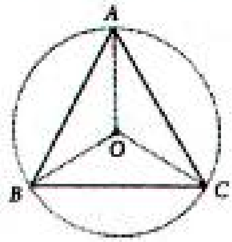
[Let r_1 and r_2 be two different radii]

Then the ratio of electric field intensities near the surface of spherical conductors,

$$\frac{E_1}{E_2} = \frac{q_1}{4\pi\varepsilon_0 r_1^2} \times \frac{4\pi\varepsilon_0 r_2^2}{q_2} = \frac{q_1}{q_2} \times \frac{r_2^2}{r_1^2} = \frac{q_1}{q_2} \times \frac{q_2}{q_1} = 1$$

i.e. $E_1 = E_2$

93. (a) : Resultant of electric intensity at O due to B and C is equal and opposite to that due to A.



94. (c) : If the charged particle is initially at rest in an electric field, it will move along the electric line of force. But when the initial velocity of charged particle makes some angle with the line of force then the resultant path is not along the line of force. Because electric line of force may not coincide with the line of velocity of the charge.

95. (c) : A body becomes negatively charged only when some electrons are transferred to the body *i.e.* the body gains some electrons. Hence its mass increases slightly. Mass of a body decreases only when body gives some electrons to some other body.

96. (b) : Coulomb's force or electric force given by Coulomb's law, is valid over nuclear distances ($\cong 10^{-15}$ m)as well as over very large distances.

From Coulomb's law, $F = \frac{k|q_1||q_2|}{r^2}$. This generally holds only for charged objects whose size are much smaller than the distance between them.

97. (a) : Work done will be zero because in rotating the charge in a circle, force is along the radius and direction of motion is perpendicular to it.

$\therefore$ Work done, $W = \vec{F}.\vec{S} = FS\cos\theta$

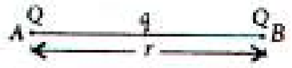
$= FS\cos 90° = 0$

98. (b) : The electric flux through the cube, $\phi = q/\varepsilon_0$.
A cube has six faces of equal area. Therefore, electric flux through each face $= \frac{1}{6}\phi = \frac{1}{6}(q/\varepsilon_0)$.

99. (d) : Electric field at the nearby point will be resultant of existing field and field due to the charge brought. It may increase or decrease if the charge is positive or negative depending on the position of the point with respect to the charge brought.

100. (c) : According to Coulomb's law, $F = k\frac{Q_1Q_2}{r^2}$.
The force on q due to A,

$$F_A = \frac{1}{4\pi\varepsilon_0}\cdot\frac{Qq}{(r/2)^2}\ \text{to the right}$$



Due to B,

$$F_B = \frac{1}{4\pi\varepsilon_0}\cdot\frac{Qq}{(r/2)^2}\ \text{to the left.}$$

$\therefore$ Their sum is zero whether q is $+\frac{Q}{4}$ or $-\frac{Q}{4}$ or any other value.
Therefore, it is not true that the third charge has to be $Q/4$ only. It can be any value.

☺☺☺

CHAPTER 2

Electrostatic Potential and Capacitance

Recap Notes

- **Electric potential :** Electric potential at a point is defined as amount of work done in bringing a unit positive charge from infinity to that point. It is denoted by symbol V.

$$V = \frac{W}{q}$$

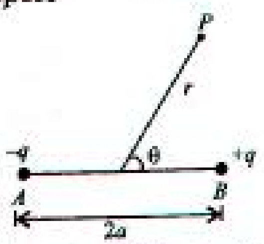
  - Electric potential is a scalar quantity. The SI unit of potential is volt and its dimensional formula is $[ML^2T^{-3}A^{-1}]$.
  - Electric potential at a point distant r from a point charge q is

$$V = \frac{q}{4\pi\varepsilon_0 r}$$

  - Electric potential due to group of charges : The electric potential at a point due to a group of charges is equal to the algebraic sum of the electric potentials due to individual charges at that point.

$$V = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1}{r_1} + \frac{q_2}{r_2} + \frac{q_3}{r_3} + \dots \frac{q_n}{r_n}\right) = \frac{1}{4\pi\varepsilon_0}\sum_{i=1}^{n}\frac{q_i}{r_i}$$

  - Electric potential at any point due to an electric dipole



The electric potential at point P due to an electric dipole

$$V = \frac{1}{4\pi\varepsilon_0}\frac{p\cos\theta}{r^2} = \frac{1}{4\pi\varepsilon_0}\frac{\vec{p}\cdot\hat{r}}{r^2}$$

- At axial point : When the point P lies on the axial line of dipole *i.e.*, $\theta = 0°$.

$$V = \frac{p}{4\pi\varepsilon_0 r^2}.$$

- At equatorial point : When the point P lies on the equatorial line of the dipole, *i.e.*, $\theta = 90° \quad \therefore \quad V = 0$.

  - Electric potential due to a uniformly charged spherical shell of uniform surface charge density σ and radius R at a distance r from the centre the shell is given as follows :

- At a point outside the shell *i.e.*, $r > R$

$$V = \frac{\sigma R^2}{\varepsilon_0 r} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$$

- At a point on the shell *i.e.*, $r = R$

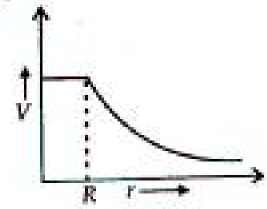
$$V = \frac{\sigma R}{\varepsilon_0} = \frac{1}{4\pi\varepsilon_0}\frac{q}{R}$$

- At a point inside the shell *i.e.*, $r < R$

$$V = \frac{\sigma R}{\varepsilon_0} = \frac{1}{4\pi\varepsilon_0}\frac{q}{R}$$

Here, $q = 4\pi R^2\sigma$

The variation of V with r for a uniformly charged thin spherical shell is shown in the figure.



  - Electric potential due to a non-conducting solid sphere of uniform volume charge density ρ and radius R at distant r from the sphere is given as follows :

- At a point outside the sphere *i.e.*, $r > R$

$$V = \frac{\rho R^3}{3\varepsilon_0 r} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$$

- At a point on the sphere *i.e.*, $r = R$

$$V = \frac{\rho R^2}{3\varepsilon_0} = \frac{1}{4\pi\varepsilon_0}\frac{q}{R}$$

- At a point inside the sphere *i.e.*, $r < R$

$$V = \frac{\rho}{3\varepsilon_0}\frac{(3R^2 - r^2)}{2} = \frac{1}{4\pi\varepsilon_0}\frac{q(3R^2 - r^2)}{2R^3}$$

Here $q = \frac{4}{3}\pi R^3 \rho$

Equipotential surface : A surface on which the electric potential is constant is known as equipotential surface.

- **Properties of an equipotential surface :**
  - Electric field lines are always perpendicular to an equipotential surface.
  - Work done in moving an electric charge from one point to another on an equipotential surface is zero.
  - Two equipotential surfaces can never intersect one another.

Relationship between $\vec{E}$ and $\vec{V}$

$$\vec{E} = -\vec{\nabla}V$$

where $\vec{\nabla} = \left(\hat{i}\frac{\partial}{\partial x} + \hat{j}\frac{\partial}{\partial y} + \hat{k}\frac{\partial}{\partial z}\right)$

–ve sign shows that the direction of $\vec{E}$ is the direction of decreasing potential.

Electric potential energy

- Electric potential energy of a system of two point charges

$$U = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{12}}$$

where r_{12} is the distance between q_1 and q_2.

- Electric potential energy of a system of n point charges

$$U = \frac{1}{4\pi\varepsilon_0}\sum_{\text{all pairs}}\frac{q_j q_k}{r_{jk}}; j > k$$

- The SI unit of electric potential energy is joule.

Conductors : Those substances which can easily allow electricity to pass through them are known as conductors. They have a large number of free charge carriers that are free to move inside the material. *e.g.*, metals, human beings, earth etc.

- Basic electrostatics properties of a conductor are as follows :
  - Inside a conductor, electric field is zero.
  - At the surface of a charged conductor, electric field must be normal to the surface at every point.
  - The interior of a conductor can have no excess charge in the static situation.
  - Electric potential is constant throughtout the volume of the conductor and has the same value (as inside) on its surface.
  - Electric field at the surface of a charged conductor, $\vec{E} = \frac{\sigma}{\varepsilon_0}\hat{n}$

  where σ is the surface charge density and $\hat{n}$ is a unit vector normal to the surface in the outward direction.
- **Electrostatic shielding :** It is the phenomenon of protecting a certain region of space from external electric field.

- **Polar and non-polar molecules**
  - Polar molecule : A polar molecule is one in which the centres of positive and negative charges are separated (even when there is no external field). A polar molecule has a permanent dipole moment *e.g.*, water (H_2O) and HCl.
  - Non-polar molecule : A non-polar molecule is one in which the centres of positive and negative charges coincide. A non-polar molecule has no permanent dipole moment. *e.g.*, oxygen (O_2) and hydrogen (H_2).

- **Capacitance :** Capacitance (C) of a capacitor is the ratio of charge (Q) given and the potential (V) to which it is raised. *i.e.*, $C = Q/V$.
  - The SI unit of capacitance is farad (F).
    - 1 millifarad (mF) = 10^{-3} farad
    - 1 microfarad (μF) = 10^{-6} farad
    - 1 picofarad (pF) = 10^{-12} farad.
  - The dimensional formula of capacitance is $[M^{-1}L^{-2}T^4A^2]$.
  - Capacitance of a spherical conductor of radius R is $C = 4\pi\varepsilon_0 R$

    Taking earth to be a conducting sphere of radius 6400 km, its capacity will be

$$C = 4\pi\varepsilon_0 R = \frac{6.4\times10^6}{9\times10^9} = 711\ \mu\text{F}$$

- **Capacitor :** A condenser or a capacitor is a device that stores electric charge. It consists of two conductors separated by an insulator or dielectric. The two conductors carry equal and opposite charges $\pm Q$.
  - Capacitance of an air filled parallel plate capacitor

$$C = \frac{\varepsilon_0 A}{d}$$

    where A is area of each plate and d is separation between the two plates.
  - Capacitance of an air filled spherical capacitor

$$C = 4\pi\varepsilon_0\frac{ab}{b-a}$$

    where a and b are the inner and outer radii.

- Capacitance of an air filled cylindrical capacitor
$$C=\frac{2\pi\varepsilon_0 L}{\ln\left(\frac{b}{a}\right)}$$
where a and b are the inner and outer radii and L is the length.
- Capacitance of a parallel plate capacitor with a dielectric slab of dielectric constant K, completely filled between the plates of the capacitor, is given by
$$C=\frac{K\varepsilon_0 A}{d}=\frac{\varepsilon_0\varepsilon_r A}{d}$$
- When a dielectric slab of thickness t and dielectric constant K is introduced between the plates, then the capacitance of a parallel plate capacitor is given by
$$C=\frac{\varepsilon_0 A}{d-t\left(1-\frac{1}{K}\right)}$$
- When a metallic conductor of thickness t is introduced between the plates, then capacitance of a parallel plate capacitor is given by
$$C=\frac{\varepsilon_0 A}{d-t}$$

- **Combination of capacitors in series and parallel**
  - Capacitors in series : For n capacitors connected in series the equivalent capacitance C_S is given by
$$\frac{1}{C_S}=\frac{1}{C_1}+\frac{1}{C_2}+....+\frac{1}{C_n}$$
  - Capacitors in parallel : For n capacitors connected in parallel, the equivalent capacitance C_P is given by
$C_P = C_1 + C_2 + ... + C_n$
  - When capacitors are connected in series, the charge through each capacitor is same. When capacitors are connected in parallel, the potential difference across each capacitor is same.
  - When two capacitors charged to different potentials are connected by a conducting wire, charge flows from the one at higher potential to the other at lower potential till their potentials become equal. The equal potential is called common potential (V), where
$$V=\frac{\text{total charge}}{\text{total capacity}}=\frac{Q_1+Q_2}{C_1+C_2}=\frac{C_1V_1+C_2V_2}{C_1+C_2}$$
It should be clearly understood that in sharing charges, there is absolutely no loss of charge. Some energy is, however, lost in the process in the form of heat etc. which is given by
$$U_1-U_2=\frac{C_1C_2(V_1-V_2)^2}{2(C_1+C_2)}.$$

- **Energy stored in a capacitor :** Work done in charging a capacitor gets stored in the capacitor in the form of its electric potential energy and it is given by
$$U=\frac{1}{2}CV^2=\frac{1}{2}QV=\frac{1}{2}\frac{Q^2}{C}$$
  - Energy density : The energy stored per unit volume in the electric field between the plates is known as energy density (u). It is given by
$$u=\frac{1}{2}\varepsilon_0 E^2$$
  - When a dielectric slab of dielectric constant K is introduced between the plates of a charged parallel plate capacitor and the charging battery remains connected, then
    - Potential difference between the plates remains constant *i.e.*, $V = V_0$
    - Capacitance C increases *i.e.*, $C = KC_0$
    - Charge on a capacitor increases *i.e.*, $Q = KQ_0$
    - Electric field between the plates remains unchanged *i.e.*, $E = E_0$
    - Energy stored in a capacitor increases *i.e.*, $U = KU_0$
  - When a dielectric slab of dielectric constant K is introduced in between the plates of a charged parallel plate capacitor and the charging battery is disconnected, then
    - Charge remains unchanged *i.e.*, $Q = Q_0$
    - Capacitance increases *i.e.*, $C = KC_0$
    - Potential difference between the plates decreases *i.e.*, $V=\frac{V_0}{K}$
    - Electric field between the plates decreases *i.e.*, $E=\frac{E_0}{K}$
    - Energy stored in the capacitor decreases *i.e.*, $U=\frac{U_0}{K}$

    where Q_0, C_0, V_0, E_0 and U_0 represents the charge, capacitance, potential difference, electric field and energy stored in the capacitor of a charged air filled parallel plate capacitor.

Practice Time

Multiple Choice Questions (MCQs)

1. Consider a uniform electric field in the z-direction. The potential is a constant
(a) for any x for a given z
(b) for any y for a given z
(c) on the x-y plane for a given z
(d) all of these

2. In a region of constant potential
(a) the electric field is uniform.
(b) the electric field is zero.
(c) there can be no charge inside the region.
(d) both (b) and (c) are correct.

3. A molecule of a substance has a permanent electric dipole moment of magnitude 10^{-30} C m. A mole of this substance is polarised by applying a strong electrostatic field of magnitude 10^7 V m^{-1}. The direction of field is changed by an angle 60°. The heat released by the substance in aligning its dipole along the new direction of the field is
(a) –6 J (b) –3 J (c) 3 J (d) 6 J

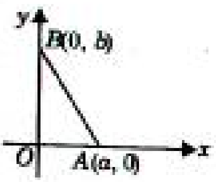
4. The potential at a point due to a charge of 5×10^{-7} C located 10 cm away is
(a) 3.5×10^5 V (b) 3.5×10^4 V
(c) 4.5×10^4 V (d) 4.5×10^5 V

5. In the previous question, work done in bringing a charge of 4×10^{-9} C from infinity to that point is
(a) 2.4×10^{-4} J (b) 1.8×10^{-4} J
(c) 3.2×10^{-5} J (d) 4.1×10^{-5} J

6. Two conducting spheres of radii r_1 and r_2 are equally charged. The ratio of their potential is
(a) $\frac{r_1}{r_2}$ (b) $\frac{r_2^2}{r_1^2}$ (c) $\frac{r_2}{r_1}$ (d) $\frac{r_1^2}{r_2^2}$

7. The electric potential at a point in free space due to a charge Q coulomb is $Q \times 10^{11}$ V. The electric field at that point is
(a) $12\pi\varepsilon_0 Q \times 10^{22}$ V m^{-1}
(b) $4\pi\varepsilon_0 Q \times 10^{22}$ V m^{-1}
(c) $12\pi\varepsilon_0 Q \times 10^{20}$ V m^{-1}
(d) $4\pi\varepsilon_0 Q \times 10^{20}$ V m^{-1}

8. A charge $+q$ is placed at the origin O of x-y axes as shown in the figure. The work done in taking a charge Q from A to B along the straight line AB is

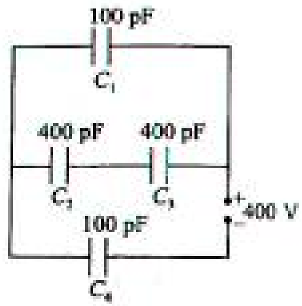


(a) $\frac{qQ}{4\pi\varepsilon_0}\left(\frac{a-b}{ab}\right)$ (b) $\frac{qQ}{4\pi\varepsilon_0}\left(\frac{b-a}{ab}\right)$

(c) $\frac{qQ}{4\pi\varepsilon_0}\left(\frac{b}{a^2}-\frac{1}{b}\right)$ (d) $\frac{qQ}{4\pi\varepsilon_0}\left(\frac{a}{b^2}-\frac{1}{b}\right)$

9. 16 pF capacitor is connected to 80 V supply. The amount of electric energy stored in the capacitor is
(a) 4.5×10^{-12} J (b) 5.1×10^{-8} J
(c) 2.5×10^{-12} J (d) 3.2×10^{-8} J

10. The equivalent capacitance for the network shown in the figure is



(a) $\frac{1200}{7}$ pF
(b) $\frac{1000}{4}$ pF
(c) $\frac{1800}{7}$ pF
(d) $\frac{1300}{3}$ pF

11. If a charged spherical conductor of radius 10 cm has potential V at a point distant 5 cm from its centre, then the potential at a point distance 15 cm from the centre will be
(a) $3V$ (b) $\frac{3}{2}V$ (c) $\frac{2}{3}V$ (d) $\frac{1}{3}V$

12. The electrostatic potential on the surface of a charged conducting sphere is 100 V. Two statements are made in this regard
(i) At any point inside the sphere, electric intensity is zero
(ii) At any point inside the sphere, the electrostatic potential is less than 100 V.
Which of the following is a correct statement?
(a) Statement (i) is true but statement (ii) is false
(b) Both statements (i) and (ii) are false
(c) Statement (i) is true, statement (ii) is also true and (i) is the cause of (ii)
(d) Statement (i) is true, statement (ii) is also true but the statements are independent.

13. A small sphere of radius r_1 and charge q_1 is enclosed by a spherical shell of radius r_2 and charge q_2. If q_1 is positive, then

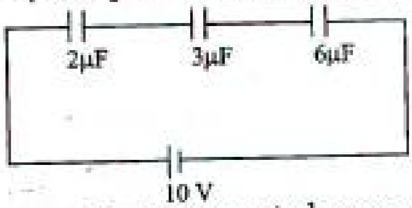
(a) charge will flow from the sphere to shell.
(b) charge will flow from the shell to sphere.
(c) charge flow will depend on the magnitude q_2.
(d) charge flow will depend on the magnitude of charge q_1.

14. When air is replaced by a dielectric medium of constant K, the maximum force of attraction between two charges separated by a distance
(a) increases K times (b) remains unchanged
(c) decreases K times (d) increases $K^{1/2}$ times

15. Two identical capacitors are joined in parallel, charged to a potential V, separated and then connected in series, the positive plate of one is connected to the negative of the other. Which of the following is true?
(a) The charges on the free plated connected together are destroyed.
(b) The energy stored in the system increases.
(c) The potential difference between the free plates is $2V$.
(d) The potential difference remains constant.

16. If dielectric constant and dielectric strength be denoted by K and X respectively, then a material suitable for use as a dielectric in a capacitor must have
(a) high K and high X (b) high K and low X
(c) low K and high X (d) low K and low X

17. The charge on 3 μF capacitor shown in the figure is
(a) 2 μC
(b) 10 μC
(c) 6 μC
(d) 8 μC



18. A parallel plate capacitor is connected across a 2 V battery and charged. The battery is then disconnected and a glass slab is introduced between plates. Which of the following pairs of quantities decreases?
(a) Charge and potential difference.
(b) Potential difference and energy stored.
(c) Energy stored and capacitance.
(d) Capacitance and charge.

19. In a quark model of elementary particles, a neutron is made of one up quark of charge $\frac{2}{3}e$ and two down quark of charges $\left(-\frac{1}{3}e\right)$. If they have a triangle configuration with side length of the order of 10^{-15} m. The electrostatic potential energy of neutron in MeV is
(a) 7.68 (b) –5.21 (c) –0.48 (d) 9.34

20. A parallel plate condenser with a dielectric constant K between the plates has a capacity C and is charged to a potential V volt. The dielectric slab is slowly removed from, between the plates and then reinserted. The net work done by the system in this process is
(a) zero (b) $\frac{1}{2}(K-1)CV^2$
(c) $\frac{CV^2(K-1)}{K}$ (d) $(K-1)CV^2$

21. Four equal charges q each are placed at four corners of a square of side a each. Work done in carrying a charge $-q$ from its centre to infinity is
(a) zero (b) $\frac{\sqrt{2}q^2}{\pi\varepsilon_0 a}$ (c) $\frac{\sqrt{2}q}{\pi\varepsilon_0 a}$ (d) $\frac{q^2}{\pi\varepsilon_0 a}$

22. In a parallel plate capacitor, the capacity increases if
(a) area of the plate is decreased
(b) distance between the plates increases
(c) area of the plate is increased
(d) dielectric constant decreases.

23. A cylindrical capacitor has two co-axial cylinders of length 20 cm and radii 1.5 cm and 1.6 cm. The outer cylinder is earthed and inner cylinder is given a charge of 4 μC. The capacitance of the system is (neglect end effects)
(a) 2.8×10^{-8} F (b) 4.2×10^{-14} F
(c) 1.7×10^{-10} F (d) 3.4×10^{-12} F

24. The capacitance of a parallel plate capacitor with air as medium is 3 μF. With the introduction of a dielectric medium between the plates, the capacitance becomes 15 μF. The permittivity of the medium is
(a) $5\ C^2\ N^{-1}\ m^{-2}$ (b) $15\ C^2\ N^{-1}\ m^{-2}$
(c) $0.44 \times 10^{-10}\ C^2\ N^{-1}\ m^{-2}$
(d) $8.854 \times 10^{-11}\ C^2\ N^{-1}\ m^{-2}$

25. A parallel plate capacitor has two square plates with equal and opposite charges. The surface charge densities on the plates are $+\sigma$ and $-\sigma$ respectively. In the region between the plates the magnitude of the electric field is
(a) $\frac{\sigma}{2\varepsilon_0}$ (b) $\frac{\sigma}{\varepsilon_0}$
(c) 0 (d) none of these

26. A metallic sphere of radius 18 cm has been given a charge of 5×10^{-6} C. The energy of the charged conductor is
(a) 0.2 J (b) 0.6 J (c) 1.2 J (d) 2.4 J

27. Energy stored in a capacitor and dissipated during charging a capacitor bear a ratio

(a) 1 : 1 (b) 1 : 2 (c) 2 : 1 (d) 1 : 3

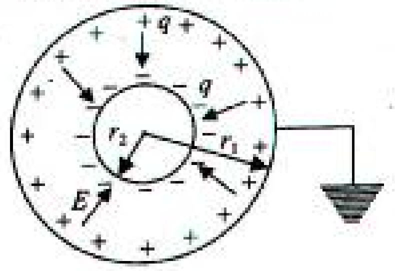
28. Two tiny spheres carrying charges 1.8 μC and 2.8 μC are located at 40 cm apart. The potential at the mid-point of the line joining the two charges is

(a) 3.8×10^4 V (b) 2.1×10^5 V
(c) 4.3×10^4 V (d) 3.6×10^5 V

29. In the previous question, the potential at a point 20 cm from the mid-point of the line joining the two charges in a plane normal to the line and passing through the mid-point is

(a) 1.4×10^5 V (b) 4.2×10^3 V
(c) 2.9×10^4 V (d) 3.7×10^5 V

30. A spherical capacitor consists of two concentric spherical conductors, held in position by suitable insulating supports as shown in figure. The capacitance C, of this spherical capacitor is



(a) $\frac{4\pi\varepsilon_0 r_1 r_2}{r_1 - r_2}$

(b) $\frac{4\pi\varepsilon_0 (r_2 - r_1)}{r_1 r_2}$

(c) $\frac{r_1 r_2}{4\pi\varepsilon_0 (r_2 - r_1)}$

(d) $\frac{(r_1 - r_2)}{4\pi\varepsilon_0 r_1 r_2}$

31. Identify the false statement.

(a) Inside a charged or neutral conductor electrostatic field is zero.
(b) The electrostatic field at the surface of the charged conductor must be tangential to the surface at any point.
(c) There is no net charge at any point inside the conductor.
(d) Electrostatic potential is constant throughout the volume of the conductor.

32. A hexagon of side 8 cm has a charge 4 μC at each of its vertices. The potential at the centre of the hexagon is

(a) 2.7×10^6 V (b) 7.2×10^{11} V
(c) 2.5×10^{12} V (d) 3.4×10^4 V

33. Minimum number of capacitors each of 8 μF and 250 V used to make a composite capacitor of 16 μF and 1000 V are

(a) 8 (b) 32 (c) 16 (d) 24

34. An infinite cylinder of radius r_0, carrying linear charge density λ. The equation of the equipotential surface for this cylinder is

(a) $r = r_0 e^{\pi\varepsilon_0 [V(r)+V(r_0)]\lambda}$
(b) $r = r_0 e^{2\pi\varepsilon_0 [V(r)-V(r_0)]\lambda^2}$
(c) $r = r_0 e^{-2\pi\varepsilon_0 [V(r)-V(r_0)]/\lambda}$
(d) $r = r_0 e^{-2\pi\varepsilon_0 [V(r)-V(r_0)]\lambda}$

35. Equipotential surfaces

(a) are closer in regions of large electric fields compared to regions of lower electric fields
(b) will be more crowded near sharp edges of a conductor
(c) will always be equally spaced
(d) both (a) and (b) are correct

36. Two metal spheres, one of radius R and the other of radius $2R$, both have same surface charge density σ. If they are brought in contact and separated, then the new surface charge densities on each of the sphere are respectively

(a) $\frac{5}{2}\sigma, \frac{5}{4}\sigma$ (b) $\frac{5}{3}\sigma, \frac{5}{6}\sigma$ (c) $\frac{3}{5}\sigma, \frac{6}{5}\sigma$ (d) $\frac{2}{3}\sigma, \frac{1}{2}\sigma$

37. Which of the following statement is true about the relation between electric field and potential?

(a) Electric field is in the direction in which the potential decreases steepest
(b) Magnitude of electric field is given by the change in the magnitude of potential per unit displacement normal to the equipotential surface at that point.
(c) In the region of strong electric field, equipotential surfaces are far apart.
(d) Both the statements (a) and (b) are correct.

38. The number of ways one can arrange three identical capacitors to obtain distinct effective capacitances is

(a) 8 (b) 6 (c) 4 (d) 3

39. Consider two conducting spheres of radii R_1 and R_2 with $R_1 > R_2$. If the two are at the same potential, and the larger sphere has more charge than the smaller sphere, then

(a) the charge density of smaller sphere is less than that of larger sphere.
(b) the charge density of smaller sphere is more than that of larger sphere.
(c) both spheres may have same charge density.
(d) None of these.

40. A spherical capacitor has an inner sphere of radius 10 cm and an outer sphere of radius 11 cm. The outer sphere is earthed and the inner

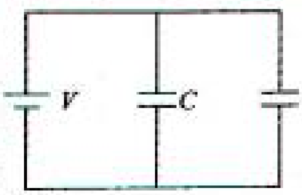
sphere is given a charge of 3.2 μC. The space between the concentric sphere is filled with a liquid of dielectric constant 28. The capacitance of capacitor is

(a) 2×10^{-9} F (b) 3.4×10^{-9} F
(c) 4.1×10^{-9} F (d) 5.2×10^{-9} F

41. Three capacitors each of capacity 4 μF are to be connected in such a way that the effective capacitance is 6 μF. This can be done by

(a) connecting them in series
(b) connecting them is parallel
(c) connecting two in series and one in parallel
(d) connecting two in parallel and one in series

42. Two condensers, one of capacity C and other of capacity $\frac{C}{2}$ are connected to a V volt battery, as shown in the figure. The work done in charging fully both the condensers is



(a) $\frac{1}{4}CV^2$ (b) $\frac{3}{4}CV^2$ (c) $\frac{1}{2}CV^2$ (d) $2\ CV^2$

43. A parallel plate air capacitor has a capacitance C. When it is half filled with a dielectric of dielectric constant 5, the percentage increase in the capacitance will be

(a) 400% (b) 66.6% (c) 33.3% (d) 200%

44. A capacitor of capacitance C_1 is charged to a potential V and then connected in parallel to an uncharged capacitor of capacitance C_2. The final potential difference across each capacitor will be

(a) $\frac{C_1V}{C_1+C_2}$ (b) $\frac{C_2V}{C_1+C_2}$ (c) $1+\frac{C_2}{C_1}$ (d) $1-\frac{C_2}{C_1}$

45. The electric field and the potential of an electric dipole vary with distance r as

(a) $\frac{1}{r}$ and $\frac{1}{r^2}$ (b) $\frac{1}{r^2}$ and $\frac{1}{r}$
(c) $\frac{1}{r^2}$ and $\frac{1}{r^3}$ (d) $\frac{1}{r^3}$ and $\frac{1}{r^2}$

46. Choose the correct statement.

(a) Polar molecules have permanent electric dipole moment.
(b) CO_2 molecule is a polar molecule.
(c) H_2O is a non-polar molecule.
(d) The dipole field at large distances falls of as $\frac{1}{r^2}$.

47. An electric dipole is placed at the centre of a hollow conducting sphere. Which of the following is correct?

(a) Electric field is zero at every point of the sphere
(b) Electric field is not zero anywhere on the sphere
(c) The flux of electric field is not zero through the sphere
(d) All of these

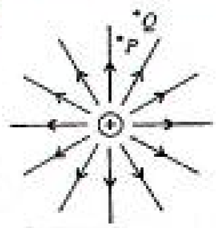
48. An electric dipole of length 20 cm having $\pm 3 \times 10^{-3}$ C charge placed at 60° with respect to a uniform electric field experiences a torque of magnitude 6 N m. The potential energy of the dipole is

(a) $-2\sqrt{3}$ J (b) $5\sqrt{3}$ J (c) $-3\sqrt{2}$ J (d) $3\sqrt{5}$ J

49. The distance between H^+ and Cl^- ions in HCl molecules is 1.38 Å. The potential due to this dipole at a distance of 10 Å on the axis of dipole is

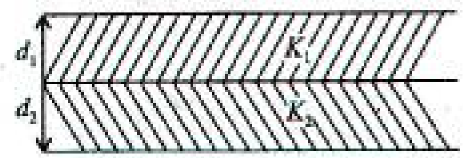
(a) 2.1 V (b) 1.8 V (c) 0.2 V (d) 1.2 V

50. Figure shows the field lines of a positive point charge. The work done by the field in moving a small positive charge from Q to P is



(a) zero
(b) positive
(c) negative
(d) data insufficient

51. A parallel plate capacitor is made of two dielectric blocks in series. One of the blocks has thickness d_1 and of dielectric constant K_1 and the other has thickness d_2 and dielectric constant K_2 as shown in figure. This arrangement can be thought as a dielectric slab of thickness $d\ (= d_1 + d_2)$ and effective dielectric constant K. The K is



(a) $\frac{K_1d_1+K_2d_2}{d_1+d_2}$ (b) $\frac{K_1d_1+K_2d_2}{K_1+K_2}$
(c) $\frac{K_1K_2(d_1+d_2)}{K_2d_1+K_1d_2}$ (d) $\frac{2K_1K_2}{K_1+K_2}$

52. Which of the following statements is false for a perfect conductor?

(a) The surface of the conductor is an equipotential surface.
(b) The electric field just outside the surface of a conductor is perpendicular to the surface.

(c) The charge carried by a conductor is always uniformly distributed over the surface of the conductor.

(d) None of these

53. A system consists of two charges 4 μC and −3 μC with no external field placed at (−5 cm, 0, 0) and (5 cm, 0, 0) respectively. The amount of work required to separate the two charges infinitely away from each other is

(a) −1.1 J (b) 2 J (c) 2.5 J (d) 3 J

54. A parallel plate air capacitor is charged to a potential difference of V volts. After disconnecting the charging battery the distance between the plates of the capacitor is increased using an insulating handle. As a result the potential difference between the plates

(a) increases (b) decreases

(c) does not change (d) becomes zero

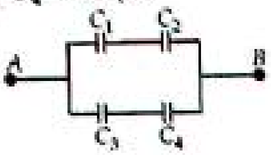
55. Find out the effective capacitance between points A and B as shown in the figure. Here $C_1 = C_2 = 20$ μF and $C_3 = C_4 = 10$ μF

(a) 10 μF

(b) 15 μF

(c) 20 μF

(d) 25 μF



56. Two identical capacitors have the same capacitance C. One of them is charged to potential V_1 and the other to V_2. The negative ends of the capacitors are connected together. When the positive ends are also connected, the decrease in energy of the combined system is

(a) $\frac{C}{4}(V_1^2 - V_2^2)$ (b) $\frac{C}{4}(V_1^2 + V_2^2)$

(c) $\frac{C}{4}(V_1 - V_2)^2$ (d) $\frac{C}{4}(V_1 + V_2)^2$

57. 1 volt is equivalent to

(a) $\frac{\text{newton}}{\text{second}}$ (b) $\frac{\text{newton}}{\text{coulomb}}$ (c) $\frac{\text{joule}}{\text{coulomb}}$ (d) $\frac{\text{joule}}{\text{second}}$

58. A capacitor is made of two circular plates of radius R each, separated by a distance $d << R$. The capacitor is connected to a constant voltage. A thin conducting disc of radius $r << R$ and thickness $t << r$ is placed at the centre of the bottom plate. Find the minimum voltage required to lift the disc if the mass of the disc is m.

(a) $\frac{\sqrt{mgd}}{\pi\varepsilon_0 r^2}$ (b) $\sqrt{\frac{mgd}{\pi\varepsilon_0 r}}$ (c) $\sqrt{\frac{mgd^2}{\pi\varepsilon_0 r^2}}$ (d) $\sqrt{\frac{mgd}{\pi\varepsilon_0 r^2}}$

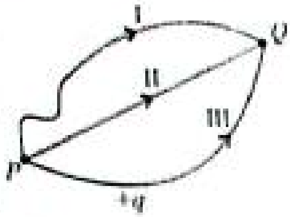
59. Which among the following statement is true about the work done in bringing a unit positive charge from point P to Q in an electrostatic field?

(a) Minimum work is done in case of path II.

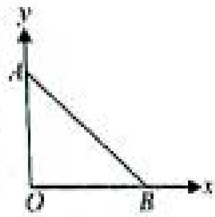
(b) Maximum work is done in case of path I.

(c) Work done is same in all the three paths.

(d) Work done is zero in case of path II.



60. As per the diagram a point charge $+q$ is placed at the origin O. Work done in taking another point charge $-Q$ from the point A [coordinates $(0, a)$] to another point B [coordinates $(a, 0)$] along the straight line AB is



(a) zero (b) $\left(\frac{qQ}{4\pi\varepsilon_0}\frac{1}{a^2}\right)\sqrt{2}a$

(c) $\left(\frac{-qQ}{4\pi\varepsilon_0}\frac{1}{a^2}\right)\sqrt{2}a$ (d) $\left(\frac{qQ}{4\pi\varepsilon_0}\frac{1}{a^2}\right)\frac{a}{\sqrt{2}}$

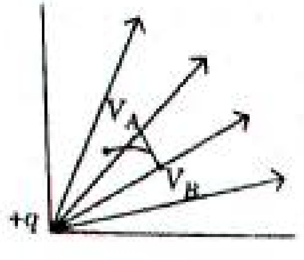
Case Based MCQs

Case I : Read the passage given below and answer the following questions from 61 to 65.

Electrostatic Potential and Potential Energy

Electrostatic potential energy of a system of point charges is defined as the total amount of work done in bringing the different charges to their respective positions from infinitely charge mutual separations. The work is stored in the system of two point charges in the form of electrostatic potential energy U of the system. Electric potential difference between any points A and B in an electric field is the amount of work done in moving a unit positive test charge from A to B along any path agents the electrostatic force

$$V_B - V_A = \frac{W_{AB}}{q_0} = \int \vec{E}.d\vec{l}\ .$$



61. A test charge is moved from lower potential point to a higher potential point. The potential energy of test charge will
(a) remain the same (b) increase
(c) decrease (d) become zero

62. Which of the following statement is not true?
(a) Electrostatic force is a conservative force.
(b) Potential energy of charge q at a point is the work done per unit charge in bringing a charge from any point to infinity.
(c) Spring force and gravitational force are conservative force.
(d) Both (a) and (c).

63. Work done in moving a charge from one point to another inside a uniformly charged conducting sphere is
(a) always zero (b) non-zero
(c) may be zero (d) none of these

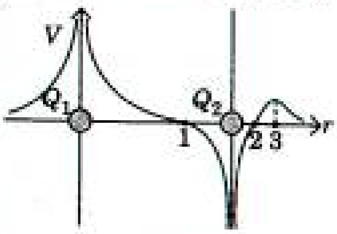
64. The work done in bringing a unit positive charge from infinite distance to a point at distance x from a positive charge Q is W. Then the potential ϕ at that point is
(a) $\frac{WQ}{x}$ (b) W (c) $\frac{W}{x}$ (d) WQ

65. If 1 μC charge is shifted from A to B and it is found that work done by an external force is 40 μJ. In doing so against electrostatics force, the potential difference V_A-V_B is
(a) 40 V (b) –40 V (c) 20 V (d) –60 V

Case II : Read the passage given below and answer the following questions from 66 to 70.

Potential of Two Point Charges

The potential at any observation point of a static electric field is defined as the work done by the external agent (or negative of work done by electrostatic field) in slowly bringing a unit positive point charge from infinity to the observation point. Figure shows the potential variation along the line of charges. Two point charges Q_1 and Q_2 lie along a line at a distance from each other.



66. At which of the points 1, 2 and 3 is the electric field is zero?
(a) 1 (b) 2
(c) 3 (d) Both (a) and (b)

67. The signs of charges Q_1 and Q_2 respectively are
(a) positive and negative
(b) negative and positive
(c) positive and positive
(d) negative and negative

68. Which of the two charges Q_1 and Q_2 is greater in magnitude?
(a) Q_2 (b) Q_1
(c) Same (d) Can't determined

69. Which of the following statement is not true?
(a) Electrostatic force is a conservative force.
(b) Potential energy of charge q at a point is the work done per unit charge in bringing a charge from any point to infinity.
(c) When two like charges lie infinite distance apart, their potential energy is zero.
(d) Both (a) and (c).

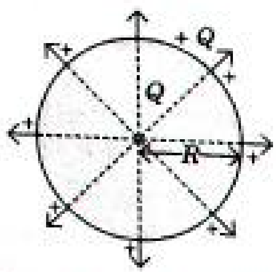
70. Positive and negative point charges of equal magnitude are kept at $\left(0, 0, \frac{a}{2}\right)$ and $\left(0, 0, \frac{-a}{2}\right)$ respectively. The work done by the electric field when another positive point charge is moved from $(-a, 0, 0)$ to $(0, a, 0)$ is
(a) positive (b) negative
(c) zero
(d) depends on the path connecting the initial and final positions.

Case III : Read the passage given below and answer the following questions from 71 to 75.

Spherical Capacitor

The electrical capacitance of a conductor is the measure of its ability to hold electric charge.

An isolated spherical conductor of radius R. The charge Q is uniformly distributed over its entire surface. It can be assumed to be concentrated at the centre of the sphere. The potential at any point on the surface of the spherical conductor will be $V=\frac{1}{4\pi\varepsilon_0}\frac{Q}{R}$.



Capacitance of the spherical conductor situated in vacuum is $C=\frac{Q}{V}=\frac{Q}{\frac{1}{4\pi\varepsilon_0}\cdot\frac{Q}{R}}$ or $C = 4\pi\varepsilon_0 R$

Clearly, the capacitance of a spherical conductor is proportional to its radius.

The radius of the spherical conductor of 1 F capacitance is $R = \frac{1}{4\pi\varepsilon_0} \cdot C$ and this radius is about 1500 times the radius of the earth ($\sim 6 \times 10^3$ km).

71. If an isolated sphere has a capacitance 50 pF. Then radius is

(a) 90 cm (b) 45 cm (c) 45 m (d) 90 m

72. How much charge should be placed on a capacitance of 25 pF to raise its potential to 10^5 V?

(a) 1 μC (b) 1.5 μC (c) 2 μC (d) 2.5 μC

73. Dimensions of capacitance is

(a) $[M L^{-2} T^4 A^2]$ (b) $[M^{-1} L^{-1} T^3 A^1]$

(c) $[M^{-} L^{-2} T^4 A^2]$ (d) $[M^0 L^{-2} T^4 A^1]$

74. Metallic sphere of radius R is charged to potential V. Then charge q is proportional to

(a) V (b) R

(c) both V and R (d) none of these.

75. If 64 identical spheres of charge q and capacitance C each are combined to form a large sphere. The charge and capacitance of the large sphere is

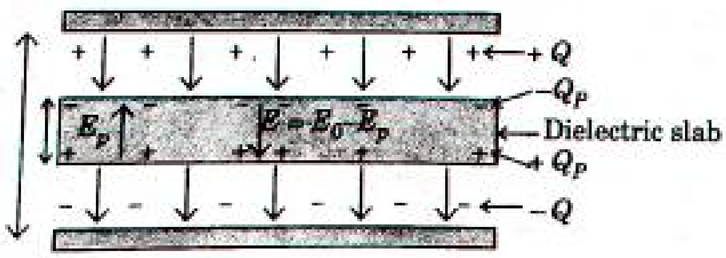
(a) $64q, C$ (b) $16q, 4C$

(c) $64q, 4C$ (d) $16q, 64C$

Case IV : Read the passage given below and answer the following questions from 76 to 80.

Dielectric Slab

A dielectric slab is a substance which does not allow the flow of charges through it but permits them to exert electrostatic forces on one another. When a dielectric slab is placed between the plates, the field E_0 polarises the dielectric. This induces charge $-Q_p$ on the upper surface and $+Q_p$ on the lower surface of the dielectric. These induced charges set up a field E_p inside the dielectric in the opposite direction of $\vec{E}_0$ as shown.



76. In a parallel plate capacitor, the capacitance increases from 4μF to 80 μF, on introducing a dielectric medium between the plates. What is the dielectric constant of the medium?

(a) 10 (b) 20 (c) 50 (d) 100

77. A parallel plate capacitor with air between the plates has a capacitance of 8 pF. The separation between the plates is now reduced half and the space between them is filled with a medium of dielectric constant 5. Calculate the value of capacitance of the capacitor in second case.

(a) 8 pF (b) 10 pF (c) 80 pF (d) 100 pF

78. A dielectric introduced between the plates of a parallel plate condenser

(a) decreases the electric field between the plates

(b) increases the capacity of the condenser

(c) increases the charge stored in the condenser

(d) increases the capacity of the condenser

79. A parallel plate capacitor of capacitance 1 pF has separation between the plates is d. When the distance of separation becomes $2d$ and wax of dielectric constant x is inserted in it the capacitance becomes 2 pF. What is the value of x?

(a) 2 (b) 4 (c) 6 (d) 8

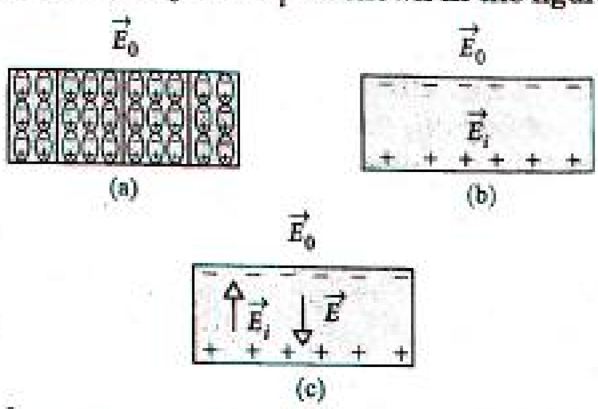
80. A parallel plate capacitor having area A and separated by distance d is filled by copper plate of thickness b. The new capacity is

(a) $\frac{\varepsilon_0 A}{d+\frac{b}{2}}$ (b) $\frac{\varepsilon_0 A}{2d}$ (c) $\frac{\varepsilon_0 A}{d-b}$ (d) $\frac{2\varepsilon_0 A}{d+\frac{b}{2}}$

Case V : Read the passage given below and answer the following questions from 81 to 85.

Polarisation of Dielectric

When an insulator is placed in an external field, the dipoles become aligned. Induced surface charges on the insulator establish a polarisation field $\vec{E}_i$ in its interior. The net field $\vec{E}$ in the insulator is the vector sum of $\vec{E}_0$ and $\vec{E}_i$ as shown in the figure.



On the application of external electric field, the effect of aligning the electric dipoles in the insulator is called polarisation and the field $\vec{E}_i$ is known as the polarisation field.

The dipole moment per unit volume of the dielectric is known as polarisation ($\vec{P}$).

For linear isotropic dielectrics, $\vec{P} = \chi \vec{E}$, where χ = electrical susceptibility of the dielectric medium.

81. Which among the following is an example of polar molecule?
(a) O_2 (b) H_2 (c) N_2 (d) HCl

82. When air is replaced by a dielectric medium of constant K, the maximum force of attraction between two charges separated by a distance
(a) increases K times (b) remains unchanged
(c) decreases K times (d) increases $2K$ times.

83. Which of the following is a dielectric?
(a) Copper (b) Glass
(c) Antimony (Sb) (d) None of these

84. For a polar molecule, which of the following statements is true ?
(a) The centre of gravity of electrons and protons coincide.
(b) The centre of gravity of electrons and protons do not coincide.
(c) The charge distribution is always symmetrical.
(d) The dipole moment is always zero.

85. When a comb rubbed with dry hair attracts pieces of paper. This is because the
(a) comb polarises the piece of paper
(b) comb induces a net dipole moment opposite to the direction of field
(c) electric field due to the comb is uniform
(d) comb induces a net dipole moment perpendicular to the direction of field

Assertion & Reasoning Based MCQs

For question numbers 86-100, two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.
(a) *Both A and R are true and R is the correct explanation of A*
(b) *Both A and R are true but R is NOT the correct explanation of A*
(c) *A is true but R is false*
(d) *A is false and R is also false*

86. Assertion (A) : When a dielectric medium is filled between the plates of a condenser, its capacitance increases.
Reason (R) : The dielectric medium reduces the potential difference between the plates of the condenser.

87. Assertion (A) : A capacitor is connected to a battery. If we move its plate further apart, work will be done against the electrostatic attraction between the plates and the energy of the capacitor gets decreased.
Reason (R) : The energy stored in capacitor is dissipated in the form of heat energy.

88. Assertion (A) : Circuits containing capacitors should be handled cautiously even when there is no current.
Reason (R) : The capacitors are very delicate and so quickly breakdown.

89. Assertion (A) : A capacitor can be broken by placing large amount of charge on it.
Reason (R) : After breakage potential, capacitor is destroyed.

90. Assertion (A) : If the distance between parallel pates of a capacitor is halved and dielectric constant is made three times, then the capacitance becomes six times.
Reason (R) : Capacitance of the capacitor does not depend upon the nature of the material of the plates.

91. Assertion (A) : Charge on all the condensers connected in series is the same.
Reason (R) : Capacitance of capacitor is directly proportional to charge on it.

92. Assertion (A) : Increasing the charge on the plates of a capacitor means increasing the capacitance.
Reason (R) : Capacitance is directly proportional to charge.

93. Assertion (A) : The surface of a conductor is an equipotential surface.
Reason (R) : Conductor allows the flow of charge.

94. Assertion (A) : Conductors having equal positive charge and volume, must also have same potential.
Reason (R) : Potential depends only on charge and volume of conductor.

95. **Assertion (A) :** No work is done in taking a positive charge from one point to other inside a positively charged metallic sphere while outside the sphere work is done in taking the charge toward the sphere.
Reason (R) : Inside the sphere electric potential is same at each potential, but outside it is different for different points.

96. **Assertion (A) :** An applied electric field will polarize the polar dielectric material.
Reason (R) : In polar dielectrics, each molecule has a permanent dipole moment but these are randomly oriented in the absence of an externally applied electric field.

97. **Assertion (A) :** Electric potential of the earth is zero.
Reason (R) : The electric field due to the earth is zero.

98. **Assertion (A) :** Capacity of a parallel plate capacitor increases when distance between the plates is decreased.
Reason (R) : Capacitance of capacitor is inversely proportional to distance between them.

99. **Assertion (A) :** When air between the plates of a parallel plate condenser is replaced by an insulating medium of dielectric constant its capacity increases.
Reason (R) : Electric field intensity between the plates with dielectric in between it is reduced.

100. **Assertion (A) :** The dielectric constant for metals is infinity.
Reason (R) : When a charged capacitor is filled completely with a metallic slab, its capacity becomes very large.

ANSWERS

1. **(d) :** As the electric field in the z-direction is uniform, equipotential surfaces are in xy plane. Hence the potential for given z is constant on x-y plane, for any x in this plane and for any y in this plane. So all the given options are correct.

2. **(d) :** In a region of constant potential

$$E = -\frac{dV}{dr} = 0 \qquad (\because \; V = \text{constant})$$

i.e., electric field is zero, so there can be no charge inside the region.

3. **(c) :** Dipole moment of each molecules = 10^{-30} C m.
As 1 mole of the substance contains 6×10^{23} molecules
Total dipole moment of all the molecules
$p = 6 \times 10^{23} \times 10^{-30}$ C m $= 6 \times 10^{-7}$ C m
Initial potential energy, $U_i = -pE\cos\theta$
$= -6 \times 10^{-7} \times 10^7 \cos 0° = -6$ J
Final potential energy, $U_f = -6 \times 10^{-7} \times 10^7 \times \cos 60° = -3$ J
Work done = − [Change in potential energy]
$= -[(-3) - (-6)] = -3$ J

4. **(c) :** Here, $q = 5 \times 10^{-7}$ C, $r = 10$ cm $= 0.1$ m

$$\text{Potential, } V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r} = \frac{9\times10^9 \times 5\times10^{-7}}{0.1} = 4.5\times10^4 \text{ V}$$

5. **(b) :** Work done, $W = q(V_f - V_i) = 4 \times 10^{-9} \times 4.5 \times 10^4 = 1.8 \times 10^{-4}$ J

6. **(c) :** Here, $V_1 = \frac{q}{4\pi\varepsilon_0 r_1}$, $V_2 = \frac{q}{4\pi\varepsilon_0 r_2}$

$$\therefore \quad \frac{V_1}{V_2} = \frac{r_2}{r_1}$$

7. **(b) :** Here, $V = \frac{Q}{4\pi\varepsilon_0 r} = Q\times10^{11}$

$$\therefore \quad 4\pi\varepsilon_0 r = 10^{-11} \qquad \text{...(i)}$$

$$\text{Now, } E = \frac{Q}{4\pi\varepsilon_0 r^2} = \frac{Q\times 4\pi\varepsilon_0}{(4\pi\varepsilon_0 r)^2} = \frac{4\pi\varepsilon_0 Q}{(10^{-11})^2} \qquad \text{(Using (i))}$$

$$E = 4\pi\varepsilon_0 Q \times 10^{22} \text{ V m}^{-1}$$

8. **(b) :** Potential at point A is

$$V_A = \frac{1}{4\pi\varepsilon_0}\frac{q}{a}$$

Potential at point B is

$$V_B = \frac{1}{4\pi\varepsilon_0}\frac{q}{b}$$

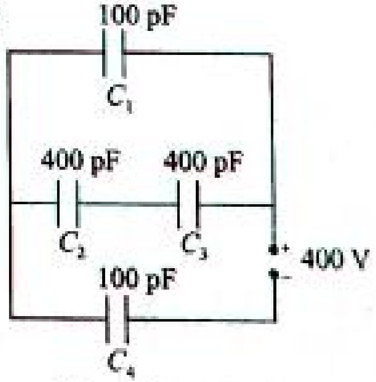
Work done in taking a charge Q from A to B is

$$W = Q(V_B - V_A) = \frac{Qq}{4\pi\varepsilon_0}\left[\frac{1}{b} - \frac{1}{a}\right] = \frac{Qq}{4\pi\varepsilon_0}\left[\frac{b-a}{ab}\right]$$

9. **(b) :** Here, $C = 16$ pF $= 16 \times 10^{-12}$ F
$V = 80$ V

$$\text{As } U = \frac{1}{2}CV^2 = \frac{1}{2}\times16\times10^{-12}\times(80)^2 = 5.1\times10^{-8} \text{ J}$$

10. **(a) :**



Capacitance of $C_1 = C_4 = 100$ pF
Capacitance of $C_2 = C_3 = 400$ pF

Supply voltage, $V = 400$ V

Capacitors C_2 and C_3 are connected in series,

Equivalent capacitance, $\frac{1}{C'} = \frac{1}{C_2} + \frac{1}{C_3}$

$\frac{1}{C'} = \frac{1}{400} + \frac{1}{400} = \frac{2}{400}$ or $C' = 200$ pF

Capacitors C_1 and C' are in parallel

Their equivalent capacitance

$C'' = C' + C_1 = 200 + 100 = 300$ pF

Capacitors C'' and C_4 are connected in series

Equivalent capacitance $\frac{1}{C_{eq}} = \frac{1}{C''} + \frac{1}{C_4} = \frac{1}{300} + \frac{1}{400}$

$\frac{1}{C_{eq}} = \frac{7}{1200}$

$\therefore \quad C_{eq} = \frac{1200}{7}$ pF

11. (c) : The potential at any point inside a charged conductor is same as on its surface,

$V = \frac{q}{4\pi\varepsilon_0 r} = \frac{q}{4\pi\varepsilon_0 \times 10} \qquad (\because r = 10 \text{ cm}) \qquad \ldots(i)$

At r = 15 cm

$V' = \frac{q}{4\pi\varepsilon_0 \times 15}$

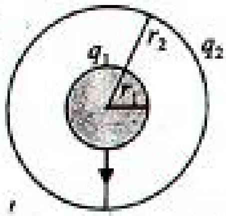
$\therefore \quad V' = \frac{10\,V}{15} = \frac{2}{3}V$ (using (i))

12. (a) : At any point inside a charged conducting sphere,

$E = 0$ and $V = \frac{Kq}{R}$ = potential on the surface = 100 V

or $\quad E = -\frac{dV}{dr} = 0 \qquad (\because V \text{ is constant})$

13. (a) :



As the charge resides always on the outer surface of the shell, therefore, when the sphere and shell are connected by a wire, charge will flow essentially from the sphere to the shell, whatever be the magnitude and sign of charge q_2.

14. (c) : As $F_m = \frac{F_o}{K}$

$\therefore$ the maximum force decreases by K times.

15. (c) : When the two capacitors charged to same potential are connected in series, then total potential difference

$V' = V_1 + V_2 = V + V = 2V$

16. (a) : The material suitable for using as a dielectric must have high dielectric strength X and large dielectric constant K.

17. (b) : Since all the capacitors are connected in series,

$\therefore$ equivalent capacitance is

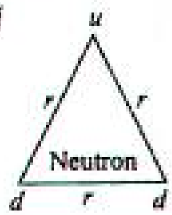
$\frac{1}{C_{eq}} = \frac{1}{2} + \frac{1}{3} + \frac{1}{6} = 1 \qquad \therefore \; C_{eq} = 1\ \mu\text{F}$

Charge on each capacitor is same $\qquad (\because V = 10\text{ V})$

$q = C_{eq}V = 1 \times 10 = 10\ \mu\text{C}$

18. (b) : When battery is disconnected, charge remains constant. On introducing glass slab, capacity increases. Potential difference and energy stored decreases.

19. (c) : Figure shows the quark model of neutron.



Here, $r = 10^{-15}$ m

Potential energy of neutron is

$U = \frac{1}{4\pi\varepsilon_0 r}[q_d q_d + q_u q_d + q_u q_d]$

$= \frac{9\times10^9}{10^{-15}}\left[\left(\frac{-e}{3}\right)\left(\frac{-e}{3}\right) + \left(\frac{2e}{3}\right)\left(\frac{-e}{3}\right) + \left(\frac{2e}{3}\right)\left(\frac{-e}{3}\right)\right] = \frac{9\times10^9}{10^{-15}}e^2\left[\frac{1}{9} - \frac{4}{9}\right]$

$= \frac{9\times10^9}{10^{-15}}(1.6\times10^{-19})^2\left(-\frac{1}{3}\right) = -7.68\times10^{-14}$ J

$= -4.8 \times 10^5$ eV $= -0.48$ MeV

20. (a)

21. (b) : Potential at the centre O of the square due to four equal charges q at four corners

$V = \frac{4q}{4\pi\varepsilon_0(a\sqrt{2})/2} = \frac{\sqrt{2}q}{\pi\varepsilon_0 a}$

$W_{0\to\infty} = -W_{\infty\to 0} = -(-q)V = \frac{\sqrt{2}q^2}{\pi\varepsilon_0 a}$

22. (c) : In a parallel plate capacitor, the capacity of capacitor

$C = \frac{K\varepsilon_0 A}{d}$

i.e., $C \propto A$

The capacity of capacitor increases if area of the plate is increased.

23. (c) : Here, length $L = 20$ cm $= 20 \times 10^{-2}$ m

inner radius $r_i = 1.5$ cm $= 1.5 \times 10^{-2}$ m

outer radius $r_0 = 1.6$ cm $= 1.6 \times 10^{-2}$ m

charge $q = 4\ \mu$C $= 4 \times 10^{-6}$ C

Capacitance,

$C = \frac{2\pi\varepsilon_0 L}{\log_e\left(\frac{r_o}{r_i}\right)} = \frac{2\pi\varepsilon_0 L}{2.3\log_{10}\left(\frac{r_o}{r_i}\right)} = \frac{2\pi\times8.85\times10^{-12}\times20\times10^{-2}}{2.303\log_{10}\left(\frac{1.6\times10^{-2}}{1.5\times10^{-2}}\right)}$

$= 1.7\times10^{-10}$ F

24. (c) : Capacitance of a parallel plate capacitor with air is

$C = \frac{\varepsilon_0 A}{d}$

Capacitance of a same parallel plate capacitor with the introduction of a dielectric medium is $C' = \frac{K\varepsilon_0 A}{d}$

where K is the dielectric constant of a medium

or $\quad \frac{C'}{C} = K$ or $K = \frac{15}{3} = 5$ or $K = \frac{\varepsilon}{\varepsilon_0}$

or $\quad \varepsilon = K\varepsilon_0 = 5 \times 8.854 \times 10^{-12} = 0.4427 \times 10^{-10}\ \text{C}^2\,\text{N}^{-1}\,\text{m}^{-2}$

25. (b) : The magnitude of the electric field between the plates is

$$E=\frac{\sigma}{2\varepsilon_0}-\left(-\frac{\sigma}{2\varepsilon_0}\right)=\frac{\sigma}{\varepsilon_0}$$

26. (b) : Here $r = 18$ cm $= 18 \times 10^{-2}$ m, $q = 5 \times 10^{-6}$ C

As $C=4\pi\varepsilon_0 r=\frac{18\times10^{-2}}{9\times10^{9}}=2\times10^{-11}$ F

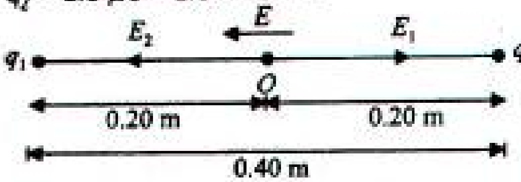
Energy of charged conductor is

$$U=\frac{q^2}{2C}=\frac{(5\times10^{-6})^2}{2\times2\times10^{-11}}=0.625\ \text{J}$$

27. (c) : Half of the energy is dissipated during charging a capacitor.

$$\therefore\ \frac{\text{Energy stored in a capacitor}}{\text{Energy dissipated during charging a capacitor}}=\frac{2}{1}$$

28. (b) : Here, $q_1 = 1.8\ \mu$C $= 1.8 \times 10^{-6}$ C,
$q_2 = 2.8\ \mu$C $= 2.8 \times 10^{-6}$ C



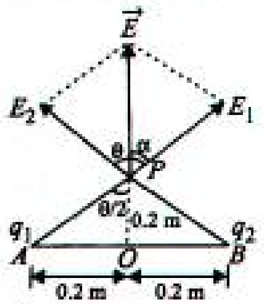
Distance between the two spheres = 40 cm = 0.4 m

For the mid-point, $r_1=r_2=\frac{0.40}{2}=0.2$ m

Potential at O,

$$V=\frac{1}{4\pi\varepsilon_0}\left[\frac{q_1}{r_1}+\frac{q_2}{r_2}\right]=\frac{9\times10^9(1.8+2.8)\times10^{-6}}{0.2}=2.1\times10^5\ \text{V}$$

29. (a) : From the figure, potential at P,

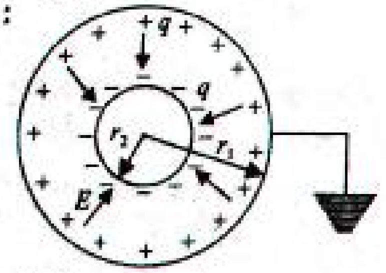


$$V=\frac{q_1}{4\pi\varepsilon_0(PA)}+\frac{q_2}{4\pi\varepsilon_0(PB)}$$

$$=\frac{1}{4\pi\varepsilon_0(PA)}(q_1+q_2)\quad(\because PA=PB=\sqrt{(0.2)^2+(0.2)^2}=0.28\ \text{m})$$

$$=\frac{9\times10^9(1.8+2.8)\times10^{-6}}{0.28}=1.4\times10^5\ \text{V}$$

30. (a) :



As shown in figure, $+q$ charge spreads uniformly on inner surface of outer sphere of radius r_1. The induced charge $-q$ spreads uniformly on the outer surface of inner sphere of radius r_2.

The outer surface of outer sphere is earthed.
Due to electrostatic shielding
$E = 0$ for $r < r_2$ and $E = 0$ for $r > r_1$
In the space between the two spheres,
Potential difference between two spheres,

$$V=\frac{q}{4\pi\varepsilon_0 r_2}-\frac{q}{4\pi\varepsilon_0 r_1}=\frac{q}{4\pi\varepsilon_0}\left[\frac{1}{r_2}-\frac{1}{r_1}\right]$$

$$V=\frac{q}{4\pi\varepsilon_0}\left(\frac{r_1-r_2}{r_1r_2}\right)\qquad\text{...(i)}$$

Also $C=\frac{q}{V}$

$$\therefore\quad C=\frac{4\pi\varepsilon_0 r_1r_2}{r_1-r_2}\qquad\text{(using (i))}$$

31. (b) : Electrostatic properties of a conductor are as follows :

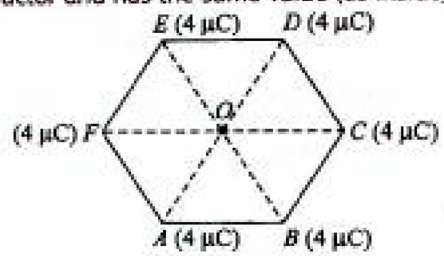
(i) Electrostatic field is zero inside a charged conductor or neutral conductor.

(ii) Electrostatic field at the surface of a charged conductor must be normal to the surface at every point.

(iii) There is no net charge at any point inside the conductor and any excess charge must reside at the surface.

(iv) Electrostatic potential is constant throughout the volume of the conductor and has the same value (as inside) on its surface.

32. (a)



As shown in the figure, O is the centre of hexagon $ABCDEF$ of each side 8 cm. As it is a regular hexagon OAB, OBC, etc., are equilateral triangles.

$\therefore\quad OA = OB = OC = OD = OE = OF = 8$ cm $= 8 \times 10^{-2}$ m

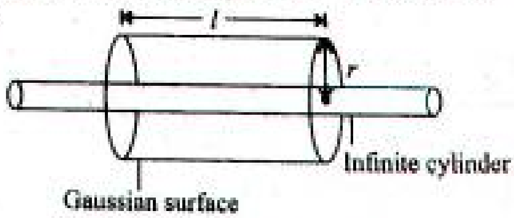
The potential at O is

$$V=6\times\frac{q}{4\pi\varepsilon_0 r}=\frac{6\times9\times10^9\times4\times10^{-6}}{8\times10^{-2}}=2.7\times10^6\ \text{V}$$

33. (b) : Minimum number of capacitors in each row $=\frac{1000}{250}=4$

Therefore, 4 capacitors connected in series.
If there are m such rows, then total capacity
$= m \times 2 = 16$
$\therefore\quad m = 16/2 = 8$
$\therefore\quad$ Minimum number of capacitors $= 4 \times 8 = 32$

34. (c) :



Gaussian surface of radius r and length l.

According to Gauss's theorem

$$\oint \vec{E} \cdot d\vec{s} = \frac{q}{\varepsilon_0} = \frac{\lambda l}{\varepsilon_0}$$

$$E(2\pi r l) = \frac{\lambda l}{\varepsilon_0} \text{ or } E = \frac{\lambda}{2\pi\varepsilon_0 r} \quad \text{...(i)}$$

$$\therefore \quad V(r) - V(r_0) = -\int_{r_0}^{r} \vec{E} \cdot d\vec{l} = \frac{\lambda}{2\pi\varepsilon_0} \log_e \frac{r_0}{r}$$

For an equipotential surface of given $V(r)$,

$$\log_e \frac{r}{r_0} = \frac{2\pi\varepsilon_0}{\lambda}[V(r) - V(r_0)]$$

$$\therefore \quad r = r_0 e^{-2\pi\varepsilon_0[V(r)-V(r_0)]/\lambda}$$

35. (d) : Electric field, $E = -\frac{dV}{dr}$ or $dr \propto \frac{1}{E}$

i.e., equipotential surfaces are closer in regions of large electric fields compared to regions of lower electric field. At sharp edges of a conductor, charge density is more. Therefore electric field is stronger. Hence equipotential surfaces are more crowded.

36. (b) : Before contact, charges of each spheres,

$q_1 = \sigma 4\pi R^2$ and $q_2 = \sigma 4\pi (2R)^2 = 4q_1$

When the two sphere are brought in contact, their charges are shared till their potentials become equal *i.e.*, $V_1 = V_2$.

$$\therefore \quad \frac{q_1'}{4\pi\varepsilon_0 R} = \frac{q_2'}{4\pi\varepsilon_0(2R)}$$

$$\therefore \quad q_2' = 2q_1' \quad \text{...(i)}$$

As there is no loss of charge in the process

$$\therefore \quad q_1' + q_2' = q_1 + q_2 = q_1 + 4q_1 = 5q_1 = 5(\sigma 4\pi R^2)$$

$$\text{or} \quad q_1' + 2q_1' = 5\sigma 4\pi R^2 \quad \text{(using (i))}$$

$$q_1' = \frac{5}{3}\sigma 4\pi R^2 \text{ and } q_2' = 2q_1' = \frac{10}{3}(\sigma 4\pi R^2)$$

Hence, $\sigma_1 = \frac{q_1'}{4\pi R^2} = \frac{5}{3}\sigma$ and $\sigma_2 = \frac{q_2'}{4\pi(2R)^2} = \frac{5}{6}\sigma$

37. (d) : In the region of strong electric fields equipotential surfaces are close together and in the region of weak electric fields, equipotential surfaces are far apart.

38. (c)

39. (b) : Here, $V_1 = V_2$

$$\text{or} \quad \frac{q_1}{4\pi\varepsilon_0 R_1} = \frac{q_2}{4\pi\varepsilon_0 R_2}$$

$$\therefore \quad \frac{q_1}{q_2} = \frac{R_1}{R_2} \quad \text{...(i)}$$

Given $R_1 > R_2$

$\therefore \quad q_1 > q_2$

$\therefore$ Larger sphere has more charge than the smaller sphere.

Now charge densities

$$\sigma_1 = \frac{q_1}{4\pi R_1^2} \text{ and } \sigma_2 = \frac{q_2}{4\pi R_2^2}$$

$$\therefore \quad \frac{\sigma_2}{\sigma_1} = \frac{q_2}{q_1}\frac{R_1^2}{R_2^2}$$

$$\text{or} \quad \frac{\sigma_2}{\sigma_1} = \frac{R_2}{R_1}\frac{R_1^2}{R_2^2} = \frac{R_1}{R_2} \quad \text{(using (i))}$$

As $R_1 > R_2$ therefore $\sigma_2 > \sigma_1$

Charge density of smaller sphere is more than the charge density of larger sphere.

40. (b) : Here, inner radius, $r_i = 10$ cm $= 10 \times 10^{-2}$ m

Outer radius, $r_o = 11$ cm $= 11 \times 10^{-2}$ m

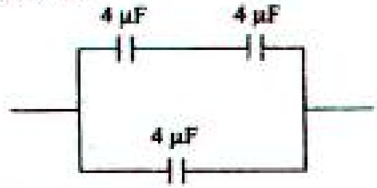
Charge, $q = 3.2$ μC $= 3.2 \times 10^{-6}$ C and $\varepsilon_r = 28$

Capacitance,

$$C = 4\pi\varepsilon_0 \frac{\varepsilon_r r_i r_0}{(r_0 - r_i)} = \frac{1}{9 \times 10^9}\left[\frac{28 \times 10 \times 10^{-2} \times 11 \times 10^{-2}}{(11-10) \times 10^{-2}}\right]$$

$$= 3.42 \times 10^{-9} \text{ F}$$

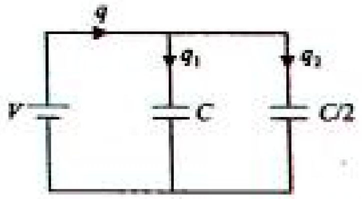
41. (c) : To get equivalent capacitance 6 μF, two 4 μF capacitors are to be connected in series and third one is connected in parallel.



From figure, equivalent capacitance,

$$C_{eq} = \frac{4 \times 4}{4 + 4} + 4 = 2 + 4 = 6 \text{ μF}$$

42. (b) :



As the capacitors are connected in parallel, therefore potential difference across both the condensors remains the same.

$$\therefore \quad q_1 = CV, \; q_2 = \frac{C}{2}V$$

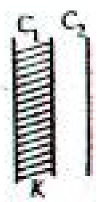
Also $\quad q = q_1 + q_2 = CV + \frac{C}{2}V = \frac{3}{2}CV$

Work done in charging fully both the condensors is given by

$$W = \frac{1}{2}qV = \frac{1}{2} \times \left(\frac{3}{2}CV\right)V = \frac{3}{4}CV^2$$

43. (b) : As, $C = \frac{\varepsilon_0 A}{d}$ ...(i)

When it is half filled with dielectric of K = 5, its capacitance becomes C_s which is a series combination of



$$C_1 = \frac{K\varepsilon_0 A}{d/2} = \frac{\varepsilon_0 A}{d/2K} = \frac{\varepsilon_0 A}{d/10}$$

$$C_2 = \frac{\varepsilon_0 A}{d/2}$$

$$\therefore \quad \frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{d/10}{\varepsilon_0 A} + \frac{d/2}{\varepsilon_0 A} = \frac{(3d/5)}{\varepsilon_0 A}$$

$$\Rightarrow \quad C_s = \frac{5}{3}\frac{\varepsilon_0 A}{d} = \frac{5C}{3} \quad \text{(Using (i))}$$

Percentage increase in capacitance

$$= \frac{C_1 - C}{C}\times 100 = \frac{\frac{5}{3}C - C}{C}\times 100 = \frac{2}{3}\times 100 = 66.6\%$$

44. (a) : When a charged capacitor of capacitance C_1 is connected in parallel to an uncharged capacitor of capacitance C_2, the charge is shared between them till both attain the common potential which is given by,

$$\text{common potential} = \frac{q_1 + q_2}{C_1 + C_2} = \frac{C_1V + 0}{C_1 + C_2} = \frac{C_1V}{C_1 + C_2}$$

45. (d)

46. (a) : Polar molecules have permanent electric dipole moment.

47. (b) : When electric dipole is held in the sphere, electric field is not zero anywhere on the sphere. However, net electric flux through the sphere is zero.

48. (a) : Here, length of dipole, $2a = 20$ cm $= 20 \times 10^{-2}$ m

Charge $q = \pm 3 \times 10^{-3}$ C, $\theta = 60°$ and torque $\tau = 6$ N m

As $\tau = pE\sin\theta$

or $\quad E = \frac{\tau}{p\sin\theta} = \frac{\tau}{q(2a)\sin\theta} \qquad (\because p = q(2a))$

$\therefore \quad E = \frac{6}{3\times10^{-3}\times20\times10^{-2}\times\sin 60°} = \frac{10^5}{5\sqrt{3}}\ \text{N C}^{-1}$

Potential energy of dipole, $U = -pE\cos\theta = -q(2a)E\cos\theta$

$$= -3\times10^{-3}(20\times10^{-2})\frac{10^5}{5\sqrt{3}}\cos 60°$$

$$= \frac{-3\times10^{-5}\times20\times10^5}{5\sqrt{3}\times2} = -2\sqrt{3}\ \text{J}$$

49. (c) : Here, $2a = 1.38 \times 10^{-10}$ m, $r = 10 \times 10^{-10}$ m

charge, $q = 1.6 \times 10^{-19}$ C

As potential, $V = \frac{p}{4\pi\varepsilon_0 r^2} = \frac{q(2a)}{4\pi\varepsilon_0 r^2}$

$$= \frac{9\times10^9\times1.6\times10^{-19}\times1.38\times10^{-10}}{(10\times10^{-10})^2} = 0.2\ \text{V}$$

50. (c) : In moving a small positive charge from Q to P, work has to be done by an external agency against the electric field. Therefore, work done by the field is negative.

51. (c) : The capacities of two individual condensers are

$C_1 = \frac{K_1\varepsilon_0 A}{d_1}$ and $C_2 = \frac{K_2\varepsilon_0 A}{d_2}$

The arrangement is equivalent to two capacitors joined in series.

$\therefore$ Equivalent capacitance, $\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{d_1}{K_1\varepsilon_0 A} + \frac{d_2}{K_2\varepsilon_0 A}$

$$= \frac{1}{\varepsilon_0 A}\left[\frac{d_1}{K_1} + \frac{d_2}{K_2}\right] = \frac{1}{\varepsilon_0 A}\left[\frac{K_2 d_1 + K_1 d_2}{K_1 K_2}\right]$$

or $\quad C_{eq} = \varepsilon_0 A\left(\frac{K_1K_2}{K_2d_1 + K_1d_2}\right) \qquad$ ... (i)

Also $C_{eq} = \frac{K\varepsilon_0 A}{d_1 + d_2} \qquad$ ... (ii)

From eq. (i) and (ii),

$$\varepsilon_0 A\left(\frac{K_1K_2}{d_2K_1 + d_1K_2}\right) = \varepsilon_0 A\left(\frac{K}{d_1 + d_2}\right)$$

$$\therefore \quad K = \frac{K_1K_2(d_1 + d_2)}{d_2K_1 + d_1K_2}$$

52. (d)

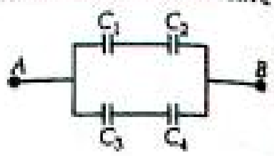
53. (a) : Here, $q_1 = 4\ \mu$C, $q_2 = -3\mu$C, $r = 10$ cm $= 0.1$ m

Electrostatic potential energy,

$$U = \frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r} = 9\times10^9\times\frac{4\times10^{-6}\times(-3)\times10^{-6}}{0.1} = -1.1\ \text{J}$$

54. (a)

55. (b) : Here, C_1 and C_2 are in series. Hence, their effective capacitance C' is given by



$\frac{1}{C'} = \frac{1}{C_1} + \frac{1}{C_2},\ \frac{1}{C'} = \frac{1}{20} + \frac{1}{20}$

$\Rightarrow \quad C' = 10\ \mu$F

Similarly, $\frac{1}{C''} = \frac{1}{C_3} + \frac{1}{C_4}$

$\frac{1}{C''} = \frac{1}{10} + \frac{1}{10} \Rightarrow C'' = 5\ \mu$F

Here C' and C'' are in parallel. Hence, the equivalent capacitance between points A and B is

$C_{AB} = C' + C'' = 10 + 5 = 15\ \mu$F

56. (c) : Initial energy of the combined system

$$U_1 = \frac{1}{2}CV_1^2 + \frac{1}{2}CV_2^2 = \frac{C}{2}\left(V_1^2 + V_2^2\right)$$

On joining the two condensers in parallel, common potential

$$V = \frac{CV_1 + CV_2}{C + C} = \frac{V_1 + V_2}{2}$$

$\therefore$ Final energy of the combined system

$$U_2 = \frac{1}{2}(C + C)\left(\frac{V_1 + V_2}{2}\right)^2$$

Decrease in energy

$$\Delta U = U_1 - U_2 = \frac{1}{2}C\left(V_1^2 + V_2^2\right) - \frac{1}{2}(2C)\left(\frac{V_1 + V_2}{2}\right)^2$$

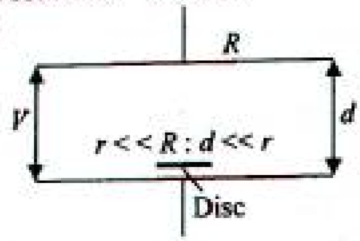
$$= \frac{C}{2}\left[2\left(V_1^2 + V_2^2\right) - (V_1 + V_2)^2\right]$$

$$= \frac{C}{4}\left[2V_1^2 + 2V_2^2 - V_1^2 - V_2^2 - 2V_1V_2\right] = \frac{C}{4}(V_1 - V_2)^2$$

57. (c) : SI unit of electrostatic potential is volt.

$$1\ \text{volt} = \frac{1\ \text{joule}}{1\ \text{coulomb}} = \frac{\text{joule}}{\text{coulomb}}$$

58. (c) :



As shown in figure, the disc is in touch with the bottom plate. The electric field on the disc is $E = V/d$

Therefore, charge q' transferred to the disc

$$q' = CV = \left(\frac{\varepsilon_0 A}{d}\right)V = \varepsilon_0 \frac{V}{d}\pi r^2$$

Force acting on the disc, $F = q'E = \left(\varepsilon_0 \frac{V}{d}\pi r^2\right)\frac{V}{d}$

$$F = \varepsilon_0 \frac{V^2}{d^2}\pi r^2$$

If the disc is to be lifted, $F \geq mg$,

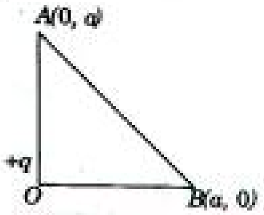
i.e., $\varepsilon_0 \frac{V^2}{d^2}\pi r^2 = mg$ (for minimum V)

$$\therefore \quad V = \sqrt{\frac{mgd^2}{\pi\varepsilon_0 r^2}}$$

59. (c) : Work done on a unit charge $+q$ by the electrostatic field due to any given charge configuration is independent of the path, and depends only on its initial and final positions.

60. (a) : Work done is equal to zero because the potential of A and B are the same $= \frac{1}{4\pi\varepsilon_0}\frac{q}{a}$

No work is done if a particle does not change its potential energy.



i.e., initial potential energy = final potential energy

61. (c) **62. (b)**

63. (a) : Since, $E = 0$ inside the conductor and has no tangential component on the surface, no work is done in moving a small test charge within the conductor and on its surface.

64. (b) : The work done in bringing unit positive charge from infinity to a point which is at a distance x from the positive charge Q is defined as the potential at the given point due to the charge Q. Therefore $\phi = W$.

65. (b) : $W_{ext} = q_0 \Delta V$

66. (c) : As $\frac{-dV}{dr} = E_r$, the negative of the slope of V versus r curve represents the component of electric field along r. Slope of curve is zero only at point 3.

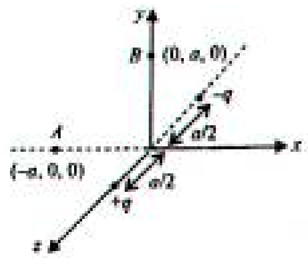
Therefore, the electric field vector is zero at point 3.

67. (a) : Near positive charge, net potential is positive and near a negative charge, net potential is negative. Thus, charge Q_1 is positive and Q_2 is negative.

68. (b) : From the figure, it can be seen that net potential due to two charges is positive everywhere in the region left to charge Q_1. Therefore the magnitude of potential due to charge Q_1 is greater than due to Q_2.

69. (b)

70. (c) : It can be seen that potential at the points both A and B are zero. When the charge is moved from A to B, work done by the electric field on the charge will be zero.



71. (b) : Here $C = 50\text{pF} = 50 \times 10^{-12}$ F,

$R = \frac{1}{4\pi\varepsilon_0} \cdot C = 9 \times 10^9 \text{ mF}^{-1} \times 50 \times 10^{-12}$ F

$= 45 \times 10^{-2}$ m = 45 cm

72. (d): As $q = CV = 25 \times 10^{-12} \times 10^5 = 2.5\ \mu$C

73. (c)

74. (c) : As charge, $q = CV = (4\pi\varepsilon_0 R)V$

$\therefore$ q depends on both V and R.

75. (c) : 64 drops have formed a single drop of radius R.

Volume of large sphere = 64 × Volume of small sphere

$\therefore \frac{4}{3}\pi R^3 = 64\frac{4}{3}\pi r^3 \Rightarrow R = 4r$ and $Q_{total} = 64q$

$C' = 4\pi\varepsilon_0 R \Rightarrow C' = (4\pi\varepsilon_0).4r \Rightarrow C' = 4C$

76. (b) : $k = \dfrac{\text{Capacitance with dielectric}}{\text{Capacitance without dielectric}}$

$= \frac{80\ \mu\text{F}}{4\ \mu\text{F}} = 20$

77. (c) : Capacitance of the capacitor with air between plates

$$C' = \frac{\varepsilon_0 A}{d} = 8 \text{ pF}$$

With the capacitor is filled with dielectric ($k = 5$) between its plates and the distance between the plates is reduced by half, capacitance become

$C = \frac{\varepsilon_0 kA}{d/2} = \frac{\varepsilon_0 \times 5 \times A}{d/2} = 10\ C' = 10 \times 8 = 80$ pF.

78. (d) : If a dielectric medium of dielectric constant K is filled completely between the plates then capacitance increases by K times.

79. (b): As $C = \frac{\varepsilon_0 A}{d} = 1 \text{ pF}$ ...(i)

$C' = \frac{x\varepsilon_0 A}{(2d)} = 2 \text{ pF}$ ... (ii)

Divide (ii) by (i), $x/2 = 2/1 \Rightarrow x = 4$

80. (c) : As capacitance, $C_0 = \frac{\varepsilon_0 A}{d}$

$\therefore$ After inserting copper plate, $C = \frac{\varepsilon_0 A}{d - b}$

81. (d) : In polar molecule the centres of positive and negative charges are separated even when there is no external field. Such molecule have a permanent dipole moment. Ionic molecule like HCl is an example of polar molecule.

82. (c) : As $F_m = \frac{F_o}{K}$

$\therefore$ The maximum force decreases by K times.

- Drift velocity depends on electric field as $v_d \propto E$. So greater the electric field, larger will be the drift velocity.
- Unit of drift velocity is m s^{-1} and its dimensions is $[M^0 L T^{-1}]$.
- Relationship between current and drift velocity
  $I = nAe\, v_d$
  where n is the number density of electrons or number of electrons per unit volume of the conductor and A is the area of cross-section of the conductor.
- Relationship between current density and drift velocity
  $j = nev_d$
  where symbols have their usual meaning.

• **Mobility :** It is defined as the magnitude of drift velocity per unit electric field. It is denoted by symbol μ.

$$\mu = \frac{|v_d|}{E} = \frac{qE\tau/m}{E} = \frac{q\tau}{m}$$

where q, τ and m are charge, relaxation time and mass of a charge carrier respectively.

- The SI unit of mobility is $m^2\, V^{-1}\, s^{-1}$ and its dimensional formula is $[M^{-1}L^0T^2A]$.

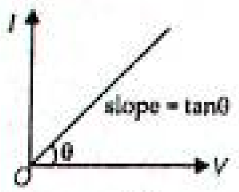
• **Ohm's law :** It states that the current (I) flowing through a conductor is directly proportional to the potential difference (V) across the ends of the conductor, provided physical conditions of the conductor such as temperature, mechanical strain etc. are kept constant.

$V \propto I$ or $V = RI$

where the constant of proportionality R is called resistance of the conductor.

- The graph between potential difference (V) and current (I) through a metallic conductor is a straight line passing through the origin as shown in figure. The reciprocal of slope of line gives resistance.

$$R = \frac{V}{I} = \frac{1}{\tan\theta\,(\text{slope of } I\text{-}V)}$$



- The resistance of a conductor is obstruction posed by the conductor to the flow of current through it.
- The SI unit of resistance is ohm (Ω) and its dimensional formula is $[ML^2T^{-3}A^{-2}]$.
- The resistance of a conductor is

$$R = \frac{m}{ne^2\tau}\frac{l}{A} = \rho\frac{l}{A} \quad \text{where } \rho = \frac{m}{ne^2\tau}$$

where m is the mass of electron, e is charge of electron, n is the number density of electrons, τ is the relaxation time, l is the length of conductor and A is its area of cross-section, ρ is the specific resistance or resistivity of the conductor.

- **Resistivity :** The specific resistance offered by the conductor of unit length and unit cross-section area. It is denoted by ρ.
  - The SI unit of resistivity is Ω m and its dimensional formula is $[ML^3T^{-3}A^{-2}]$.
- If the conductor is in the form of wire of length l and a radius r, then its resistance is

$$R = \frac{\rho l}{\pi r^2}$$

- If a conductor has mass m, volume V and density d, then its resistance R is

$$R = \frac{\rho l}{A} = \frac{\rho l^2}{Al} = \frac{\rho l^2}{V} = \frac{\rho l^2 d}{m}$$

- If length of a given metallic wire of resistance R is stretched to n times, its resistance becomes n^2R but its resistivity remains unchanged.
- If radius of the given metallic wire of resistance R becomes n times, its resistance becomes $(1/n^4)R$.
- If the area of cross-section of the given metallic wire of resistance R becomes n times, then its resistance becomes $(1/n^2)R$.
- **Conductivity :** The reciprocal of resistivity is known as conductivity or specific conductance. It is denoted by symbol σ.

$$\sigma = \frac{1}{\rho} = \frac{ne^2\tau}{m} = ne\mu \qquad \left[\text{As } \mu = \frac{v_d}{E} = \frac{e\tau}{m}\right]$$

  - The SI unit of conductivity is $\Omega^{-1}\, m^{-1}$ or S m^{-1} or mho m^{-1} and its dimensional formula is $[M^{-1}L^{-3}T^3A^2]$.

• **Relationship between j, σ and E**

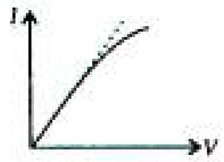
$j = \sigma E$

It is a microscopic form of Ohm's law.

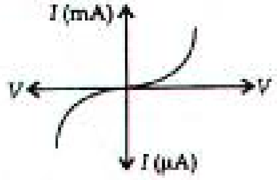
• **Ohmic and non-ohmic conductors**

- **Ohmic conductors :** Those conductors which obey Ohm's law are known as ohmic conductors, *e.g.* metals. For ohmic conductors, the graph between current and potential difference is a straight line passing through the origin.

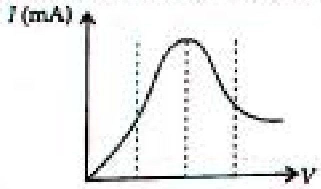
- **Non-ohmic conductors** : Those conductors which do not obey Ohm's law are known as non-ohmic conductors *e.g.* diode valve, junction diode.
- For non-ohmic conductors, the graph between the current (I) and potential difference (V) has one or more of the following characteristics:
  - The relation between V and I is non-linear.



  - The relation between V and I depends on the sign of V.



  - The relation between V and I is not unique, *i.e.*, there is more than one value of V for the same current I.



- **Effect of temperature on resistance and resistivity**
  - The resistance of a metallic conductor increases with increase in temperature.
  - The resistance of a conductor at temperature t°C is given by
    $R_t = R_0(1 + \alpha t)$
    where R_t is the resistance at t °C, R_0 is the resistance at 0°C and α is the characteristics constants of the material of the conductor.
    - Over a limited range of temperatures, that is not too large. The resistivity of a metallic conductor is approximately given by $\rho_t = \rho_0(1 + \alpha t)$.
      where α is the temperature coefficient of resistivity. Its unit is K^{-1} or C^{-1}.
    - In the temperature range in which resistivity increases linearly with temperature, the temperature coefficient of resistivity α is defined as the fractional increase in resistivity per unit increase in temperature.
  - For metals, α is positive *i.e.*, resistance increases with rise in temperature.
  - For insulators and semiconductors, α is negative *i.e.*, resistance decreases with rise in temperature.
- **Cells, emf, internal resistance**
  - **Electrochemical cell** : It is a device which, converts chemical energy into electrical energy, maintains the flow of charge in a circuit.
  - **Electromotive force (emf) of a cell**
    - It is defined as the potential difference between the two terminals of a cell in an open circuit *i.e.*, when no current flows through the cell. It is denoted by symbol ε.
    - The SI unit of emf is joule/coulomb or volt and its dimensional formula is $[ML^2T^{-3}A^{-1}]$.
    - The emf of a cell depends upon the nature of electrodes, nature and the concentration of electrolyte used in the cell and its temperature.
  - **Terminal potential difference** : It is defined as the potential difference between two terminals of a cell in a closed circuit *i.e.*, when current is flowing through the cell.
  - **Internal resistance of a cell**
    - It is defined as the resistance offered by the electrolyte and electrodes of a cell when the current flows through it.
    - Internal resistance of a cell depends upon the following factors:
      Distance between the electrodes.
      The nature of the electrolyte.
      The nature of electrodes.
      Area of the electrodes, immersed in the electrolyte.
  - **Relationship between ε, V and r** : When a cell of emf ε and internal resistance r is connected to an external resistance R as shown in the figure,
    The voltage across R is

$V = IR$

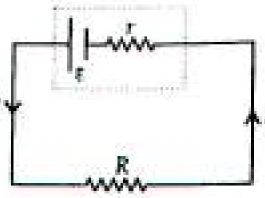
$= \frac{\varepsilon}{R+r} R$

or $\varepsilon = IR + Ir$

or $V = \varepsilon - Ir$

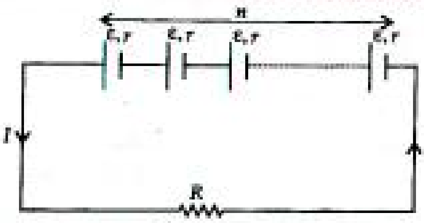
or $\varepsilon = V + Ir$

or $r = R\left(\frac{\varepsilon}{V} - 1\right)$



- During discharging of a cell, terminal potential difference = emf of a cell − voltage drop across the internal resistance of a cell. *i.e.*, terminal potential difference across it is less than emf of the cell. The direction of current inside the cell is from negative terminal to positive terminal.
- During charging of a cell, terminal potential difference = emf of a cell + voltage drop across internal resistance of a cell *i.e.*, terminal potential difference becomes greater than the emf of the cell. The direction of current inside the cell is from positive terminal to negative terminal.

- **Grouping of cells :** Cells can be grouped in the following three ways:
  Series grouping
  Parallel grouping
  Mixed grouping
  - **Series grouping :** If n identical cells each of emf ε and internal resistance r are connected to the external resistor of resistance R as shown in the figure, they are said to be connected in series grouping.



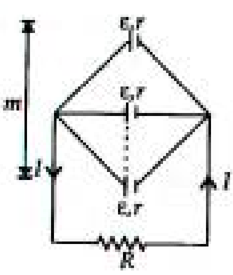
$\varepsilon_{eq} = n\varepsilon$ and $r_{eq} = nr$

$\therefore$ Current in the circuit, $I = \frac{n\varepsilon}{R + nr}$

Special cases :

- If $R << nr$, then $I = \frac{n\varepsilon}{nr} = \frac{\varepsilon}{r}$.
- If $R >> nr$, then $I = \frac{n\varepsilon}{R}$.

  - **Parallel grouping :** If m identical cells each of emf ε and internal resistance r are connected to the external resistor of resistance R as shown in figure, they are said to be connected in parallel grouping.



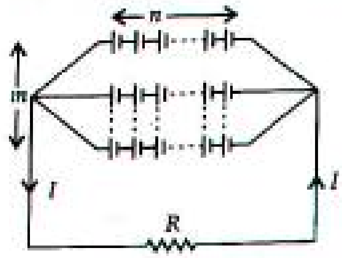
$\varepsilon_{eq} = \varepsilon$ and $r_{eq} = \frac{r}{m}$.

$\therefore$ The current in the circuit, $I = \frac{\varepsilon}{R + \left(\frac{r}{m}\right)}$

Special cases :

- If $\frac{r}{m} << R$, then $I = \frac{\varepsilon}{R}$.
- If $\frac{r}{m} >> R$, then $I = m\frac{\varepsilon}{r}$.

  - **Mixed grouping :** If the cells are connected as shown in figure they are said to be connected in mixed grouping. Let there be n cells in series in one row and m such rows of cells in parallel. Suppose all the cells are identical. Let each cell be of emf ε and internal resistance r.



$\varepsilon_{eq} = n\varepsilon$ and $r_{eq} = \frac{nr}{m}$ $\quad \therefore I = \frac{n\varepsilon}{R + \left(\frac{nr}{m}\right)}$

In case of mixed grouping of cells, current in the circuit will be maximum, when

$R = \frac{nr}{m}$

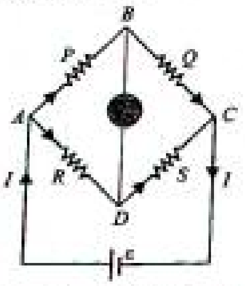
i.e., external resistance = total internal resistance of all cells

- **Kirchhoff's laws :** Kirchhoff in 1942 put forward the following two laws to solve the complicated circuits. These two laws are stated as follows :
  - Kirchhoff's first law or Kirchhoff's junction rule or Kirchhoff's current law : It states that the algebraic sum of the currents meeting at a junction is zero.
    - Kirchhoff's first law supports the law of conservation of charge.
    - According to sign convention the current flowing towards a junction is taken as positive and the current flowing away from the junction is taken as negative.
  - Kirchhoff's second law or Kirchhoff's loop law or Kirchhoff's voltage law : It states that in a closed loop, the algebraic sum

of the emfs is equal to the algebraic sum of the products of the resistance and the respective currents flowing through them. $\Sigma\varepsilon = \Sigma IR$

- Kirchhoff's second law supports the law of conservation of energy.
- According to sign convention while traversing a closed loop (in clockwise or anti-clockwise direction), if negative pole of the cell is encountered first then its emf is positive, otherwise negative. The product of resistance and current in an arm of the circuit is taken positive if the direction of current in that arm is in the same sense as one moves in a closed loop and is taken negative if the direction of current in that arm is opposite to the sense as one moves in the closed loop.

- **Wheatstone bridge :** It is an arrangement of four resistances P, Q, R and S connected as shown in the figure.

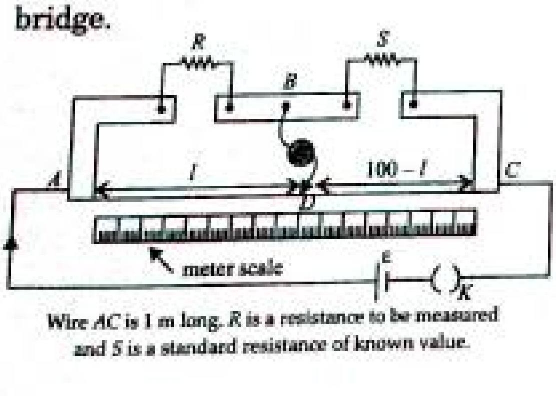


Their values are so adjusted that the galvanometer G shows no deflection. The bridge is then said to be balanced. When this happens, the points B and D are at the same potential and it can be shown that .

$$\frac{P}{Q} = \frac{R}{S}$$

This is called the balancing condition. If any three resistances are known, the fourth can be found.

- **Meter bridge or slide wire bridge**
  - It is based on the principle of Wheatstone bridge.



Wire AC is 1 m long. R is a resistance to be measured and S is a standard resistance of known value.

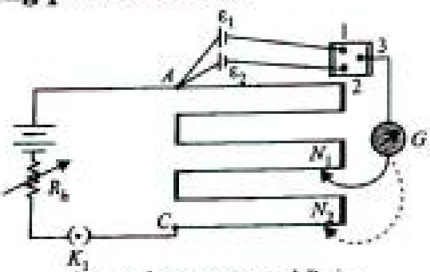
  - The unknown resistance, $R = \frac{Sl}{100 - l}$, where l is the balancing length of metre bridge.

- **Potentiometer**
  - **Principle of potentiometer :** It is based on the fact that the fall of potential across any portion of the wire is directly proportional to the length of that portion provided the wire is of uniform area of cross-section and a constant current is flowing through it.

    i.e., $V \propto l$ (If I and A are constant)

    or $V = Kl$

    where K is known as potential gradient *i.e.*, fall of potential per unit length of the given wire.
  - **Comparison of emfs of two cells by using potentiometer**

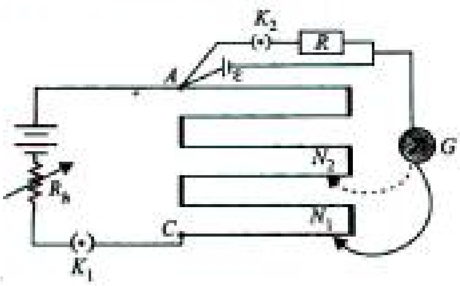


G is a galvanometer and R_h is rheostat. 1, 2, 3, are terminals of a two way key

$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{l_1}{l_2}$$

where l_1, l_2 are the balancing lengths of potentiometer wire for the emfs ε_1 and ε_2 of two cells respectively.

  - **Determination of internal resistance of a cell by potentiometer**



$$r = \left(\frac{l_1 - l_2}{l_2}\right)R$$

where l_1 = balancing length of potentiometer wire corresponding to emf of the cell, l_2 = balancing length of potentiometer wire corresponding to terminal potential difference of the cell when a resistance R is connected in series with the cell whose internal resistance is to be determined.

- **Joule's Law of Heating :** According to Joule's heating effect of current, the amount of heat produced (H) in a conductor of resistance R, carrying current I for time t is $H = I^2Rt$ (in joule)

  or $H = \frac{I^2Rt}{J}$ (in calorie)

  where J is Joule's mechanical equivalent of heat (= 4.2 J/cal).

- **Electric power :** It is defined as the rate at which work is done by the source of emf in maintaining the current in the electric circuit.

  $$\text{Electric power } P = \frac{\text{electric work done}}{\text{time taken}}$$

  $$P = VI = I^2R = \frac{V^2}{R}.$$

  ▶ SI unit and Dimensions :
  - The SI unit of power is watt (W).
  - The practical unit of power is kilowatt (kW) and horse power (hp).
  - Dimension of power $[ML^2 T^{-3} A^2]$

  ▶ Power dissipated in connecting wires, which is wasted is P_c given by

  $$P_c = I^2R_c = \frac{P^2R_c}{V^2}$$

  ▶ If P_1, P_2, P_3 .... are the powers of electric appliances in series with source of rated voltage V, the effective power consumed is

  $$\frac{1}{P_S} = \frac{1}{P_1} + \frac{1}{P_2} + \frac{1}{P_3} + \ldots\ldots$$

  ▶ If P_1, P_2, P_3 are the powers of electric appliances in parallel with a source of rated voltage V, the effective power consumed is

  $$P_P = P_1 + P_2 + P_3 + \ldots..$$

- **Electric energy :** It is defined as the total electric work done or energy supplied by the source of emf in maintaining the current in an electric circuit for a given time.

  Electric energy = electric power × time = $P \times t$.

  ▶ The SI unit of electrical energy is joule (J).

  ▶ The commercial unit of electric energy is kilowatt-hour (kWh),
  1 kWh = 1000 Wh = 3.6×10^6 J = one unit of electricity consumed.

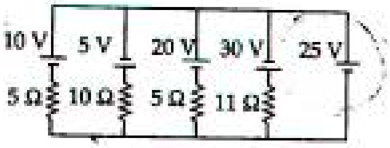
  ▶ The number of units of electricity consumed is n = (total wattage × time in hour)/1000.

Practice Time

Multiple Choice Questions (MCQs)

1. The direction of the flow of current through electric circuit is
(a) from low potential to high potential
(b) from high potential to low potential
(c) does not depend upon potential value
(d) current cannot flow through circuit.

2. In the circuit shown, current flowing through 25 V cell is



(a) 7.2 A (b) 10 A
(c) 12 A (d) 14.2 A

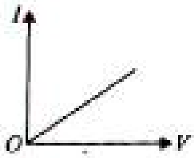
3. In a Wheatstone bridge if the battery and galvanometer are interchanged then the deflection in galvanometer will be
(a) change in previous direction
(b) not change
(c) change in opposite direction
(d) none of these.

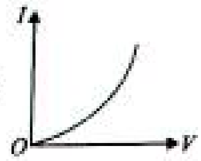
4. Which of the following velocity of electrons determines the current in a conductor?
(a) Drift velocity only.
(b) Thermal velocity only.
(c) Both drift velocity and thermal velocity.
(d) Neither drift nor thermal velocity.

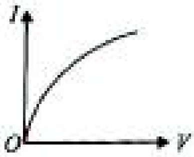
5. In a potentiometer of 10 wires, the balance point is obtained on the 7th wire. To shift the balance point to 9th wire, we should
(a) decrease resistance in the main circuit
(b) increase resistance in the main circuit
(c) decrease resistance in series with the cell whose emf is to be measured
(d) increase resistance in series with the cell whose emf is to be determined.

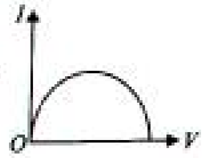
6. The resistance of the wire in the platinum resistance thermometer at ice point is 5 Ω and at steam point is 5.25 Ω. When the thermometer is inserted in an unknown hot bath its resistance is found to be 5.5 Ω. The temperature of the hot bath is
(a) 100°C (b) 200°C (c) 300°C (d) 350°C

7. Which of the following I-V graph represents for ohmic conductors?

(a)


(b)


(c)


(d)


8. In parallel combination of n cells, we obtain
(a) more voltage (b) more current
(c) less voltage (d) less current

9. If n cells each of emf ε and internal resistance r are connected in parallel, then the total emf and internal resistances will be
(a) $\varepsilon, \frac{r}{n}$ (b) ε, nr (c) $n\varepsilon, \frac{r}{n}$ (d) $n\varepsilon, nr$

10. In the series combination of n cells each cell having emf ε and internal resistance r. If three cells are wrongly connected, then total emf and internal resistance of this combination will be
(a) $n\varepsilon, (nr - 3r)$ (b) $(n\varepsilon - 2\varepsilon), nr$
(c) $(n\varepsilon - 4\varepsilon), nr$ (d) $(n\varepsilon - 6\varepsilon), nr$

11. 1 Ampere current is equivalent to
(a) 6.25×10^{18} electrons s^{-1}
(b) 2.25×10^{18} electrons s^{-1}
(c) 6.25×10^{14} electrons s^{-1}
(d) 2.25×10^{14} electrons s^{-1}

12. A current in a wire is given by the equation, $I = 2t^2 - 3t + 1$, the charge through cross section of wire in time interval $t = 3$ s to $t = 5$ s is
(a) 32.33 C (b) 43.34 C
(c) 45.5 C (d) 42 C

13. A current carrying wire in the shape of a circle as the current progresses along the wire the direction of current density changes in an exact manner while the current I remains unaffected. The responsible factor for it is

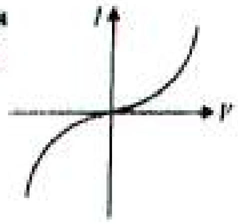
(a) the charges ahead

(b) electric field produced by charges accumulated on the surface of wire.

(c) the charges just behind a given segment of wire which push them, just right way by repulsion.

(d) none of these.

14. The I-V characteristics shown in figure is represent for



(a) ohmic conductors

(b) non-ohmic conductors

(c) insulators

(d) superconductors.

15. The electrical resistance of a conductor depends upon

(a) size of conductor

(b) temperature of conductor

(c) geometry of conductor

(d) all of above.

16. The battery of a trunk has an emf of 24 V. If the internal resistance of the battery is 0.8 Ω. What is the maximum current that can be drawn from the battery ?

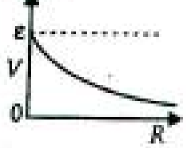
(a) 30 A (b) 32 A (c) 33 A (d) 34 A

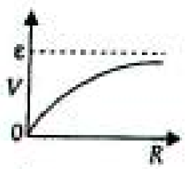
17. A battery having 12 V emf and internal resistance 3 Ω is connected to a resistor. If the current in the circuit is 1 A, then the resistance of resistor and lost voltage of the battery when circuit is closed will be

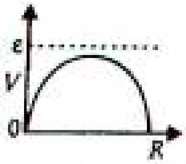
(a) 7 Ω, 7 V (b) 8 Ω, 8 V

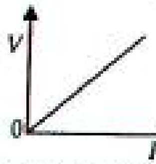
(c) 9 Ω, 9 V (d) 9 Ω, 10 V

18. A cell having an emf ε and internal resistance r is connected across a variable external resistance R. As the resistance R is increased, the plot of potential difference V across R is given by

(a) 

(b) 

(c) 

(d) 

19. A uniform wire of length l and radius r has a resistance of 100 Ω. It is recast into a wire of radius $\frac{r}{2}$. The resistance of new wire will be

(a) 400 Ω (b) 100 Ω (c) 200 Ω (d) 1600 Ω

20. Range of resistivity for metals is

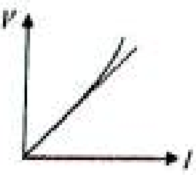
(a) 10^{-6} Ω m to 10^{-4} Ω m

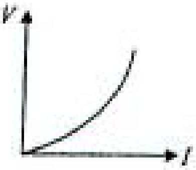
(b) 10^{-7} Ω m to 10^{-5} Ω m

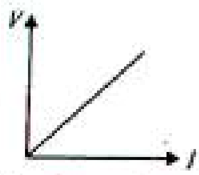
(c) 10^{-8} Ω m to 10^{-6} Ω m

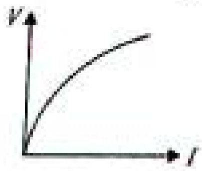
(d) 10^{-9} Ω m to 10^{-7} Ω m

21. Which of the following is correct for V-I graph a good conductor?

(a) 

(b) 

(c) 

(d) 

22. A charged particle having drift velocity of 7.5×10^{-4} m s^{-1} in electric field of 3×10^{-10} V m^{-1}, mobility is

(a) 6.5×10^{4} m^2 V^{-1} s^{-1}

(b) 2.5×10^{6} m^2 V^{-1} s^{-1}

(c) 6.5×10^{6} m^2 V^{-1} s^{-1}

(d) 6.5×10^{4} m^2 V^{-1} s^{-1}

23. The resistance of a 10 m long wire is 10 Ω. Its length is increased by 25% by stretching the wire uniformly. Then the resistance of the wire will be

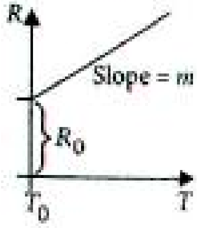
(a) 12.5 Ω (b) 14.5 Ω (c) 15.6 Ω (d) 16.6 Ω

24. A wire has a resistance of 2.5 Ω at 28 °C and a resistance of 2.9 Ω at 100 °C. The temperature coefficient of resistivity of material of the wire is

(a) 1.06×10^{-3} °C^{-1} (b) 3.5×10^{-2} °C^{-1}

(c) 2.22×10^{-3} °C^{-1} (d) 3.95×10^{-2} °C^{-1}

25. Variation of resistance of the conductor with temperature is as shown. The temperature coefficient (α) of the conductor is



(a) $\frac{R_0}{m}$

(b) mR_0

(c) m^2R_0

(d) $\frac{m}{R_0}$

26. An electric bulb marked as 50W-200V is connected across a 100 V supply. The present power of the bulb is

(a) 37.5 W (b) 25 W (c) 12.5 W (d) 10 W

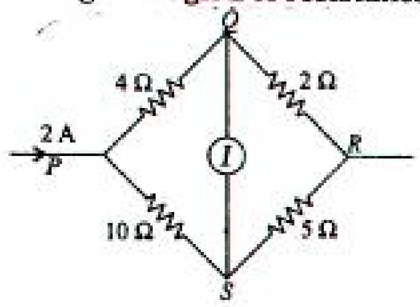
27. Resistances P, Q, S and R are arranged in a cyclic order to form a balanced Wheatstone's network. The ratio of power consumed in the branches $(P + Q)$ and $(R + S)$ is

(a) 1 : 1 (b) $R : P$ (c) $P^2 : Q^2$ (d) $P^2 : R^2$

28. Four resistances of 3, 3, 3 and 4 Ω respectively are used to form a Wheatstone bridge. The 4 Ω resistance is short circuited with a resistance R in order to get bridge balanced value of R will be

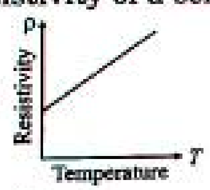
(a) 10 Ω (b) 11 Ω (c) 12 Ω (d) 13 Ω

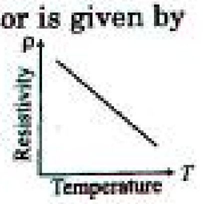
29. In the given figure bridge is balanced, the current flowing through 2 Ω resistance is

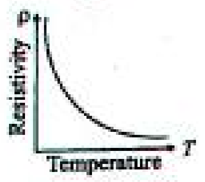


(a) $\frac{10}{7}$ A (b) $\frac{11}{7}$ A (c) $\frac{13}{7}$ A (d) $\frac{8}{7}$ A

30. The temperature dependence of the resistivity of a semiconductor is given by

(a)


(b)


(c)


(d)


31. In a Wheatstone's network, $P = 2\ \Omega$, $Q = 2\ \Omega$, $R = 2\ \Omega$ and $S = 3\ \Omega$. The resistance with which S is to be shunted in order that the bridge may be balanced is

(a) 1 Ω (b) 2 Ω (c) 4 Ω (d) 6 Ω

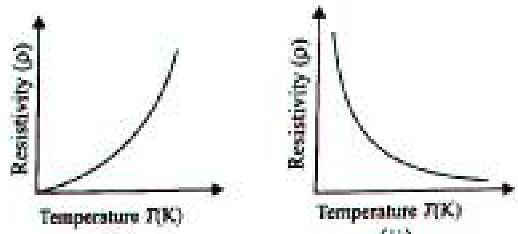
32. In a potentiometer a cell of emf 1.5 V gives a balanced point at 32 cm length of the wire. If the cell is replaced by another cell then the balance point shifts to 65.0 cm then the emf of second cell is

(a) 3.05 V (b) 2.05 V (c) 4.05 V (d) 6.05 V

33. In a potentiometer the balancing with a cell is at length of 220 cm. On shunting the cell with a resistance of 3 Ω balance length becomes 130 cm. What is the internal resistance of this cell ?

(a) 4.5 Ω (b) 7.8 Ω (c) 6.3 Ω (d) 2.08 Ω

34. Figure (i) and figure (ii) both are showing the variation of resistivity (ρ) with temperature (T) for some materials. Identify the type of these materials.



(i) (ii)

(a) Conductor and semi conductor.
(b) Conductor and Insulator.
(c) Insulator and semiconductor.
(d) Both are conductors.

35. With increase in temperature the conductivity of

(a) metals increases and of semiconductor decreases
(b) semiconductors increases and of metals decreases
(c) in both metals and semiconductors increases
(d) in both metal and semiconductor decreases.

36. A battery of emf 15 V and internal resistance of 4 Ω is connected to a resistor. If the current in the circuit is 2 A and the circuit is closed. Resistance of the resistor and terminal voltage of the battery will be

(a) 2.5 Ω, 6 V (b) 3.5 Ω, 6 V
(c) 2.5 Ω, 7 V (d) 3.5 Ω, 7 V

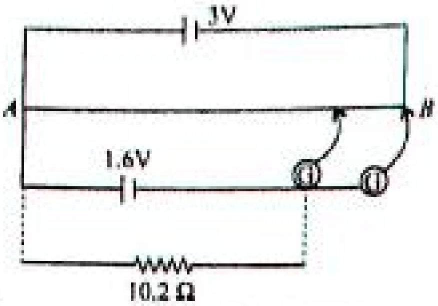
37. Point out the right statements about the validity of Kirchhoff's junction rule.

(a) It is based on conservation of charge.
(b) Outgoing currents add up and are equal to incoming currents at a junction.
(c) Bendingorreorientingthewiredoesnotchange the validity of Kirchhoff's junction rule.
(d) All of these.

38. The resistance of a heating element is 99 Ω at room temperature. What is the temperature of the element if the resistance is found to be 116 Ω ? (Temperature coefficient of the material of the resistor is $1.7 \times 10^{-40}\ {}^\circ C^{-1}$)

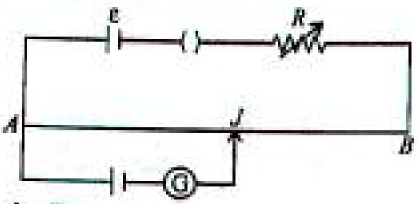
(a) 999.9 °C (b) 1005.3 °C
(c) 1020.2 °C (d) 1037.1 °C

39. 3 V potentiometer used for the determination of internal resistance of a 2.4 V cell. The balance point of the cell in open circuit is 75.8 cm. When a resistor of 10.2 Ω is used in the external circuit of the cell the balance point shifts to 68.3 cm length of the potentiometer wire. The internal resistance of the cell is



(a) 2.5 Ω (b) 2.25 Ω
(c) 1.12 Ω (d) 3.2 Ω

40. AB is a wire of potentiometer with the increase in the value of resistance R, the shift in the balance point J will be



(a) towards B
(b) towards A
(c) remains constant
(d) first towards B then back towards A.

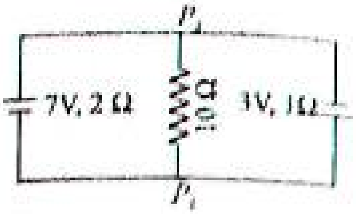
41. A wire connected in the left gap of a meter bridge balance a 10 Ω resistance in the right gap to a point, which divides the bridge wire in the ratio 3 : 2. If the length of the wire is 1 m. The length of one ohm wire is

(a) 0.057 m (b) 0.067 m
(c) 0.37 m (d) 0.134 m

42. Five cells each of emf E and internal resistance r send the same amount of current through an external resistance R whether the cells are connected in parallel or in series. Then the ratio $\left(\frac{R}{r}\right)$ is

(a) 2 (b) $\frac{1}{2}$ (c) $\frac{1}{5}$ (d) 1

43. A of battery 7 V with internal resistance 3 Ω and a 3 V battery with internal resistance 1 Ω are connected to a 10 Ω resistor as shown in figure, the current in 10 Ω resistor is

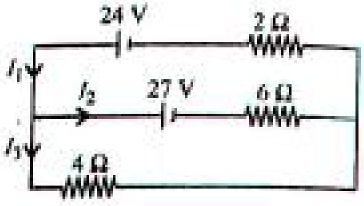


(a) 0.27 A (b) 0.31 A (c) 0.031 A (d) 0.53 A

44. In a circuit a cell with internal resistance r is connected to an external resistance R. The condition for the maximum current that drawn from the cell is

(a) $R = r$ (b) $R < r$ (c) $R > r$ (d) $R = 0$

45. In given circuit, the value of currents I_1, I_2 and I_3 are

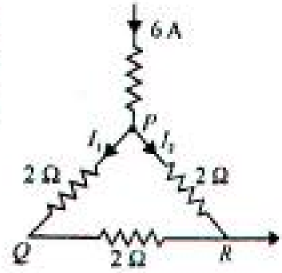


(a) $3\text{ A}, \frac{-3}{2}\text{ A}, \frac{9}{2}\text{ A}$ (b) $\frac{9}{2}\text{ A}, 3\text{ A}, \frac{-3}{2}\text{ A}$
(c) 5 A, 4 A, –3 A (d) $7\text{ A}, \frac{5}{4}\text{ A}, \frac{9}{2}\text{ A}$

46. When a current of 2 A flows in a battery from negative to positive terminal, the potential difference across it is 12 V. If a current of 3 A flowing in the opposite direction produces a potential difference of 15 V, the emf of the battery is

(a) 12.6 V (b) 13.2 V
(c) 13.5 V (d) 14.0 V

47. A current of 6 A enters one corner P of an equilateral triangle PQR having 3 wires of resistances 2 Ω each and leaves by the corner R. Then the currents I_1 and I_2 are



(a) 2 A, 4 A
(b) 4 A, 2 A
(c) 1 A, 2 A
(d) 2 A, 3 A

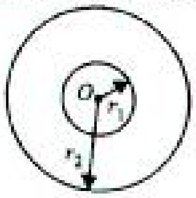
48. A charged particle having drift velocity of 7.5×10^{-4} m s^{-1} in electric field of 4×10^{-12} V m^{-1}, mobility is

(a) 6.5×10^{7} m^2 V^{-1} s^{-1}
(b) 1.8×10^{8} m^2 V^{-1} s^{-1}

(c) $7.2 \times 10^6\ m^2\ V^{-1}\ s^{-1}$

(d) $4.5 \times 10^4\ m^2\ V^{-1}\ s^{-1}$

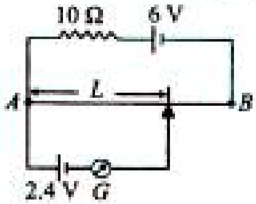
49. Space between two concentric spheres of radii r_1 and r_2, such that $r_1 < r_2$, is filled with a material of resistivity ρ. Find the resistance between inner and outer surface of the material.



(a) $\frac{r_1}{r_2}\frac{\rho}{2}$ (b) $\frac{r_2 - r_1}{r_1 r_2}\frac{\rho}{4\pi}$

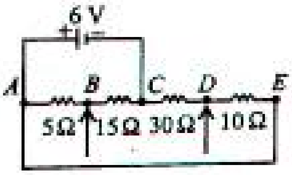
(c) $\frac{r_1 r_2}{r_2 - r_1}\frac{\rho}{4\pi}$ (d) None of these

50. A potentiometer wire of length 200 cm has a resistance of 20 Ω. It is connected in series with a resistance of 10 Ω and an accumulator of emf 6 V having negligible internal resistance. A source of 2.4 V is balanced against a length L of the potentiometer wire. The value of L is



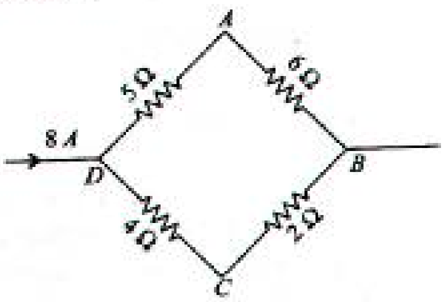
(a) 100 cm (b) 120 cm (c) 110 cm (d) 1 4 0 cm

51. Four resistors are connected as shown in the figure. A 6 V battery of negligible resistance is connected across terminals A and C. The potential difference across terminals B and D will be



(a) Zero (b) 1.5 V (c) 2 V (d) 3 V

52. A current of 8 A flows in a system of resistors as shown in figure. The potential difference $V_C - V_A$ will be

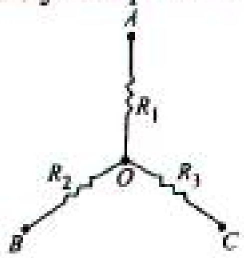


(a) $\frac{45}{23}$ V (b) 6.6 V (c) 3.3 V (d) 9.9 V

53. A potentiometer wire of length 100 cm has a resistance of 10 Ω. It is connected in series with a resistance and a cell of emf 2 V and of negligible internal resistance. A source of emf 10 mV is balanced against a length of 40 cm of the potentiometer wire. What is the value of external resistance ?

(a) 790 Ω (b) 890 Ω (c) 990 Ω (d) 1090 Ω

54. A circuit has a section ABC as shown in figure. If the potentials at points A, B and C are V_1, V_2 and V_3 respectively. The potential at point O is



(a) $V_1 + V_2 + V_3$

(b) $\left[\frac{V_1}{R_1}+\frac{V_2}{R_2}+\frac{V_3}{R_3}\right]\left[\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}\right]^{-1}$

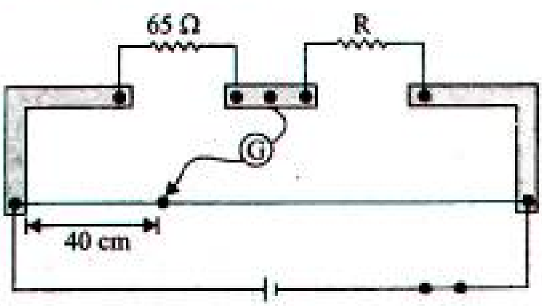
(c) Zero

(d) $\left[\frac{V_1}{R_1}+\frac{V_2}{R_2}+\frac{V_3}{R_3}\right](R_1+R_2+R_3)$

55. Figure shows currents in a part of an electric circuit, then current I is

(a) 1.7 A (b) 3.7 A (c) 1.3 A (d) 1 A

56. What is the value of unknown resistance R, if galvanometer shows null deflection in the given meter bridge set up ?



(a) 97.50 Ω (b) 105 Ω

(c) 150 Ω (d) 110 Ω

57. Which of the following is the correct Kirchhoff's loop rule?

(a) The algebraic sum of the currents meeting at a junction is zero.
(b) The algebraic sum of potential drops across all resistors in a circuit is zero.
(c) The algebraic sum of the currents across all the resistors in a circuit is zero.
(d) The algebraic sum of potential drops across all resistors plus those across sources in a circuit is zero.

58. Copper and Germanium are cooled from room temperature to 100 K. Then the resistance of

(a) Germanium decreases, Copper increases
(b) Germanium decreases, Copper decreases
(c) Germanium increases, Copper decreases
(d) Germanium increases, Copper increases.

59. Which statement is true ?

(i) Kirchhoff's law is not equally applicable to both AC and DC.
(ii) Semiconductors have a positive temperature coefficient of resistance.
(iii) Meter bridge is least sensitive when the resistance of all the four arms of the bridge are of the same order.
(iv) The emf of a cell depends upon the size and area of electrodes.

(a) (i) and (iv) (b) (ii) and (iv)
(c) (iii) and (iv) (d) None of these

60. When a metal conductor connected to left gap of a meter bridge is heated, the balancing point

(a) shifts towards right (b) shifts towards left
(c) remains unchanged (d) remains at zero

Case Based MCQs

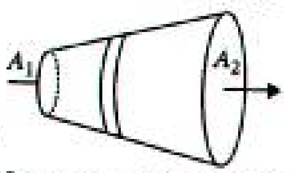
Case I : Read the passage given below and answer the following questions from 61 to 65.

Electric Current and Current Density

The flow of charge in a particular direction constitutes the electric current. Current is measured in ampere. Quantitatively, electric current in a conductor across an area held perpendicular to the direction of flow of charge is defined as the amount of charge is flowing across that area per unit time.

Current density at a point in a conductor is the ratio of the current at that point in the conductor to the area of cross section of the conductor of that point.

The given figure shows a steady current flows in a metallic conductor of non uniform cross section. Current density depends inversely on area, so, here $J_1 > J_2$, as $A_1 < A_2$.



61. What is the current flowing through a conductor, if one million electrons are crossing in one millisecond through a cross-section of it ?

(a) 2.5×10^{-10} A (b) 1.6×10^{-10} A
(c) 7.5×10^{-9} A (d) 8.2×10^{-11} A

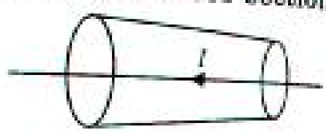
62. SI unit of electric current is

(a) C s (b) N s^{-2} (c) C s^{-1} (d) $C^{-1} s^{-1}$

63. A steady current flows in a metallic conductor of non-uniform cross-section. Which of these quantities is constant along the conductor?

(a) Electric field (b) Drift velocity
(c) Current (d) Current density

64. A constant current I is flowing along the length of a conductor of variable cross-section as shown in the figure. The quantity which does not depend upon the area of cross-section is



(a) electron density (b) current density
(c) drift velocity (d) electric field

65. When a current of 40 A flows through a conductor of area 10 m^2, then the current density is

(a) 4 A/m^2 (b) 1 A/m^2
(c) 2 A/m^2 (d) 8 A/m^2

Case II : Read the passage given below and answer the following questions from 66 to 70.

Temperature Dependence of Resistivity

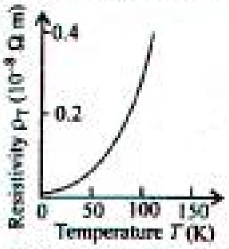
The resistance of a conductor at temperature $t°$ C is given by $R_t = R_0(1 + \alpha t)$ where R_t is the resistance at t °C, R_0 is the resistance at 0°C and α is the characteristics constants of the material of the conductor.

Over a limited range of temperatures, that is not too large. The resistivity of a metallic conductor is approximately given by $\rho_t = \rho_0(1 + \alpha t)$.

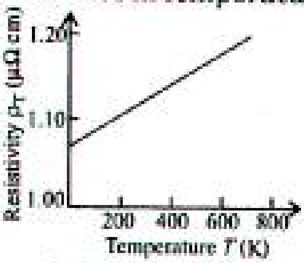
where α is the temperature coefficient of resistivity. Its unit is K^{-1} or C^{-1}.

For metals, α is positive *i.e.*, resistance increases with rise in temperature.

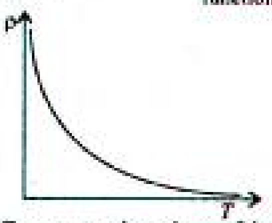
For insulators and semiconductors, α is negative *i.e.*, resistance decreases with rise in temperature.



Resistivity ρ_T of copper as a function of temperature T



Resistivity ρ_T of nichrome as a function of temperature T



Temperature dependence of the resistivity of a typical semiconductor

66. Fractional increase in resistivity per unit increase in temperature is defined as

(a) resistivity

(b) temperature coefficient of resistivity

(c) conductivity

(d) drift velocity

67. The material whose resistivity is insensitive to temperature is

(a) silicon (b) copper

(c) silver (d) nichrome

68. The temperature coefficient of the resistance of a wire is 0.00125 per C. At 300 K its resistance is 1 ohm. The resistance of wire will be 2 ohms at

(a) 1154 K (b) 1100 K

(c) 1400 K (d) 1127 K

69. The temperature coefficient of resistance of an alloy used for making resistors is

(a) small and positive (b) small and negative

(c) large and positive (d) large and negative

70. For a metallic wire, the ratio V/I (V = applied potential difference and I = current flowing) is

(a) independent of temperature

(b) increases as the temperature rises

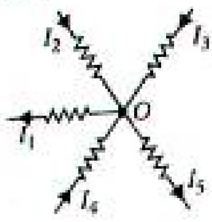
(c) decreases as the temperature rises

(d) increases or decreases as temperature rises depending upon the metal

Case III : Read the passage given below and answer the following questions from 71 to 75.

Kirchhoff's Rules

In 1942, a German physicist Kirchhoff extended Ohm's law to complicated circuits and gave two laws, which enable us to determine current in any part of such a circuit.



According to Kirchhoff's first rule, the algebraic sum of the currents meeting at a junction in a closed electric circuit is zero. The current flowing in a conductor towards the junction is taken as positive and the current flowing away from the junction is taken as negative. According to Kirchhoff's second rule, in a closed loop, the algebraic sum of the emf's and algebraic sum of the products of current and resistance in the various arms of the loop is zero. While traversing a loop, if negative pole of the cell is encountered first, then its emf is negative, otherwise positive.

71. Kirchhoff's Ist law follows

(a) law of conservation of energy

(b) law of conservation of charge

(c) law of conservation of momentum

(d) Newton's third law of motion.

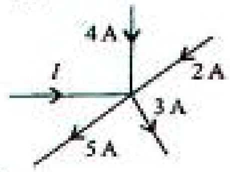
72. The value of current I in the given circuit is

(a) 4.5 A

(b) 3.7 A

(c) 2.0 A

(d) 2.5 A



73. Kirchhoff's IInd law is based on

(a) law of conservation of momentum of electron

(b) law of conservation of charge and energy

(c) law of conservation of energy

(d) none of these.

74. Point out the right statements about the validity of Kirchhoff's Junction rule.

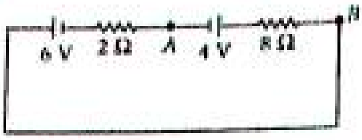
(a) The current flowing towards the junction are taken as positive.

(b) The currents flowing away from the junction are taken as negative.

(c) bending or reorienting the wire does not change the validity of Kirchhoff's Junction rule.

(d) All of the above

75. Potential difference between A and B in the circuit shown here is

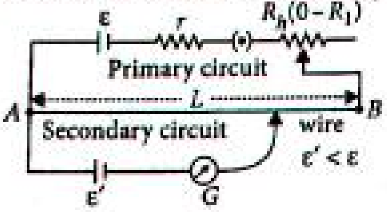


(a) 4 V
(b) 5.6 V
(c) 2.8 V
(d) 6 V

Case IV : Read the passage given below and answer the following questions from 76 to 80.

Potentiometer : An Ideal Voltmeter

Potentiometer is an apparatus used for measuring the emf of a cell or potential difference between two points in an electrical circuit accurately. It is also used to determine the internal resistance of a primary cell. The potentiometer is based on the principle that, if V is the potential difference across any portion of the wire of length l and resistance R, then $V \propto l$ or $V = kl$ where k is the potential gradient. Thus, potential difference across any portion of potentiometer wire is directly proportional to length of the wire of that portion. The



potentiometer wire must be uniform. The resistance of potentiometer wire should be high.

76. Which one of the following is true about potentiometer?
(a) Its sensitivity is low.
(b) It measures the emf of a cell very accurately.
(c) It is based on deflection method.
(d) None of the above.

77. A current of 1.0 mA is flowing through a potentiometer wire of length 4 cm and of resistance 4 Ω. The potential gradient of the potentiometer wire is
(a) 10^{-3} V m^{-1} (b) 10^{-5} V m^{-2}
(c) 2×10^{-3} V m^{-1} (d) 4×10^{-3} V m^{-1}

78. Sensitivity of a potentiometer can be increased by
(a) decreasing potential gradient along the wire
(b) increasing potential gradient along the wire
(c) decreasing current through the wire
(d) increasing current through the wire

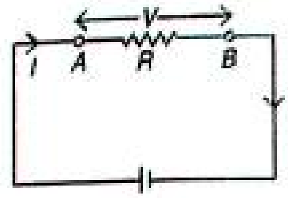
79. A potentiometer is an accurate and versatile device to make electrical measurements of EMF because the method involves
(a) potential gradients
(b) a condition of no current flow through the galvanometer
(c) a combination of cells, galvanometer and resistances
(d) cells.

80. In a potentiometer experiment, the balancing length is 8 m, when the two cells E_1 and E_2 are joined in series. When the two cells are connected in opposition the balancing length is 4 m. The ratio of the e. m. f. of two cells (E_1/E_2) is
(a) 1 : 2 (b) 2 : 1
(c) 1 : 3 (d) 3 : 1

Case V : Read the passage given below and answer the following questions from 81 to 85.

Heat produced by Electric Current

Whenever an electric current is passed through a conductor, it becomes hot after some time. The phenomenon of the production of heat in a resistor by the flow of an electric current through it is called heating effect of current or Joule heating. Thus, the electrical energy supplied by the source of



emf is converted into heat. In purely resistive circuit, the energy expended by the source entirely appears as heat. But if the circuit has an active element like a motor, then a part of the energy supplied by the source goes to do useful work and the rest appears as heat. Joule's law of heating form the basis of various electrical appliances such as electric bulb, electric furnace, electric press etc.

81. Which of the following is a correct statement?
(a) Heat produced in a conductor is independent of the current flowing.
(b) Heat produced in a conductor varies inversely as the current flowing.
(c) Heat produced in a conductor varies directly as the square of the current flowing.
(d) Heat produced in a conductor varies inversely as the square of the current flowing.

82. If the coil of a heater is cut to half, what would happen to heat produced ?
(a) Doubled. (b) Halved.
(c) Remains same. (d) Becomes four times.

83. A 25 W and 100 W are joined in series and connected to the mains. Which bulbs will glow brighter ?

(a) 100 W (b) 25 W
(c) both bulbs will glow brighter
(d) none will glow brighter.

84. A rigid container with thermally insulated wall contains a coil of resistance 100 Ω, carrying current 1 A. Change in its internal energy after 5 min will be
(a) 0 kJ (b) 10 kJ
(c) 20 kJ (d) 30 kJ

85. The heat emitted by a bulb of 100 W in 1 min is
(a) 100 J (b) 1000 J (c) 600 J (d) 6000 J

Assertion & Reasoning Based MCQs

For question numbers 86-100, two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.

(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is NOT the correct explanation of A
(c) A is true but R is false
(d) A is false and R is also false

86. Assertion (A) : The drift velocity of electrons in a metallic wire will decrease, if the temperature of the wire is increased.
Reason (R) : On increasing temperature, conductance of metallic wire decreases.

87. Assertion (A) : The current flowing through a conductor is directly proportional to the drift velocity.
Reason (R) : As the drift velocity increases the current following through the conductor decreases.

88. Assertion (A) : Chemical reactions involved in primary cells are irreversible and in secondary cells are reversible.
Reason (R) : Primary cells can be recharged, but secondary cells can not be recharged.

89. Assertion (A) : The average thermal velocity of the electrons in a conductor is zero.
Reason (R) : Direction of motion of electrons are randomly oriented.

90. Assertion (A) : If the length of the conductor is doubled, the drift velocity will become half of the original value (keeping potential difference unchanged).
Reason (R) : At constant potential difference, drift velocity is inversely proportional to the length of the conductor.

91. Assertion (A) : The temperature coefficient of resistance is always positive only for metals.
Reason (R) : On increasing the temperature, the resistance of metals and alloys increases.

92. Assertion (A) : Material used in the construction of a standard resistance is constantan or manganin.
Reason (R) : Temperature coefficient of constantan is very small.

93. Assertion (A) : kWh is a commercial unit used for expressing consumed electric energy.
Reason (R) : Kilo-watt hour is the unit of electric power.

94. Assertion (A) : The 200 W bulbs glows with more brightness than 100 W bulbs.
Reason (R) : A 100 watt bulb has more resistance than a 200 W bulb.

95. Assertion (A) : Heater wire must have high resistance and high melting point.
Reason (R) : If resistance is high, the electric conductivity will be less.

96. Assertion (A) : Fuse wire must have high resistance and low melting point.
Reason (R) : Fuse is used for small current flow only.

97. Assertion (A) : A person touching a high power line gets stuck with the line.
Reason (R) : The current carrying wire attracts the man towards it.

98. Assertion (A) : Though the same current flows through the live wires and the filament of the bulb but heat produced in the filament is much higher than that in live wires.
Reason (R) : The filament of bulbs is made of a material of high resistance and high melting point.

99. Assertion (A) : The current in a wire is due to flow of free electrons in a definite direction.
Reason (R) : A current carrying wire should have non-zero charge.

100. Assertion (A) : Current is a scalar quantity.
Reason (R) : Electric current arises due to continuous flow of charged particles or ions.

W.

ANSWERS

1. **(b)** : The direction of flow of current through in electric circuit is from high potential to low potential.

2. **(c)**

3. **(b)** : The deflection in galvanometer will not be changed due to interchange of battery and the galvanometer.

4. **(a)** :Current in conductor $I = neAv_d$

$\Rightarrow I \propto v_d$

Hence current in a conductor is determined by drift velocity and does not depend upon thermal velocity.

5. **(d)** : To shift the balance point on higher length, the potential gradient of the wire is to be decreased. The same can be obtained by decreasing the current of the main circuit, which is possible by increasing the resistance in series of potentiometer wire.

6. **(b)** : Here, $R_0 = 5\ \Omega$, $R_{100} = 5.25\ \Omega$

$R_t = 5.5\ \Omega$

As $R_t = R_0(1 + \alpha t)$ $\therefore$ $R_{100} = R_0(1 + \alpha 100)$

$$\alpha = \frac{R_{100} - R_0}{R_0 \times 100} \quad \text{...(i)}$$

Let the temperature of hot bath be t°C

$R_t = R_0(1 + \alpha t)$

$$\alpha = \frac{R_t - R_0}{R_0 \times t} \quad \text{...(ii)}$$

From equations (i) and (ii), we get

$$\frac{R_{100} - R_0}{R_0 \times 100} = \frac{R_t - R_0}{R_0 \times t}$$

$$t = \frac{R_t - R_0}{R_{100} - R_0} \times 100 = \frac{5.5 - 5}{5.25 - 5} \times 100$$

$$= \frac{0.5}{0.25} \times 100 = 200°\text{C}$$

7. **(a)** : Ohm's law $V = IR$ is an equation of straight line. Hence I - V characteristics for ohmic conductors is also a straight line and its slope gives resistance of the conductor.

8. **(b)** : In parallel combination of cells the voltage across the terminals is same and resistance is minimum. Therefore from $V = IR$. The current drawn from cell combination will be more.

9. **(a)** : In the parallel combination,

$$\frac{\varepsilon_{eq}}{r_{eq}} = \frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{r_2} + ... + \frac{\varepsilon_n}{r_n}$$

$$\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2} + ... + \frac{1}{r_n}$$

$$\left(\begin{array}{l}\because \quad \varepsilon_1 = \varepsilon_2 = \varepsilon_3 = ... = \varepsilon_n = \varepsilon \\ \text{and} \quad r_1 = r_2 = r_3 = ... r_n = r\end{array}\right)$$

$$\therefore \quad \frac{\varepsilon_{eq}}{r_{eq}} = \frac{\varepsilon}{r} + \frac{\varepsilon}{r} + ... + \frac{\varepsilon}{r} = n\frac{\varepsilon}{r} \quad \text{...(i)}$$

$$\frac{1}{r_{eq}} = \frac{1}{r} + \frac{1}{r} + ... + \frac{1}{r} = \frac{n}{r}$$

$$r_{eq} = r/n \quad \text{...(ii)}$$

From (i) and (ii),

$$\varepsilon_{eq} = n\frac{\varepsilon}{r} \times r_{eq} = n \times \frac{\varepsilon}{r} \times \frac{r}{n} = \varepsilon$$

10. **(d)** : Since due to wrong connection of each cell the total emf reduced to 2ε then for wrong connection of three cells the total emf will reduced to $(n\varepsilon - 6\varepsilon)$ whereas the total or equivalent resistance of cell combination will be nr.

11. **(a)** : $Q = It$

also $Q = ne$ $\quad [e = 1.6 \times 10^{-19}\ \text{C}]$

$\therefore \quad ne = It$

or $$n = \frac{It}{e} = \frac{1\ A \times 1\ s}{1.6 \times 10^{-19}} = 6.25 \times 10^{18} \text{ electrons/sec}$$

12. **(b)** : Current, $I = \frac{dQ}{dt}$

$dQ = Idt$

$dQ = (2t^2 - 3t + 1)\ dt$

$$\int dQ = \int_{t=3}^{t=5} (2t^2 - 3t + 1)dt$$

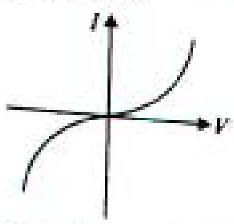
$$Q = \left[\frac{2t^3}{3} - \frac{3t^2}{2} + t\right]_3^5$$

$$= \left[\frac{2}{3}(5^3 - 3^3) - \frac{3}{2}(5^2 - 3^2) + (5 - 3)\right]$$

$$= \left[\frac{2}{3}(125 - 27) - \frac{3}{2}(25 - 9) + 2\right] = 43.34\ \text{C}$$

13. **(b)** : The direction of current density is the direction of flow of positive change in the circuit which is possible due to electric field produced by charges accumulated on the surface of wire.

14. **(a)** : The figure is showing I-V characteristics of non-ohmic or non linear conductors.



15. **(d)** : The electrical resistance of a conductor is depend upon all factors size, temperature and geometry of conductor.

16. (a) : Here, $\varepsilon = 24$ V and $r = 0.8\ \Omega$
For the maximum current from the battery.

$$\varepsilon = Ir \qquad (\because\ R = 0)$$

$$\therefore\quad I = \frac{\varepsilon}{r} = \frac{24}{0.8} = 30\text{ A}$$

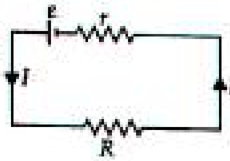
17. (c) : Here, $\varepsilon = 12$ V, $r = 3\ \Omega$ and $I = 1$ A

$$V = IR = \varepsilon - Ir$$

$$\therefore\quad R = \frac{\varepsilon - Ir}{I} = \frac{12 - 1\times 3}{1} = 12 - 3 = 9\ \Omega$$

and $V = IR = 1 \times 9 = 9$ V

18. (b) :



Current in the circuit,

$$I = \frac{\varepsilon}{R + r}$$

Potential difference across R,

$$V = IR = \left(\frac{\varepsilon}{R + r}\right)R$$

$$V = \frac{\varepsilon}{1 + \frac{r}{R}}$$

When $R = 0$, $V = 0$

$R = \infty$, $V = \varepsilon$

19 (d) : Resistance of a wire of length l and radius r is given by

$$R = \frac{\rho l}{A} = \frac{\rho l}{A} \times \frac{A}{A} = \frac{\rho V}{A^2} = \frac{\rho V}{\pi^2 r^4} \qquad (\because V = Al)$$

i.e., $R \propto \frac{1}{r^4}$; $\therefore\ \frac{R_1}{R_2} = \left(\frac{r_2}{r_1}\right)^4$

Here, $R_1 = 100\ \Omega$, $r_1 = r$, $r_2 = \frac{r}{2}$, $R_2 = ?$

$$\therefore\quad R_2 = R_1\left(\frac{r_1}{r_2}\right)^4 = 16R_1 = 1600\ \Omega$$

20. (c) : The typical range of resistivity for metals is $10^{-8}\ \Omega$ m to $10^{-6}\ \Omega$ m.

21. (a) : For a good conductor the graph between voltage and current does not obey exactly ohm's law, it shows some deviation from straight line.

22. (b) : Mobility of charged particle

$$\mu = \frac{|v_d|}{E} = \frac{7.5 \times 10^{-4}}{4 \times 10^{-12}}$$

$$= 2.5 \times 10^{6}\ \text{m}^2\ \text{V}^{-1}\ \text{s}^{-1}$$

23. (c) : Resistance of a wire, $R = \rho\frac{l}{A} = 10\ \Omega$

where l is the length and A be area of cross-section of wire.

New length, $l' = l + \frac{25}{100}l = \frac{5}{4}l$

As the volume of wire remains unchanged on increasing length, hence, $A'l' = Al$

$$A' = A\left(\frac{l}{l'}\right) = \frac{4}{5}A$$

New resistance, $R' = \rho\frac{l'}{A'} = \dfrac{\rho\left(\frac{5}{4}l\right)}{\left(\frac{4}{5}A\right)} = \frac{25}{16}\rho\frac{l}{A}$

$$= \frac{25}{16} \times 10 = 15.6\ \Omega$$

24. (c) : Here, $R_1 = 2.5\ \Omega$, $T_1 = 28$ °C

$R_2 = 2.9\ \Omega$ and $T_2 = 100$ °C

As $R_2 = R_1[1 + \alpha(T_2 - T_1)]$

$\therefore\quad 2.9 = 2.5\,[1 + \alpha(100 - 28)]$

$$\frac{2.9}{2.5} - 1 = \alpha[72]$$

or $\quad \alpha = \frac{1}{72} \times \frac{2.9 - 2.5}{2.5}$

$$= \frac{1}{72} \times \frac{0.4}{2.5} = 2.22 \times 10^{-3}\ °\text{C}^{-1}$$

25. (d) : Equation of the line,

$R = R_0 + m\,(T - T_0)$ ...(i)

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

Comparing eqns. (i) and (ii), we get

$$R_0\,\alpha = m \quad \therefore\ \alpha = \frac{m}{R_0}$$

26. (c)

27. (b) : For balanced Wheatstone's bridge

$$\frac{P}{Q} = \frac{R}{S} \qquad \text{...(i)}$$

Power dissipation in resistance R with voltage V is V^2/R.

$$\therefore\quad \frac{P_{P+Q}}{P_{R+S}} = \frac{R+S}{P+Q} \qquad \text{...(ii)}$$

From equation (i)

$$\frac{P}{Q} + 1 = \frac{R}{S} + 1$$

$$\frac{P+Q}{Q} = \frac{R+S}{S} \text{ or } \frac{R+S}{P+Q} = \frac{S}{Q}$$

Using (i), we get

$$\frac{R+S}{P+Q} = \frac{R}{P} \quad \therefore\quad \frac{P_{P+Q}}{P_{R+S}} = \frac{R}{P}$$

28. (c) : The bridge will be balanced when the shunted resistance is of the value of 3 Ω

$$\therefore\quad 3 = \frac{4 \times R}{4 + R}$$

$12 + 3R = 4R \quad \therefore\quad R = 12$

29. (a) : Let I be the current flowing through PQR then the current flowing through PSR is $(2 - I)$ A.

Now since, galvanometer shows no deflection then the voltage through arm PQR is same as the voltage through arm PSR

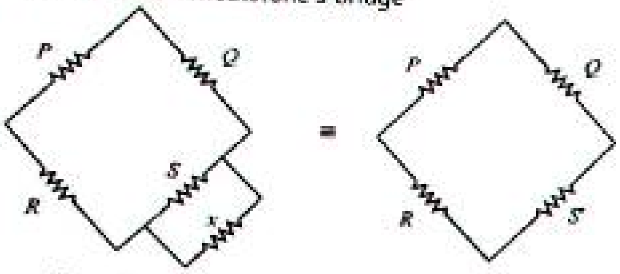
$$I \cdot (4 + 2) = (2 - I)(10 + 5)$$
$$6I = 30 - 15I$$
$$21I = 30$$
$$I = \frac{30}{21} = \frac{10}{7}\text{ A}$$

Hence the current through 2 Ω resistor is $\frac{10}{7}$ A

30. (c) : The graph (a) is true for conductors whose resistivity increases with temperature. But for semiconductors, resistivity decreases as the number of conducting electrons increase with rise of temperature.

31. (d) : Let x be the resistance shunted with S for the bridge to be balanced.

For a balance Wheatstone's bridge



$$\frac{P}{Q} = \frac{R}{S'} \quad \text{or} \quad \frac{2}{2} = \frac{2}{S'} \quad \text{or} \quad S' = 2\,\Omega$$

From figure, $\frac{1}{S'} = \frac{1}{S} + \frac{1}{x}$ or $\frac{1}{2} = \frac{1}{3} + \frac{1}{x}$

or $\frac{1}{x} = \frac{1}{2} - \frac{1}{3} = \frac{1}{6}$ or $x = 6\,\Omega$

32. (a) : Here, in the balance condition of potentiometer

$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{l_1}{l_2}$$

$\varepsilon_1 = 1.5$ V, $l_1 = 32$ cm, $l_2 = 65$ cm

$$\therefore \quad \varepsilon_2 = \varepsilon_1 \times \frac{l_2}{l_1}$$
$$= 1.5 \times \frac{65}{32} = 3.05\text{ V}$$

33. (d) : Here, $l_1 = 220$ cm , $l_2 = 130$ cm

$R = 3\,\Omega$

$$\therefore \quad \text{Internal resistance, } r = \left(\frac{l_1 - l_2}{l_2}\right)R$$
$$= \left(\frac{220 - 130}{130}\right) \times 3 = 2.08\,\Omega$$

34. (a) : *In conductors due to increase in temperature the resistivity increases and in semiconductors it decreases exponentially.*

35. (b) : Semiconductors having negative temperature coefficient of resistivity whereas metals are having positive temperature coefficient of resistivity with increase in temperature the resistivity of metal increases whereas resistivity of semiconductor decreases.

36. (d) : Given, $\varepsilon = 15$ V, $r = 4\,\Omega$, $I = 2$ A

Now, for resistance of the resistors

$$\varepsilon - Ir = V = IR$$
$$15 - 2 \times 4 = 2 \times R$$
$$15 - 8 = 2R$$
$$R = \frac{7}{2} = 3.5\,\Omega.$$

Terminal voltage of battery

$$V = IR = 2 \times 3.5 = 7\text{ V}$$

37. (d)

38. (d) : Here, $R_0 = 99\,\Omega$, $T_0 = 27°\text{C}$

$R_T = 116\,\Omega$

$\alpha = 1.7 \times 10^{-4}\ °\text{C}^{-1}$

$$\therefore \quad R_T = R_0\,[(1 + \alpha(T - T_0)]$$
$$\therefore \quad \frac{R_T}{R_0} - 1 = \alpha(T - T_0)$$
$$\Rightarrow \quad \frac{116}{99} - 1 = \alpha(T - T_0)$$
$$T - T_0 = \frac{1}{\alpha}\left[\frac{116 - 99}{99}\right] = \frac{17}{99\,\alpha} = \frac{1}{1.7 \times 10^{-4}} \times \frac{17}{99}$$
$$\therefore \quad T - T_0 = \frac{10^5}{99} = 1010.10\,°\text{C}$$
$$\Rightarrow \quad T = 1010.1 + T_0 = 1010.1 + 27 = 1037.1\ °\text{C}$$

39. (c) : Internal resistance of cell

$$r = R\left(\frac{l_1}{l_2} - 1\right)$$

$R = 10.2\,\Omega$, $l_1 = 75.8$ cm

$l_2 = 68.3$ cm

$$\therefore \quad r = 10.2\left(\frac{75.8}{68.3} - 1\right) = 1.12\,\Omega$$

40. (a) : Due to increase in resistance R the current through the wire will decrease and hence the potential gradient also decreases, which results in increase in balancing length. So J will shift towards B.

41. (b) : Here, $\frac{R}{S} = \frac{3}{2}$, $S = 10\,\Omega$

$$\therefore \quad R = \frac{3}{2} \times S = \frac{3}{2} \times 10 = 15\,\Omega$$

As the length of wire is 1 m.

$\therefore$ length of one ohm wire = 1/15 = 0.067 m

42. (d) : In series, the current through the external resistance R is

$$I=\frac{nE}{nr+R}=\frac{5E}{5r+R} \quad \text{...(i)}$$

In parallel, the current through the external resistance R is

$$I'=\frac{E}{\frac{r}{n}+R}=\frac{nE}{r+nR}=\frac{5E}{r+5R} \quad \text{...(ii)}$$

As per question, $I = I'$

$$\therefore \frac{5E}{5r+R}=\frac{5E}{r+5R} \text{ or } 5r+R=r+5R$$

or $R=r$ or $\frac{R}{r}=1$

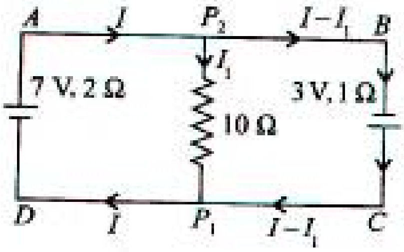
43. (c) : Using kirchhoffs law in loop $A\,P_2\,P_1\,DA$

$\therefore\ 10I_1+2I-7=0$

$10I_1+2I=7 \quad \text{... (i)}$

Using kirchhoff's law in loop $P_2P_1CBP_2$

$-3+1(I-I_1)-10\,I_1=0$



$I-11I_1=3$

$I=3+11\,I_1 \quad \text{...(ii)}$

From (i) and (ii),

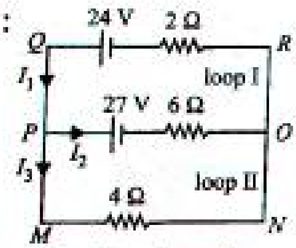
$10\,I_1+2\,(3+11\,I_2)=7$

$10\,I_1+6+22\,I_1=7 \quad \therefore\ 32\,I_1=1$

$I_1=1/32=0.031\text{ A}$

44. (d)

45. (a) :



Applying Kirchhoff's voltage law

In loop I $-27-6I_2-2I_1+24=0$

$6I_2+2I_1=-3 \quad \text{...(i)}$

In loop II $-27-6I_2+4I_3=0$

$6I_2-4I_3=-27 \quad \text{...(ii)}$

At junction P, $I_1-I_2-I_3=0 \quad \text{...(iii)}$

Solving equations (i), (ii) and (iii), we get

$I_1=3\text{ A},\ I_2=-3/2\text{ A},\ I_3=9/2\text{ A}.$

46. (b) : Let ε be emf and r be internal resistance of the battery.

In first case,

$12=\varepsilon-2r \quad \text{...(i)}$

In second case,

$15=\varepsilon+3r \quad \text{...(ii)}$

Substract (ii) from (i), we get

$$r=\frac{3}{5}\ \Omega$$

Putting this value of r in eqn. (i), we get

$$\varepsilon=12+\frac{2\times3}{5}=\frac{60+6}{5}=\frac{66}{5}=13.2\text{ V}$$

47. (a) : Applying Kirchhoff's first law at the junction P, we get

$6=I_1+I_2 \quad \text{... (i)}$

Applying Kirchhoff's second law to the closed loop $PQRP$, we get

$-2I_1-2I_1+2I_2=0$ or, $2I_1+2I_1-2I_2=0$

or, $4I_1-2I_2=0 \quad \text{... (ii)}$

Solve (i) and (ii), we get

$I_1=2\text{ A},\ I_2=4\text{ A}.$

48. (b) : Mobility of charged particle

$$\mu=\frac{|v_d|}{E}=\frac{7.5\times10^{-4}}{4\times10^{-12}}=1.8\times10^{8}\text{ m}^2\text{ V}^{-1}\text{ s}^{-1}$$

49. (b) : Since $R=\rho\frac{l}{a}$

$$\therefore\ dR=\rho\frac{dl}{4\pi l^2}.$$

(where l is any radius and dl is small element).

Total resistance,

$$R=\frac{\rho}{4\pi}\int_{r_1}^{r_2}\frac{dl}{l^2}=\frac{\rho}{4\pi}\left[-\frac{1}{l}\right]_{r_1}^{r_2}=\frac{\rho}{4\pi}\left[\frac{1}{r_1}-\frac{1}{r_2}\right].$$

$$R=\left[\frac{r_2-r_1}{r_1r_2}\right]\frac{\rho}{4\pi}.$$

50. (b) : The current in the potentiometer wire AB is

$$I=\frac{6}{20+10}=0.2\text{ A}$$

The potential difference across the potentiometer wire is

V = current × resistance = $0.2\times20=4$ V

The length of the wire is l = 200 cm. So, the potential gradient along the wire is

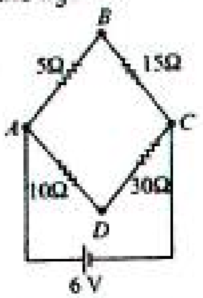
$$k=\frac{V}{l}=\frac{4}{200}=0.02\text{ V cm}^{-1}$$

The emf 2.4 V is balanced against a length L of the potentiometer wire.

i.e. $2.4=kL$

or $$L=\frac{2.4}{k}=\frac{2.4}{0.02}=120\text{ cm}$$

51. (a) : The given figure is a circuit of balanced Wheatstone bridge as shown in the figure.



Points B and D would be at the same potential,

i.e., $V_B - V_D = 0$ volt

52. (b) : Let I be the current is flowing through arm DAB, then the current flowing through DCB will be $(8 - I)$

Then, $I(5 + 6) = (8 - I)(4 + 2)$

$$11\,I = 8 \times 6 - 6\,I$$

$$17\,I = 48$$

$$\therefore \quad I = \frac{48}{17}\text{ A}$$

Voltage across 5 Ω resistance

$$V_D - V_A = I \times R = \frac{48}{17} \times 5 = \frac{240}{17}\text{ V} \qquad \text{...(i)}$$

Voltage across 4 Ω resistance

$$V_D - V_C = (8 - I) \times 4$$

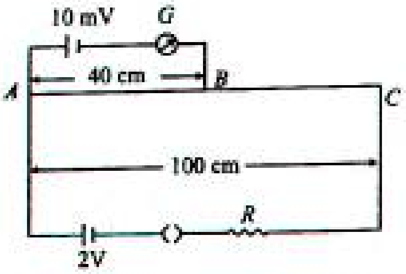
Subtracting (i) by (ii) we get,

$$V_D - V_A - (V_D - V_C) = \frac{240}{17} - \frac{352}{17} \qquad \text{...(ii)}$$

$$\Rightarrow \quad V_A - V_C = -6.6\text{ V}$$

53. (a) : The current in the potentiometer wire AC is

$$I = \frac{2}{10 + R}$$



The potential difference across the potentiometer wire is

V = current × resistance $= \dfrac{2}{10 + R} \times 10$

The length of the wire is $l = 100$ cm.

So, the potential gradient along the wire is

$$k = \frac{V}{l} = \left(\frac{2}{10 + R}\right) \times \frac{10}{100} \qquad \text{...(i)}$$

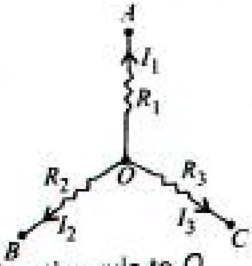
The source of emf 10 mV is balanced against a length of 40 cm of the potentiometer wire

i.e. $10 \times 10^{-3} = k \times 40$

or $10 \times 10^{-3} = \dfrac{2}{(10 + R)} \times \dfrac{40}{10}$ (Using (ii))

or $R = 790\ \Omega$.

54. (b) :



Applying junction rule to O

$$-I_1 - I_2 - I_3 = 0$$

i.e., $I_1 + I_2 + I_3 = 0$ ... (i)

Let, V_0 be the potential at point O. By Ohm's law for resistances R_1, R_2 and R_3 respectively, we get

$$(V_0 - V_1) = I_1 R_1;$$

$$(V_0 - V_2) = I_2 R_2 \quad \text{and} \quad (V_0 - V_3) = I_3 R_3$$

or $\quad I_1 = \dfrac{(V_0 - V_1)}{R_1}; \quad I_2 = \dfrac{(V_0 - V_2)}{R_2}; \quad I_3 = \dfrac{(V_0 - V_3)}{R_3}$

So substituting these values of I_1, I_2 and I_3 in eqn. (i), we get

$$V_0\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right] - \left[\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right] = 0$$

$$V_0 = \left[\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right]\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right]^{-1}$$

55. (a) : Applying Kirchhoff's first law,

$I = 2 + 2 - 1 - 1.3 = 1.7$ A

56. (a) : For null deflection in meter bridge

$$\frac{R_1}{R_2} = \frac{l}{(100 - l)}$$

$$\therefore \quad \frac{65}{R_1} = \frac{40}{100 - 40} = \frac{40}{60}$$

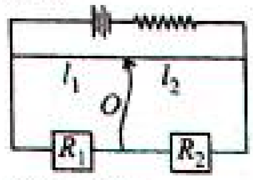
$$R_1 = 65 \times \frac{60}{40} = 97.5\ \Omega$$

57. (c) : Kirchhoff's loop rule : It states that the algebraic sum of potential drops across all resistors plus those across sources in a circuit is zero.

58. (c) : The temperature coefficient of copper is positive and of germanium is negative. Hence the resistance of copper decreases and germanium increases when they are cooled from room temperature to 100 K.

59. (a)

60. (a) : When metal wire is heated, its resistance increases R_1 increases, I_1 increases.



The null point shift to the right.

61. (b): $q = 10^6 \times 1.6 \times 10^{-19}\text{ C} = 1.6 \times 10^{-13}\text{ C}$

$t = 10^{-3}$ s

$$I = \frac{q}{t} = \frac{1.6 \times 10^{-13}}{10^{-3}} = 1.6 \times 10^{-10}\text{ A}$$

62. (c) : The unit of electric current is Cs^{-1}

63. (c) : The current flowing through a conductor of non-uniform cross-section remain same in the whole of the conductor.

64. (a) : When a constant current is flowing through a conductor of non-uniform cross-section, electron density does not depend upon the area of cross section, while current density, drift velocity and electric field all vary inversely with area of cross-section.

65. (a) : Given, $I = 40$ A ; $A = 10$ m^2

$\therefore$ Current density, $J = \frac{I}{A}$ or $J = \frac{40}{10} = 4$ A/m^2

66. (b) : Temperature coefficient of resistivity is defined as the fractional increase in resistivity per unit increase in temperature.

67. (d) : Nichrome (which is an alloy of nickel, iron and chromium) exhibits a very weak dependence of resistivity with temperature.

68. (d) : Using, $R_T = R_0(1 + \alpha T)$

$$\therefore \quad \frac{R_{T_2}}{R_{T_1}} = \frac{R_0(1+\alpha T_2)}{R_0(1+\alpha T_1)} = \frac{2}{1} = \frac{(1+\alpha T_2)}{(1+\alpha\times 300)}$$

$$\Rightarrow \quad 2 + \alpha \times 600 = 1 + \alpha\, T_2$$

$$\Rightarrow \quad 1 = \alpha\,(T_2 - 600) \Rightarrow \frac{1}{0.00125} = (T_2 - 600)$$

$$\Rightarrow \quad 800°\text{C} = T_2 - 600$$

$$T_2 = 800 - 273 + 600$$

$$T_2 = 1127 \text{ K}$$

69. (a) : The temperature coefficient of resistance of an alloy used for making resistors is small and positive.

70. (b) : The resistance of a metallic wire at temperature t°C is given by

$R_t = R_0\,(1 + \alpha t)$, where α is the temperature coefficient of resistance and R_0 is the resistance of a wire at 0°C.

For metals, α is positive. Hence, resistance of a wire increases with increase in temperature.

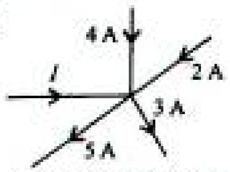
Also, from Ohm's law

$$\frac{V}{I} = R$$

Hence on increasing the temperature, the ratio $\frac{V}{I}$ increases.

71. (a) : Kirchhoff's I[st] law is based on law of conservation of charge whereas Kirchhoff's II[nd] law is based on law of conservation of energy.

72. (c) :



According to Kirchhoff's junction law

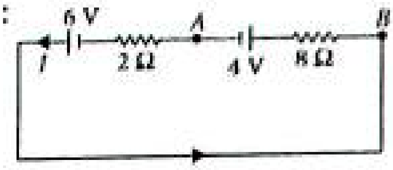
$(+ I) + (+ 4\text{ A}) + (+ 2\text{ A}) + (- 5\text{ A}) + (- 3\text{ A}) = 0$

$I + 6\text{ A} - 8\text{ A} = 0$ or $I = 2$ A

73. (c)

74. (d)

75 (b) :



Apply KVL in the given circuit,

$$6 - 8I - 4 - 2I = 0$$

or, $2 - 10I = 0$ or, $I = 2/10 = 0.2$ A

$$V_{AB} = 4 + I \times 8 = 4 + 0.2 \times 8 = 5.6 \text{ V}$$

76. (b)

77. (a) : Given, $I = 1.0$ mA $= 10^{-3}$ A; $R = 4\ \Omega$; $L = 4$ m

Potential drop across potentiometer wire,

$$V = IR = 10^{-3} \times 4 \text{ V}$$

Potential gradient, $k = \frac{V}{L} = \frac{4\times10^{-3}}{4} = 10^{-3}$ V m^{-1}

78. (a)

79. (b) : A potentiometer is an accurate and versatile device to make electrical measurements of EMF because the method involves a condition of no current flow through the galvanometer. It can be used to measure potential difference, internal resistance of a cell and compare EMF's of two sources.

80. (d) : $\frac{E_1}{E_2} = \frac{l_1 + l_2}{l_1 - l_2} = \frac{8+4}{8-4} = \frac{12}{4} = \frac{3}{1}$

81. (c) : According to Joule's law of heating,

Heat produced in a conductor, $H = I^2Rt$

where, I = Current flowing through the conductor

R = Resistance of the conductor

t = Time for which current flows through the conductor.

$\therefore \quad H \propto I^2$

82. (a) : If the coil is cut into half, its resistance is also halved.

As $H = \frac{V^2}{R}t \quad \therefore \quad H' = 2$

83. (b) : $P = \frac{V^2}{R}$ or $R = \frac{V^2}{P}$

The bulbs are joined in series. Current in both the bulbs will same.

$\therefore$ The heat produced in them is given by $H = I^2 Rt$

or $\quad H \propto R \Rightarrow H \propto \frac{1}{P}$

Therefore the bulb with low wattage or high resistance will glow brighter or we can say the 25 W bulb will glow brighter than the 100 W bulb.

84. (d) : $R = 100\ \Omega$; $I = 1\ A$; $t = 5$ min. $= 5 \times 60 = 300$ s
change in internal energy = heat generated in coil
$= I^2 Rt = ((1)^2 \times 100 \times 300)$ J
$= 30000$ J $= 30$ kJ

85. (d) : Here, $P = 100$ W, $t = 1$ min $= 60$ s
Heat developed in time t
$H = P \times t = (100\ W)(60\ s) = 6000$ J

86. (b) : On increasing temperature of wire the kinetic energy of free electrons increase and so they collide more rapidly with each other and hence their drift velocity decreases. Also when temperature increases, resistance increase and resistance is inversely proportional to conductivity of material.

87. (c) : Consider a conductor of length l and area of cross section A. Time taken by the free electrons to cross the conductor, $t = l/v_d$

Hence, current, $I = \frac{q}{t} = \frac{Al \times ne}{l / v_d}$
or, $I = Anev_d$
or, $I \propto v_d$
Thus current is directly proportional to drift velocity.

88. (c) : Primary cells cannot be recharged because they involve irreversible reactions. Secondary cells can be recharged because they involve reversible reactions.

89. (a) : In normal conductor, the direction of electrons are randomly oriented such that the total sum of their velocities is equal to zero.

90. (a) : Drift velocity of free electrons is given by,

$$v_d = \frac{eE}{m}\tau$$

where, $E = \frac{\text{Potential difference}}{\text{length}} = \frac{V}{l}$

$\therefore\quad v_d = \frac{eV}{ml}\tau$ i.e., $v_d \propto 1/l$ where, $\frac{eV\tau}{m}$ is constant.

It mean if l is doubled, the drift velocity will become half of the original value.

91. (b) : The value of temperature coefficient of resistance is positive only for metals and alloys and is negative for semiconductors and insulators.

92. (a) : These alloys (constantan or manganin) are used for making standard resistance because they possess high resistivity and low temperature coefficient of resistance.

93. (c) : 1 kWh = 1 kW × 1 hour
= 1000 (joule/sec) × 3600 sec $= 36 \times 10^5$ joule
i.e., kWh is the unit of electric energy and used for expressing consumed electric energy.

94. (b) : The resistance, $R = \frac{V^2}{P}$, *i.e.*, $R \propto 1/P$
i.e., higher is the wattage of a bulb, lesser is the resistance and so it will glow bright.

95. (b) : Heater wire must have high resistance and high melting point, because in series current remains same, therefore according to Joule's law $H = I^2Rt / 4.2$, heat produced is high if R is high. Melting point must be high, so that wire may not melt with increase in temperature.

96. (c) : Fuse wire must have high resistance because in series, current remains same. Therefore according to Joule's law $H = \frac{i^2Rt}{4.2}$, heat produced is high if R is high. The melting point must be low so that wire may melt with increase in temperature. As a current larger than the specified value flows through the circuit the temperature of the fuse wire increases. This melts the fuse wire and breaks the circuit.

97. (d) : Because there is no special attractive force that keeps a person stuck with a high power line. The actual reason is that a current of the order of 0.05 A or even less is enough to bring disorder in our nervous system. As a result of it, the affected person may lose temporarily his ability to control his nervous system to get himself free from the high power line.

98. (b) : As filament of bulb and live wire are in series, hence current through both is same. Now, because $H = \frac{i^2Rt}{4.2}$ and resistance of the filament of the bulb is much higher than that of live wires, hence heat produced in the filament is much higher than that in line wires.

99. (c) : The current in a wire is due to flow of free electrons in a definite direction. But the number of protons in the wire at any instant is equal to number of electrons and charge on electrons is equal and opposite to that of proton. Hence, net charge on the wire is zero.

100.(b) : Current is a scalar quantity, it is justified by the following two observations

(i) If current carrying wire is bent at some point, then also current in the wire remains same, while a vector quantity always changes by changing its direction.

(ii) Current flowing in the circuit do not follow the laws of vector addition. It follows according to ordinary rule of algebra. This makes it clear that current is not a vector but a scalar quantity. Also current is defined as rate of flow of charge through the wire $I = dq/dt$.

☺☺☺

Multiple Choice Questions (MCQs)

1. A cup contains 250 g of water. Find the number of positive charges present in the cup of water.

(a) 1.34×10^{19} C (b) 1.34×10^{7} C
(c) 2.43×10^{19} C (d) 2.43×10^{7} C

2. The number of electrons present in -1 C of charge is

(a) 6×10^{18} (b) 1.6×10^{19}
(c) 6×10^{19} (d) 1.6×10^{18}

3. Consider the charges q, q and $-q$ placed at the vertices of an equilateral triangle of each side l. The force on each charge is

(a) $F = \frac{q^2}{4\pi\varepsilon_0 l}$ (b) $F = \frac{q^2}{4\pi\varepsilon_0 l}$
(c) $F = \frac{q^2}{4\pi\varepsilon_0 l^2}$ (d) zero

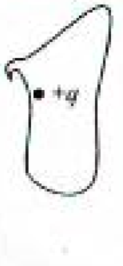
4. Which of the following statements is not true about electric field lines?

(a) Electric field lines start from positive charge and end at negative charge.
(b) Two electric field lines can never cross each other.
(c) Electrostatic field lines do not form any closed loops.
(d) Electric field lines cannot be taken as continuous curve.

5. The electric field at a point is

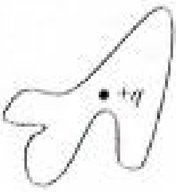
(a) always continuous
(b) continuous if there is no charge at that point
(c) discontinuous if there is a charge at that point
(d) both (b) and (c) are correct.

6. The electric flux through the surface

I. 

II. 

III. 

IV. 

(a) in figure (IV) is largest
(b) in figure (III) is the least
(c) in figure (II) is same as in figure (III) but is smaller than figure (IV)
(d) is the same for all figures.

7. Which of the following statements about dipole moment is not true?

(a) The dimensions of dipole moment is [LTA].
(b) The unit of dipole moment is cm.
(c) Dipole moment is vector quantity and directed from negative to positive charge.
(d) Dipole moment is a vector quantity has magnitude (charge) $q \times$ (separation between charge) a.

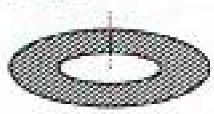
8. The SI unit of electric flux is

(a) N C^{-1} m^2 (b) N C m^{-2}
(c) N C^{-2} m^2 (d) N C^{-1} m^{-2}

9. The electrostatic force on a small sphere of charge 0.2 μC due to another small sphere of charge -0.4 μC in air is 0.4 N. The distance between the two spheres is

(a) 4.2×10^{-6} m (b) 4.2×10^{-3} m
(c) 1.8×10^{-3} m (d) 1.8×10^{-6} m

10. A thin disc of radius $b = 2a$ has a concentric hole of radius a in it (see figure). It carries uniform surface charge σ on it. If the electric field on its axis at height h ($h << a$) from its centre is given as Ch then value of C is



(a) $\frac{\sigma}{a\varepsilon_0}$ (b) $\frac{\sigma}{2a\varepsilon_0}$ (c) $\frac{\sigma}{4a\varepsilon_0}$ (d) $\frac{\sigma}{8a\varepsilon_0}$

11. The force between two small charged spheres having charges of 1×10^{-7} C and 2×10^{-7} C placed 20 cm apart in air is

CHAPTER 4

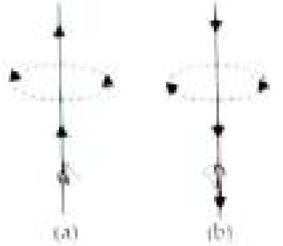
Moving Charges and Magnetism

Recap Notes

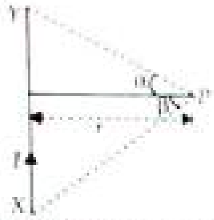
- **Magnetic field :** It is a region or space around a magnet or current carrying conductor or a moving charge, in which its magnetic effect can be felt.
  - ▸ Magnetic field is a vector quantity and its dimensional formula is $[ML^0T^{-2}A^{-1}]$. The SI unit of magnetic field is tesla (T) or weber/metre^2 (Wb/m^2). The CGS unit of magnetic field is gauss (G).
    1 tesla = 10^4 gauss
  - ▸ The sources of magnetic fields are :
    - A current carrying conductor
    - Changing electric field
    - Moving charged particle
    - Permanent magnet and electromagnet etc.
  - ▸ Conventionally the direction of the field perpendicular to the plane of the paper is represented by ⊗ if into the page, and by ⊙ if out of the page.
- **Force on a charged particle in a uniform magnetic field :**
  - ▸ When a charged particle of charge q, moving with velocity $\vec{v}$ is subjected to a uniform magnetic field $\vec{B}$, the force acting on it is
    $\vec{F} = q(\vec{v} \times \vec{B})$ or $F = qvB\sin\theta$
    where θ is the angle between $\vec{v}$ and $\vec{B}$.
    - The direction of this force is perpendicular to the plane containing $\vec{v}$ and $\vec{B}$.
    - $\vec{F} = 0$ if $\vec{v} = 0$, *i.e.*, a charge at rest does not experience any magnetic force.
    - $\vec{F} = 0$ if $\theta = 0^\circ$ or 180° *i.e.*, the magnetic force vanishes if $\vec{v}$ is either parallel or antiparallel to the direction of $\vec{B}$.
    - Force will be maximum if $\theta = 90^\circ$, *i.e.*, if $\vec{v}$ is perpendicular to $\vec{B}$, the magnetic force has a maximum value and is given by $F_{max} = qvB$.
- **Lorentz force :** When a charged particle of charge q moving with velocity $\vec{v}$ is subjected to an electric field $\vec{E}$ and magnetic field $\vec{B}$, the total force acting on the particle is
  $\vec{F} = \vec{F}_e + \vec{F}_m = q\vec{E} + q(\vec{v} \times \vec{B}) = q(\vec{E} + \vec{v} \times \vec{B})$
  This force is known as Lorentz force.
- **Biot-Savart law**
  According to this law, the magnetic field at a point P due to a current element of length $d\vec{l}$, carrying current I, at a distance r from the element is

  $$dB = \frac{\mu_0}{4\pi}\frac{Idl\sin\theta}{r^2} \quad ; \quad d\vec{B} = \frac{\mu_0}{4\pi}\frac{I(d\vec{l} \times \vec{r})}{r^3}$$
  where θ is the angle between $d\vec{l}$ and $\vec{r}$ and μ_0 is the permeability of free space.
  $\mu_0 = 4\pi \times 10^{-7}$ T m A^{-1} = $4\pi \times 10^{-7}$ Wb A^{-1} m^{-1}
  or $\frac{\mu_0}{4\pi} = 10^{-7}$ henry/m.
  - ▸ The dimensional formula of μ_0 is $[MLT^{-2}A^{-2}]$. The direction of $d\vec{B}$ is to that of $d\vec{l} \times \vec{r}$, which is perpendicular to the plane containing $d\vec{l}$ and $\vec{r}$, and is directed as given by right hand screw rule.
  - ▸ The direction of magnetic field due to a straight current carrying wire is given by right hand thumb rule. According to this rule, if you grasp the wire in your right hand with your exten[illegible] thumb pointing

in the direction of the current. Your fingers curling around the wire give the direction of the magnetic field lines.

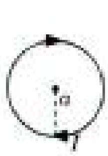


- **Magnetic field due to a straight current carrying wire**



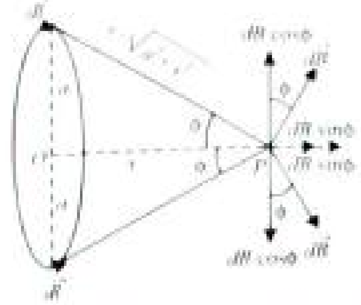
  - The magnetic field B at a point P due to a straight wire of finite length carrying current I at a perpendicular distance r is
    $B = \frac{\mu_0 I}{4\pi r}[\sin\alpha + \sin\beta]$
  - **Special cases :**
    - If the wire is of infinite length and the point P lies near the centre of the straight wire, then $\alpha = \beta = 90°$
      $\therefore\ B = \frac{\mu_0 2I}{4\pi r} = \frac{\mu_0 I}{2\pi r}$
    - If the wire is of infinite length and the point P lies near one end, then
      $\alpha = \frac{\pi}{2},\ \beta = 0° \quad \therefore \quad B = \frac{\mu_0 I}{4\pi r}$

- **Magnetic field at the centre of a current carrying circular loop**



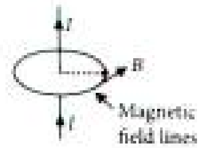
  The magnetic field at the centre of a circular coil of radius a carrying current I is
  $B = \frac{\mu_0}{4\pi}\frac{2\pi I}{a} = \frac{\mu_0 I}{2a}$
  If the circular loop consists of N turns, then
  $B = \frac{\mu_0}{4\pi}\frac{2\pi NI}{a} = \frac{\mu_0 NI}{2a}$
  The direction of magnetic field at the centre of a circular coil carrying current is given by right hand thumb rule.

- **Magnetic field at a point on the axis of a circular current carrying loop**



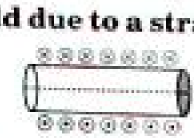
  The magnetic field at a point on the axis of the circular current carrying coil is
  $B = \frac{\mu_0}{4\pi}\frac{2\pi NIa^2}{(a^2+x^2)^{3/2}}$
  where a is the radius of coil, x is the distance of the point on the axis from the centre of the coil, N is the number of turns in the coil.
  - **Special cases :**
    - If the point lies at the centre of the coil, *i.e.*, $x = 0$, then
      $B = \frac{\mu_0}{4\pi}\frac{2\pi NIa^2}{(a^2)^{3/2}} = \frac{\mu_0}{4\pi}\cdot\frac{2\pi NI}{a} = \frac{\mu_0 NI}{2a}$
    - If $x >> a$, then
      $B = \frac{\mu_0}{4\pi}\frac{2\pi NIa^2}{x^3} = \frac{\mu_0}{4\pi}\frac{2NIA}{x^3} = \frac{\mu_0}{4\pi}\frac{2M}{x^3}$
      where, $NIA = M$ = magnetic dipole moment of current loop, A = cross sectional area of loop.

- **Ampere's circuital law :** The line integral of the magnetic field B around any closed loop is equal to μ_0 times the total current I threading through the loop, *i.e.*,



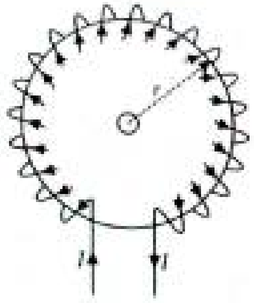
  $\oint \vec{B}\cdot d\vec{l} = \mu_0 I$
  - Magnitude of magnetic field due to a straight wire using Ampere's circuital law
    $B = \frac{\mu_0 I}{2\pi r}$

- **Magnetic field due to a straight solenoid**

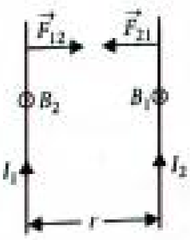


  - At any point inside the solenoid, $B = \mu_0 nI$
    where, n = number of turns per unit length.
  - At the ends of the solenoid, $B = \frac{1}{2}\mu_0 nI$

- **Magnetic field due to toroidal solenoid**

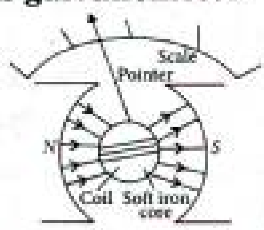


  - Inside the toroidal solenoid, $B = \mu_0 nI$, where $n = \dfrac{N}{2\pi r}$, N = total number of turns
  - In the open space, interior or exterior of toroidal solenoid, the magnetic field is zero.
- **Motion in a magnetic field :** When a charged particle of charge q and mass m moves with velocity $\vec{v}$ in a uniform magnetic field $\vec{B}$, the force acting on it is $F = qvB\sin\theta$.
- The following two cases arise :
  - **Case I :** When the charged particle is moving perpendicular to the field *i.e.*, $\theta = 90°$. In this case path is circular.
    Radius of circular path is
    $$R = \frac{mv}{Bq} = \frac{\sqrt{2mK}}{qB}$$
    and time period of revolution is
    $$T = \frac{2\pi R}{v} = \frac{2\pi m}{qB}$$
  - **Case II :** When the charged particle is moving at an angle θ to the field (other than 0°, 90° or 180°). In this case, path is helical.
    Due to component of v, perpendicular to $\vec{B}$, *i.e.*, $v_\perp = v\sin\theta$, the particle describes a circular path of radius R, such that
    $$\frac{mv_\perp^2}{R} = qv_\perp B \quad \text{or} \quad R = \frac{mv_\perp}{qB} = \frac{mv\sin\theta}{qB}$$
    Time period of revolution is
    $$T = \frac{2\pi R}{v\sin\theta} = \frac{2\pi m}{qB}$$
- **Force between two parallel current carrying conductors :** Two parallel conductors carrying currents in the same direction attract each other while those carrying currents in the opposite direction repel each other.



  - When two parallel conductors separated by a distance r carry currents I_1 and I_2, the magnetic field of one will exert a force on the other. The force per unit length on either conductor is $F = \dfrac{\mu_0}{4\pi}\dfrac{2I_1I_2}{r}$
  - The force of attraction or repulsion acting on each conductor of length l due to currents in two parallel conductors is
    $F = \dfrac{\mu_0}{4\pi}\dfrac{2I_1I_2}{r}l.$
  - When two charges q_1 and q_2 moving with velocities v_1 and v_2 respectively are at a distance r apart, then the force acting between them is
    $$F = \frac{\mu_0}{4\pi}\frac{q_1q_2\,v_1v_2}{r^2}$$
- **Torque on a current carrying coil placed in a uniform magnetic field :** When a current carrying coil is placed in a uniform magnetic field, the net force on it is always zero but different parts of the coil experience forces in different directions. Due to it, the coil may experience a torque or couple.

  When a coil of area A having N turns, carrying current I is placed in a uniform magnetic field B, it will experience torque which is given by
  $\tau = NIAB\sin\theta$
- **Moving coil galvanometer**



  It is an instrument used for the detection and measurement of small currents. It works on the principle that when a current carrying coil is placed in a magnetic field, it experiences a torque.

  In moving coil galvanometer the current I passing through the galvanometer is directly proportional to its deflection (θ).

  $$I \propto \theta \quad \text{or,} \quad I = G\theta$$

  where $G = \dfrac{k}{NAB}$ = galvanometer constant

  A = area of the coil, N = number of turns in the coil, B = strength of magnetic field,

k = torsional constant of the spring *i.e.*, restoring torque per unit twist.

- **Current sensitivity :** It is defined as the deflection produced in the galvanometer, when unit current flows through it.

$$I_s = \frac{\theta}{I} = \frac{NAB}{k}$$

The unit of current sensitivity is rad A^{-1} or div A^{-1}.

- **Voltage sensitivity :** It is defined as the deflection produced in the galvanometer when a unit voltage is applied across the two terminals of the galvanometer.

$$V_s = \frac{\theta}{V} = \frac{\theta}{IR} = \frac{NAB}{kR}$$

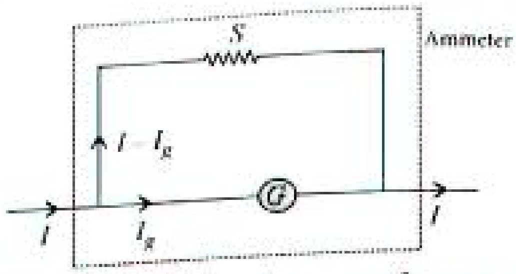
The unit of voltage sensitivity is rad V^{-1} or div V^{-1}.

$$V_s = \frac{1}{R} I_s$$

- **Conversion of galvanometer into an ammeter :** A galvanometer can be converted into an ammeter of given range by connecting a suitable low resistance S called shunt in parallel to the given galvanometer, whose value is given by

$$S = \left(\frac{I_g}{I - I_g}\right) G$$

where I_g is the current for full scale deflection of galvanometer, I is the current to be measured by the galvanometer and G is the resistance of galvanometer.

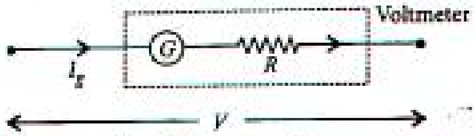


In order to increase the range of an ammeter n times, the value of shunt resistance to be connected in parallel is $S = G/(n-1)$.

- **Conversion of galvanometer into voltmeter :** A galvanometer can be converted into voltmeter of given range by connecting a suitable resistance R in series with the galvanometer, whose value is given by

$$R = \frac{V}{I_g} - G$$

where V is the voltage to be measured, I_g is the current for full scale deflection of galvanometer and G is the resistance of galvanometer.



Voltmeter is a high resistance instrument and it is always connected in parallel with the circuit element across which potential difference is to be measured. An ideal voltmeter has infinite resistance.

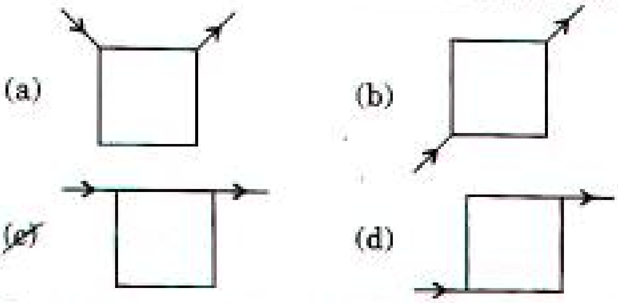
In order to increase the range of voltmeter n times the value of resistance to be connected in series with galvanometer is $R = (n-1)G$.

Practice Time

Multiple Choice Questions (MCQs)

1. When a magnetic compass needle is carried nearby to a straight wire carrying current, then
(I) the straight wire cause a noticeable deflection in the compass needle.
(II) the alignment of the needle is tangential to an imaginary circle with straight wire as its centre and has a plane perpendicular to the wire
(a) (I) is correct
(b) (II) is correct
(c) both (I) and (II) are correct
(d) neither (I) nor (II) is correct

2. Current flows through uniform, square frames as shown in the figure. In which case is the magnetic field at the centre of the frame not zero?



3. A galvanometer of resistance 10 Ω gives full-scale deflection when 1 mA current passes through it. The resistance required to convert it into a voltmeter of reading upto 2.5 V is
(a) 24.9 Ω (b) 249 Ω
(c) 2490 Ω (d) 24900 Ω

4. A 4 A current carrying loop consists of three identical quarter circles of radius 5 cm lying in the positive quadrants of the x-y, y-z and z-x planes with their centres at the origin joined together, value of $\vec{B}$ at the origin is
(a) $\frac{\mu_0}{10}(\hat{i}+\hat{j}-\hat{k})$ T (b) $\frac{\mu_0}{10}(-\hat{i}+\hat{j}+\hat{k})$ T
(c) $\frac{\mu_0}{5}(\hat{i}+\hat{j}+\hat{k})$ T (d) $10\mu_0(\hat{i}+\hat{j}+\hat{k})$ T

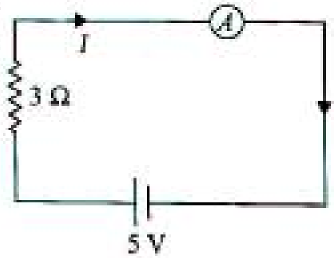
5. A voltmeter which can measure 2 V is constructed by using a galvanometer of resistance 12 Ω and that produces maximum deflection for the current of 2 mA, then the resistance R is

(a) 888 Ω
(b) 988 Ω
(c) 898 Ω
(d) 999 Ω

6. A long straight wire carrying current of 30 A rests on a table. Another wire AB of length 1 m, mass 3 gm carries the same current but in the opposite direction, the wire AB is free to slide up and down. The height upto which AB will rise is
(a) 0.6 cm (b) 0.7 cm
(c) 0.4 cm (d) 0.5 cm

7. Two moving coil metres M_1 and M_2 have the following particulars, $R_1 = 10\ \Omega$; $N_1 = 30$; $A_1 = 3.6 \times 10^{-3}\ \text{m}^2$; $B_1 = 0.25$ T; $R_2 = 14\ \Omega$; $N_2 = 42$; $A_2 = 1.8 \times 10^{-3}\ \text{m}^2$; $B_2 = 0.50$ T
The spring constants are identical for the two metres. What is the ratio of current sensitivity and voltage sensitivity of M_2 to M_1?
(a) 1.4 : 1 (b) 1.4 : 0
(c) 2.8 : 2 (d) 2.8 : 0

8. The value of current in the given circuit if the ammeter is a galvanometer with a resistance $R_G = 50\ \Omega$ is



(a) 0.048 A
(b) 0.023 A
(c) 0.061 A
(d) 0.094 A

9. A galvanometer of resistance 70 Ω, is converted to an ammeter by a shunt resistance $r_s = 0.03\ \Omega$. The value of its resistance will become
(a) 0.025 Ω (b) 0.022 Ω
(c) 0.035 Ω (d) 0.030 Ω

10. A circular coil of radius 10 cm having 100 turns carries a current of 3.2 A. The magnetic field at the center of the coil is
(a) 2.01×10^{-3} T
(b) 5.64×10^{-3} T
(c) 2.64×10^{-4} T
(d) 5.64×10^{-4} T

11. For a circular coil of radius 5 cm having 100 turns and carrying a current of 2.0 A, the magnetic moment is
(a) 12.95 A m^2 (b) 25.79 A m^2
(c) 1.6 A m^2 (d) 24.79 A m^2

12. The nature of parallel and anti-parallel currents are
(a) parallel currents repel and antiparallel currents attract
(b) parallel currents attract and antiparallel currents repel
(c) both currents attract
(d) both currents repel.

13. A straight wire having mass of 1.2 kg and length of 1 m carries a current of 5 A. If the wire is suspended in mid-air by a uniform horizontal magnetic field, then the magnitude of field is
(a) 0.65 T (b) 1.53 T
(c) 2.4 T (d) 3.2 T

14. The energy of an electron having a speed of 2.98×10^7 m s^{-1} is ($m_e = 9.1 \times 10^{-31}$ kg)
(a) 2.2 keV (b) 2.5 keV
(c) 2.8 keV (d) 3.0 keV

15. A cubical region of space is filled with some uniform electric and magnetic field. An electron enters the cube across one of its faces with velocity v and a positron enters via opposite face with velocity $-v$. At this instant, which one of the following is not correct?
(a) the electric forces on both the particles cause identical accelerations.
(b) the magnetic forces on both the particles cause equal acceleration.
(c) both particles gain or loose energy at the same rate.
(d) the motion of the centre of mass (CM) is determined by B alone.

16. A circular loop of radius R carrying a current I is placed in a uniform magnetic field of B perpendicular to the loop. The force on the loop is
(a) $2\pi RIB$ (b) $2\pi RI^2B^3$
(c) $\pi R^2 IB$ (d) zero

17. 2.5 meter long straight wire having mass of 500 gm is suspended in mid air by a uniform horizontal magnetic field B. If a current of 4 A is passing through the wire then the magnitude of the field is ($g = 10$ m s^{-2})
(a) 0.5 T (b) 0.6 T
(c) 0.25 T (d) 0.8 T

18. A galvanometer of resistance 50 Ω is connected to a battery of 3 V along with a resistance of 2950 Ω in series. A full scale deflection of 30 divisions is obtained in the galvanometer. In order to reduce this deflection to 20 divisions, the resistance in series should be
(a) 6050 Ω (b) 4450 Ω
(c) 5050 Ω (d) 5550 Ω

19. The magnitude of the magnetic field at the centre of the tightly wound 150 turn coil of radius 12 cm carrying a current of 2 A is
(a) 18 G (b) 19.7 G
(c) 15.7 G (d) 17.7 G

20. A straight wire carrying a current of 13 A is bent into a semi-circular arc of radius 2 cm as shown in figure. The magnetic field is 1.5×10^{-4} T at the centre of arc, then the magnetic field due to straight segment is

(a) 1.5×10^{-4} T (b) 2.5×10^{-4} T
(c) zero (d) 3×10^{-4} T

21. A current of 10 A is flowing in a wire of length 1.5 m. A force of 15 N acts on it when it is placed in a uniform magnetic field of 2 T. The angle between the magnetic field and the direction of the current is
(a) 30° (b) 45°
(c) 60° (d) 90°

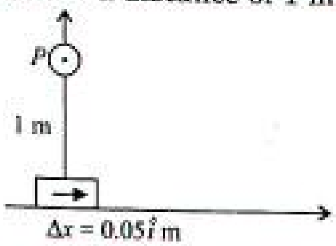
22. A solenoid of length 50 cm, having 100 turns carries a current of 2.5 A. The magnetic field at one end of the solenoid is
(a) 3.14×10^{-4} T (b) 6.28×10^{-4} T
(c) 1.57×10^{-4} T (d) 9.42×10^{-4} T

23. Two identical current carrying coaxial loops, carry current I in opposite sense. A simple amperian loop passes through both of them once. Calling the loop as C, then which statement is correct?
(a) $\oint_C \vec{B}\cdot d\vec{l} = \mp 2\mu_0 I$
(b) the value of $\oint_C \vec{B}\cdot d\vec{l}$ is independent of sense of C.
(c) there may be a point on C where B and dl are parallel.
(d) none of these.

24. A galvanometer having a resistance of 50 Ω, gives a full scale deflection for a current of 0.05 A. The length in meters of a resistance wire of area of cross section 3×10^{-2} cm^2 that can be used to convert the galvanometer into an ammeter which can read a maximum of 5 A current is (Specific resistance of the wire $\rho = 5 \times 10^{-7}$ Ω m)
(a) 9 (b) 6
(c) 3 (d) 1.5

25. A tightly wound 90 turn coil of radius 15 cm has a magnetic field of 4×10^{-4} T at its centre. The current flowing through it is
(a) 1.06 A (b) 2.44 A
(c) 3.44 A (d) 4.44 A

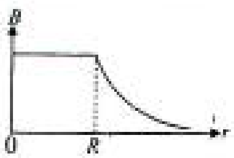
26. An element of $0.05\hat{i}$ m is placed at the origin as shown in figure which carries a large current of 10 A. The magnetic field at a distance of 1 m in perpendicular direction is
(a) 4.5×10^{-8} T
(b) 5.5×10^{-8} T
(c) 5.0×10^{-8} T
(d) 7.5×10^{-8} T

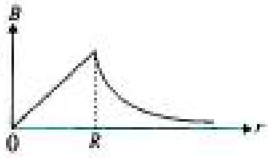


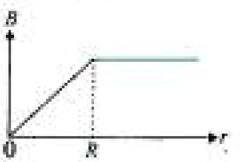
27. A circular loop of radius 3 cm is having a current of 12.5 A. The magnitude of magnetic field at a distance of 4 cm on its axis is
(a) 5.65×10^{-5} T (b) 5.27×10^{-5} T
(c) 6.54×10^{-5} T (d) 9.20×10^{-5} T

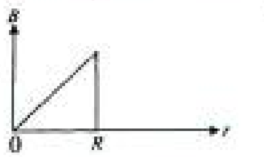
28. If an electron is moving in a magnetic field of 5.4 10^{-4} T on a circular path of radius 32 cm having a frequency of 2.5 MHz, then its speed will be
(a) 8.56×10^{6} m s^{-1} (b) 5.024×10^{6} m s^{-1}
(c) 8.56×10^{4} m s^{-1} (d) 5.024×10^{4} m s^{-1}

29. The correct plot of the magnitude of magnetic field $\vec{B}$ *vs* distance *r* from centre of the wire is, if the radius of wire is *R*

(a)


(b)


(c)


(d)


30. Ampere's circuital law is given by
(a) $\oint \vec{H} \cdot d\vec{l} = \mu_0 I_{enc}$ (b) $\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{enc}$
(c) $\oint \vec{B} \cdot d\vec{l} = \mu_0 J$ (d) $\oint \vec{H} \cdot d\vec{l} = \mu_0 J$

31. Two particles of equal charges after being accelerated through the same potential difference enter in a uniform transverse magnetic field and describe circular paths of radii R_1 and R_2. Then the ratio of their respective masses (M_1/M_2) is
(a) R_1/R_2 (b) $(R_1/R_2)^2$
(c) (R_2/R_1) (d) $(R_2/R_1)^2$

32. A solenoid of length 0.6 meter has a radius of 2 cm and is made up of 600 turns If it carries a current of 4 A, then the magnitude of the magnetic field inside the solenoid is
(a) 6.024×10^{-3} T (b) 8.024×10^{-3} T
(c) 5.024×10^{-3} T (d) 7.024×10^{-3} T

33. Which of the following statements is correct?
(a) The magnetic field in the open space inside the toroid is constant.
(b) The magnetic field in the open space exterior to the toroid is constant.
(c) The magnetic field inside the core of toroid is constant.
(d) The magnetic field inside the core of toroid is zero.

34. The inner and outer radius of a toroid core are 28 cm and 29 cm respectively and around the core 3700 turns of a wire are wounded. If the current in the wire is 10 A, then the magnetic field inside the core of the toroid is
(a) 2.60×10^{-2} T (b) 2.60×10^{-3} T
(c) 4.52×10^{-2} T (d) 4.52×10^{-3} T

35. A 200 turn closely wound circular coil of radius 15 cm carries a current of 4 A. The magnetic moment of this coil is
(a) 36.5 A m^2 (b) 56.5 A m^2
(c) 66.5 A m^2 (d) 108 A m^2

36. A current carrying loop is placed in a uniform magnetic field. The torque acting on it does not depend upon
(a) shape of loop (b) area of loop
(c) value of current (d) magnetic field

37. A circular coil of wire consisting of 100 turns each of radius 9 cm carries a current of 0.4 A. The magnitude of magnetic field at the centre of the coil is
(a) 2.4×10^{-4} T (b) 3.5×10^{-4} T
(c) 2.79×10^{-4} T (d) 3×10^{-4} T

38. If a long straight wire carries a current of 40 A, then the magnitude of the field *B* at a point 15 cm away from the wire is
(a) 5.34×10^{-5} T (b) 8.34×10^{-5} T
(c) 9.6×10^{-5} T (d) 10.2×10^{-5} T

39. A circular coil of 70 turns and radius 5 cm carrying a current of 8 A is suspended vertically in a uniform horizontal magnetic field of magnitude 1.5 T. The field lines make an angle of 30° with the normal of the coil then the magnitude of the counter torque that must be applied to prevent the coil from turning is

(a) 33 N m (b) 3.3 N m

(c) 3.3×10^{-2} N m (d) 3.3×10^{-4} N m

40. Two long and parallel straight wires A and B are carrying currents of 4 A and 7 A in the same direction are separated by a distance of 5 cm. The force acting on a 8 cm section of wire A is

(a) 3×10^{-6} N (b) 6×10^{-6} N

(c) 9×10^{-6} N (d) 12×10^{-6} N

41. An 8 cm long wire carrying a current of 10 A is placed inside a solenoid perpendicular to its axis. If the magnetic field inside the solenoid is 0.3 T, then magnetic force on the wire is

(a) 0.14 N (b) 0.24 N

(c) 0.34 N (d) 0.44 N

42. The magnetic force per unit length on a wire carrying a current of 10 A and making an angle of 45° with the direction of a uniform magnetic field of 0.20 T is

(a) $2\sqrt{2}$ N m^{-1} (b) $\frac{2}{\sqrt{2}}$ N m^{-1}

(c) $\frac{\sqrt{2}}{2}$ N m^{-1} (d) $4\sqrt{2}$ N m^{-1}

43. A circular coil of 25 turns and radius 12 cm is placed in a uniform magnetic field of 0.5 T normal to the plane of the coil. If the current in the coil is 6 A, then total torque acting on the coil is

(a) zero (b) 3.4 N m

(c) 3.8 N m (d) 4.4 N m

44. In a moving coil galvanometer, the deflection (ϕ) on the scale by a pointer attached to the spring is

(a) $\left(\frac{NA}{kB}\right)I$ (b) $\left(\frac{N}{kAB}\right)I$

(c) $\left(\frac{NAB}{k}\right)I$ (d) $\left(\frac{NAB}{kI}\right)$

45. If the current sensitivity of a galvanometer is doubled, then its voltage sensitivity will be

(a) doubled (b) halved

(c) unchanged (d) four times

46. A long straight wire in the horizontal plane carries a current of 75 A in north to south direction, magnitude and direction of field B at a point 3 m east of the wire is

(a) 4×10^{-6} T, vertical up

(b) 5×10^{-6} T, vertical down

(c) 5×10^{-6} T, vertical up

(d) 4×10^{-6} T, vertical down

47. A galvanometer coil has a resistance of 15 Ω and the metre shows full scale deflection for a current of 4 mA. To convert the meter into a voltmeter of range 0 to 18 V, the required resistance is

(a) 5885 Ω in series

(b) 4485 Ω in series

(c) 5885 Ω in parallel

(d) 4485 Ω in parallel

48. If an electron is projected with uniform velocity along the axis of a current carrying long solenoid, then

(a) the electron will be accelerated along the axis.

(b) the electron will continue to move with uniform velocity along the axis of the solenoid.

(c) the electron path will be circular about the axis.

(d) the electron will experience a force at 45° to the axis and hence executes a helical path.

49. A 90 cm long solenoid has six layers of windings of 450 turns each. If the diameter of solenoid is 2.2 cm and current carried is 6 A, then the magnitude of field inside the solenoid, near its centre is

(a) 50π G (b) 60π G

(c) 72π G (d) 80π G

50. The magnitude of torque experienced by a square coil of side 12 cm which consists of 25 turns and carries a current 10 A suspended vertically and the normal to the plane of coil makes an angle of 30° with the direction of a uniform horizontal magnetic field of magnitude 0.9 T is

(a) 1.6 N m (b) 1.2 N m

(c) 1.4 N m (d) 1.8 N m

51. A circular coil of 20 turns and 10 cm radius is placed in a uniform magnetic field of 0.10 T normal to the plane of the coil. If the current in the coil is 5 A, cross-sectional area is 10^{-5} m^2 and coil is made up of copper wire having free electron density about 10^{29} m^{-3}, then the average force on each electron in the coil due to magnetic field is

(a) 2.5×10^{-25} N (b) 5×10^{-25} N

(c) 4×10^{-25} N (d) 3×10^{-25} N

52. A proton and an α-particle enter in a uniform magnetic field perpendicularly with same speed. The ratio of time periods of both particles $\left(\frac{T_p}{T_\alpha}\right)$ will be

(a) 1 : 2 (b) 1 : 3
(c) 2 : 1 (d) 3 : 1

53. A conductor of length 2 m carrying current 2 A is held parallel to an infinitely long conductor carrying current of 12 A at a distance of 100 mm, the force on small conductor is

(a) 8.6×10^{-5} N (b) 6.6×10^{-5} N
(c) 7.6×10^{-5} N (d) 9.6×10^{-5} N

54. If a velocity has both perpendicular and parallel components while moving through a magnetic field, what is the path followed by a charged particle ?

(a) Linear (b) Circular
(c) Helical (d) Elliptical

55. The range of voltmeter of resistance 300 Ω is 5 V. The resistance to be connected to convert it into an ammeter of range 5 A is

(a) 1 Ω in series (b) 1 Ω in parallel
(c) 0.1 Ω in series (d) 0.1 Ω in parallel

56. Which one of the following is correct statement about magnetic forces?

(a) Magnetic forces always obey Newton's third law.
(b) Magnetic forces do not obey Newton's third law.
(c) For very high current, magnetic forces obey Newton's third law.
(d) Inside low magnetic field, magnetic forces obey Newton's third law.

57. If the galvanometer current is 10 mA, resistance of the galvanometer is 40 W and shunt of 2 W is connected to the galvanometer, the maximum current which can be measured by this ammeter is

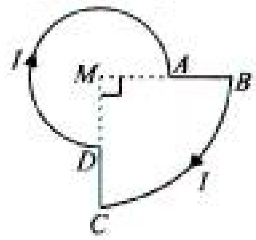
(a) 0.21 A (b) 2.1 A
(c) 210 A (d) 21 A

58. The final torque on a coil having magnetic moment 25 A m^2 in a 5 T uniform external magnetic field, if the coil rotates through an angle of 60° under the influence of the magnetic field is

(a) 216.5 N m (b) 108.25 N m
(c) 102.5 N m (d) 258.1 N m

59. A current I is flowing through a loop. The direction of the current and the shape of the loop are as shown in the figure. The magnetic field at the centre of the loop is $\frac{\mu_0 I}{R}$ times

(Here, $MA = R$, $MB = 2R$, $\angle DMA = 90°$)



(a) $\frac{5}{16}$, out of the plane of the paper.

(b) $\frac{5}{16}$, into the plane of the paper.

(c) $\frac{7}{16}$, out of the plane of the paper.

(d) $\frac{7}{16}$, into the plane of the paper.

60. A moving coil galvanometer can be converted into an ammeter by

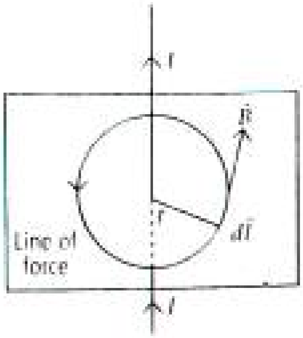
(a) introducing a shunt resistance of large value in series.
(b) introducing a shunt resistance of small value in parallel.
(c) introducing a resistance of small value in series.
(d) introducing a resistance of large value in parallel.

Case Based MCQs

Case I : Read the passage given below and answer the following questions from 61 to 65.

Ampere's Circuital Law

Ampere's law gives a method to calculate the magnetic field due to given current distribution. According to it, the circulation $\oint \vec{B} \cdot d\vec{l}$ of the resultant magnetic field along a closed plane curve is equal to μ_0 times the total current crossing the area bounded by the closed curve provided the electric field inside the loop remains constant. Ampere's law is more useful under certain symmetrical conditions. Consider one such case of a long straight wire with circular cross-section (radius R) carrying current I uniformly distributed across this cross-section.



61. The magnetic field at a radial distance r from the centre of the wire in the region $r > R$, is

(a) $\frac{\mu_0 I}{2\pi r}$ (b) $\frac{\mu_0 I}{2\pi R}$

(c) $\frac{\mu_0 I R^2}{2\pi r}$ (d) $\frac{\mu_0 I r^2}{2\pi R}$

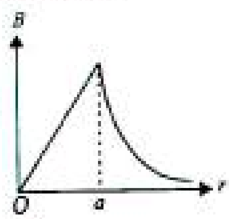
62. The magnetic field at a distance r in the region $r < R$ is

(a) $\frac{\mu_0 I}{2r}$ (b) $\frac{\mu_0 I r^2}{2\pi R^2}$

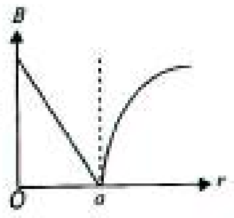
(c) $\frac{\mu_0 I}{2\pi r}$ (d) $\frac{\mu_0 I r}{2\pi R^2}$

63. A long straight wire of a circular cross-section (radius a) carries a steady current I and the current I is uniformly distributed across this cross-section. Which of the following plots represents the variation of magnitude of magnetic field B with distance r from the centre of the wire?

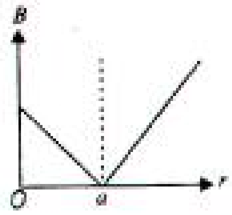
(a)



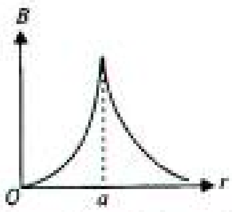
(b)



(c)



(d)



64. A long straight wire of radius R carries a steady current I. The current is uniformly distributed across its cross-section. The ratio of magnetic field at $R/2$ and $2R$ is

(a) $\frac{1}{2}$ (b) 2

(c) $\frac{1}{4}$ (d) 1

65. A direct current I flows along the length of an infinitely long straight thin walled pipe, then the magnetic field is

(a) uniform throughout the pipe but not zero

(b) zero only along the axis of the pipe

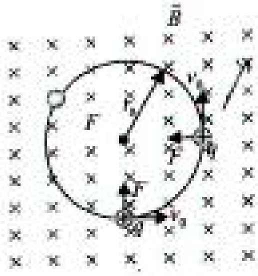
(c) zero at any point inside the pipe

(d) maximum at the centre and minimum at the edges.

Case II : Read the passage given below and answer the following questions from 66 to 70.

Motion of Charge in Magnetic Field

An electron with speed $v_0 << c$ moves in a circle of radius r_0 in a uniform magnetic field. This electron is able to traverse a circular path as magnetic field is perpendicular to the velocity of the electron. A force acts on the particle perpendicular to both $\vec{v}_0$ and $\vec{B}$. This force continuously deflects the particle sideways without changing its speed and the particle will move along a circle perpendicular to the field. The time required for one revolution of the electron is T_0.



66. If the speed of the electron is now doubled to $2v_0$. The radius of the circle will change to

(a) $4r_0$ (b) $2r_0$

(c) r_0 (d) $r_0/2$

67. If $v_0 = 2v_0$, then the time required for one revolution of the electron will change to

(a) $4T_0$ (b) $2T_0$

(c) T_0 (d) $T_0/2$

68. A charged particle is projected in a magnetic field $\vec{B} = (2\hat{i} + 4\hat{j}) \times 10^2$ T. The acceleration of the particle is found to be $\vec{a} = (x\hat{i} + 2\hat{j})\ \mathrm{m\,s^{-2}}$. Find the value of x.

(a) $4\ \mathrm{m\,s^{-2}}$ (b) $-4\ \mathrm{m\,s^{-2}}$

(c) $-2\ \mathrm{m\,s^{-2}}$ (d) $2\ \mathrm{m\,s^{-2}}$

69. If the given electron has a velocity not perpendicular to B, then trajectory of the electron is

(a) straight line (b) circular

(c) helical (d) zig-zag

70. If this electron of charge (e) is moving parallel to uniform magnetic field with constant velocity v, the force acting on the electron is

(a) Bev (b) $\frac{Be}{v}$

(c) $\frac{B}{ev}$ (d) zero

Case III : Read the passage given below and answer the following questions from 71 to 75.

Biot-Savart Law

A magnetic field can be produced by moving, charges or electric currents. The basic equation governing the magnetic field due to a current distribution is the Biot-Savart law.

Finding the magnetic field resulting from a current distribution involves the vector product, and is inherently a calculus problem when the distance from the current to the field point is continuously changing.

According to this law, the magnetic field at a point due to a current element of length $d\vec{l}$ carrying current I, at a distance r from the element is $dB = \frac{\mu_0}{4\pi}\frac{I(d\vec{l}\times\vec{r})}{r^3}$.

Biot-Savart law has certain similarities as well as difference with Coloumb's law for electrostatic field e.g., there is an angle dependence in Biot-Savart law which is not present in electrostatic case.

71. The direction of magnetic field $d\vec{B}$ due to a current element $Id\vec{l}$ at a point of distance $\vec{r}$ from it, when a current I passes through a long conductor is in the direction

(a) of position vector $\vec{r}$ of the point

(b) of current element $d\vec{l}$

(c) perpendicular to both $d\vec{l}$ and $\vec{r}$

(d) perpendicular to $d\vec{l}$ only

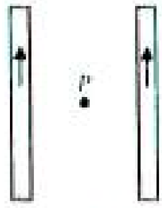
72. The magnetic field due to a current in a straight wire segment of length L at a point on its perpendicular bisector at a distance r $(r >> L)$

(a) decreases as $\frac{1}{r}$. (b) decreases as $\frac{1}{r^2}$.

(c) decreases as $\frac{1}{r^3}$.

(d) approaches a finite limit as $r \to \infty$

73. Two long straight wires are set parallel to each other. Each carries a current i in the same direction and the separation between them is $2r$. The intensity of the magnetic field midway between them is



(a) $\mu_0 i/r$ (b) $4\mu_0 i/r$

(c) zero (d) $\mu_0 i/4r$

74. A long straight wire carries a current along the z-axis for any two points in the $x-y$ plane. Which of the following is always false?

(a) The magnetic fields are equal.

(b) The directions of the magnetic fields are the same.

(c) The magnitudes of the magnetic fields are equal.

(d) The field at one point is opposite to that at the other point.

75. Biot-Savart law can be expressed alternatively as

(a) Coulomb's Law

(b) Ampere's circuital law

(c) Ohm's Law

(d) Gauss's Law

Case IV : Read the passage given below and answer the following questions from 76 to 80.

Conversion of Galvanometer to Voltmeter

A galvanometer can be converted into voltmeter of given range by connecting a suitable resistance R_s in series with the galvanometer, whose value is given by

$$R_s = \frac{V}{I_g} - G$$

where V is the voltage to be measured, I_g is the current for full scale deflection of galvanometer and G is the resistance of galvanometer.

Series resistor(R_s) increases range of voltmeter and the effective resistance of galvanometer. It also protects the galvanometer from damage due to large current.

Voltmeter is a high resistance instrument and it is always connected in parallel with the circuit element across which potential difference is to be measured. An ideal voltmeter has infinite resistance.

In order to increase the range of voltmeter n times the value of resistance to be connected in series with galvanometer is $R_s = (n-1)G$.

76. 10 mA current can pass through a galvanometer of resistance 25 Ω. What resistance in series should be connected through it, so that it is converted into a voltmeter of 100 V?

(a) 0.975 Ω (b) 99.75 Ω

(c) 975 Ω (d) 9975 Ω.

77. There are 3 voltmeter A, B, C having the same range but their resistance are 15,000 Ω, 10,000 Ω and 5,000 Ω respectively. The best voltmeter amongst them is the one whose resistance is

(a) 5000 Ω (b) 10, 000 Ω

(c) 15, 000 Ω (d) all are equally good

78. A milliammeter of range 0 to 25 mA and resistance of 10 Ω is to be converted into a voltmeter with a range of 0 to 25 V. The resistance that should be connected in series will be

(a) 930 Ω (b) 960 Ω

(c) 990 Ω (d) 1010 Ω

79. To convert a moving coil galvanometer (MCG) into a voltmeter

(a) a high resistance R is connected in parallel with MCG

(b) a low resistance R is connected in parallel with MCG

(c) a low resistance R is connected in series with MCG

(d) a high resistance R is connected in series with MCG

80. The resistance of an ideal voltmeter is

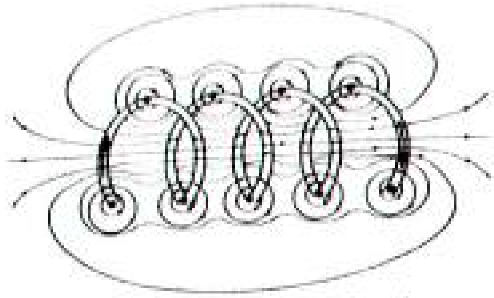
(a) zero (b) low

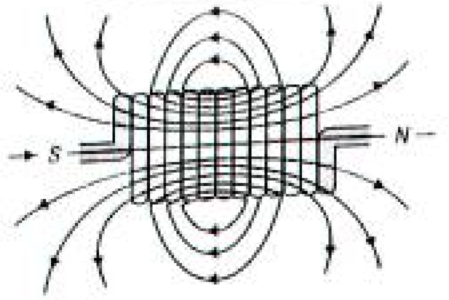
(c) high (d) infinity

Case V : Read the passage given below and answer the following questions from 81 to 85.

Magnetic Field Due to Solenoid

A solenoid is a long coil of wire tightly wound in the helical form. Solenoid consists of closely stacked rings electrically insulated from each other wrapped around a non-conducting cylinder. Figure below shows the magnetic field lines of a solenoid carrying a steady current I. We see that if the turns are closely spaced, the resulting magnetic field inside the solenoid becomes fairly uniform, provided that the length of the solenoid is much greater than its diameter. For an "ideal" solenoid, which is infinitely long with turns tightly packed, the magnetic field inside the solenoid is uniform and parallel to the axis, and vanishes outside the solenoid.





81. A long solenoid has 800 turns per metre length of solenoid. A current of 1.6 A flows through it. The magnetic induction at the end of the solenoid on its axis is

(a) 16×10^{-4} T (b) 8×10^{-4} T

(c) 32×10^{-4} T (d) 4×10^{-4} T

82. Choose the correct statement from the following.

(a) The magnetic field inside the solenoid is less than that of outside.

(b) The magnetic field inside an ideal solenoid is not at all uniform.

(c) The magnetic field at the centre, inside an ideal solenoid is atmost twice that at the ends.

(d) The magnetic field at the centre, inside an ideal solenoid is almost half of that at the ends.

83. The magnetic field (B) inside a long solenoid having n turns per unit length and carrying current I when iron core is kept in it is (μ_0 = permeability of vacuum, χ = magnetic susceptibility)

(a) $\mu_0 nI(1-\chi)$ (b) $\mu_0 nI\chi$

(c) $\mu_0 nI^2(1+\chi)$ (d) $\mu_0 nI(1+\chi)$

84. A solenoid of length l and having n turns carries a current I in anticlockwise direction. The magnetic field is

(a) $\mu_0 nI$

(b) $\mu_0 \frac{nI}{l^2}$

(c) along the axis of solenoid

(d) perpendicular to the axis of coil

85. The magnitude of the magnetic field inside a long solenoid is increased by
(a) decreasing its radius
(b) decreasing the current through it
(c) increasing its area of cross-section
(d) introducing a medium of higher permeability

Assertion & Reasoning Based MCQs

For question numbers 86-100, two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is NOT the correct explanation of A
(c) A is true but R is false
(d) A is false and R is also false

86. **Assertion (A) :** In electric circuits, wires carrying currents in opposite directions are often twisted together.
Reason (R) : If the wire are not twisted together, the combination of the wires forms a current loop. The magnetic field generated by the loop might affect adjacent circuits or components.

87. **Assertion (A) :** When two long parallel wires, carrying Current in the same direction, hanging freely are connected in parallel to a battery, they come closer to each other.
Reason (R) : Wires carrying current in opposite direction repel each other.

88. **Assertion (A) :** When the observation point lies along the length of the current element, magnetic field is zero.
Reason (R) : Magnetic field close to current element is zero.

89. **Assertion (A) :** A solenoid tends to expand, when a current passes through it.
Reason (R) : Two straight parallel metallic wires carrying current in same direction repel each other.

90. **Assertion (A) :** In a conductor, free electrons keep on moving but no magnetic force acts on a conductor in a magnetic field.
Reason (R) : Force on free electron due to magnetic field always acts perpendicular to its direction of motion.

91. **Assertion (A) :** When force is zero, the charged particle follows linear path.
Reason (R) : A charged particle enters in a uniform magnetic field, whose velocity makes an angle θ with magnetic field will cover a linear path.

92. **Assertion (A) :** When current is represented by a straight line, the magnetic field will be circular.
Reason (R) : According to Fleming's left hand rule, direction of force is parallel to the magnetic field.

93. **Assertion (A) :** An electron and proton enters a magnetic field with equal velocities, then, the force experienced by proton will be more than electron.
Reason (R) : The mass of proton is 1999 times more than the mass of electron.

94. **Assertion (A) :** Magnetic field is useful in producing parallel beam of charged particle.
Reason (R) : Magnetic field inhibits the motion of charged particle moving across it.

95. **Assertion (A) :** When a magnetic dipole is placed in a non uniform magnetic field, only a torque acts on the dipole.
Reason (R) : Force would act on dipole if magnetic field is uniform.

96. **Assertion (A) :** Magnetic moment is measured in joule/tesla or amp m^2.
Reason (R) : Joule/tesla is equivalent to amp m^2.

97. **Assertion (A) :** Voltmeter is connected in parallel with the circuit.
Reason (R) : Resistance of a voltmeter is very large.

98. **Assertion (A) :** Magnetic field lines can be entirely confined within the core of a toroid, but not within a straight solenoid.
Reason (R) : The magnetic field inside the solenoid is uniform.

99. **Assertion (A) :** An ammeter is connected in series in the circuit.
Reason (R) : An ammeter is a high resistance galvanometer.

100. **Assertion (A) :** The magnetic field intensity at the centre of a circular coil carrying current changes, if the current through the coil is doubled.
Reason (R) : The magnetic field intensity is dependent on current in conductor.

ANSWERS

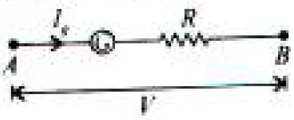
1. **(c)** : Both points are correct and these are the result of experiments done by Danish physicist Hans Christian Oersted in 1820.

2. **(c)** : In arrangements (a), (b) and (d), the field at the centre due to the currents flowing in the square frames is zero. The field here in option (c) due to the currents flowing in and out of the frame is non-zero.

3. **(c)** : Here, $I_g = 1$ mA $= 1 \times 10^{-3}$ A, $G = 10\ \Omega$.

$V = 2.5$ V

From the figure



$V = I_g(G + R)$ or $R = \dfrac{V}{I_g} - G$

Substituting the given values, we get,

$$R = \frac{2.5\text{ V}}{1\times10^{-3}\text{ A}} - 10\ \Omega = 2500\ \Omega - 10\ \Omega = 2490\ \Omega$$

4. **(d)** : As $\vec{B} = \vec{B}_{xy} + \vec{B}_{yz} + \vec{B}_{zx}$ ...(i)

where $\vec{B}_{xy} = \dfrac{\mu_0}{4\pi}\dfrac{I}{R}\theta\hat{k}$, $\vec{B}_{yz} = \dfrac{\mu_0}{4\pi}\dfrac{I}{R}\theta\hat{i}$, $\vec{B}_{zx} = \dfrac{\mu_0}{4\pi}\dfrac{I}{R}\theta\hat{j}$.

Substituting these values in equation (i) we get,

$$\vec{B} = \frac{\mu_0}{4\pi}\frac{I}{R}\theta[\hat{i} + \hat{j} + \hat{k}]$$

Here, $\theta = \dfrac{\pi}{2}$, $I = 4$ A and $R = 5$ cm $= 5\times10^{-2}$ m

$$\therefore\quad \vec{B} = \frac{\mu_0}{4\pi}\times\frac{4}{5\times10^{-2}}\times\frac{\pi}{2}(\hat{i} + \hat{j} + \hat{k})$$

$$= 10\mu_0(\hat{i} + \hat{j} + \hat{k})\text{ T}$$

5. **(b)** : $R = \dfrac{V}{I_g} - G$

Putting $V = 2$ V, $I_g = 2$ mA $= 2 \times 10^{-3}$ A, $G = 12\ \Omega$,

$$\therefore\quad R = \frac{2}{2\times10^{-3}} - 12 = 1000 - 12 = 988\ \Omega$$

6. **(a)** : Here $I_1 = I_2 = 30$ A, $l = 1$ m,

$m = 3$ g $= 3 \times 10^{-3}$ kg

In equilibrium position,

$$mg = \frac{\mu_0}{4\pi}\frac{2I_1I_2l}{h}$$

$$h = \frac{\mu_0}{4\pi}\times\frac{2I_1I_2l}{mg} = 10^{-7}\times\frac{2\times30\times30\times1}{3\times10^{-3}\times10} = 0.6\text{ cm}$$

7. **(a)** : For meter M_1, $R_1 = 10\ \Omega$; $N_1 = 30$; $A_1 = 3.6\times10^{-3}$ m^2; $B_1 = 0.25$ T; $k_1 = k$

For meter M_2, $R_2 = 14\ \Omega$; $N_2 = 42$, $A_2 = 1.8 \times 10^{-3}$ m^2; $B_2 = 0.50$ T; $k_2 = k$

So, current sensitivity, $I_s = \dfrac{NBA}{K}$

$$\frac{I_{s_2}}{I_{s_1}} = \frac{N_2B_2A_2/k_2}{N_1B_1A_1/k_1} = \frac{42\times0.50\times1.8\times10^{-3}/k}{30\times0.25\times3.6\times10^{-3}/k} = 1.4$$

and voltage sensitivity, $V_s = \dfrac{nBA}{kR}$

$$\text{Now, } \frac{V_{s_2}}{V_{s_1}} = \frac{N_2B_2A_2/(k_2R_2)}{N_1B_1A_1/(k_1R_1)} = \frac{N_2B_2A_2R_1k_1}{N_1B_1A_1R_2k_2}$$

$$\text{So, } = \frac{42\times0.50\times(1.8\times10^{-3})\times10\times k}{30\times0.25\times(3.6\times10^{-3})\times14\times k} = 1.$$

$\therefore$ The ratio of current sensitivity and voltage sensitivity of the M_2 to M_1 is 1.4 : 1

8. **(d)** : $R_G = 50\ \Omega$, $R = 3\ \Omega$,

$\therefore$ Total resistance of circuit in series,

$R_{eq} = R_G + R = 50 + 3 = 53\ \Omega$

$\therefore$ Current, $I = \dfrac{5}{53} = 0.094$ A.

9. **(d)** : $R = \dfrac{R_Gr_s}{R_G + r_s}$

Here, $R_G = 70\ \Omega$, $r_s = 0.03\ \Omega$

$$\therefore\quad R = \frac{70\times0.03}{70 + 0.03} = 0.02998 = 0.03\ \Omega$$

10. **(a)** : As $B = \dfrac{\mu_0NI}{2R}$, Here $N = 100$, $I = 3.2$ A,

$R = 10$ cm $= 10\times10^{-2}$ m

$$\therefore\quad B = \frac{4\pi\times10^{-7}\times100\times3.2}{2\times0.1} = 2.01\times10^{-3}\text{ T}$$

11. **(c)** : The magnetic moment is given by

$m = NIA = NI\pi r^2$

$= 100 \times 2.0 \times 3.14 \times (5 \times 10^{-2})^2$

$= 100 \times 2.0 \times 3.14 \times 25 \times 10^{-4} = 1.6$ A m^2

12. **(b)**

13. **(c)** : For mid-air suspension, the upward force F on wire due to magnetic field B must be balanced by the force due to gravity, then

$IlB = mg$

$$B = \frac{mg}{Il}$$

Here, $m = 1.2$ kg, $g = 10$ m s^{-2}, $I = 5$ A, $l = 1$ m

$$B = \frac{1.2\times10}{5\times1} = 2.4\text{ T}$$

14. **(b)** : Given $v = 2.98 \times 10^7$ m s^{-1}

$m_e = 9.1 \times 10^{-31}$ kg

As electron is a moving charged particle, its total energy is contributed by kinetic energy only.

$$\therefore \quad E = \frac{1}{2}mv^2 = \frac{1}{2} \times 9.1 \times 10^{-31} \times (2.98 \times 10^7)^2 = 40 \times 10^{-17} \text{ J}$$

$$= \frac{40 \times 10^{-17}}{1.6 \times 10^{-19}} = 25 \times 100 = 2.5 \times 10^3 \text{ eV} = 2.5 \text{ keV}$$

15. **(a)**

16. **(d)**

17. **(a)** : Here, $m = 500$ g $= 0.5$ kg,

$I = 4$ A; $l = 2.5$ m

As $\vec{F} = I\vec{l} \times \vec{B} \Rightarrow F = IlB\sin\theta$

$mg = IlB \sin 90°$, $\quad (\because \theta = 90°$ and $F = mg)$

$$\therefore \quad B = \frac{mg}{Il} = \frac{0.5 \times 10}{4 \times 2.5} = 0.5 \text{ T}$$

18. **(b)** : Total initial resistance $= G + R$

$= 50\ \Omega + 2950\ \Omega = 3000\ \Omega$

$$\text{Current, } I = \frac{3 \text{ V}}{3000\ \Omega} = 1 \times 10^{-3} \text{ A} = 1 \text{ mA}$$

If the deflection has to be reduced to 20 divisions, then current

$$I' = \frac{1 \text{ mA}}{30} \times 20 = \frac{2}{3} \text{ mA}$$

Let x be the effective resistance of the circuit,

$$3 \text{ V} = 3000\ \Omega \times 1 \text{ mA} = x\ \Omega \times \frac{2}{3} \text{ mA}$$

$$\text{or} \quad x = 3000 \times 1 \times \frac{3}{2} = 4500\ \Omega$$

$\therefore$ Resistance to be added $= (4500\ \Omega - 50\ \Omega) = 4450\ \Omega$

19. **(c)** : Here, $N = 150$;

$r = 12$ cm $= 12 \times 10^{-2}$ m

$I = 2$ A

$$B = \frac{\mu_0 NI}{2R} = \frac{2\pi \times 10^{-7} \times 150 \times 2}{12 \times 10^{-2}} = 1.57 \times 10^{-3} \text{ T}$$

$= 1.57 \times 10^{-3}$ T $= 15.7 \times 10^{-4}$ T $= 15.7$ G

20. **(c)** : Since dl and r for each element of the straight segments are parallel. Therefore

$d\vec{l} \times \vec{r} = 0$

Hence, B is also zero.

21. **(a)** : $F = IlB\sin\theta$ or $\sin\theta = \dfrac{F}{IlB}$

$$\sin\theta = \frac{15}{10 \times 1.5 \times 2} = \frac{1}{2}$$

or $\theta = 30°$

22. **(a)** : Here, $I = 2.5$ A, $l = 50$ cm $= 0.50$ m

and $n = \dfrac{100}{0.50} = 200 \text{ m}^{-1}$

$$\therefore \quad B = \frac{\mu_0 nI}{2} = \frac{4\pi \times 10^{-7} \times 200 \times 2.5}{2} = 3.14 \times 10^{-4} \text{ T}$$

23. **(b)**

24. **(c)** : $S = \dfrac{I_g G}{I - I_g} = \dfrac{0.05 \times 50}{5 - 0.05} = \dfrac{2.5}{4.95} = \dfrac{250}{495} = \dfrac{50}{99}\ \Omega$

$$\because \quad S = \frac{\rho l}{A} \text{ or } l = \frac{SA}{\rho}$$

$$\therefore \quad l = \frac{50}{99} \times \frac{(3 \times 10^{-6} \text{ m}^2)}{(5 \times 10^{-7}\ \Omega \text{ m})} = 3.0 \text{ m}$$

25. **(a)** : Here, $N = 90$

$R = 15$ cm $= 15 \times 10^{-2}$ m, $B = 4 \times 10^{-4}$ T

$$\because \quad B = \frac{\mu_0 NI}{2R}$$

$$\therefore \quad I = \frac{2RB}{N\mu_0} = \frac{2 \times 15 \times 10^{-2} \times 4 \times 10^{-4}}{4\pi \times 10^{-7} \times 90} = 1.06 \text{ A.}$$

26. **(c)** : $dB = \dfrac{\mu_0}{4\pi} \dfrac{Idl\sin\theta}{r^2}$

Here, $dl = \Delta x = 0.05$ m, $I = 10$ A, $r = 1$ m

$\sin\theta = \sin 90° = 1$,

$$\therefore \quad dB = 10^{-7} \times \frac{10 \times 0.05 \times 1}{(1)^2} = 0.50 \times 10^{-7} = 5.0 \times 10^{-8} \text{ T}$$

27. **(a)** : $B = \dfrac{\mu_0 IR^2}{2(R^2 + x^2)^{3/2}}$

Here, $I = 12.5$ A, $R = 3$ cm $= 3 \times 10^{-2}$ m

$x = 4$ cm $= 4 \times 10^{-2}$ m

$$\therefore \quad B = \frac{4\pi \times 10^{-7} \times 12.5 \times (3 \times 10^{-2})^2}{2[(3 \times 10^{-2})^2 + (4 \times 10^{-2})^2]^{3/2}} = 5.65 \times 10^{-5} \text{ T}$$

28. **(b)** : Here, $B = 5.4 \times 10^{-4}$ T;

$r = 32$ cm $= 32 \times 10^{-2}$ m;

$\upsilon = 2.5$ MHz $= 2.5 \times 10^6$ Hz

The speed of electron on circular path

$v = r \times 2\pi\upsilon$

$= 32 \times 10^{-2} \times 2 \times 3.14 \times 2.5 \times 10^6$

$= 502.4 \times 10^4 = 5.024 \times 10^6$ m s^{-1}

29. **(b)** : The magnetic field from the centre of wire of radius R is given by

$$B = \left(\frac{\mu_0 I}{2R^2}\right) r \quad (r < R) \Rightarrow B \propto r$$

$$\text{and} \quad B = \frac{\mu_0 I}{2\pi r} \quad (r > R) \Rightarrow B \propto \frac{1}{r}$$

From the above descriptions, we can say that the graph (b) is a correct representation.

30. **(b)**

31. **(b)** : $qV = \frac{1}{2}Mv^2$ or $v = \sqrt{\frac{2qV}{M}}$ ...(i)

And $Bqv = \frac{Mv^2}{R}$

or $Bq = \frac{Mv}{R} = \frac{M}{R}\sqrt{\frac{2qV}{M}} = \frac{\sqrt{2qVM}}{R}$ (Using (i))

or $M = \frac{B^2q^2R^2}{2qV} = \frac{B^2qR^2}{2V}$

$\therefore M \propto R^2$ $\left(\because B, q \text{ and } V \text{ are same for the given two particles}\right)$

Hence $\frac{M_1}{M_2} = \left(\frac{R_1}{R_2}\right)^2$

32. **(c)** : Here,

$n = \frac{600}{0.6} = 1000$ turns / m, $I = 4$ A

$l = 0.6$ m, $r = 0.02$ m $\therefore \frac{l}{r} = 30$ *i.e.* $l >> r$

Hence, we can use long solenoid formula,

$\therefore B = \mu_0 nI = 4\pi\times10^{-7}\times10^3\times4 = 50.24\times10^{-4}$

$= 5.024\times10^{-3}$ T

33. **(c)**

34. **(a)** : The number of turns per unit length for the given toroid $n = \frac{N}{2\pi r_{av}}$

The average radius of toroid

$r_{av} = \frac{28+29}{2} = 28.5$ cm $= 28.5\times10^{-2}$ m

$\therefore n = \frac{3700}{2\times3.14\times28.5\times10^{-2}} = 2067.27 = 2067$

Now, $B = \mu_0 nI = 4\pi\times10^{-7}\times2067\times10$

$= 259615.2\times10^{-7}$ T $= 2.60\times10^{-2}$ T

35. **(b)** : The magnetic moment is given by

$|\vec{m}| = NIA = NI\pi r^2$

$= 200\times4\times3.14\times(15\times10^{-2})^2$

$= 200\times4\times3.14\times15\times15\times10^{-4} = 56.5$ Am^2

36. **(a)**

37. **(c)** : Here $N = 100$

$R = 9$ cm $= 9\times10^{-2}$ m and $I = 0.4$ A

Now, $B = \frac{\mu_0 NI}{2R} = \frac{2\pi\times10^{-7}\times100\times0.4}{9\times10^{-2}}$

$= \frac{2\times3.14\times0.4}{9}\times10^{-3} = 0.279\times10^{-3}\text{ T} = 2.79\times10^{-4}\text{ T}$

38. **(a)** : $I = 40$ A

$r = 15$ cm $= 15\times10^{-2}$ m

$\therefore B = \frac{\mu_0 I}{2\pi R} = \frac{2\times10^{-7}\times40}{15\times10^{-2}} = \frac{80}{15}\times10^{-5} = 5.34\times10^{-5}$ T

39. **(b)** : $N = 70$

$r = 5$ cm $= 5\times10^{-2}$ m, $I = 8$ A

$B = 1.5$ T and $\theta = 30°$

The counter torque to prevent the coil from turning will be equal and opposite to the torque acting on the coil,

$\therefore \tau = NIAB\sin\theta = NI\pi r^2 B\sin30°$

$= 70\times8\times3.14\times(5\times10^{-2})^2\times1.5\times\frac{1}{2} = 3.297$ N m

≈ 3.3 N m

40. **(c)** : Here, $I_1 = 4$ A, $I_2 = 7$ A

$d = 5$ cm $= 5\times10^{-2}$ m, $l = 8$ cm $= 8\times10^{-2}$ m

$\therefore F = \frac{\mu_0}{4\pi}\frac{2I_1I_2l}{d} = \frac{10^{-7}\times2\times4\times7}{5\times10^{-2}}\times8\times10^{-2}$

$= 89.6\times10^{-7}$ N $= 9\times10^{-6}$ N

41. **(b)** : $F = IlB\sin\theta$

Here, $\theta = 90°$, $I = 10$ A,

$l = 8$ cm $= 8\times10^{-2}$ m, $B = 0.3$ T

$\therefore F = 10\times8\times10^{-2}\times0.3\times\sin90° = 0.24$ N

42. **(b)** : $I = 10$ A, $\theta = 45°$, $B = 0.2$ T

$\therefore \vec{F} = I\vec{l}\times\vec{B} \Rightarrow F = IlB\sin\theta$

$\therefore \frac{F}{l} = IB\sin45° = 10\times0.2\times\frac{1}{\sqrt{2}} = \frac{2}{\sqrt{2}}$ N m^{-1}

43. **(a)** : The torque acting on the coil $|\vec{\tau}| = |\vec{m}\times\vec{B}| = mB\sin\theta$

Here the circular coil is placed normal to the direction of magnetic field thus the angle between the direction of magnetic moment $(\vec{m})$ and magnetic field $(\vec{B})$ is zero.

$\therefore \tau = mB\sin\theta = mB\sin0° = 0$ $\therefore \tau = 0$

44. **(c)** : Since magnetic torque on the coil, $\tau = NIAB$

This torque is balanced by counter torque

$\therefore k\phi = NIAB$ or $\phi = \left(\frac{NAB}{k}\right)I$

where k is torsional constant. It is a scalar quantity having dimension of torque or energy *i.e.* [ML^{2}T^{-2}].

45. **(c)** : Current sensitivity of galvanometer is deflection per unit current *i.e.*

$$\frac{\phi}{I} = \frac{NAB}{k} \quad ...(i)$$

Similarly voltage sensitivity is deflection per unit voltage *i.e.*

$$\frac{\phi}{V} = \left(\frac{NAB}{k}\right)\frac{I}{V} = \left(\frac{NAB}{k}\right)\frac{1}{R} \quad ...(ii)$$

From (i) and (ii)

Voltage sensitivity = current sensitivity × $\frac{1}{\text{Resistance}}$

Now if current sensitivity is doubled, then the resistance in the circuit will also be doubled since it is proportional to the length of the wire, then voltage sensitivity

$$= (2\times\text{current sensitivity})\times\frac{1}{(2\times\text{Resistance})}$$

$$(\text{current sensitivity})\times\frac{1}{\text{Resistance}}$$

Hence, voltage sensitivity will remain unchanged.

46. (c) : From ampere circuital law

$$\oint \vec{B}\cdot d\vec{l} = \mu_0 I_{enc}$$

$$B\times 2\pi R = \mu_0 I_{enc}$$

$$B = \frac{\mu_0 I_{enc}}{2\pi R} = 2\times10^{-7}\times\frac{75}{3} = 5\times10^{-6}\ \text{T}$$

The direction of field at the given point will be vertical up determined by the screw rule or right hand rule.

47. (b) : The galvanometer can be transformed into a voltmeter by applying a high resistance in series. If the series resistance is R, then total resistance in circuit = $(15 + R)\ \Omega$

Now $15+R=\frac{V}{I}=\frac{18}{4\times10^{-3}}=\frac{18\times10^{3}}{4}=4.5\times10^{3}$

$\therefore\ R = 4500 - 15 = 4485\ \Omega$

48. (b) : Let the electron (e) is projected with a uniform velocity (v) in a uniform magnetic field B. The magnitude of force on it is

$$|\vec{F}| = -e|\vec{v}\times\vec{B}| = -evB\sin\theta$$

As $\theta = 0$, $|\vec{F}| = -evB\sin\theta = 0$

Hence the electron will continue to move with a uniform velocity along the axis of the solenoid.

49. (c) : For six Layers of windings, th[illegible] of turns $= 6\times 450 = 2700$

Now number of turns per unit length

$$n=\frac{N}{l}=\frac{2700}{90\times10^{-2}}=3000$$

Then the field inside the solenoid near the centre

$B = \mu_0 nI = 4\pi\times10^{-7}\times 3000\times 6 = 72\pi\times10^{-4}\ \text{T} = 72\pi\ \text{G}$

50. (a) : $\tau = NIAB\sin\theta$

Here, $N = 25$, $I = 10$ A, $B = 0.9$ T, $\theta = 30°$

$A = a^2 = 12\times10^{-2}\times12\times10^{-2} = 144\times10^{-4}\ \text{m}^2$

$\therefore\ \tau = 25\times10\times144\times10^{-4}\times0.9\times\sin30° = 1.6$ N m

51. (b) : Force on each electron, $ev_dB=\frac{IB}{nA}\left[\begin{array}{l}\because\ I = neAv_d\\ \therefore\ ev_d=\frac{I}{nA}\end{array}\right]$

Here, $I = 5$ A, $B = 0.1$ T, $n = 10^{29}\ \text{m}^{-3}$, $A = 10^{-5}\ \text{m}^2$

So, $F=\frac{5\times0.1}{10^{29}\times10^{-5}} = 5\times10^{-25}$ N

52. (a) : The time period of revolution of a charged particle in a magnetic field is

$$T=\frac{2\pi m}{Bq}$$

For proton, $m_p = m$, $q_p = q$

$$\therefore\quad T_p=\frac{2\pi m}{Bq}$$

Now, for α-particle,

$$m_\alpha = 4m,\ q_\alpha = 2q$$

$$\therefore\quad T_\alpha=\frac{2\pi(4m)}{B(2q)}=2\left(\frac{2\pi m}{Bq}\right)\ \text{or}\ \frac{T_p}{T_\alpha}=\frac{1}{2}$$

53. (d) : Here, $I_1 = 2$ A, $I_2 = 12$ A

$r = 100$ mm = 0.1 m, $l = 2$ m

The force per unit length on small conductor due to long conductor

$$f=\frac{\mu_0}{4\pi}\frac{2I_1I_2}{r}$$

Now total force on length l of small conductor

$$F = fl = \frac{\mu_0}{4\pi}\times\frac{2I_1I_2}{r}l = \frac{10^{-7}\times2\times2\times12\times2}{0.1} = 9.60\times10^{-5}\ \text{N}$$

54. (c) : Due to perpendicular component the charged particle will describe a circular path and due to parallel component it will move linear distance along the magnetic field. Hence, it will follow a helical path.

55. (b) : A voltmeter is a galvanometer having a high resistance connected in series with it. The current through the galvanometer is

$$I_g=\frac{5\ \text{V}}{300\ \Omega}=\frac{1}{60}\ \text{A}$$

An ammeter is a galvanometer having a low resistance connected in parallel with it. The shunt resistance S is determined from

$$\frac{I_g}{I-I_g}=\frac{S}{G}$$

where $G = 300\ \Omega$ (Given)

For $I = 5$ A, we get

$$\frac{1/60}{5-(1/60)}=\frac{S}{300}\ \Rightarrow\ S = 1\ \Omega$$

56. ([illegible] [illegible]n and reaction are instantaneous in Newtons [illegible] magnetic forces transmit with finite speed c.

57. **(a)** : $I = \left(\frac{S+G}{S}\right)I_g = \left(\frac{2+40}{2}\right) \times 0.01 = 0.21\ \text{A}$

58. **(b)** : $|\vec{\tau}| = |\vec{m} \times \vec{B}| = mB\sin\theta$

Here, $m = 25\ \text{A m}^2$; $\theta = 60°$; $B = 5\ \text{T}$

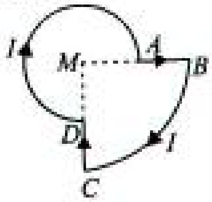
$\therefore\quad \tau = 25 \times 5 \times \sin 60°$

or $\quad \tau = 125 \times \frac{\sqrt{3}}{2} = 108.25\ \text{N m}$

59. **(d)** : Magnetic field at the centre M due to current through the curved portion DA is

$B_1 = \frac{\mu_0 I}{4\pi R} \times \left(\frac{3\pi}{2}\right)$ into the plane of the paper

$= \frac{3\mu_0 I}{8R}$ into the plane of the paper



Magnetic field at the centre M due to current through the straight portion AB is $B_2 = 0$

($\because$ Point M lies on the axis of the straight portion AB)

Magnetic field at the centre M due to current through the curved portion BC is

$B_3 = \frac{\mu_0 I}{4\pi(2R)} \times \frac{\pi}{2}$ into the plane of the paper

$= \frac{\mu_0 I}{16R}$ into the plane of the paper

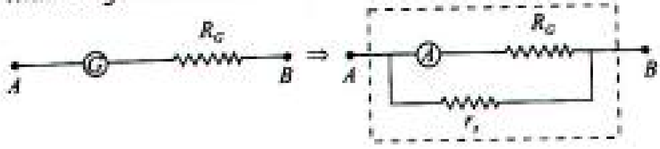
Magnetic field at the centre M due to current through the straight portion CD is $B_4 = 0$

($\because$ point M lies on the axis of the straight portion CD)

The resultant magnetic field at M is

$$B = B_1 + B_2 + B_3 + B_4$$
$$= \frac{3\mu_0 I}{8R} + 0 + \frac{\mu_0 I}{16R} + 0 = \frac{3\mu_0 I}{8R} + \frac{\mu_0 I}{16R}$$
$$= \frac{7\mu_0 I}{16R} \text{ into the plane of the paper}$$

60. **(b)** : To utilise a galvanometer (G) as ammeter, there is the difficulty in measurement of current due to the sensitivity of galvanometer and also connection of galvanometer with a very large resistance in series that may change the value of current in the circuit. To overcome these difficulties one attaches a small resistance r_s called shunt resistance in parallel with the galvanometer coil as shown in the figure.



61. **(a)** : Magnetic field due to a long current carrying wire at r

$$B = \frac{\mu_0}{2\pi}\frac{I}{r}$$

62. **(d)** : Let I' be the current in region $r < R$

Then, $I' = \frac{I}{\pi R^2}\pi(r^2)$ or $I' = \frac{Ir^2}{R^2}$

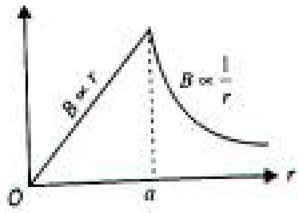
So, magnetic field, $B = \frac{\mu_0 I'}{2\pi r} = \frac{\mu_0 I r^2}{2\pi R^2 r} = \frac{\mu_0 I r}{2\pi R^2}$

63. **(a)** : Magnetic field due to a long straight wire of radius a carrying current I at a point distant r from the centre of the wire is given as follows

$B = \frac{\mu_0 I r}{2\pi a^2}$ for $r < a$

$B = \frac{\mu_0 I}{2\pi a}$ for $r = a$

$B = \frac{\mu_0 I}{2\pi r}$ for $r > a$



The variation of magnetic field B with distance r from the centre of wire is shown in the figure.

64. **(d)** : Let the magnetic fields due to a long straight wire of radius R carrying a steady current I at a distance r from the centre of the wire are

$$B_1 = \frac{\mu_0 I r}{2\pi R^2} \quad (\text{For } r < R)$$

and $B_2 = \frac{\mu_0 I}{2\pi R}$ $\quad$ (For $r > R$)

So, the magnetic field at $r = \frac{R}{2}$ is $B_1 = \frac{\mu_0 I}{2\pi R^2}\left(\frac{R}{2}\right) = \frac{\mu_0 I}{4\pi R}$

and at $r = 2R$ is $B_2 = \frac{\mu_0 I}{2\pi(2R)} = \frac{\mu_0 I}{4\pi R}$

$\therefore$ Their corresponding ratio is

$$\frac{B_1}{B_2} = \frac{(\mu_0 I/4\pi R)}{(\mu_0 I/4\pi R)} = 1$$

65. **(c)**

66. **(b)**: As, $r_0 = \frac{mv}{qB} \Rightarrow r' = \frac{m(2v_0)}{qB} = 2r_0$

67. **(c)** : As, $T = \frac{2\pi m}{qB}$

Thus, it remains same as it is independent of velocity.

68. **(b)** : As $F \perp B$

Hence, $a \perp B$

$\therefore\quad \vec{a} \cdot \vec{B} = 0$

$\Rightarrow\quad (x\hat{i} + 2\hat{j}) \cdot (2\hat{i} + 4\hat{j}) = 0$

$2x + 8 = 0 \Rightarrow x = -4\ \text{m s}^{-2}$

69. (c) : If the charged particle has a velocity not perpendicular to $\vec{B}$, then component of velocity along $\vec{B}$ remains unchanged as the motion along $\vec{B}$ will not be affected by $\vec{B}$.
Then, the motion of the particle in a plane perpendicular to $\vec{B}$ is as before circular one. Thereby, producing helical motion.

70. (d) : The force on electron $F = qvB\sin\theta$
As the electron is moving parallel to B
So, $\theta = 0° \Rightarrow qvB\sin 0° = 0$

71. (c) : According to Biot-Savart's law, the magnetic induction due to a current element is given by

$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{Id\vec{l} \times \vec{r}}{r^3}$$

This is perpendicular to both $d\vec{l}$ and $\vec{r}$.

72. (b) : From Biot-savart's law,

$$dB = \frac{\mu_0}{4\pi}\frac{Idl}{r^2} \ \ i.e.\ dB \propto \frac{1}{r^2}$$

73. (c) : $B = \frac{\mu_0}{2\pi}\cdot\frac{i}{r} - \frac{\mu_0}{2\pi}\cdot\frac{i}{r} = 0$

74. (a)

75. (b) : Biot-Savart law can be expressed alternatively as Ampere's circuital law.

76. (d) : A galvanometer can be converted into a voltmeter of given range by connecting a suitable high resistance R in series with the galvanometer, which is given by

$$R = \frac{V}{I_g} - G = \frac{100}{10 \times 10^{-3}} - 25 = 10000 - 25 = 9975\ \Omega$$

77. (c) : An ideal voltmeter should have a very high resistance.

78 (c) : Resistance of voltmeter $= \frac{25}{25 \times 10^{-3}} = 1000\ \Omega$
$\therefore\ \ X = 1000 - 10 = 990\ \Omega$

79. (d) : To convert a moving coil galvanometer into a voltmeter, it is connected with a high resistance in series. The voltmeter is connected in parallel to measure the potential difference. As the resistance is high, the voltmeter itself does not consume current.

80. (d) : The resistance of an ideal voltmeter is infinity.

81. (b) : As $B = \frac{\mu_0 nI}{2} = \frac{(4\pi \times 10^{-7}) \times 800 \times 1.6}{2}$
$= 8 \times 10^{-4}$ T

82. (c) : Magnetic field at one end of a solenoid carrying current is $B = \frac{\mu_0 nI}{2}$

Magnetic field inside the solenoid is uniform and is given by $B_c = \mu_0 nI$

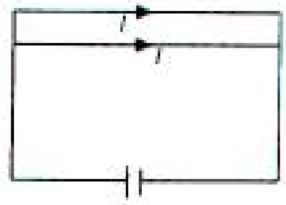
83. (d) : Magnetic field inside a long solenoid with an iron core inside it is $B = \mu nI$
But $\mu = \mu_0(1 + \chi)$ $\therefore$ $B = \mu_0(1 + \chi)nI$

84. (c) : A solenoid of length l and having n turns carries a current I in anticlockwise direction. The magnetic field is $\frac{\mu_0 nI}{l}$. Its direction will be along the axis of solenoid.

85. (d)

86. (a) : If the wires are twisted together, they can be modelled as a single wire carrying current in the opposite directions. In this model, no magnetic field is induced in the wires which does not affect adjacent circuits.

87. (b) : The wires are parallel to each other but the direction of current in it is in same direction so they attract each other. If the current in the wires is in opposite direction then wires repel each other. When the currents are in opposite directions, the magnetic forces are reversed and the wires repels each other.



88. (c) : Since $dB \propto \sin\theta$, where θ is angle between the direction of the flow of current and the line joining the elementary portion to the observation point which is zero in this case, so the magnetic field is also zero (because $\sin\theta$ is equal to zero).

89. (d) : When current flows through a solenoid, the currents in the various turns of the solenoid are parallel and in the same direction. Since the currents flowing through parallel wires in the same direction lead to force of attraction between them, the turns of the solenoid will also attract each other and as a result,the solenoid tends to contract.

90. (c) : In a conductor, the average velocity of electrons is zero. Hence no current flows through the conductor. Hence, no force acts on this conductor.

91. (c) : When charged particle enters the uniform field they makes angle θ with the field. Then its path is decided by combined effect of two component of velocity. $v\cos\theta$ is parallel to the field. Due to the parallel field the charge will follow a linear path and due to the perpendicular component ($v\sin\theta$) of the field will be circular. This results in a helical path whose axis is parallel to the parallel component of the field.

92. (c) : When current is straight, it means the current is passing through a straight conductor, the magnetic field produced due to current through a straight conductor is in the form of concentric circular magnetic lines of force whose centres lie on the linear conductor and are in a plane perpendicular to the plane of linear conductor. It means the magnetic field is circular.

93. (d) : The force experienced by a charge particle in a magnetic field is given by,

$$\vec{F} = q(\vec{v} \times \vec{B})$$

which is independent of mass. As q, v and B are same for both the electron and proton, hence both will experience same force.

94. (a)

95. (d) : In a non-uniform magnetic field, a torque and a net force both act on the dipole. If magnetic field is uniform, net force on dipole would be zero.

96. (a) : Magnetic moment $= \dfrac{\text{joule}}{\text{tesla}} = \dfrac{W}{B} = \dfrac{W}{F/qv}$

$$= \frac{Wqv}{F} = \frac{[ML^2T^{-2}][AT][LT^{-1}]}{[MLT^{-2}]}$$

$= AL^2 =$ amp m^2

97. (a) : A voltmeter is always connected in parallel. This has a large resistance.

98. (b) : Magnetic field lines can be entirely confined to the core of a toroid because toroid has no ends. It can confine the field within its core. A straight solenoid has two ends. If the entire flux were confined between these ends, the flux throughout the cross-section at each end would be non-zero.

99. (c) : An ammeter is a low resistance galvanometer. It is used to measure the current in amperes. To measure the current of a circuit, the ammeter is connected in series in the circuit so that the current to be measured must pass through it. Since, the resistance of ammeter is low, so its inclusion in series in the circuit does not change the resistance and hence the main current in the circuit.

100.(a) : The magnetic field at the centre of circular coil is given by,

$$B = \frac{\mu_0}{4\pi}\frac{2\pi nI}{a}$$

So if current through coil is doubled then magnetic field is $B' = 2B$.

The magnetic field also get doubled. The magnetic field is directly proportional to the current in conductor.

☺☺☺

CHAPTER 5

Magnetism and Matter

Recap Notes

- **Magnetic dipole :** A magnetic dipole consists of two unlike poles of equal strength and separated by a small distance. For example a bar magnet, a compass needle etc., are magnetic dipoles.
  - **Magnetic dipole moment :** It is defined as the product of strength of either pole (m) and the magnetic length ($2\vec{l}$) of the magnet. It is denoted by $\vec{M}$.
    Magnetic dipole moment = strength of either pole magnetic length
    $$\vec{M} = m\,(2\vec{l})$$
    - Magnetic dipole moment is a vector quantity and it is directed from south to north pole of the magnet.
    - The SI unit of magnetic dipole moment is A m^2.
    - If a magnet of moment M and pole strength m is cut into two equal parts along its length, then pole strength of each part is $m/2$ and the magnetic moment of each part is $M/2$.
    - If a magnet of magnetic moment M and pole strength m is cut into two equal halves along perpendicular to its length, the pole strength of each part is m and magnetic moment of each part is $M/2$.
- **Circular Current Loop as a Magnetic Dipole**
  - Magnetic moment of circular current loop, $m = I\,A = I\,\pi\,R^2$
  - Magnetic field perpendicular to the loop,
    $$B_\perp = \frac{\mu_0 I\,R^2}{2x^3} \quad (\text{For } x >> R)$$
    $$B_\perp = \frac{\mu_0}{4\pi}\cdot\frac{2m}{x^3}$$
  - Magnetic field in the plane of the loop
    $$B_{\|} = \frac{\mu_0}{4\pi}\,\frac{m}{x^3} \qquad (x >> R) \qquad \text{Also, } B_\perp = 2\times B_{\|}$$
    Here, x is distance from the centre of the loop of the radius R.
  - These expressions are analogous to the electric field due to short dipole.
- **Torque on a magnetic dipole placed in a uniform magnetic field :** When a magnetic dipole of dipole moment $\vec{M}$ is placed in a uniform magnetic field $\vec{B}$, it will experience a torque and is given by
  $$\tau = NIAB\sin\theta$$
  $$\Rightarrow \quad \vec{\tau} = \vec{M}\times\vec{B} \quad \text{or} \quad \tau = MB\sin\theta$$
  where magnetic moment, $M = NIA$ and θ is the angle between $\vec{M}$ and $\vec{B}$.
  - Torque acting on a dipole is maximum ($\tau_{max} = MB$) when dipole is perpendicular to the field and minimum ($\tau = 0$) when dipole is parallel or antiparallel to the field.
  - When a dipole is placed in a uniform magnetic field, it will experience only torque and the net force on the dipole is zero while when it is placed in a non uniform magnetic field, it will experience both torque and net force.
- **Work done in rotating the magnetic dipole in a uniform magnetic field :** Work done in rotating the magnetic dipole from θ_1 to θ_2 with respect to uniform magnetic field is
  $$W = \int_{\theta_1}^{\theta_2} MB\sin\theta\, d\theta = -MB(\cos\theta_2 - \cos\theta_1)$$
  $$= MB(\cos\theta_1 - \cos\theta_2)$$

- ▶ If the dipole is rotated from field direction *i.e.*, $\theta_1 = 0°$ to position θ *i.e.*, $\theta_2 = \theta$
  $W = MB\,(1 - \cos\theta)$.

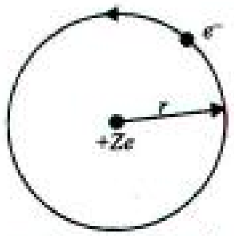
- **Potential energy of a magnetic dipole :** Potential energy of a magnetic dipole in a uniform magnetic field is

  $$U = -\vec{M} \cdot \vec{B} = -MB\cos\theta$$

  ▶ The potential energy of the dipole will be minimum ($= -MB$) when $\theta = 0°$, *i.e.*, the dipole is parallel to the field, and maximum ($= MB$) when $\theta = 180°$, *i.e.*, the dipole is antiparallel to the field.

- **Magnetic Dipole Moment of a Revolving Electron**

  ▶ Orbital current, $I = \dfrac{e}{T} = \dfrac{ev}{2\pi r}$



Hydrogen-like atom in Bohr model

  ▶ Magnetic moment,

  $$\mu_l = I\pi r^2 = \frac{evr}{2} = \frac{e}{2m_e}L$$
  $$(\because L = m_e vr)$$

  ▶ Vectorially, $\vec{\mu}_l = -\dfrac{e}{2m_e}\vec{L}$

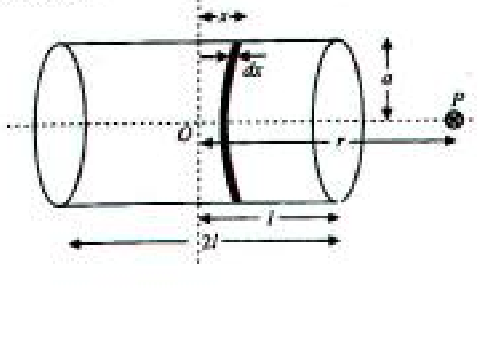
  ▶ Gyromagnetic ratio, $\dfrac{\mu_l}{L} = \dfrac{e}{2m_e}$

  ▶ Bohr magneton,

  $$(\mu_l)_{\min} = \frac{e}{4\pi m_e}h = 9.27 \times 10^{-24}\ \text{A m}^2$$

- **Bar Magnet as an Equivalent Solenoid**

  ▶ Given figure is used for calculation of the axial field of a finite solenoid in order to demonstrate its similarity to that of a bar magnet.



  ▶ Magnitude of the magnetic field at point P due to a circular element shown in the figure.

  $$dB = \frac{\mu_0 n\,dx\,Ia^2}{2[(r-x)^2 + a^2]^{3/2}}$$

  Net magnetic field

  $$B = \frac{\mu_0 nIa^2}{2}\int_{-l}^{l}\frac{dx}{[(r-x)^2 + a^2]^{3/2}}$$

  For a far axial point of the solenoid *i.e.*, $r >> a$ and $r >> l$. $[(r-x)^2 + a^2]^{3/2} = r^3$

  $$\therefore\ B = \frac{\mu_0 nIa^2}{2r^3}\int_{-l}^{l}dx = \frac{\mu_0 nI}{2}\frac{2la^2}{r^3}$$

  Magnetic moment of solenoid, $m = n(2l)\,I\,(\pi a^2)$

  $$\therefore\ B = \frac{\mu_0}{4\pi}\frac{2m}{r^3}$$

  Which is the magnetic field due to a bar magnet at far axial point obtained experimentally.
  Hence a bar magnet and a solenoid produce similar magnetic fields.

- **Gauss's law for magnetism** : Gauss's law for magnetism states that the net magnetic flux through any closed surface is zero.

  $$\phi = \sum_{\substack{\text{all area}\\ \text{elements}}} \vec{B} \cdot \Delta\vec{S} = 0$$

  This law establishes that isolated magnetic poles do not exist.

- **Elements of the earth's magnetic field**

  ▶ **Magnetic declination** : The vertical plane passing through the geographical north pole and south pole at given place is known as the geographical meridian of that place. And a vertical plane passing through the axis of a freely suspended or pivoted magnet is known as magnetic meridian. Magnetic declination at a place is defined as the angle between the geographic meridian and magnetic meridian.

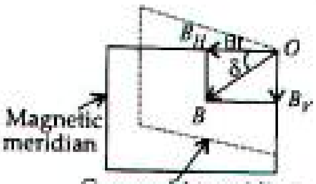
  ▶ **Magnetic dip or inclination :** Magnetic dip at a place is defined as the angle made by the earth's magnetic field with the horizontal in the magnetic meridian. It is denoted by δ.

  ▶ **Horizontal component** : It is the component of earth's magnetic field along the horizontal direction in the magnetic meridian. It is denoted by B_H.

- If B is intensity of earth's total magnetic field, then the horizontal component of earth's magnetic field is given by
  $B_H = B\cos\delta$
- The Earth always has a horizontal component except at the poles.

▶ The vertical component of earth's magnetic field, $B_V = B\sin\delta$

$$\therefore\ B = \sqrt{B_H^2 + B_V^2}\ \text{and}\ \tan\delta = \frac{B_V}{B_H}$$



- The Earth always has a vertical component except at equator.
- In a vertical plane at an angle θ to magnetic meridian
  $B'_H = B_H\cos\theta$ and $B'_V = B_V$

$$\therefore\ \tan\delta' = \frac{B'_V}{B'_H} = \frac{B_V}{B_H\cos\theta} = \frac{\tan\delta}{\cos\theta}$$

$$\tan\delta' = \frac{\tan\delta}{\cos\theta}$$

▶ If at a given place δ_1 and δ_2 are angles of dip in two arbitrary vertical planes which are perpendicular to each other, the true angle of dip δ is given by
$\cot^2\delta = \cot^2\delta_1 + \cot^2\delta_2$

▶ Angle of dip δ at a place is related to its magnetic latitude λ through the relation
$\tan\delta = 2\tan\lambda$

Practice Time

Multiple Choice Questions (MCQs)

1. The earth behaves as a magnet with magnetic field pointing approximately from the geographic
(a) North to South (b) South to North
(c) East to West (d) West to East

2. Magnetic moment for a solenoid and corresponding bar magnet is
(a) equal for both (b) more for solenoid
(c) more for bar magnet (d) none of these

3. The magnetic moment of electron due to orbital motion is proportional to (n = principle quantum number)
(a) $\frac{1}{n^2}$ (b) $\frac{1}{n}$ (c) n^2 (d) n

4. A solenoid of cross-sectional area 2×10^{-4} m^2 and 900 turns has 0.6 A m^2 magnetic moment. Then the current flowing through it is
(a) 2.24 A (b) 2.34 m A
(c) 3.33 A (d) 3.33 m A

5. The strength of the earth's magnetic field is
(a) constant everywhere
(b) zero everywhere
(c) having very high value
(d) vary from place to place on the earth surface

6. The equatorial magnetic field of earth is 0.4 G. Then its dipole moment on equator is
(a) 1.05×10^{23} A m^2 (b) 2.05×10^{23} A m^2
(c) 1.05×10^{21} A m^2 (d) 2.05×10^{21} A m^2

7. In the magnetic meridian of a certain place the horizontal component of earth's magnetic field is 0.25 G and dip angle is 60°. The magnetic field of the earth at this location is
(a) 0.50 G (b) 0.52 G (c) 0.54 G (d) 0.56 G

8. A circular coil of radius 10 cm and 100 turns carries a current 1 A. What is the magnetic moment of the coil ?
(a) 3.142 A m^2 (b) 3.142×10^4 A m^2
(c) 3 A m^2 (d) 10^4 A m^2

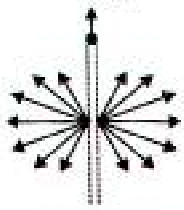
9. Which of the following is correct about magnetic monopole?
(a) Magnetic monopole exist.
(b) Magnetic monopole does not exist.
(c) Magnetic monopole have constant value of monopole momentum.
(d) The monopole momentum increase due to increase at its distance from the field.

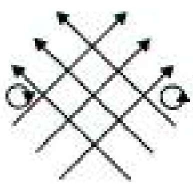
10. A current loop in a magnetic field
(a) can be in equilibrium in two orientations, both the equilibrium states are unstable.
(b) can be in equilibrium in two orientations, one stable while the other is unstable.
(c) experiences a torque whether the field is uniform or non uniform in all orientations.
(d) can be in equilibrium in one orientation.

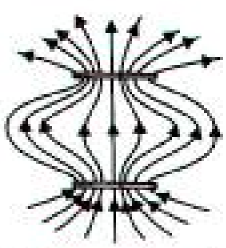
11. Relation between magnetic moment and angular velocity is
(a) $M \propto \omega$ (b) $M \propto \omega^2$
(c) $M \propto \sqrt{\omega}$ (d) None of these

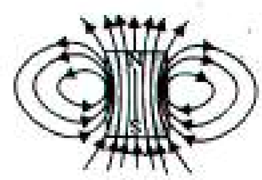
12. A planar coil having 12 turns carries 15 A current. The coil is oriented with respect to the uniform magnetic field $\vec{B} = 0.2\hat{i}$ T such that its directed area is $\vec{A} = -0.04\hat{i}$ m^2. The potential energy of the coil in the given orientation is
(a) 0 (b) +0.72 J (c) +1.44 J (d) −1.44 J

13. Point out the correct direction of magnetic field in the given figures.

(a)


(b)


(c)


(d)


14. The graph of magnetic moment μ of a revolving electron around the nucleus versus principal quantum number n is
(a) Straight line (b) Hyperbola
(c) Parabola (d) Circle

15. The ratio of the magnetic dipole moment to the angular momentum of the electron in the 1st orbit of hydrogen atom is

(a) $\frac{e}{2m}$ (b) $\frac{e}{m}$ (c) $\frac{2m}{e}$ (d) $\frac{m}{e}$

16. An electron of charge e is orbiting in a circular path of radius r with a uniform speed v. Its magnetic moment will be

(a) $\frac{evr}{2}$ (b) evr (c) $\frac{er}{2v}$ (d) $2evr$

17. Magnetic field at the centre of a circular loop of area A is B. The magnetic moment of the loop is

(a) $\frac{BA^2}{\mu_0\pi}$ (b) $\frac{BA\sqrt{A}}{\mu_0}$

(c) $\frac{BA\sqrt{A}}{\mu_0\pi}$ (d) $\frac{2BA\sqrt{A}}{\mu_0\sqrt{\pi}}$

18. The dip angle at a location in southern India is about 18°. Then the dip angle in Britain will be

(a) Greater than 18° (b) Lesser than 18°
(c) equal to 18° (d) zero

19. A 100 turn closely wound circular coil of radius 10 cm carries a current of 3.2 A. The magnetic moment of the coil is, approximately,

(a) 5 A m^2 (b) 10 A m^2 (c) 20 A m^2 (d) 40Am^2

20. A closely wound solenoid of 2000 turns and area of cross-section 1.5×10^{-4} m^2 carries a current of 2.0 A. It is suspended through its centre and perpendicular to its length, allowing it to turn in a horizontal plane in a uniform magnetic field 5×10^{-2} tesla making an angle of 30° with the axis of the solenoid. The torque on the solenoid will be

(a) 3×10^{-3} N m (b) 1.5×10^{-3} N m
(c) 1.5×10^{-2} N m (d) 3×10^{-2} N m

21. A closely wound solenoid of 750 turns and area of cross section 5×10^{-4} m^2 carries a current of 3.0 A. Its associated magnetic moment is

(a) 4.12 J T^{-1} (b) 3.12 J T^{-1}
(c) 2.12 J T^{-1} (d) 1.13 J T^{-1}

22. A circular coil of 25 turns and radius of 12 cm is placed in a uniform magnetic field of 0.5 T normal to the plane of coil. If the current in the coil is 5 A, then total torque experienced by the coil is

(a) 1.5 N m (b) 2.5 N m (c) 3.5 N m (d) zero

23. The ratio of magnetic field and magnetic moment at the centre of a current carrying circular loop is x. When both the current and radius is doubled the ratio will be

(a) $\frac{x}{8}$ (b) $\frac{x}{4}$ (c) $\frac{x}{2}$ (d) $2x$

24. At certain place, the horizontal component of earth's magnetic field is 3.0 G and the angle dip at that place is 30°. The magnetic field of earth at that location

(a) 4.5 G (b) 5.1 G (c) 3.5 G (d) 6.0 G

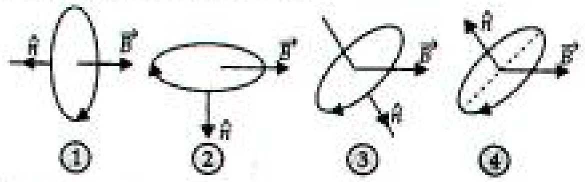
25. At a given place on earth's surface the horizontal component of earths magnetic field is 2×10^{-5} T and resultant magnetic field is 4×10^{-5} T. The angle of dip at this place is

(a) 30° (b) 60° (c) 90° (d) 45°

26. The angles of dip at the poles and the equator respectively are

(a) 30°, 60° (b) 0°, 90° (c) 45°, 90° (d) 90°, 0°

27. A current carrying loop is placed in a uniform magnetic field in four different orientations as shown in figure. Arrange them in the decreasing order of potential energy.



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

28. A jet plane is travelling west at 450 metres per second. If the horizontal component of earths magnetic field is 4×10^{-4} Tesla and angle of dip is 30°, then the vertical component is

(a) 3×10^{-4} T (b) 4×10^{-4} T
(c) 2.3×10^{-4} T (d) 12.308×10^{-4} T

29. The earth's field departs from its dipole shape substantially at large distance (greater than about 3000 km). The responsible factor for this distortion is

(a) motion of ions in earth's ionosphere
(b) motion of ions in earth's atmosphere
(c) motion of ions in earth's lithosphere
(d) motion of ions in the space.

30. If magnetic lines of force are drawn by keeping magnet vertical, then number of neutral points will be

(a) One (b) Two (c) Three (d) Four

31. Intensity of magnetic field due to Earth at a point inside a hollow steel-box is

(a) Less than outside (b) Same as outside
(c) More than outside (d) Zero

32. A circular coil of 100 turns, radius 10 cm carries a current of 5 A. It is suspended vertically in a uniform horizontal magnetic field of 0.5 T and the field lines make an angle of 60° with the plane of the coil. The magnitude of the torque that must be applied on it to prevent it from turning is

(a) 2.93 N m (b) 3.43 N m
(c) 3.93 N m (d) 4.93 N m

33. Assume the dipole model for earth's magnetic field B which is given by the vertical component of magnetic field, $B_V = \frac{\mu_0}{4\pi}\frac{2m\cos\theta}{r^3}$ and the horizontal component of magnetic field $B_H = \frac{\mu_0}{4\pi}\frac{m\sin\theta}{r^3}$, where $\theta = 90° -$ latitude as measured from magnetic equator, then the loci of point for which dip angle is ± 45°.

(a) $\tan^{-1}(3)$ (b) $\tan^{-1}(2)$
(c) $\tan^{-1}(0.5)$ (d) $\tan^{-1}(1)$

34. If you made a map of magnetic field lines at melbourne in Australia, then the magnetic field lines seem to be

(a) go into the ground
(b) come out of the ground
(c) maintain a spiral path on the surface of earth
(d) move on helical path above the surface of ground

35. The horizontal and vertical components of earth's magnetic field at a place are 0.3 G and 0.52 G. The earth's magnetic field and the angle of dip are

(a) 0.3 G and $\delta = 30°$ (b) 0.4 G and $\delta = 40°$
(c) 0.5 G and $\delta = 50°$ (d) 0.6 G and $\delta = 60°$

36. At two different places the angles of dip are respectively 30° and 45°. At these two places the ratio of horizontal component of earth's magnetic field is

(a) $\sqrt{3} : \sqrt{2}$ (b) $1 : \sqrt{2}$ (c) 1 : 2 (d) $1 : \sqrt{3}$

37. The magnetic lines of force relevant to horizontal component of Earth's magnetic field will be

(a) Circular (b) Elliptical
(c) Convergent
(d) Horizontal and parallel

38. A compass needle which is allowed to move in a horizontal plane is taken to a geomagnetic pole. It

(a) will become rigid showing no movement
(b) will stay in any position
(c) will stay in north-south direction only
(d) will stay in east-west direction only

39. A line passing through places having zero value of magnetic dip is called

(a) Isoclinic line (b) Agonic line
(c) Isogonic line (d) Aclinic line.

40. The angle which the total magnetic field of earth makes with the surface of the earth is called

(a) declination (b) magnetic meridian
(c) geographic meridian (d) inclination

41. Which of the following is responsible for the earth's magnetic field?

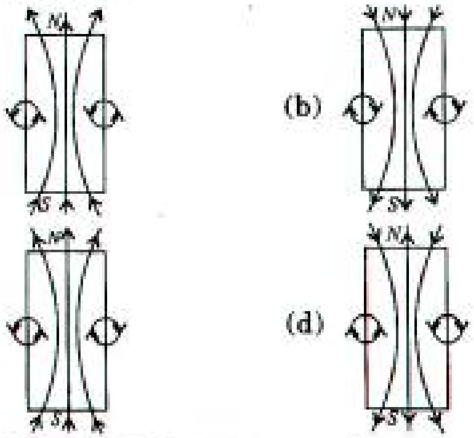
(a) Convective currents in earth's core.
(b) Diversive current in earth's core.
(c) Rotational motion of earth.
(d) Translational motion of earth.

42. If the horizontal component of the earth's magnetic field is 0.30 G, and the dip angle is 60° at a given place, then the value of earth's total magnetic field is

(a) 0.15 G (b) $0.15\sqrt{3}$ G
(c) $0.15\sqrt{2}$ G (d) 0.60 G

43. Choose the correct figure showing the direction of lines of magnetic induction due to a bar magnet.

(a) (b)
(c) (d)



44. Which of the following statements is not correct about the magnetic field?

(a) The magnetic lines form a closed loop.
(b) Inside the magnet, the magnetic lines go from north to south pole of the magnet.
(c) Magnetic lines of force do not intersect each other.
(d) Tangents to the magnetic lines of force give the direction of the magnetic field.

45. A circular coil of magnetic moment 0.355 J T^{-1} rests with its plane normal to an external field of magnitude 5.0×10^{-2} T. The coil is free to turn about an axis in its plane perpendicular to the field direction. When the coil is turned slightly and released, it oscillates about its stable equilibrium with a frequency of 2 Hz. The moment of inertia of the coil about its axis of rotation is

(a) 1.13×10^{-1} kg m^2 (b) 1.13×10^{-2} kg m^2
(c) 1.13×10^{-3} kg m^2 (d) 1.13×10^{-4} kg m^2

46. If $B_H = 4 \times 10^{-5}$ T and $B_V = 2 \times 10^{-5}$ T, then the Earth's total field at the place is (in T)

(a) 6×10^{-5} T (b) $2\sqrt{5} \times 10^{-5}$ T
(c) 4×10^{-5} T (d) 3×10^{-5} T

47. A magnetic dipole is under the influence of two magnetic fields. The angle between the field directions is 60° and one of the fields has a magnitude of 1.2×10^{-2} T. If the dipole comes to stable equilibrium at an angle of 30° with this field, then the magnitude of the field is

(a) 1.2×10^{-4} T (b) 2.4×10^{-2} T
(c) 1.2×10^{-2} T (d) 2.4×10^{-2} T

48. A vector needs three quantities for its specification. Which of the following independent quantities is not used to specify the earth's magnetic field?

(a) Magnetic declination (θ).
(b) Magnetic dip (δ).
(c) Horizontal component of earth's field (B_H).
(d) Vertical component of earth's field (B_V).

49. A dip circle is at right angles to the magnetic meridian. The apparent dip will be

(a) 0° (b) 30° (c) 60° (d) 90°

50. The angle of dip at a certain place on earth is 60° and the magnitude of earth's horizontal component of magnetic field is 0.26 G. The magnetic field at the place on earth is

(a) 0.13 G (b) 0.26 G (c) 0.52 G (d) 0.65 G

51. If μ_e and μ_p denote magnetic momentum of electron and proton, then

(a) $\mu_e >> \mu_p$ (b) $\mu_e << \mu_p$
(c) $\mu_e = \mu_p$ (d) $\mu_e \propto 1/\mu_p$

52. The angle which the total magnetic field of earth makes with the surface of the earth is called

(a) declination
(b) magnetic meridian
(c) geographic meridian
(d) inclination

53. Angle between magnetic meridian and geographical meridian is called

(a) angle of dip
(b) angle of declination
(c) angle of depression
(d) both (a) and (b)

54. A dip needle in a plane perpendicular to magnetic meridian will remain

(a) Vertical
(b) Horizontal
(c) In any direction
(d) At an angle of dip to the horizontal

55. If a magnet is suspended at angle 30° to the magnetic meridian, it makes an angle of 45° with the horizontal. The real dip is

(a) $\tan^{-1}\left(\frac{\sqrt{3}}{2}\right)$ (b) $\tan^{-1}\sqrt{3}$

(c) $\tan^{-1}\left(\sqrt{\frac{3}{2}}\right)$ (d) $\tan^{-1}\left(\frac{2}{\sqrt{3}}\right)$

56. A magnetised thin rod of length L and magnetic moment M is bent in the form of a semicircle. Its new magnetic moment will be

(a) M (b) $2M/\pi$ (c) M/π (d) $M\pi$

57. The lines joining the places of the same horizontal intensity are known as

(a) Isogonic lines (b) Agonic line
(c) Isoclinic lines (d) Isodynamic lines.

58. Ratio between total intensity of magnetic field at equator to poles is

(a) 1 : 1 (b) 1 : 2 (c) 2 : 1 (d) 1 : 4

59. A magnetic field of Earth can be modelled by that of a point dipole placed at the centre of the Earth. The dipole axis makes an angle of 11.3° with the axis of Earth. At Mumbai, declination is nearly zero. Then,

(a) the declination varies between 11.3° W to 11.3°E.
(b) the least declination is 0°.
(c) the plane defined by dipole axis and Earth axis passes through Greenwich.
(d) declination averaged over Earth must be always negative.

60. A current carrying loop placed in a magnetic field behaves like a

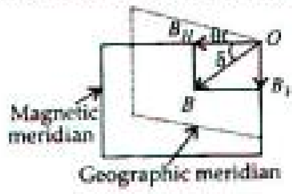
(a) Magnetic dipole (b) Magnetic substance
(c) Magnetic pole (d) All are true

Case Based MCQs

Case I : Read the passage given below and answer the following questions from 61 to 65.

Elements of the Earth's Magnetic Field

The earth's magnetic field at a point on its surface is usually characterised by three quantities : (a) declination (b) inclination or dip and (c) horizontal component of the field. These are known as the elements of the earth's magnetic field. At a place, angle between geographic meridian and magnetic meridian is defined as magnetic declination, whereas angle made by the earth's magnetic field with the horizontal in magnetic meridian is known as magnetic dip.



61. In a certain place, the horizontal component of magnetic field is $\frac{1}{\sqrt{3}}$ times the vertical component. The angle of dip at this place is
(a) zero (b) $\pi/3$ (c) $\pi/2$ (d) $\pi/6$

62. The angle between the true geographic north and the north shown by a compass needle is called as
(a) inclination
(b) magnetic declination
(c) angle of meridian
(d) magnetic pole.

63. The angles of dip at the poles and the equator respectively are
(a) 30°, 60° (b) 0°, 90° (c) 45°, 90° (d) 90°, 0°

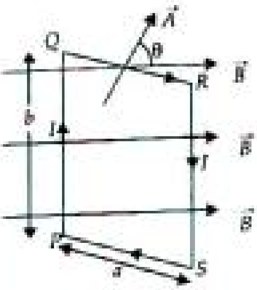
64. A compass needle which is allowed to move in a horizontal plane is taken to a geomagnetic pole. It
(a) will become rigid showing no movement
(b) will stay in any position
(c) will stay in north-south direction only
(d) will stay in east-west direction only.

65. Select the correct statement from the following.
(a) The magnetic dip is zero at the centre of the earth.
(b) Magnetic dip decreases as we move away from the equator towards the magnetic pole.
(c) Magnetic dip increases as we move away from the equator towards the magnetic pole.
(d) Magnetic dip does not vary from place to place.

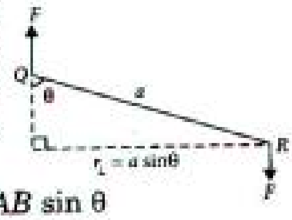
Case II : Read the passage given below and answer the following questions from 66 to 70.

Torque on a Rectangular Loop Placed in Uniform Magnetic Field

When a rectangular loop $PQRS$ of sides 'a' and 'b' carrying current I is placed in uniform magnetic field $\vec{B}$, such that area vector $\vec{A}$ makes an angle θ with direction of magnetic field, then forces on the arms QR and SP of loop are equal, opposite and collinear, thereby perfectly cancel each other, whereas forces on the arms PQ and RS of loop are equal and opposite but not collinear, so they give rise to torque on the loop.



Force on side PQ or RS of loop is $F = IbB \sin 90° = Ib\,B$ and perpendicular distance between two non-collinear forces is $r_\perp = a \sin\theta$



So, torque on the loop, $\tau = IAB \sin\theta$

In vector form torque, $\vec{\tau} = \vec{M} \times \vec{B}$

where $\vec{M} = NI\vec{A}$ is called magnetic dipole moment of current loop and is directed in direction of area vector $\vec{A}$ *i.e.*, normal to the plane of loop.

66. A circular loop of area 1 cm², carrying a current of 10 A is placed in a magnetic field of 0.1 T perpendicular to the plane of the loop. The torque on the loop due to the magnetic field is
(a) zero (b) 10^{-4} N m
(c) 10^{-2} N m (d) 1 N m

67. Relation between magnetic moment and angular velocity is
(a) $M \propto \omega$ (b) $M \propto \omega^2$
(c) $M \propto \sqrt{\omega}$ (d) none of these

68. A current loop in a magnetic field
(a) can be in equilibrium in two orientations, both the equilibrium states are unstable
(b) can be in equilibrium in two orientations, one stable while the other is unstable
(c) experiences a torque whether the field is uniform or non uniform in all orientations
(d) can be in equilibrium in one orientation.

69. The magnetic moment of a current I carrying circular coil of radius r and number of turns N varies as

(a) $\frac{1}{r^2}$ (b) $\frac{1}{r}$ (c) r (d) r^2

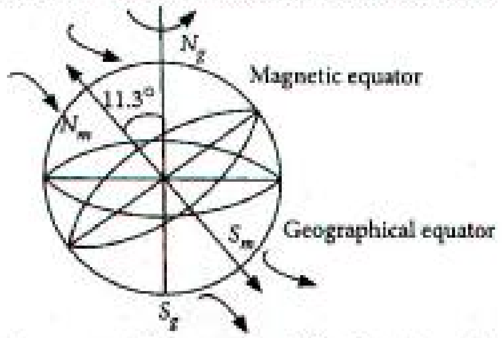
70. A rectangular coil carrying current is placed in a non-uniform magnetic field. On that coil the total

(a) force is non-zero (b) force is zero
(c) torque is zero (d) none of these

Case III : Read the passage given below and answer the following questions from 71 to 75.

Earth's Magnetic Field

The magnetic field lines of the earth resemble that of a hypothetical magnetic dipole located at the centre of the earth. The axis of the dipole is presently tilted by approximately 11.3° with respect to the axis of rotation of the earth.



The pole near the geographic North pole of the earth is called the North magnetic pole and the pole near the geographic South pole is called South magnetic pole.

71. The strength of the earth's magnetic field varies from place to place on the earth's surface, its value being of the order of

(a) 10^5 T (b) 10^{-6} T (c) 10^{-5} T (d) 10^8 T

72. A bar magnet is placed North-South with its North-pole due North. The points of zero magnetic field will be in which direction from centre of magnet?

(a) North-South (b) East-West
(c) North-East and South-West
(d) None of these.

73. The value of angle of dip is zero at the magnetic equator because on it

(a) V and H are equal
(b) the values of V and H zero
(c) the value of V is zero
(d) the value of H is zero.

74. The angle of dip at a certain place, where the horizontal and vertical components of the earth's magnetic field are equal, is

(a) 30° (b) 90° (c) 60° (d) 45°

75. At a place, angle of dip is 30°. If horizontal component of earth's magnetic field is H, then the total intensity of magnetic field will be

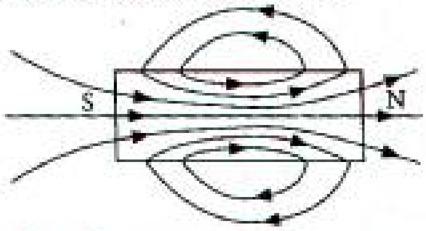
(a) $\frac{H}{2}$ (b) $\frac{2H}{\sqrt{3}}$ (c) $H\sqrt{\frac{3}{2}}$ (d) $2H$

Case IV : Read the passage given below and answer the following questions from 76 to 80.

Gauss's Law for Magnetism

By analogy to Gauss's law of electrostatics, we can write Gauss's law of magnetism as $\oint \vec{B}\cdot d\vec{s} = \mu_0 m_{\text{inside}}$ where $\oint \vec{B}\cdot d\vec{s}$ is the magnetic flux and m_{inside} is the net pole strength inside the closed surface.

We do not have an isolated magnetic pole in nature. At least none has been found to exist till date. The smallest unit of the source of magnetic field is a magnetic dipole where the net magnetic pole is zero. Hence, the net magnetic pole enclosed by any closed surface is always zero. Correspondingly, the flux of the magnetic field through any closed surface is zero.



76. Consider the two idealised systems

(i) a parallel plate capacitor with large plates and small separation and
(ii) a long solenoid of length $L >> R$, radius of cross-section.

In (i) $\vec{E}$ is ideally treated as a constant between plates and zero outside. In (ii) magnetic field is constant inside the solenoid and zero outside. These idealised assumptions, however, contradict fundamental laws as below

(a) case (i) contradicts Gauss's law for electrostatic fields.
(b) case (ii) contradicts Gauss's law for magnetic fields.
(c) case (i) agrees with $\oint \vec{E}\cdot d\vec{l} = 0$.
(d) case (ii) contradicts $\oint \vec{H}\cdot d\vec{l} = I_{en}$.

77. The net magnetic flux through any closed surface, kept in a magnetic field is

(a) zero (b) $\frac{\mu_0}{4\pi}$ (c) $4\pi\mu_0$ (d) $\frac{4\mu_0}{\pi}$

78. A closed surface S encloses a magnetic dipole of magnetic moment $2ml$. The magnetic flux emerging from the surface is

(a) $\mu_0 m$ (b) zero (c) $2\mu_0 m$ (d) $\frac{2m}{\mu_0}$

79. Which of the following is not a consequence of Gauss's law?

(a) The magnetic poles always exist as unlike pairs of equal strength.
(b) If several magnetic lines of force enter in a closed surface, then an equal number of lines of force must leave that surface.
(c) There are abundant sources or sinks of the magnetic field inside a closed surface.
(d) Isolated magnetic poles do not exist.

80. The surface integral of a magnetic field over a surface

(a) is proportional to mass enclosed
(b) is proportional to charge enclosed
(c) is zero
(d) equal to its magnetic flux through that surface.

Assertion & Reasoning Based MCQs

For question numbers 81-95, two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.

(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is NOT the correct explanation of A
(c) A is true but R is false
(d) A is false and R is also false

81. **Assertion (A) :** Magnetic moment of an atom is due to both, the orbital motion and spin motion of every electron.

Reason (R) : A charged particle produces a magnetic field.

82. **Assertion (A) :** The earth's magnetic field is due to iron present in its core.

Reason (R) : At a low temperature magnet losses its magnetic property or magnetism.

83. **Assertion (A) :** The ends of a magnet suspended freely point out always along north south.

Reason (R) : Earth behaves as a huge magnet.

84. **Assertion (A) :** A compass needle when placed on the magnetic north pole of the earth rotates in vertical direction.

Reason (R) : The earth has only horizontal component of its magnetic field at the north poles.

85. **Assertion (A) :** At neutral point, a compass needle point out in any arbitrary direction.

Reason (R) : Magnetic field of earth is balanced by field due to magnets at the neutral points.

86. **Assertion (A) :** Magnetic moment is measured in joule/tesla or amp m^2.

Reason (R) : Joule/tesla is equivalent to amp m^2.

87. **Assertion (A) :** Earth's magnetic field does not affect the working of a moving coil galvanometer.

Reason (R) : The earth's magnetic field is quite weak as compared to magnetic field produced in the moving coil galvanometer.

88. **Assertion (A) :** Aclinic lines on the magnetic map represents lines of equal dip.

Reason (R) : When the horizontal and vertical components of the earth's magnetic field are equal, the angle of dip is 60°.

89. **Assertion (A) :** The true geographic north direction is found by using a compass needle.

Reason (R) : The magnetic meridian of the earth is along the axis of rotation of the earth.

90. **Assertion (A) :** There is only one neutral points on a horizontal board when a magnet is held vertically on the board.

Reason (R) : At the neutral point the net magnetic field due to the magnet and magnetic field of the earth is zero.

91. **Assertion (A) :** When radius of a circular loop carrying current is doubled, its magnetic moment becomes four times.

Reason (R) : Magnetic moment depends on area of the loop.

92. **Assertion (A) :** A planar circular loop of area A and carrying current I is equivalent to magnetic dipole of dipole moment $M = IA$.

Reason (R) : At large distances, magnetic field of circular loop and magnetic dipole is same.

93. **Assertion (A) :** The magnetic poles of earth do not coincide with the geographic poles.

Reason (R) : The discrepancy between the orientation of a compass and true north-south direction is known as magnetic declination.

94. **Assertion (A) :** The magnetic field lines of the earth resemble that of a magnetic dipole located at the centre of the earth.

Reason (R) : The axis of the dipole coincide with the axis of rotation of the earth.

95. **Assertion (A) :** Gauss's law of magnetism is different from that for electrostatics.

Reason (R) : Isolated magnetic poles are not known to exist.

ANSWERS

1. **(b)**

2. **(a) :** Since a bar magnet and a corresponding solenoid produce similar magnetic fields. Hence the magnetic moment of a bar magnet is equal to the magnetic moment of an equivalent solenoid that produces the same magnetic field.

3. **(d) :** The magnetic moment of electron is $M = \frac{e}{2m_0} \times l$

where l = angular momentum $= \frac{nh}{2\pi}$; $\therefore M \propto n$

4. **(c) :** Here, $N = 900$ turns, $A = 2 \times 10^{-4}$ m^2, $m_s = 0.6$ A m^2

The magnetic moment of solenoid

$m_s = NIA$

The current flowing through the solenoid is

$$I = \frac{m_s}{NA} = \frac{0.6}{900 \times 2 \times 10^{-4}} = 3.33 \text{ A}$$

5. **(d) :** The strength of the earth's magnetic field is not constant. It varies from one place to other place on the surface of earth. Its value being of the order of 10^{-5} T.

6. **(a) :** Here, $B_E = 0.4$ G $= 0.4 \times 10^{-4}$ T

$r = 6.4 \times 10^6$ m

As $B_E = \frac{\mu_0}{4\pi} \frac{m}{r^3}$

$$\therefore \quad m = \frac{B_E r^3}{\mu_0 / 4\pi}$$

$$= \frac{0.4 \times 10^{-4} \times (6.4 \times 10^6)^3}{10^{-7}} = 1.05 \times 10^{23} \text{ A m}^2.$$

7. **(a) :** Here, $H_E = 0.25$ G and $\delta = 60°$

$$\because \quad \cos\delta = \frac{H_E}{B_E}$$

$\therefore$ The magnetic field of earth at the given location is

$$B_E = \frac{H_E}{\cos 60°} = \frac{0.25}{1/2} = 0.50 \text{ G}$$

8. **(a) :** Here, radius, $r = 10$ cm $= 10 \times 10^{-2}$ m

Number of turns, $N = 100$

Current, $I = 1$ A

Area of the coil, $A = \pi r^2$

Magnetic moment of the coil, $M = NIA = NI\pi r^2$

$= 100 \times 1 \times 3.142 \times (10 \times 10^{-2})^2$ A m^2 $= 3.142$ A m^2

9. **(b)**

10. **(b) :** When a current loop is placed in a magnetic field it experiences a torque. It is given by $\vec{\tau} = \vec{M} \times \vec{B}$

where $\vec{M}$ is the magnetic moment of the loop and $\vec{B}$ is the magnetic field.

or $\tau = MB \sin\theta$ where θ is angle between M and B

When $\vec{M}$ and $\vec{B}$ are parallel (*i.e.* $\theta = 0°$) the equilibrium is stable and when they are antiparallel (*i.e.* $\theta = \pi$) the equilibrium is unstable.

11. **(a) :** Magnetic moment, $M = IA = I(\pi r^2) = \frac{q}{T} \times \pi r^2$

As $\quad \omega = \frac{2\pi}{T} \quad \therefore \quad M = \frac{q\omega r^2}{2} \quad$ or $\quad M \propto \omega$

12. **(c) :** Here, $\vec{B} = 0.2\hat{i}$ T; $I = 15$ A; $N = 12$;

$\vec{A} = -0.04\hat{i}$ m^2

Magnetic moment of the coil

$\vec{M} = NI\vec{A} = (12)(15\text{ A})(-0.04\hat{i}\text{ m}^2) = -7.2\hat{i}$ A m^2

The potential energy of the coil in the given orientation is

$U = -\vec{M} \cdot \vec{B} = -(-7.2\hat{i}\text{ A m}^2)\cdot(0.2\hat{i}\text{ T}) = +1.44$ J

13. **(d) :** The magnetic field lines due to a bar magnet are closed continuous curves directed from N to S outside the magnet and directed from S to N inside the magnet. Hence option (d) is correct.

14. **(a) :** $L = \frac{nh}{2\pi}$; $\mu = \frac{eL}{2m}$; $\therefore \mu = \frac{neh}{4\pi m}$ or $\mu \propto n$

Clearly μ versus n graph will be a straight line.

15. **(a) :** Magnetic dipole moment of the electron in the 1st orbit is $M = \frac{eh}{4\pi m}$ ...(i)

Angular momentum of the electron in the 1st orbit is

$$L = \frac{h}{2\pi} \quad \text{...(ii)}$$

Divide (i) by (ii), we get, $\frac{M}{L} = \frac{eh}{4\pi m} \times \frac{2\pi}{h} = \frac{e}{2m}$

16. **(a) :** An orbiting electron behaves as a current loop. The current due to motion of electron is

$$I = \frac{e}{T} = \frac{e}{(2\pi r / v)} = \frac{ev}{2\pi r}$$

Area of the loop, $A = \pi r^2$

$\therefore$ Magnetic moment $= IA = \frac{ev}{2\pi r}\pi r^2 = \frac{evr}{2}$

17. (d) : Let r be the radius of the circular loop.

$\therefore \quad A = \pi r^2 \quad$ or $\quad r = \sqrt{\frac{A}{\pi}}$

Magnetic field at the centre of the loop is

$$B = \frac{\mu_0 I}{2r} = \frac{\mu_0 I}{2\sqrt{\frac{A}{\pi}}} \quad \text{or} \quad I = \frac{2B}{\mu_0}\sqrt{\frac{A}{\pi}}$$

The magnetic moment of the loop is

$$M = IA = \frac{2B}{\mu_0}\sqrt{\frac{A}{\pi}}A = \frac{2BA\sqrt{A}}{\mu_0\sqrt{\pi}}$$

18. (a) : As Britain is located close to North pole hence dip angle in Britain is greater and its approximate value is $\delta = 70°$.

19. (b) : Here, $N = 100$

$r = 10$ cm $= 10 \times 10^{-2}$ m $= 0.1$ m, $I = 3.2$ A

Magnetic moment of the coil,

$M = NIA = 100 \times 3.2 \times \pi r^2$

$= 100 \times 3.2 \times 3.14 \times (0.1)^2 = 10$ A m^2

20. (c) : Magnetic moment of the loop

$M = NIA = 2000 \times 2 \times 1.5 \times 10^{-4} = 0.6$ J/T

Torque $\tau = MB\sin 30° = 0.6 \times 5 \times 10^{-2} \times \frac{1}{2}$

$= 1.5 \times 10^{-2}$ N m

21. (d) : Here, $n = 750$ turns, $A = 5 \times 10^{-4}$ m^2, $I = 3$ A

Then, magnetic moment

$m = nIA = 750 \times 3 \times 5 \times 10^{-4} = 11250 \times 10^{-4}$

$= 1.125$ J T^{-1} along the axis of solenoid.

22. (d) : Here, $n = 25$ turns, $r = 12$ cm, $B = 0.5$ T

Since the coil is placed in uniform magnetic field normal to the plane of the coil.

Hence the angle between magnetic moment and magnetic field direction is zero (*i.e.* $\theta = 0°$)

$\tau = mB\sin\theta = mB\sin 0° \quad \Rightarrow \quad \tau = 0$

23. (a) : Magnetic field at the centre of a circular loop of radius R carrying current I is

$$B = \frac{\mu_0 2\pi I}{4\pi R} = \frac{\mu_0 I}{2R}$$

Its magnetic moment is $M = IA = I(\pi R^2)$

$$\therefore \quad \frac{B}{M} = \frac{\mu_0 I}{2R} \times \frac{1}{I\pi R^2} = \frac{\mu_0}{2\pi R^3} = x \qquad \text{[Given]}$$

When both, the current and radius, are doubled, the ratio becomes $\frac{B'}{M'} = \frac{\mu_0}{2\pi(2R)^3} = \frac{1}{8}\left(\frac{\mu_0}{2\pi R^3}\right) = \frac{x}{8}$

24. (c) : Given $B_H = B\cos\theta = 3$ G, $\theta = 30°$

$$B = \frac{B_H}{\cos 30°} = \frac{3}{\sqrt{3}/2} = 2\sqrt{3} = 3.5 \text{ G}$$

25. (b) : Since $B_H = B\cos\delta$

Here, $B = 4 \times 10^{-5}$ T, $B_H = 2 \times 10^{-5}$ T

$$\therefore \cos\delta = \frac{B_H}{B} = \frac{2 \times 10^{-5}}{4 \times 10^{-5}} = \frac{1}{2} = \cos 60°$$

$\Rightarrow \quad \delta = 60°$

26. (d) : Since angle of dip at a place is defined as the angle δ, which is the direction of total intensity of earth's magnetic field B makes with a horizontal line in magnetic meridian,

At poles $B = B_V$ and $B_V = B\sin\delta \quad \therefore \quad \sin\delta = 1 \Rightarrow \delta = 90°$

At equator $B = B_H$ and $B_H = B\cos\delta \quad \therefore \quad \cos\delta = 1 \Rightarrow \delta = 0°$.

27. (b) : Potential energy, $U = -\vec{M}\cdot\vec{B} = -MB\cos\theta$

(1) $U = -MB\cos 180° = MB$

(2) $U = -MB\cos 90° = 0$

(3) $U = -MB\cos\theta$

(4) $U = +MB\cos\theta$

28. (c) : Given, $H = 4 \times 10^{-4}$ T, $\delta = 30°$

As $V = H\tan\delta = 4 \times 10^{-4} \times \tan 30° = 2.3 \times 10^{-4}$ T

29. (a) : Due to motion of ions in earth's ionosphere, the earth's magnetic field gets modified.

30. (a) : At neutral point, magnetic field due to magnet is equal and opposite to magnetic field due to Earth. One neutral point will be obtained when a magnet is held vertical.

31. (d) : Intensity of magnetic field inside a steel box is zero. No magnetic lines of force pass through the box.

32. (c) : Here, $N = 100$, $r = 10$ cm $= 0.10$ m, $I = 5$ A, $B = 0.5$ T,

$\theta = 90° - 60° = 30°$

Area of the coil, $A = \pi r^2 = 3.14 \times (0.1)^2$

$\tau = NIBA\sin\theta$

$= 100 \times 5 \times 0.5 \times 3.14 \times (0.1)^2 \times \sin 30° = 3.931$ N m

33. (b) : Here, $B_V = \frac{\mu_0}{4\pi}\frac{2m\cos\theta}{r^3}$

$B_H = \frac{\mu_0}{4\pi}\frac{m\sin\theta}{r^3}$ and $\delta = 45°$

$\therefore \quad \tan\delta = \frac{B_V}{B_H}$

Hence, $\tan 45° = \frac{2\cos\theta}{\sin\theta} = 2\cot\theta$

$\therefore \quad 1 = \frac{2}{\tan\theta} \Rightarrow \tan\theta = 2$

or $\theta = \tan^{-1}(2)$ is the loci of points.

34. (b) : As Melbourne is situated in southern hemisphere where north pole of earth's magnetic field lies therefore magnetic lines of force seem to come out of the ground.

35. (d) : Here, $B_H = 0.3$ G ; $B_V = 0.52$ G

The earth's magnetic field

$$B = \sqrt{B_H^2 + B_V^2} = \sqrt{(0.3)^2 + (0.52)^2} = \sqrt{0.09 + 0.2704}$$

$$= \sqrt{0.3604} = 0.6 \text{ G}$$

and angle of dip $\tan\delta = \frac{B_V}{B_H} = \frac{0.52}{0.3} = 1.734$

$\delta = \tan^{-1}(1.734) = 60°$

36. (a) : Horizontal component, $B_H = B_e\cos\theta$

$\therefore \quad B_{H_1} = B_e\cos30°$ and $B_{H_2} = B_e\cos45°$

Thus, $\frac{B_{H_1}}{B_{H_2}} = \frac{\cos30°}{\cos45°} = \frac{\frac{\sqrt{3}}{2}}{\frac{1}{\sqrt{2}}} = \frac{\sqrt{3}}{\sqrt{2}}$

37. (d) : Horizontal component is a uniform magnetic field. It is represented by horizontal and parallel magnetic lines of force.

38. (b) : A compass needle which is allowed to move in a horizontal plane is taken to a geomagnetic pole. It will stay in any position as the horizontal component of earth's magnetic field becomes zero at the geomagnetic pole.

39. (d) : Aclinic line joins places of zero angle of dip.

40. (d) : The angle which the total magnetic field of the earth makes with the surface of the earth is called inclination or angle of dip.

41. (a) : The earth's core is hot and molten. Hence, convective current in earth's core is responsible for it's magnetic field.

42. (d) : $B_H = 0.30$ G, $\delta = 60°$

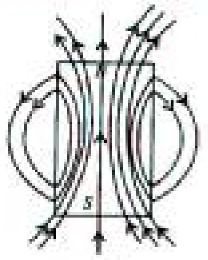
Let earth's total magnetic field = R

Then, $R\cos\delta = B_H$

$\Rightarrow \quad R = \frac{B_H}{\cos\delta} = \frac{0.30}{\cos60°} = 0.60\ \text{G}$

43. (c) : Lines of magnetic induction B are continuous curves which run continuously through the bar and out side from south to north pole. Hence figure (c) is a correct representation.

44. (b) : The direction of magnetic line of force of a bar magnet from south to north pole inside the magnet and from north to south outside the magnet.



45. (d) : Here, $M = 0.355\ \text{J T}^{-1}$

$B = 5.0 \times 10^{-2}$ T

$\upsilon = 2$ Hz

As $\quad \upsilon = \frac{1}{2\pi}\sqrt{\frac{MB}{I}} \quad \therefore \quad \upsilon^2 = \frac{1}{4\pi^2}\frac{MB}{I}$

$\Rightarrow \quad I = \frac{MB}{4\pi^2\upsilon^2} = \frac{0.355\times5\times10^{-2}}{4\times(3.14)^2\times2^2} = \frac{1775\times10^{-2}}{157.75}$

$= 1.13 \times 10^{-4}$ kg m^2

46. (b) : Given : $B_H = 4 \times 10^{-5}$ T, $B_V = 2 \times 10^{-5}$ T

The total earth's magnetic field B at the given place is

$B = \sqrt{B_V^2 + B_H^2}$

$= (\sqrt{4^2 + 2^2}) \times 10^{-5}\ \text{T} = \sqrt{20} \times 10^{-5}\ \text{T} = 2\sqrt{5} \times 10^{-5}\ \text{T}$

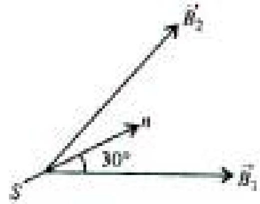
47. (c) : Here, $\theta = 60°$, $B_1 = 1.2 \times 10^{-2}$ T

$\theta_1 = 30°$ and $\theta_2 = 60° - 30° = 30°$

in stable equilibrium, torques due to two fields must be balanced

i.e. $\tau_1 = \tau_2$

$\Rightarrow \quad MB_1 \sin\theta_1 = MB_2 \sin\theta_2$



or $\quad B_2 = B_1\frac{\sin\theta_1}{\sin\theta_2}$

$= B_2\frac{\sin30°}{\sin30°} = B_1$

$= 1.2 \times 10^{-2}$ T

48. (d) : Vertical component of earth's field (B_v) is not used to specify the earth's magnetic field.

49. (d) : The apparent dip is 90° when a dip circle is at right angles to magnetic meridian.

50. (c) : Horizontal component of the earth's magnetic field, $B_H = 0.26$ G

Angle of dip, $\delta = 60°$

$\cos\delta = \frac{B_H}{B_E}$ where B_E is the magnetic field of the earth

$\therefore \quad B_E = \frac{B_H}{\cos\delta} = \frac{0.26\ \text{G}}{\cos60°} = \frac{0.26\ \text{G}}{(1/2)} = 0.52\ \text{G}$

51. (a) : Since

$\mu_e = \frac{e\hbar}{2m_e}$ and $\mu_p = \frac{e\hbar}{2m_p}$

then the ratio $\frac{\mu_p}{\mu_e} = \frac{m_e}{m_p}$

as $\quad m_e << m_p$

so $\quad \mu_p << \mu_e \quad \Rightarrow \quad \mu_e >> \mu_p$

52. (d) : The angle which the total magnetic field of the earth makes with the surface of the earth is called inclination or angle of dip.

53. (b) : Angle between magnetic meridian and geographical meridian is known as angle of declination or magnetic declination.

54. (a) : In a plane perpendicular to magnetic meridian, a dip needle remains vertical. Angle of dip is 90°.

55. (a) : $\tan\theta = \frac{B_v}{B_H}$ where θ denotes real dip.

Let ϕ denote apparent dip,

α = Angle with magnetic meridian

$$\tan\phi = \frac{B_V}{B_H \times \cos\alpha} = \frac{B_V}{B_H \times \cos 30^\circ} = \frac{2B_V}{B_H \times \sqrt{3}}$$

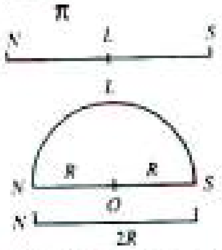
$$\Rightarrow \tan 45^\circ = \frac{2}{\sqrt{3}} \tan\theta \Rightarrow \theta = \tan^{-1}\left(\frac{\sqrt{3}}{2}\right).$$

56. **(b)** : Circumference

$= 2\pi R$,

Semi-circumfrence $= \pi R$

$L = \pi R \Rightarrow R = \frac{L}{\pi}$



New magnetic moment $= m \times 2R$

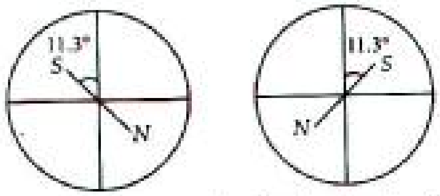
$$M' = \frac{M}{L}\frac{2L}{\pi} = \frac{2M}{\pi}$$

57. **(d)** : Isodynamic lines join places of same horizontal intensity of Earth's magnetic field.

58. **(a)** : Total intensity of Earth's magnetic field does not change from place to place. It is same at equator as at poles.

Ratio $= \frac{I_{eq}}{I_p} = \frac{1}{1}$

59. **(a)** :



Since the axis of the magnetic dipole placed at the centre of earth makes an angle of 11.3° with the axis of earth, the two possibilities arise as shown in above figure. Hence, the declination varies between 11.3° W to 11.3° E.

60. **(a)** : A current carrying loop, placed in a magnetic field behaves like a magnetic dipole. The magnetic field acts along the axis of the coil.

61. **(b)** : $\tan\theta = \frac{B_V}{B_H}$ and $B_H = \frac{B_V}{\sqrt{3}}$

$\therefore\ \tan\theta = \sqrt{3}$ *i.e.*, $\theta = \frac{\pi}{3}$

62. **(b)** : The angle between the true geographic north and the north shown by a compass needle is called as magnetic declination or simply declination.

63. **(d)** : Since angle of dip at a place is defined as the angle δ, which is the direction of total intensity of earth's magnetic field B makes with a horizontal line in magnetic meridian, At poles $B = B_V$ and $B_V = B\sin\delta\ \therefore\ \sin\delta = 1 \Rightarrow \delta = 90^\circ$

At equator $B = B_H$ and $B_H = B\cos\delta$

$\therefore\ \cos\delta = 1 \Rightarrow \delta = 0^\circ$.

64. **(a)** : A compass needle which is allowed to move in a horizontal plane is taken to a geomagnetic pole. It will stay in any position as the horizontal component of earth's magnetic field becomes zero at the geomagnetic pole.

65. **(c)** : At equator, $\delta = 0^\circ$

At poles, $\delta = 90^\circ$

$\therefore$ δ increases as we move from equator towards poles.

66. **(a)** : Torque on a current carrying loop in magnetic field,

$\tau = IBA\sin\theta$

Here, $I = 10$ A, $B = 0.1$ T, $A = 1\text{ cm}^2 = 10^{-4}\text{ m}^2$, $\theta = 0^\circ$

$\therefore\quad \tau = 10 \times 0.1 \times 10^{-4}\sin 0^\circ = 0$

67. **(a)** : Magnetic moment, $M = IA = I(\pi r^2) = \frac{q}{T} \times \pi r^2$

As $\omega = \frac{2\pi}{T}\quad \therefore\quad M = \frac{q\omega r^2}{2}$ or $M \propto \omega$

68. **(b)**: When a current loop is placed in a magnetic field it experiences a torque. It is given by

$\vec{\tau} = \vec{M} \times \vec{B}$

where $\vec{M}$ is the magnetic moment of the loop and $\vec{B}$ is the magnetic field.

or $\tau = MB\sin\theta$ where θ is angle between M and B

When $\vec{M}$ and $\vec{B}$ are parallel (*i.e.* $\theta = 0^\circ$) the equilibrium is stable and when they are antiparallel (*i.e.* $\theta = \pi$) the equilibrium is unstable.

69. **(d)** : Magnetic moment, $M = NIA = NI\pi r^2$ *i.e.*, $M \propto r^2$

70. **(a)** **71.** **(c)** **72.** **(b)**

73. **(c)** : At equator vertical component of magnetic fields is zero.

74. **(d)** : Given : $V = H$

$\therefore\ \tan\delta = \frac{V}{H} = 1$ or $\delta = 45^\circ$

75. **(b)**

76. **(b)** : According to Gauss's law in magnetism $\oint \vec{B}\cdot d\vec{S} = 0$, which implies that number of magnetic field lines entering the Gaussian surface is equal to the number of magnetic field lines leaving it. Therefore, case (ii) is not possible.

77. **(a)** : The net magnetic flux through a closed surface will be zero, *i.e.*, $\oint \vec{B}\cdot d\vec{s} = 0$, because there are no magnetic monopoles.

78. **(b)**

79. **(c)** : Gauss's law indicates that there are no sources or sinks of the magnetic field inside a closed surface. In other words, there are no free magnetic charges.

80. **(d)** : The surface integral of a magnetic field over a surface gives magnetic flux through that surface.

81. (c) : In an atom, electrons revolve around the nucleus and as such the circular orbits of electrons may be considered as the small current loops. In addition to orbital motion, an electron has got spin motion also. So the total magnetic moment of electron is the vector sum of its magnetic moments due to orbital and spin motion.

82. (d) : The temperature inside the earth is so high that it is impossible for iron core to behave as a magnet and act as a source of magnetic field. The magnetic field of earth is considered to be due to circulating electric current in the iron (in molten state) and other conducting materials inside the earth.

83. (a) : Earth's magnetic field can be represented as the field of a huge bar magnet. If the magnet is freely suspended its north-pole points towards geographic north pole (really a south magnet pole of earth).

84. (d) : The earth has only vertical component of its magnetic field at the magnetic poles. Since compass needle is only free to rotate in horizontal plane. At north pole the vertical component of earth's field will exert torque on the magnetic needle so as to align it along its direction. As the compass needle can not rotate in vertical plane, it will rest horizontally, when placed on the magnetic north pole of the earth.

85. (a) : A neutral point in the magnetic field of a bar magnet is that point, where the field due to magnet is completely neutralised by the horizontal component of earth's magnetic field. The net horizontal field is zero at such a point. If a compass needle is placed at such a point, it can stay in any position.

86. (a) : Magnetic moment $= \frac{\text{joule}}{\text{tesla}} = \frac{W}{B} = \frac{W}{F/qv}$

$$= \frac{Wqv}{F} = \frac{[ML^2T^{-2}][AT][LT^{-1}]}{[MLT^{-2}]}$$

$= [AL^2] = \text{amp m}^2$

87. (a) : The field magnet used in a moving coil galvanometer is very strong. The earth's magnetic field is quite weak as compared to the magnetic field produced by the field magnet. Practically the coil rotates under the effect of the strong magnetic field due to the field magnet and the weak magnetic field due to the earth does not affect the working of the moving coil galvanometer.

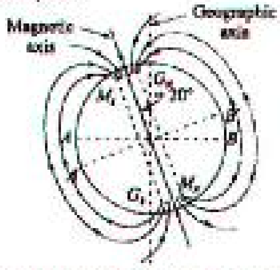
88. (d) : The angle of dip is the angle between the axis of the dip needle in the magnetic meridian and the horizontal direction.

$$\tan\theta = \frac{\text{Vertical component of the earth's magnetic field}}{\text{Horizontal component of the earth's magnetic field}}$$

$= \frac{B_V}{B_H}$. when $B_V = B_H$, $\tan\theta = 1 \Rightarrow \theta = 45°$

Lines joining points of zero dip are called Aclinic lines. Lines joining points of equal dip are called isoclinic lines.

89. (d) : From the compass we are able to know the direction of the magnetic poles. The north of compass points towards the magnetic south pole.



If we know the magnetic declination at that particular place (which is angle between geographic meridian and magnetic meridian) we can easily find out the true geographic north-south direction.

Imaginary lines drawn along the earth's surface in the direction of the horizontal component of the magnetic field of the earth at all points passing through the north and south magnetic poles. This is similar to the longitudes of the earth, which pass through the geographic north and south poles.

90. (b) : There will be only one neutral point on the horizontal board. This is because field of earth magnetic field is from south to north; and the field of pole on the board is radially outwards. At any point towards south of magnetic pole, field of earth and field of pole will cancel out to give a neutral point.

91. (a) : Magnetic dipole moment of the current loop = Ampere turns × Area of the coil or $M = NI\pi r^2$

When radius of the coil becomes double, new magnetic moment will be $M_1 = NI\pi(2r)^2 = 4NI\pi r^2 = 4M$

Hence magnetic moment becomes four times when radius is doubled.

92. (a) : Magnetic field due to a circular loop carrying current I is given as $B = \frac{\mu_0}{4\pi}\frac{2\pi I r^2}{(r^2 + x^2)^{3/2}}$

where, r = radius of loop, x = distance from centre of loop

For large distances, $(x >> r)$. $\therefore$ $B = \frac{\mu_0}{4\pi}\frac{2IA}{x^3} = \frac{\mu_0}{4\pi}\frac{2M}{x^3}$

where $M = IA$ = magnetic dipole moment of current loop which is equal to the magnetic field due to magnetic dipole. Thus, the current loop can be considered as a magnetic dipole.

93. (a)

94. (c) : The magnetic field lines of the earth resemble that of a hypothetical magnetic dipole located at the centre of the earth. The axis of the dipole does not coincide with the axis of rotation of the earth but is presently tilted by approximately 11.3° with respect to the later.

95. (a) : Gauss's law of magnetism is different from that for electrostatics because electric charges do not necessarily exist in pairs but magnetic monopoles do not exist.

☺☺☺

CHAPTER 6

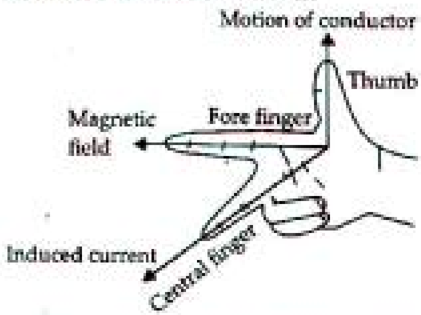
Electromagnetic Induction

Recap Notes

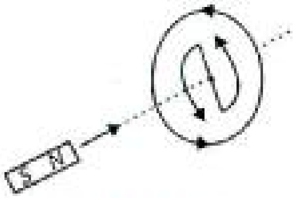
- **Magnetic flux :** The number of magnetic lines of force crossing a surface is known as magnetic flux linked with that surface.

  It is given by $\phi = \vec{B} \cdot \vec{A} = BA\cos\theta$

  where B is the strength of magnetic field, A is the area of surface and θ is the angle between normal to area and field direction.
  - When $\vec{B}$ is perpendicular to the surface *i.e.*, $\theta = 0^\circ$, $\phi = NBA$ (maximum value).
  - When $\vec{B}$ is parallel to the surface *i.e.*, $\theta = 90^\circ$, $\phi = 0$ (minimum value).
  - In case of a coil of area A having N turns $\phi = NBA\cos\theta$
  - Magnetic flux is a scalar quantity. It can be positive, negative or zero.
  - The dimensional formula of magnetic flux is $[ML^2T^{-2}A^{-1}]$.
  - The SI unit of magnetic flux is weber.
  - The CGS unit of magnetic flux is maxwell.
  - 1 weber = 10^8 maxwell
- **Electromagnetic induction :** It is the phenomenon of generating an emf by changing the number of magnetic lines of force (*i.e.*, magnetic flux) associated with the circuit. The emf so generated is known as induced emf. If the circuit is closed the current which flows in it due to induced emf is known as induced current.
- **Faraday's law of electromagnetic induction**
  - **First law :** Whenever the amount of magnetic flux linked with a circuit changes, an emf is induced in the circuit. This induced emf persists as long as the change in magnetic flux continues.
  - **Second law :** The magnitude of the induced emf is equal to the time rate of change of magnetic flux. Mathematically, induced emf is given by $\varepsilon = -\frac{d\phi}{dt}$ where negative sign indicates the polarity of ε.
- **Lenz's law :** This law gives us the direction of induced emf. According to this law, the polarity of induced emf in a circuit is such that it opposes the change in magnetic flux responsible for its production. Lenz's law is in accordance with the principle of conservation of energy.
  - **Fleming's right hand rule :** Fleming's right hand rule also gives us the direction of induced emf or current, in a conductor moving in a magnetic field. According to this rule, if we stretch the fore finger, central finger and thumb of our right hand in mutually perpendicular directions such that fore finger points along the direction of the field and thumb is along the direction of motion of the conductor, then the central finger would give us the direction of induced current or emf.

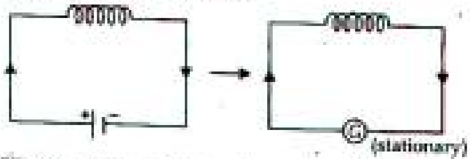


  - **Applications of Lenz's law**
    - When a north pole of a bar magnet is moved towards a coil, the current induced in the coil will be in anticlockwise direction as shown in the figure.

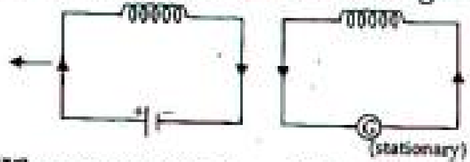


- When a north pole of a bar magnet is moved away from the coil, the current induced in the coil will be in clockwise direction as shown in the figure.

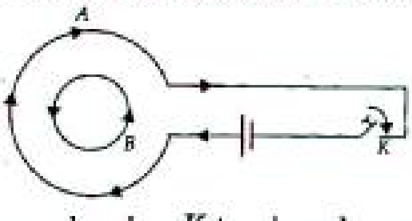
- When a current carrying coil is moved towards a stationary coil, the direction of current induced in stationary coil is as shown in figure.



- When a current carrying coil is moved away from a stationary coil, the direction of current induced in stationary coil is as shown in figure.



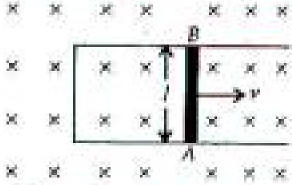
- When two coils A and B are arranged as shown in figure, then on pressing K, current in A increases in clockwise direction. Therefore, induced current in B will be in anticlockwise direction.



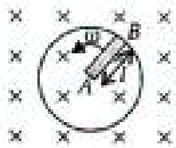
However, when key K is released, current in A decreases in clockwise direction. Therefore, induced current in B will be in clockwise direction.

- When current in a straight conductor AB is increased, induced current in loop will be in clockwise direction as shown in the figure. If current in AB is decreasing, the induced current in the loop will be in anticlockwise direction.

- **Motional emf :** When a conducting rod of length l, moves with a velocity v perpendicular to a uniform magnetic field B, the induced emf across its ends is $|\varepsilon| = Blv$. This emf is known as motional emf.

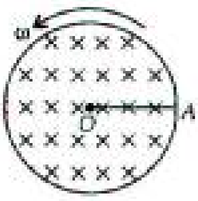


  - If the rod makes an angle θ with the direction of the field, then induced emf is $|\varepsilon| = Blv\sin\theta$
  - When a conducting rod of length l is rotated perpendicular to a uniform magnetic field B, then induced emf between the ends of the rod is $|\varepsilon| = \dfrac{B\omega l^2}{2} = \dfrac{B(2\pi\upsilon)l^2}{2}$



    $|\varepsilon| = B\upsilon(\pi l^2) = B\upsilon A$

    where, ω is angular frequency and υ is frequency of rod, $A = \pi l^2$.
  - When a conducting solid disc of radius r is rotating with a uniform angular velocity ω with its plane perpendicular to a uniform magnetic field B, the emf induced between the centre and rim of disc is



    $$|\varepsilon| = \frac{B\omega r^2}{2} = B\upsilon A$$

- **Eddy currents :** Eddy currents are basically the currents induced in the body of a conductor due to change in magnetic flux linked with the conductor.
  - The direction of eddy currents is given by Lenz's law, or Fleming's right hand rule.
  - According to Lenz's law, eddy currents set up in a metallic conductor flow in such a direction so as to oppose the change in magnetic flux linked with it.
  - Eddy currents cannot be eliminated but can be minimised by
    - laminating the core
    - by taking the metallic core in the form of thin laminated sheets attached together.

- Eddy currents are useful in
  - Electromagnetic damping
  - Induction furnace
  - Electric brakes
  - Speedometers

- **Inductor :** An inductor is a device for storing energy in a magnetic field. An inductor is generally called as inductance. In usual practice a coil or solenoid is treated as inductor. It is denoted by symbol -ᥲᥲᥲ-.
  - **Self induction :** Whenever the current passing through a coil or circuit changes, the magnetic flux linked with it will also change. As a result of this, an emf is induced in the coil or the circuit which opposes the change that causes it. This phenomenon is known as self induction and the emf induced is known as self induced emf or back emf.
    - When a current I flows through a coil and ϕ is the magnetic flux linked with the coil, then $\phi \propto I$ or $\phi = LI$ where L is coefficient of self induction or self inductance of the coil.
    - The self induced emf is $\varepsilon = -\frac{d\phi}{dt} = -L\frac{dI}{dt}$
    - The SI unit of L is henry (H) and its dimensional formula is $[ML^2T^{-2}A^{-2}]$.
    - Self inductance of a solenoid is $L = \mu_0 n^2 lA$ where l is length of the solenoid, n is number of turns per unit length of a solenoid and A is area of cross section of the solenoid.
    - Self inductance of a circular coil is $L = \frac{\mu_0 N^2 \pi R}{2}$ where R is the radius of a coil and N is the number of turns.
  - **Mutual induction :** Whenever the current passing through a coil or circuit changes, the magnetic flux linked with a neighbouring coil or circuit will also change. Hence an emf will be induced in the neighbouring coil or circuit. This phenomenon is known as mutual induction. The coil or circuit in which the current changes is known as primary while the other in which emf is set up is known as secondary.
    - Let I_P be the current flowing through primary coil at any instant. If ϕ_S is the flux linked with secondary coil then $\phi_S \propto I_P$ or $\phi_S = MI_P$ where M is coefficient of mutual inductance of the two coils.
    - The emf induced in the secondary coil is given by $\varepsilon_s = -M\frac{dI_P}{dt}$
    - The SI unit of M is henry (H) and its dimensional formula is $[ML^2T^{-2}A^{-2}]$.
  - **Coefficient of coupling (K) :** Coefficient of coupling of two coils is a measure of the coupling between the two coils and is given by

    $$K = \frac{M}{\sqrt{L_1 L_2}}$$

    where L_1 and L_2 are coefficients of self inductance of the two coils and M is coefficient of mutual inductance of the two coils.
  - The coefficient of mutual inductance of two long co-axial solenoids, each of length l, area of cross section A, wound on air core is

    $$M = \frac{\mu_0 N_1 N_2 A}{l}$$

    where N_1, N_2 are total number of turns of the two solenoid.
  - **Combination of inductances**
    - Two inductors of self-inductances L_1 and L_2 are kept so far apart that their mutual inductance is zero. These are connected in series. Then the equivalent inductance is $L = L_1 + L_2$
    - Two inductors of self-inductance L_1 and L_2 are connected in series and they have mutual inductance M. Then the equivalent inductance of the combination is $L = L_1 + L_2 \pm 2M$
    - The plus sign occurs if windings in the two coils are in the same sense, while minus sign occurs if windings are in opposite sense.
    - Two inductors of self-inductance L_1 and L_2 are connected in parallel. The inductors are so far apart that their mutual inductance is negligible. Then their equivalent inductance is

      $$\frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2} \text{ or } L = \frac{L_1 L_2}{L_1 + L_2}$$

- **Energy stored in an inductor :** When a current I flows through an inductor, the energy stored in it is given by $U = \frac{1}{2}LI^2$
  - The energy stored in an inductor is in the form of magnetic energy.

Practice Time

Multiple Choice Questions (MCQs)

1. Whenever there is a relative motion between a coil and a magnet, the magnitude of induced emf set up in the coil does not depend upon the
(a) relative speed between the coil and magnet
(b) magnetic moment of the coil
(c) resistance of the coil.
(d) number of turns in the coil.

2. A short solenoid of radius a, number of turns per unit length n_1, and length L is kept coaxially inside a very long solenoid of radius b, number of turns per unit length n_2. What is the mutual inductance of the system?
(a) $\mu_0 \pi b^2 n_1 n_2 L$ (b) $\mu_0 \pi a^2 n_1 n_2 L^2$
(c) $\mu_0 \pi a^2 n_1 n_2 L$ (d) $\mu_0 \pi b^2 n_1 n_2 L^2$

3. Two identical circular coils A and B are kept on a horizontal tube side by side without touching each other. If the current in the coil A increases with time, in response, the coil B
(a) is attracted by A (b) remains stationary
(c) is repelled (d) rotates.

4. The magnetic flux linked with a coil of N turns of area of cross section A held with its plane parallel to the field B is
(a) $\frac{NAB}{2}$ (b) NAB (c) $\frac{NAB}{4}$ (d) zero

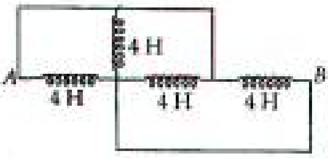
5. Which of the following does not use the application of eddy current?
(a) Electric power meters.
(b) Induction furnace.
(c) LED lights.
(d) Magnetic brakes in trains.

6. A boy peddles a stationary bicycle the pedals of the bicycle are attached to a 200 turn coil of area 0.10 m^2. The coil rotates at half a revolution per second and it is placed in a uniform magnetic field of 0.02 T perpendicular to the axis of rotation of the coil. The maximum voltage generated in the coil is
(a) 1.26 V (b) 2.16 V (c) 3.24 V (d) 4.12 V

7. The self inductance L of a solenoid of length l and area of cross-section A, with a fixed number of turns increases as
(a) both l and A increase
(b) l decreases and A increases
(c) l increases and A decreases
(d) both l and A decrease.

8. Induction furnace make use of
(a) self induction (b) mutual induction
(c) eddy current (d) none of these.

9. The equivalent inductance between A and B is



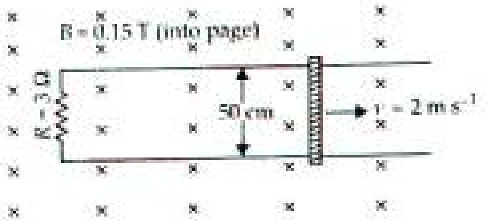
(a) 1 H (b) 4 H (c) 0.8 H (d) 16 H

10. The mutual inductance M_{12} of a coil 1 with respect to coil 2
(a) increases when they are brought nearer
(b) depends on the current passing through the coils
(c) increases when one of them is rotated about an axis
(d) both (a) and (b) are correct.

11. A jet plane is travelling west at the speed of 1600 km h^{-1}. The voltage difference developed between the ends of the wing having a span of 20 m, if the earth's magnetic field at the location has a magnitude of 5×10^{-4} T and the dip angle is 30° is
(a) 4.1 V (b) 2.2 V (c) 3.2 V (d) 3.8 V

12. A long solenoid with 10 turns per cm has a small loop of area 3 cm^2 placed inside, normal to the axis of the solenoid. If the current carried by the solenoid changes steadily from 2 A to 4 A in 0.2 s, what is the induced voltage in the loop, while the current is changing?
(a) 4.2×10^{-8} V (b) 2.8×10^{-8} V
(c) 7.3×10^{-6} V (d) 3.8×10^{-6} V

13. As shown in the figure, a metal rod makes contact with a partial circuit and completes the circuit. The circuit area is perpendicular to a magnetic field with $B = 0.15$ T. If the resistance of the total circuit is 3 Ω, the force needed to move the rod as indicated with a constant speed of 2 m s^{-1} will be equal to



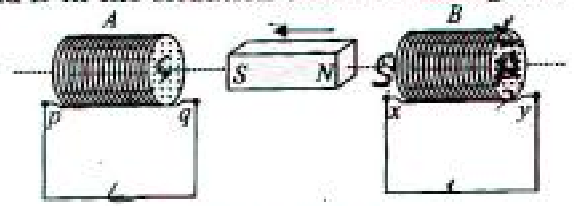
(a) 3.75×10^{-3} N (b) 2.75×10^{-3} N
(c) 6.57×10^{-4} N (d) 4.36×10^{-4} N

14. A 2 m long metallic rod rotates with an angular frequency of 200 rad s^{-1} about an axis normal to the rod passing through its one end. The other end of the rod is in contact with a circular metallic ring. A constant magnetic field of 0.5 T parallel to the axis exists everywhere. The emf developed between the centre and the ring is
(a) 100 V (b) 200 V (c) 300 V (d) 400 V

15. Two coils, A and B are as shown in the figure. A current starts flowing in B as shown, when A is moved toward B and stops when A stops moving. The current in A is counterclockwise. B is kept stationary when A moves. We can infer that

(a) there is a constant current in the clockwise direction of A
(b) there is a no current in A
(c) there is a varying current in A
(d) there is a constant current in the counterclockwise direction in A.

16. The direction of induced current in the coils A and B in the situation shown in the figure is



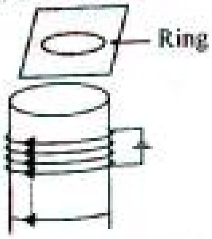
(a) p to q in coil A and x to y in coil B
(b) q to p in coil A and x to y in coil B
(c) p to q in coil A and y to x in coil B
(d) q to p in coil A and y to x in coil B.

17. If N is the number of turns in a coil, the value of self-inductance varies as
(a) N^0 (b) N (c) N^2 (d) N^{-2}

18. Two solenoids of equal number of turns have their lengths and the radii in the same ratio 1 : 2. The ratio of their self inductances will be
(a) 1 : 2 (b) 2 : 1 (c) 1 : 1 (d) 1 : 4

19. If the number of turns per unit length of a coil of solenoid is doubled, the self-inductance of the solenoid will
(a) remain unchanged (b) be halved
(c) be doubled (d) become four times

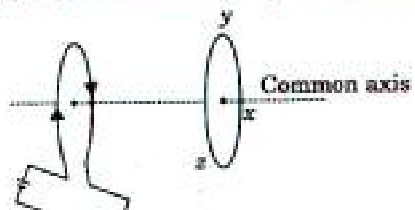
20. A metal ring kept (supported by a cardboard) on the top of a fixed solenoid carry a current I as shown in figure. The centre of the ring coincides with the axis of the solenoid. If the current in the solenoid is switched off, then



(a) magnetic flux linked with the metal ring increases
(b) current induced in the metal ring in clockwise direction
(c) metal ring will not remain on the cardboard
(d) both (a) and (b) are correct.

21. A circular coil of radius 6 cm and 20 turns rotates about its vertical diameter with an angular speed of 40 rad s^{-1} in a uniform horizontal magnetic field of magnitude 2×10^{-2} T. If the coil form a closed loop of resistance 8 Ω, then the average power loss due to joule heating is
(a) 2.07×10^{-3} W (b) 1.23×10^{-3} W
(c) 3.14×10^{-3} W (d) 1.80×10^{-3} W

22. The direction of induced current in the right loop in the situation shown by the given figure is



(Tapping key just closed)

(a) along the common axis
(b) along xzy
(c) along xyz
(d) none of these.

23. The coefficient of mutual inductance of two coils depends on
(a) medium between the coils
(b) distance between the two coils
(c) orientation of the two coils
(d) all of these.

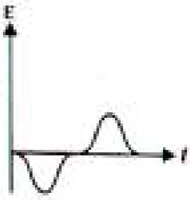
24. A disc of radius 0.1 m is rotating with a frequency 10 rev/sec in a normal magnetic field of strength 0.1 tesla. Net induced emf is
(a) $2\pi \times 10^{-2}$ V
(b) $4\pi \times 10^{-2}$ V
(c) $\pi \times 10^{-2}$ V
(d) $3\pi \times 10^{-2}$ V

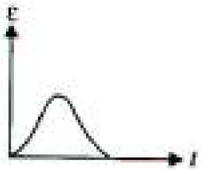
25. The total charge induced in a conducting loop when it is moved in magnetic field depend on
(a) the rate of change of magnetic flux
(b) initial magnetic flux only
(c) the total change in magnetic flux and resistance
(d) final magnetic flux only.

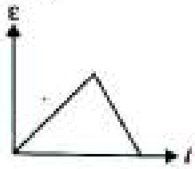
26. A solenoid is connected to a battery so that a steady current flows through it. If an iron core is inserted into the solenoid, the current will
(a) increase
(b) decrease
(c) remains same
(d) first increase then decrease.

27. The variation of induced emf (ε) with time (t) in a coil if a short bar magnet is moved along its axis with a constant velocity is best represented as

(a)


(b)


(c)


(d)


28. If number of turns in primary and secondary coils is increased to two times each, the mutual inductance
(a) becomes 4 times
(b) becomes 2 times
(c) becomes $\frac{1}{4}$ times
(d) remains unchanged.

29. An infinitely long cylinder is kept parallel to a uniform magnetic field B directed along positive z axis. The direction of induced current on the surface of cylinder as seen from the z-axis will be
(a) clockwise of the positive z-axis
(b) anticlockwise of the positive z-axis
(c) zero
(d) along the magnetic field.

30. Two inductors of inductance L each are connected in series with opposite magnetic fluxes. The resultant inductance is
(Ignore mutual inductance)
(a) zero
(b) L
(c) $2L$
(d) $3L$

31. A copper rod of length l rotates about its end with angular velocity ω in a uniform magnetic field B. The emf developed between the ends of the rod if the field is normal to the plane of rotation is
(a) $B\omega l^2$
(b) $\frac{1}{2}B\omega l^2$
(c) $2B\omega l^2$
(d) $\frac{1}{4}B\omega l^2$

32. A loop, made of straight edges has six corners at $A(0, 0, 0)$, $B(L, 0, 0)$, $C(L, L, 0)$, $D(0, L, 0)$, $E(0, L, L)$ and $F(0, 0, L)$. A magnetic field $\vec{B} = B_0(\hat{i} + \hat{k})$ T is present in the region. The flux passing through the loop $ABCDEFA$ in that order is
(a) B_0L^2 Wb
(b) $2B_0L^2$ Wb
(c) $\sqrt{2}B_0L^2$ Wb
(d) $4B_0L^2$ Wb

33. A current of 1 A through a coil of inductance of 200 mH is increasing at a rate of 0.5 A s^{-1}. The energy stored in the inductor per second is
(a) 0.5 J s^{-1}
(b) 5.0 J s^{-1}
(c) 0.1 J s^{-1}
(d) 2.0 J s^{-1}

34. A conducting circular loop is placed in a uniform magnetic field, B = 0.025 T with its plane perpendicular to the loop. The radius of the loop is made to shrink at a constant rate of 1 mm s^{-1}. The induced emf when the radius is 2 cm, is
(a) 2π μV
(b) π μV
(c) $\frac{\pi}{2}$ μV
(d) 2 μV

35. Two similar circular loops carry equal currents in the same direction. On moving the coils further apart, the electric current will
(a) remain unaltered
(b) increases in one and decreases in the second
(c) increase in both
(d) decrease in both.

36. A small square loop of wire of side l is placed inside a large square loop of wire of side L ($>> l$). The loops are coplanar and their centres coincide. What is the mutual inductance of the system?
(a) $2\sqrt{2}\frac{\mu_0}{\pi}\frac{l^2}{L}$
(b) $8\sqrt{2}\frac{\mu_0}{\pi}\frac{l^2}{L}$
(c) $2\sqrt{2}\frac{\mu_0}{2\pi}\frac{l^2}{L}$
(d) $2\sqrt{2}\frac{\mu_0 L^2}{\pi l}$

37. A conducting loop is placed in a uniform magnetic field with its plane perpendicular to the field. An emf is induced in the loop if
(a) it is rotated about its axis
(b) it is rotated about a diameter
(c) it is not moved
(d) it is given translational motion in the field.

38. A circular disc of radius 0.2 m is placed in a uniform magnetic field of induction $\left(\frac{1}{\pi}\right)$ Wb m^{-2} is such a way that its axis makes an angle of 60° with $\vec{B}$. The magnetic flux linked with the disc is
(a) 0.02 Wb (b) 0.06 Wb
(c) 0.08 Wb (d) 0.01 Wb

39. A circular copper disc 10 cm in diameter rotates at 1800 revolution per minute about an axis through its centre and at right angles to disc. A uniform field of induction B of 1 Wb m^{-2} is perpendicular to disc. What potential difference is developed between the axis of the disc and the rim?
(a) 0.023 V (b) 0.23 V (c) 23 V (d) 230 V

40. When a wire loop is rotated in a magnetic field, the direction of induced emf changes in every
(a) one revolution (b) $\frac{1}{2}$ revolution
(c) $\frac{1}{4}$ revolution (d) 2 revolution

41. The energy stored in an inductor of self inductance L henry carrying a current of I ampere is
(a) $\frac{1}{2}L^2I$ (b) $\frac{1}{2}LI^2$ (c) LI^2 (d) L^2I

42. Faraday's laws are consequence of the conservation of
(a) charge (b) energy
(c) magnetic field (d) both (b) and (c).

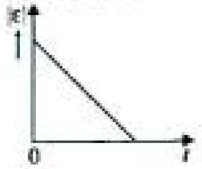
43. A solenoid of length 30 cm with 10 turns per centimetre and area of cross-section 40 cm^2 completely surrounds another co-axial solenoid of same length, area of cross-section 20 cm^2 with 40 turns per centimetre. The mutual inductance of the system is
(a) 10 H (b) 8 H (c) 3 mH (d) 30 mH

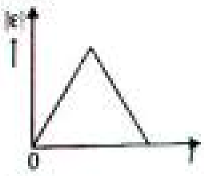
44. Two identical coaxial coils P and Q carrying equal amount of current in the same direction are brought nearer. The current in
(a) P increases while in Q decreases
(b) Q increases while in P decreases
(c) both P and Q increases
(d) both P and Q decreases.

45. An electromagnet has stored 648 J of magnetic energy when a current of 9 A exists in its coils. What average emf is induced if the current is reduced to zero in 0.45 s?
(a) 320 V (b) 620 V (c) 260 V (d) 230 V

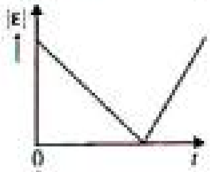
46. The north pole of a bar magnet is moved towards a coil along the axis passing through the centre of the coil and perpendicular to the plane of the coil. The direction of the induced current in the coil when viewed in the direction of the motion of the magnet is
(a) clockwise (b) anticlockwise
(c) no current in the coil
(d) either clockwise or anti-clockwise.

47. A long solenoid S has n turns per metre, with diameter a. At the centre of this coil, we place a smaller coil of N turns and diameter b ($b < a$). If the current in the solenoid increases linearly with time, then the emf will be induced in the smaller coil. Which of the following is the correct graph showing $|\varepsilon|$ verses t if current varies as a function of $mt^2 + C$?

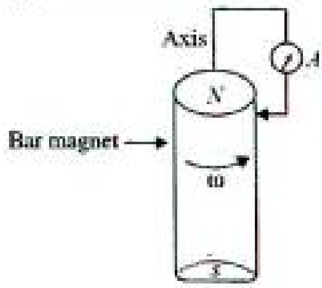
(a)


(b)


(c)


(d)


48. A cylindrical bar magnet is rotated about its axis as shown in figure. A wire is connected from the axis and is made to touch the cylindrical surface through a contact. Then



(a) a direct current flows in the ammeter A
(b) no current flows through the ammeter A
(c) an alternating sinusoidal current flows through the ammeter A with a time period, $T = \frac{2\pi}{\omega}$
(d) a time varying non sinusoidal current flows through the ammeter A.

49. The unit of inductance is equivalent to

(a) $\frac{\text{volt} \times \text{ampere}}{\text{second}}$ (b) $\frac{\text{ampere}}{\text{volt} \times \text{second}}$

(c) $\frac{\text{volt}}{\text{ampere} \times \text{second}}$ (d) $\frac{\text{volt} \times \text{second}}{\text{ampere}}$

50. When the rate of change of current is unity, the induced emf is equal to
(a) thickness of coil
(b) number of turns in coil
(c) coefficient of self inductance
(d) total flux linked with coil.

51. In a uniform magnetic field B a wire in the form of a semicircle of radius r rotates about the diameter of the circle with angular frequency ω. The axis of rotation is perpendicular to the field. If the total resistance of the circuit is R, the mean power generated per period of rotation is

(a) $\frac{B\pi r^2\omega}{2R}$ (b) $\frac{(B\pi r^2\omega)^2}{8R}$

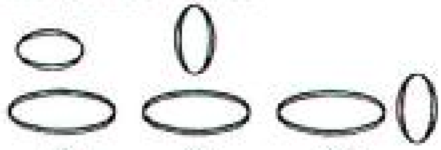
(c) $\frac{(B\pi r\omega)^2}{2R}$ (d) $\frac{(B\pi r\omega^2)^2}{8R}$

52. The magnetic flux through a coil perpendicular to its plane and directed into paper is varying according to the relation $\phi = (2t^2 + 4t + 6)$ mWb. The emf induced in the loop at $t = 4$ s is
(a) 0.12 V (b) 2.4 V (c) 0.02 V (d) 1.2 V

53. A 100 mH coil carries a current of 1 A. Energy stored in its magnetic field is
(a) 0.5 J (b) 0.05 J (c) 1 J (d) 0.1 J

54. If the self inductance of 500 turns coil is 125 mH, then the self inductance of the similar coil of 800 turns is
(a) 48.8 mH (b) 200 mH
(c) 290 mH (d) 320 mH

55. Two circular coils can be arranged in any of three situations as shown in the figure. Their mutual inductance will be



(i) (ii) (iii)

(a) maximum in situation (i)
(b) maximum in situation (ii)
(c) maximum in situation (iii)
(d) same in all situations.

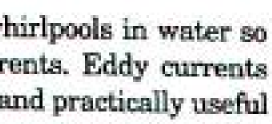
56. By a change of current from 5 to 10 amperes in 0.1 second, the self induced emf is 10 V. The change in the energy of the magnetic field of a coil will be
(a) 5 J (b) 6 J (c) 7.5 J (d) 9 J

57. In an inductor of self-inductance $L = 2$ mH, current changes with time according to relation, $I = t^2e^{-t}$
At what time emf is zero?
(a) 4 s (b) 3 s (c) 2 s (d) 1 s

58. The equivalent quantity of mass in electricity is
(a) current (b) self inductance
(c) potential (d) charge.

59. Two coils of self-inductance 2 mH and 8 mH are placed so close together that the effective flux in one coil is completely linked with the other. The mutual inductance between these coils are
(a) 16 mH (b) 10 mH (c) 6 mH (d) 4 mH

60. A circular coil with a cross-sectional area of 4 cm^2 has 10 turns. It is placed at the centre of a long solenoid that has 15 turns/cm and a cross-sectional area of 10 cm^2, as shown in the figure. The axis of the coil coincides with the axis of the solenoid. What is their mutual inductance?



(a) 7.54 μH (b) 8.54 μH
(c) 9.54 μH (d) 10.54 μH

Case Based MCQs

Case I : Read the passage given below and answer the following questions from 61 to 65.

Eddy Currents and their Effects

Currents can be induced not only in conducting coils, but also in conducting sheets or blocks. Current is induced in solid metallic masses when the magnetic flux threading through them changes. Such currents flow in the form of irregularly shaped loops throughout the body of the metal. These currents look like eddies or whirlpools in water so they are known as eddy currents. Eddy currents have both undesirable effects and practically useful applications. For example it causes unnecessary heating and wastage of power in electric motors, dynamos and in the cores of transformers.

61. The working of speedometers of trains is based on
(a) wattless currents (b) eddy currents
(c) alternating currents (d) pulsating currents.

62. Identify the wrong statement.
(a) Eddy currents are produced in a steady magnetic field.
(b) Induction furnace uses eddy currents to produce heat.
(c) Eddy currents can be used to produce braking force in moving trains.
(d) Power meters work on the principle of eddy currents.

63. Which of the following is the best method to reduce eddy currents?
(a) Laminating core. (b) Using thick wires.
(c) By reducing hysteresis loss.
(d) None of these.

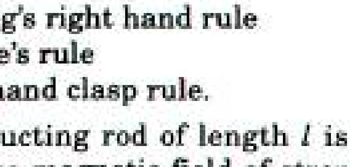
64. The direction of eddy currents is given by
(a) Fleming's left hand rule
(b) Biot-Savart law
(c) Lenz's law
(d) Ampere-circuital law

65. Eddy currents can be used to heat localised tissues of the human body. This branch of medical therapy is called
(a) Hyperthermia (b) Diathermy
(c) Inductothermy (d) none of these.

Case II : Read the passage given below and answer the following questions from 66 to 70.

Motional EMF from Lorentz Force

The emf induced across the ends of a conductor due to its motion in a magnetic field is called motional emf. It is produced due to the magnetic Lorentz force acting on the free electrons of the conductor. For a circuit shown in figure, if a conductor of length l moves with velocity v in a magnetic field B perpendicular to both its length and the direction of the magnetic field, then all the induced parametres are possible in the circuit.



66. Direction of current induced in a wire moving in a magnetic field is found using
(a) Fleming's left hand rule
(b) Fleming's right hand rule
(c) Ampere's rule
(d) Right hand clasp rule.

67. A conducting rod of length l is moving in a transverse magnetic field of strength B with velocity v. The resistance of the rod is R. The current in the rod is
(a) $\dfrac{Blv}{R}$ (b) Blv (c) zero (d) $\dfrac{B^2v^2l^2}{R}$

68. A 0.1 m long conductor carrying a current of 50 A is held perpendicular to a magnetic field of 1.25 mT. The mechanical power required to move the conductor with a speed of 1 m s^{-1} is
(a) 62.5 mW (b) 625 mW
(c) 6.25 mW (d) 12.5 mW

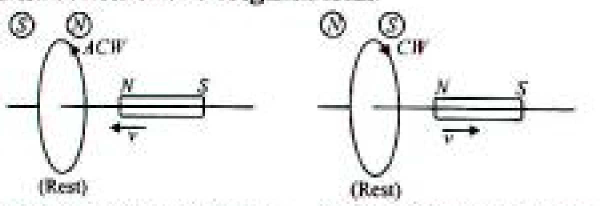
69. A bicycle generator creates 1.5 V at 15 km/hr. The EMF generated at 10 km/hr is
(a) 1.5 volts (b) 2 volts
(c) 0.5 volts (d) 1 volt

70. The dimensional formula for emf ε in MKS system will be
(a) $[ML^2T^{-3}A^{-1}]$ (b) $[ML^2T^{-1}A]$
(c) $[ML^2A]$ (d) $[MLT^{-2}A^{-2}]$

Case III : Read the passage given below and answer the following questions from 71 to 75.

Direction of Induced Current

Lenz's law states that the direction of induced current in a circuit is such that it opposes the change which produces it. Thus, if the magnetic flux linked with a closed circuit increases, the induced current flows in such a direction that a magnetic flux is created in the opposite direction of the original magnetic flux. If the magnetic flux linked with the closed circuit decreases, the induced current flows in such a direction so as to create a magnetic flux in the direction of the original flux.



(Rest) (Coil face behaves as North pole to oppose the motion of magnet.)

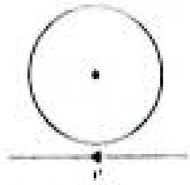
(Rest) (Coil face behaves as South pole to oppose the motion of magnet.)

71. Which of the following statements is correct?
(a) The induced e.m.f is not in the direction opposing the change in magnetic flux so as to oppose the cause which produces it.
(b) The relative motion between the coil and magnet produces change in magnetic flux.
(c) Emf is induced only if the magnet is moved towards coil.
(d) Emf is induced only if the coil is moved towards magnet.

72. The polarity of induced emf is given by
(a) Ampere's circuital law
(b) Biot-Savart law
(c) Lenz's law
(d) Fleming's right hand rule.

73. Lenz's law is a consequence of the law of conservation of
(a) charge (b) mass
(c) momentum (d) energy.

74. Near a circular loop of conducting wire as shown in the figure, an electron moves along a straight line. The direction of the induced current if any in the loop is
(a) variable
(b) clockwise
(c) anticlockwise
(d) zero.

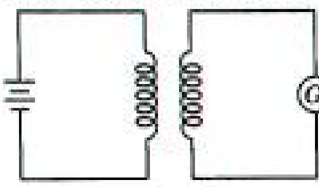


75. Two identical circular coils A and B are kept in a horizontal tube side by side without touching each other. If the current in the coil A increases with time, in response, the coil B
(a) is attracted by A
(b) remains stationary
(c) is repelled
(d) rotates.

Case IV : Read the passage given below and answer the following questions from 76 to 80.

Mutual Inductance

Mutual inductance is the phenomenon of inducing emf in a coil, due to a change of current in the neighbouring coil. The amount of mutual inductance that links one coil to another depends very much on the relative positioning of the two coils, their geometry and relative separation between them. Mutual inductance between the two coils increases μ_r times if the coils are wound over an iron core of relative permeability μ_r.



76. A short solenoid of radius a, number of turns per unit length n_1, and length L is kept coaxially inside a very long solenoid of radius b, number of turns per unit length n_2. What is the mutual inductance of the system?
(a) $\mu_0 \pi b^2 n_1 n_2 L$ (b) $\mu_0 \pi a^2 n_1 n_2 L^2$
(c) $\mu_0 \pi a^2 n_1 n_2 L$ (d) $\mu_0 \pi b^2 n_1 n_2 L^2$

77. If a change in current of 0.01 A in one coil produces a change in magnetic flux of 2×10^{-2} weber in another coil, then the mutual inductance between coils is
(a) 0 (b) 0.5 H (c) 2 H (d) 3 H

78. Mutual inductance of two coils can be increased by
(a) decreasing the number of turns in the coils
(b) increasing the number of turns in the coils
(c) winding the coils on wooden cores
(d) none of these.

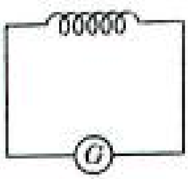
79. When a sheet of iron is placed in between the two co-axial coils, then the mutual inductance between the coils will
(a) increase (b) decrease
(c) remains same (d) cannot be predicted.

80. The SI unit of mutual inductance is
(a) ohm (b) mho
(c) henry (d) none of these.

Case V : Read the passage given below and answer the following questions from 81 to 85.

Self Inductance

When a current I flows through a coil, flux linked with it is $\phi = LI$, where L is a constant known as self inductance of the coil. Any change in current sets up an induced emf in the coil. Thus, self inductance of a coil is the induced emf set up in it when the current passing through it changes at the unit rate. It is a measure of the opposition to the growth or the decay of current flowing through the coil. Also, value of self inductance depends on the number of turns in the solenoid, its area of cross-section and the relative permeability of its core material.



81. The inductance in a coil plays the same role as
(a) inertia in mechanics
(b) energy in mechanics
(c) momentum in mechanics
(d) force in mechanics.

82. A current of 2.5 A flows through a coil of inductance 5 H. The magnetic flux linked with the coil is
(a) 0.5 Wb (b) 12.5 Wb
(c) zero (d) 2 Wb

83. The inductance L of a solenoid depends upon its radius R as
(a) $L \propto R$ (b) $L \propto 1/R$
(c) $L \propto R^2$ (d) $L \propto R^3$

84. The unit of self-inductance is
(a) weber ampere (b) weber^{-1} ampere
(c) ohm second (d) farad

85. The induced e.m.f. in a coil of 10 henry inductance in which current varies from 9 A to 4 A in 0.2 second is
(a) 200 V (b) 250 V (c) 300 V (d) 350 V

Assertion & Reasoning Based MCQs

For question numbers 86-100, two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.

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

(b) Both A and R are true but R is NOT the correct explanation of A

(c) A is true but R is false

(d) A is false and R is also false

86. Assertion (A) : Magnetic flux can produce induced e.m.f.

Reason (R) : Faraday does not established induced e.m.f. experimentally.

87. Assertion (A) : Induced e.m.f. depends on number of turns and area of the coil.

Reason (R) : Induced e.m.f. increases with increase in number of turns of coil.

88. Assertion (A) : The direction of induced e.m.f. is always such as to oppose the change that causes it.

Reason (R) : The direction of induced e.m.f. is given by Lenz's law.

89. Assertion (A) : When number of turns in a coil doubled, coefficient of self inductance of the coil becomes four times.

Reason (R) : Coefficient of self inductance is proportional to the square of number of turns.

90. Assertion (A) : The coil in the resistance boxes are made by doubling the wire.

Reason (R) : Thick wire is required in resistance box.

91. Assertion (A) : The resistance of a coil for direct current is 5 ohms. An alternating current is sent through it. The resistance will remain same.

Reason (R) : The resistance of a coil does not depend upon nature of current.

92. Assertion (A) : Acceleration of a magnet falling through a copper ring decreases.

Reason (R) : The induced current produced in a circuit always flow in such direction that it opposes the change or the cause that produced it.

93. Assertion (A) : An artificial satellite with a metal surface is moving above the earth in a circular orbit. A current will be induced in satellite if the plane of the orbit is inclined to the plane of the equator.

Reason (R) : The current will be induced only when the speed of satellite is more than 8 km/sec.

94. Assertion (A) : Self-inductance is called the inertia of electricity.

Reason (R) : Self-inductance is the phenomenon, according to which an opposing induced e.m.f. is produced in a coil as a result of change in current or magnetic flux linked with the coil.

95. Assertion (A) : An aircraft flies along the meridian, the potential develops at the ends of its wings.

Reason (R) : Whenever there is change in the magnetic flux e.m.f. induces.

96. Assertion (A) : When two coils are wound on each other, the mutual induction between the coils is maximum.

Reason (R) : Mutual induction does not depend on the orientation of the coils.

97. Assertion (A) : An induced current is developed when the number of magnetic lines of force associated with conductor is changed.

Reason (R) : An induced current develop in a conductor moved in a direction parallel to the magnetic field.

98. Assertion (A) : A copper sheet is placed in a magnetic field. If we pull it out of the field or push it into the field, we experience an opposing force.

Reason (R) : According to Lenz's law, eddy current produced in sheet opposes the motion of the sheet.

99. Assertion (A) : Changing magnetic flux can produce induced e.m.f.

Reason (R) : Faraday established induced e.m.f. experimentally.

100. Assertion (A) : Inductance coil are made of copper.

Reason (R) : Induced current is more in wire having less resistance.

ANSWERS

1. **(c)** : The magnitude of induced emf set up in the coil does not depend upon the resistance of the coil whereas induced current set up in the coil depend upon the resistance of the coil.

2. **(c)** : The mutual inductance of the system is $M = \mu_0 \pi a^2 n_1 n_2 L$

3. **(c)**

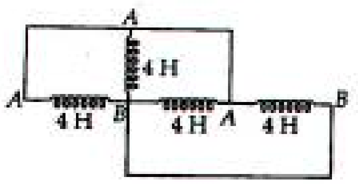
4. **(d)** : Magnetic flux linked with a coil
$\phi = NBA\cos\theta$
Since the magnetic field B is parallel to the area A, *i.e.*, $\theta = 90°$.
$\therefore \quad \phi = 0$

5. **(c)**

6. **(a)** : Here $\upsilon = 0.5$ Hz, $N = 200$, $A = 0.1$ m^2 and $B = 0.02$ T
Maximum voltage generated is $\varepsilon_0 = NBA(2\pi\upsilon)$
$= 200 \times 0.02 \times 0.1 \times (2\pi \times 0.5) = 1.26$ V

7. **(b)** : The self inductance L of a solenoid of length l and area of cross section A with fixed number of turns is
$$L = \frac{\mu_0 N^2 A}{l}$$
So, L increases when l decreases and A increases.

8. **(c)**

9. **(a)** : 

The equivalent circuit diagram is as shown in the figure.

Here, all the inductances are connected in parallel. Hence, the equivalent inductance between A and B is
$$\frac{1}{L_{AB}} = \frac{1}{4} + \frac{1}{4} + \frac{1}{4} + \frac{1}{4} = \frac{4}{4} = 1 \text{ or } L_{AB} = 1 \text{ H}$$

10. **(a)** : The mutual inductance M_{12} of coil 1 with respect to coil 2 increases when they are brought nearer.

11. **(b)** : Here, $v = 1600$ km h^{-1} $= 1600 \times \frac{5}{18} = 444$ m s^{-1}
$l = 20$ m , $B = 5 \times 10^{-4}$ T and $\delta = 30°$
As $\varepsilon = Blv = Vlv$
(where V is the vertical component of earth's field)
$= (B \sin \delta)\, lv \qquad (\because\ V = B \sin\delta)$
$= 5 \times 10^{-4} \sin 30° \times 20 \times 444 = 2.2$ V

12. **(d)** : Here, $\frac{N}{l} = 10$ turns per cm $= 1000$ turns per m
$A = 3$ cm^2 $= 3 \times 10^{-4}$ m^2
or $\frac{di}{dt} = \frac{4-2}{0.2} = 10$ A s^{-1}
Also $\varepsilon = \frac{d\phi}{dt} = \frac{d}{dt}(BA) = A\frac{d}{dt}\left(\mu_0 \frac{N}{l} i\right) = A\mu_0\left(\frac{N}{l}\right)\frac{di}{dt}$
$= 3 \times 10^{-4} \times 4\pi \times 10^{-7} \times 1000 \times 10 = 3.8 \times 10^{-6}$ V

13. **(a)** : The emf induced in the rod causes a current to flow anticlockwise direction in the circuit. Because of this current in the rod, it experiences a force to the left due to the magnetic field. In order to pull the rod to the right with constant speed, this force must be balanced by the puller.
The emf induced in the rod is
$|e| = Blv = (0.15 \text{ T})(0.5 \text{ m})(2 \text{ m s}^{-1}) = 0.15$ V
Current induced in the rod is
$$I = \frac{|e|}{R} = \frac{0.15\text{V}}{3\Omega} = 0.05 \text{ A}$$
$\therefore \quad F = ilB \sin 90° = (0.05 \text{ A})(0.5 \text{ m})(0.15 \text{ T})(1)$
$= 3.75 \times 10^{-3}$ N

14. **(b)** : The emf developed between the centre and the ring is
$$\varepsilon = \frac{1}{2}Bl^2\omega = \frac{0.5 \times 2^2 \times 200}{2} = 200 \text{ V}$$

15. **(d)** : Coil A must be carrying a constant current in counter clockwise direction. Because of that, when A moves towards B, current induced in B is counterclockwise direction as per Lenz's law. The current in B would stop when A stops moving.

16. **(b)** : In coil A, south pole is developed at q and in coil B also south pole is developed at x. Therefore, induced current in coil A will be from q to p and induced current in the coil B will be from x to y.

17. **(c)** : Self inductance $= \frac{\mu_0 N^2 A}{l}$

18. **(a)** : Self inductance of a solenoid,
$$L = \frac{\mu_0 N^2 A}{l} = \frac{\mu_0 N^2 \pi r^2}{l}$$
where l is the length of the solenoid, N is the total number of turns of the solenoid and A is the area of cross-section of the solenoid.

$\therefore \frac{L_1}{L_2} = \left(\frac{N_1}{N_2}\right)^2 \left(\frac{r_1}{r_2}\right)^2 \left(\frac{l_2}{l_1}\right)$

Here, $N_1 = N_2$, $\frac{l_1}{l_2} = \frac{1}{2}$, $\frac{r_1}{r_2} = \frac{1}{2}$

$\therefore \frac{L_1}{L_2} = \left(\frac{1}{2}\right)^2 \left(\frac{2}{1}\right) = \frac{1}{2}$

19. (d) : Self inductance of a solenoid $= \mu_0 n^2 Al$
where n is the number of turns per length.
$\therefore$ Self inductance is directly proportional to n^2. Self inductance becomes 4 times when n is doubled.

20. (b) : When the current in the solenoid is switch off, magnetic flux linked with the solenoid and hence with metal ring decreases. Current induced in the metal ring is clockwise, *i.e.* in the same direction as the solenoid current. So, they will attract each other. Therefore, the metal ring will remain on the cardboard.

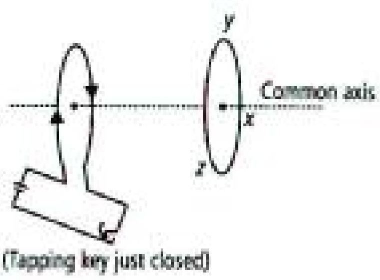
21. (a) : Here, $r = 6$ cm
$= 6 \times 10^{-2}$ m, $N = 20$, $\omega = 40$ rad s^{-1}
$B = 2 \times 10^{-2}$ T, $R = 8\ \Omega$
Maximum emf induced, $\varepsilon = NAB\omega = N(\pi r^2)B\omega$
$= 20 \times \pi \times (6 \times 10^{-2})^2 \times 2 \times 10^{-2} \times 40 = 0.18$ V
Average value of emf induced over a full cycle $\varepsilon_{av} = 0$
Maximum value of current in the coil,

$I = \frac{\varepsilon}{R} = \frac{0.18}{8} = 0.023$ A

Average power dissipated,

$P = \frac{\varepsilon I}{2} = \frac{0.18 \times 0.023}{2} = 2.07 \times 10^{-3}$ W

22. (c) : The induced current in the right loop will be along xyz.



(Tapping key just closed)

23. (d)

24. (c) : Induced emf $= BAv$
$= 0.1 \times \pi(0.1)^2 \times 10 = 0.1 \times 0.01\pi \times 10$
$= \pi \times 10^{-3} \times 10 = \pi \times 10^{-2}$ V.

25. (c) : As $q = \int I dt = \frac{1}{R}\int \varepsilon dt = \frac{1}{R}\int \frac{d\phi}{dt} dt$
$= \frac{1}{R}\int d\phi$

Hence total charge induced in the conducting loop depend upon the total change in magnetic flux and resistance.

26. (b) : The current will decrease. This is because on inserting an iron core in the solenoid, the magnetic field increases and hence magnetic flux linked with the solenoid increases. As per Lenz's law, the emf induced in the solenoid will oppose this increase, which can be achieved by a decrease in current.

27. (b) : The polarity of emf will be opposite in the two cases while the magnet enters the coil and while the magnetic leaves the coil. Only in option (b) polarity is changing.

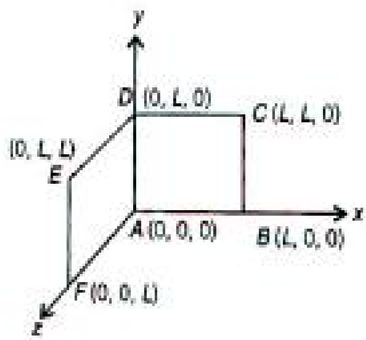
28. (a) : $M = \frac{\mu_0 N_1 N_2 A}{l}$
$\therefore$ M becomes 4 times.

29. (c) : Since the magnetic field is uniform, hence there is no change in the magnetic flux linked with cylindrical wire and hence no current will be induced on the surface of cylindrical wire.

30. (c) : When magnetic fluxes are in opposite direction
$L' = L_1 + L_2 - 2M$
Ignoring $M = 0$
The resultant inductance is $L' = L + L = 2L$.

31. (b)

32. (b) : Here, $\vec{B} = B_0(\hat{i} + \hat{k})$ T



Area vector of $ABCD = L^2\hat{k}$

Area vector of $DEFA = L^2\hat{i}$

Total area vector, $\vec{A} = L^2(\hat{i} + \hat{k})$

Total magnetic flux, $\phi = \vec{B} \cdot \vec{A}$

$= B_0(\hat{i} + \hat{k}) \cdot L^2(\hat{i} + \hat{k}) = B_0 L^2 (1 + 1) = 2 B_0 L^2$ Wb

33. (c) : The energy stored in the inductor is
$U = \frac{1}{2}LI^2$

The energy stored in the inductor per second is
$\frac{dU}{dt} = LI\frac{dI}{dt}$

$= (200 \times 10^{-3}\text{H})(1\text{A})(0.5\text{ A s}^{-1}) = 0.1\text{ J s}^{-1} = 0.1\text{ J s}^{-1}$

34. (b) : Here,

Magnetic field, $B = 0.025$ T
Radius of the loop, $r = 2$ cm $= 2 \times 10^{-2}$ m
Constant rate at which radius of the loop shrinks,

$\frac{dr}{dt} = 1 \times 10^{-3}\ \text{m s}^{-1}$

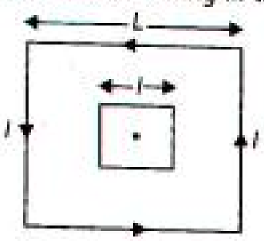
Magnetic flux linked with the loop is
$\phi = BA\cos\theta = B(\pi r^2)\cos 0° = B\pi r^2$
The magnitude of the induced emf is

$$|\varepsilon| = \frac{d\phi}{dt} = \frac{d}{dt}(B\pi r^2) = B\pi 2r\frac{dr}{dt}$$

$= 0.025 \times \pi \times 2 \times 2 \times 10^{-2} \times 1 \times 10^{-3}$
$= \pi \times 10^{-6}$ V $= \pi\ \mu$V

35. (c) : Two circular loops carrying current in the same direction will attract each other. If they are now separated, induced currents will try to keep status quo, by increasing the current in both the coils.

36. (a) : Let the current I be flowing in the larger loop.



The larger loop is made up of four wires each of length L, the field at the centre *i.e.*, at a distance $\frac{L}{2}$ from each wire, will be

$$B = 4 \times \frac{\mu_0 I}{4\pi(L/2)}(\sin 45° + \sin 45°)$$

$$= 4 \times \frac{\mu_0}{4\pi}\frac{2I}{L}\frac{2}{\sqrt{2}} = 2\sqrt{2}\frac{\mu_0}{\pi}\frac{I}{L}$$

Flux linked with smaller loop

$$\phi_2 = BA_2 = 2\sqrt{2}\frac{\mu_0}{\pi}\frac{I}{L} \times l^2$$

Hence, $M = \frac{\phi_2}{I} \Rightarrow M = 2\sqrt{2}\frac{\mu_0}{\pi}\frac{l^2}{L}$

37. (b) : An emf is induced only when magnetic flux linked with the loop changes. This is possible when the loop is rotated about a diameter.

38. (a) : Here, $r = 0.2$ m, $B = \frac{1}{\pi}$ Wb m^{-2}, $\theta = 60°$

$\therefore$ Magnetic flux,
$\phi = BA\cos\theta = B(\pi r^2)\cos\theta$

$$= \frac{1}{\pi}\pi(0.2)^2\cos 60° = 0.02 \text{ Wb}$$

39. (b) : Here, $l = r = 5$ cm $= 5 \times 10^{-2}$ m,

$\omega = 2\pi\left(\frac{1800}{60}\right)$ rad s^{-1} $= 60\pi$ rad s^{-1}, $B = 1$ Wb m^{-2}

$$\varepsilon = \frac{1}{2}Bl^2\omega = \frac{1}{2} \times 1 \times (5 \times 10^{-2})^2 \times 60\pi = 0.23 \text{ V}$$

40. (b) : The direction of induced emf is reversed after every half revolution of the loop.

41. (b) : The energy stored in an inductor is

$U = \frac{1}{2}LI^2$

42. (b)

43. (c) : Mutual inductance of the system, $M = \mu_0 n_1 n_2 A_2 l$ where A_2 is the area of inner solenoid.
$n_1 = 10$ cm^{-1} $= 1000$ m^{-1}
$n_2 = 40$ cm^{-1} $= 4000$ m^{-1}
$l = 30$ cm $= 30 \times 10^{-2}$ m
$A_2 = 20$ cm^2 $= 20 \times 10^{-4}$ m^2
$\therefore\ M = 4\pi \times 10^{-7} \times 1000 \times 4000 \times 20 \times 10^{-4} \times 30 \times 10^{-2}$
$= 301.44 \times 10^{-5}$ H $= 3$ mH

44. (d) : When the coils P and Q are brought nearer, the magnetic flux linked with each coil will increase and so the induced current will try to decrease the flux and hence current in both P and Q decreases.

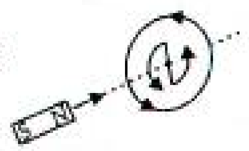
45. (a) : Magnetic energy, $U = \frac{1}{2}LI^2$

$$\therefore\ L = \frac{2U}{I^2} = \frac{2 \times 648}{(9)^2} = 16 \text{ H}$$

Induced emf,

$$\varepsilon = -L\frac{dI}{dt} = \frac{-(16\text{ H})(0-9\text{ A})}{0.45\text{ s}} = 320 \text{ V}$$

46. (b) :



47. (c) : As per the data given in the question, magnetic field due to current in solenoid S, $B = \mu_0 nI$
Magnetic flux linked with the smaller coil due to this field is
$\phi = NBA$, where A = area of smaller coil $= \pi b^2$
$\therefore$ emf induced in the smaller coil,

$$\varepsilon = -\frac{d\phi}{dt} = -\frac{d}{dt}(NB\pi b^2)$$

$$= -N\pi b^2\frac{d}{dt}(\mu_0 nI) = -N\pi b^2\mu_0\frac{dI}{dt}$$

As current I varies as a function of $(mt^2 + C)$

$$\therefore\ \varepsilon = -Nn\mu_0\pi b^2\frac{d}{dt}(mt^2 + C)$$

$= -Nn\pi\mu_0 b^2(2mt)$ ...(i)
From (i), $|\varepsilon| \propto t$
So correct option is (c).

48. (b) : As there is no change in magnetic flux associated with the circuit, no current is induced in the circuit. The ammeter *A* shows no deflection.

49. (d) : As $\varepsilon = L\frac{dI}{dt}$,

$L = \varepsilon\frac{dt}{dI} \Rightarrow L = \frac{\text{volt} \times \text{second}}{\text{ampere}}$

50. (c) : As, $\varepsilon = L\frac{dI}{dt}$

When $\frac{dI}{dt} = 1 \quad \therefore \varepsilon = L$

51. (b) : $\phi = B\frac{\pi r^2}{2}\cos\omega t$

$\therefore \quad \varepsilon = -\frac{d\phi}{dt} = \frac{1}{2}B\pi r^2\omega\sin\omega t$

$\therefore \quad P = \frac{\varepsilon^2}{R} = \frac{B^2\pi^2r^4\omega^2\sin^2\omega t}{4R}$

$\therefore \quad \langle P \rangle = \frac{(B\pi r^2\omega)^2}{8R} \quad (\because \langle \sin^2\omega t \rangle = \frac{1}{2})$

52. (c) : Given, $\phi = (2t^2 + 4t + 6)$ mWb

As, $\varepsilon = \frac{d\phi}{dt}$

$= \frac{d}{dt}(2t^2 + 4t + 6) \times 10^{-3}$ Wb s^{-1}

$= (4t + 4) \times 10^{-3}$ V

At $t = 4$ s

$\varepsilon = (4 \times 4 + 4) \times 10^{-3}$ V $= 20 \times 10^{-3}$ V $= 0.02$ V

53. (b) : Here, $L = 100$ mH $= 100 \times 10^{-3}$ H; $I = 1$ A

As $U = \frac{1}{2}LI^2 = \frac{1}{2} \times (100 \times 10^{-3}) \times 1^2 = 0.05$ J

54. (d) : As $\frac{L_1}{L_2} = \frac{N_1^2}{N_2^2}$

Here self inductance of 500 turns coil = 125 mH

$\therefore$ L for the coil of 800 turns $= \frac{125}{(500)^2} \times (800)^2 = 320$ mH

55. (a)

56. (c) : $|\varepsilon| = L\frac{\Delta I}{\Delta t}$

$L = \frac{|\varepsilon|\Delta t}{\Delta I} = \frac{10 \times 0.1}{(10-5)} = 0.2$ H

The magnetic field energies for currents I_1 and I_2 are

$U_1 = \frac{1}{2}LI_1^2$ and $U_2 = \frac{1}{2}LI_2^2$

Change in energy $= U_2 - U_1$

$= \frac{1}{2}LI_2^2 - \frac{1}{2}LI_1^2 = \frac{L}{2}(I_2^2 - I_1^2) = \frac{0.2}{2}(10^2 - 5^2) = 7.5$ J

57. (c) : $L = 2$ mH $= 2 \times 10^{-3}$ H

$I = t^2e^{-t}$

$\frac{dI}{dt} = t^2e^{-t}(-1) + e^{-t}(2t) = te^{-t}(-t + 2)$

$\text{Emf} = L\frac{dI}{dt} = 2 \times 10^{-3}te^{-t}(-t + 2)$

Now, emf = 0, when $(-t + 2) = 0$ or $t = 2$ s.

58. (b)

59. (d) : Mutual inductance between coils is

$M = k\sqrt{L_1L_2}$

$= 1\sqrt{2 \times 10^{-3} \times 8 \times 10^{-3}} \quad (\because k = 1)$

$= 4 \times 10^{-3}$ H $= 4$ mH

60. (a) : Let us refer to the coil as circuit 1 and the solenoid as circuit 2. The field in the central region of the solenoid is uniform, so the flux through the coil is

$\phi_{12} = B_2A_1 = (\mu_0n_2I_2)A_1$

where $n_2 = N_2/l = 1500$ turns/m.

The mutual inductance is

$M = \frac{N_1\phi_{12}}{I_2} = \mu_0n_2N_1A_1$

$= (4\pi \times 10^{-7}$ T m A$^{-1})(1500$ m$^{-1})(10)$ $(4 \times 10^{-4}$ m$^2)$

$= 7.54 \times 10^{-6}$ H $= 7.54$ mH

61. (b) : The working of speedometers is based on eddy currents.

62. (a)

63. (a) : To reduce the eddy currents in the metal armature of motors, wire is wrapped around a number of thin metal sheets called lamination.

64. (c) : Eddy currents also oppose the change in magnetic flux, so their direction is given by Lenz's law.

65. (c)

66. (b) : Direction of current induced in a wire moving in a magnetic field is found by using Fleming's right hand rule.

67. (a) : Induced e.m.f, $\varepsilon = Blv$

Current in the rod, $I = \frac{\varepsilon}{R} = \frac{Blv}{R}$

68. (c) : Here, $l = 0.1$ m, $v = 1$ m s^{-1}

$I = 50$ A, $B = 1.25$ mT $= 1.25 \times 10^{-3}$ T

The induced emf is, $\varepsilon = Blv$

The mechanical power is

$P = \varepsilon I = BlvI = 1.25 \times 10^{-3} \times 0.1 \times 1 \times 50$

$= 6.25 \times 10^{-3}$ W $= 6.25$ mW

69. (d) : Emf induced, $\varepsilon = Blv$

Here, $\vec{B}$, $\vec{l}$ and $\vec{v}$ are mutually perpendicular

For given B and l, $\varepsilon \propto v$.

$\therefore \quad \frac{\varepsilon_1}{\varepsilon_2} = \frac{v_1}{v_2}$

Here, $\varepsilon_1 = 1.5$ V, $v_1 = 15$ km/hr $= 15\times\frac{5}{18}$ ms^{-1}

$v_2 = 10$ km/hr $= 10\times\frac{5}{18}$ ms^{-1}, $\varepsilon_2 = ?$

So, $\frac{1.5}{\varepsilon_2} = \frac{15\times\frac{5}{18}}{10\times\frac{5}{18}} = \frac{3}{2}$; $\varepsilon_2 = 1$ V

70. (a) : $\varepsilon = \frac{[W]}{[q]} = \frac{ML^2T^{-2}}{AT} = ML^2T^{-3}A^{-1}$

71. (b) : The relative motion between the coil and the magnet produces change in the magnetic flux in the coil. The induced emf is always in such a direction that it opposes the change in the flux.

72. (c)

73. (d)

74. (a) : When an electron is moving from right to left, the flux linked with loop (which is going into the page) will first increase and then decrease as the electron passes by. So the induced current I_i in the loop will be first clockwise and will change direction (*i.e.* will become anticlockwise) as the electron passes by.

75. (c) : When current in coil *A* increases with time, there will be a change of flux in coil *B* which will induce a current in *B*. Now, according to Lenz's law, the direction of induced current in *B* will be opposite to the direction of current in *A*. Thus, if two loops carry current in opposite direction they will repel each other.

76. (c) : The mutual inductance of the system is
$M = \mu_0 n_1 n_2 \pi a^2 L$

77. (c) : Here, $\phi_B = 2\times10^{-2}$ Wb, $I = 0.01$ A
As $\phi_B = MI$
$\therefore$ Mutual inductance between two coils is

$$M = \frac{\phi_B}{I} = \frac{2\times10^{-2}\,\text{Wb}}{0.01\,\text{A}} = 2\,\text{H}$$

78. (b) : Mutual inductance of coils, $M = \frac{\mu_0\mu_r N_1 N_2 A}{l}$

It is clear that mutual inductance of coils can be increased by increasing the number of turns in the coils.

79. (a) : We know that the mutual inductance depends (directly proportional) on the permeability of the medium surrounding the coils. When the permeability of the medium is increased by inserting a sheet of iron, then the mutual inductance between the coils also increases.

80. (c)

81. (a) : The inductance in a coil plays the same role as inertia in mechanics.

82. (b) : Here, $I = 2.5$ A, $L = 5$ H

Magnetic flux linked with the coil is
$\phi_B = LI = (5\text{ H})(2.5\text{ A}) = 12.5$ Wb

83. (c) : The inductance of a solenoid is $L = \mu_0 n^2 Al$ where *A* is the area of cross-section of the solenoid, *l* its length and *n* is the number of turns per unit length.
As $A = \pi R^2$, where *R* is the radius of the solenoid.
$\therefore\ L = \mu_0 n^2 \pi R^2 l \Rightarrow L \propto R^2$

84. (c) : The magnitude of induced emf is

$|\varepsilon| = L\frac{dI}{dt} \Rightarrow L = \frac{|\varepsilon|dt}{dI}$

or, $L = \frac{\text{volt}\times\text{second}}{\text{ampere}} = \text{ohm second}$

85. (b) : Here $L = 10$ henry $I_1 = 9$ A, $I_2 = 4$ A
and $\Delta I = 0.2$ second
Then induced e.m.f.

$$\varepsilon_1 = -L\frac{dI}{dt} = -L\frac{(I_2 - I_1)}{\Delta t} = \frac{-10\times(4-9)}{0.2} = \frac{50}{0.2} = 250\text{ V}$$

86. (d) : E.m.f. induces, when there is change in magnetic flux. The magnitude of induced e.m.f. depends upon the rate at which the magnetic flux changes. When magnetic flux is steady or constant no e.m.f. is induced. Faraday did experiment in which, there is relative motion between the coil and magnet, the flux linked with the coil changes and e.m.f. induces.

87. (d) : According to Faraday's law, the induced e.m.f. (*E*) is given by $E = \frac{-d(N\phi)}{dt} = -\frac{d(NBA)}{dt} = -NA\frac{dB}{dt}$.
Thus the induced e.m.f. depends on the rate of change of magnetic flux, number of turns of coil and area of the coil. If any of these factor increases (or decreases) then induced e.m.f. also increases (or decreases).

88. (b) : According to Lenz's law when magnet is moved towards the coil, the direction of the induced current is such that the coil repels magnet and when the magnet moves away from the coil, the coil attracts the magnet.

89. (a) : The coefficient of self inductance of the coil is given by $L = \frac{\mu_0 N^2 A}{l}$

where *N* is number of turns, *l* is length of the coil and *A* is area of coil, so $L \propto N^2$.

90. (c) : The coil in the resistance boxes are made from double wire. Due to this current in two wires flows in opposite directions, *i.e.*, magnetic flux linked with the each coil cancel each other. Thus, no e.m.f. is induced in the resistance.

91. (d) : When an alternating current is sent through the coil then effective resistance of the coil will be $\sqrt{R^2 + (\omega L)^2}$

Here, $\varepsilon_1 = 1.5$ V, $v_1 = 15$ km/hr $= 15\times\frac{5}{18}$ ms^{-1}

$v_2 = 10$ km/hr $= 10\times\frac{5}{18}$ ms^{-1}, $\varepsilon_2 = ?$

So, $\frac{1.5}{\varepsilon_2} = \frac{15\times\frac{5}{18}}{10\times\frac{5}{18}} = \frac{3}{2}$; $\varepsilon_2 = 1$ V

70. (a) : $\varepsilon = \frac{[W]}{[q]} = \frac{ML^2T^{-2}}{AT} = ML^2T^{-3}A^{-1}$

71. (b) : The relative motion between the coil and the magnet produces change in the magnetic flux in the coil. The induced emf is always in such a direction that it opposes the change in the flux.

72. (c)

73. (d)

74. (a) : When an electron is moving from right to left, the flux linked with loop (which is going into the page) will first increase and then decrease as the electron passes by. So the induced current I_i in the loop will be first clockwise and will change direction (*i.e.* will become anticlockwise) as the electron passes by.

75. (c) : When current in coil *A* increases with time, there will be a change of flux in coil *B* which will induce a current in *B*. Now, according to Lenz's law, the direction of induced current in *B* will be opposite to the direction of current in *A*. Thus, if two loops carry current in opposite direction they will repel each other.

76. (c) : The mutual inductance of the system is
$M = \mu_0 n_1 n_2 \pi a^2 L$

77. (c) : Here, $\phi_B = 2\times10^{-2}$ Wb, $I = 0.01$ A
As $\phi_B = MI$
$\therefore$ Mutual inductance between two coils is

$$M = \frac{\phi_B}{I} = \frac{2\times10^{-2}\text{ Wb}}{0.01\text{ A}} = 2\text{H}$$

78. (b) : Mutual inductance of coils, $M = \frac{\mu_0\mu_r N_1 N_2 A}{l}$

It is clear that mutual inductance of coils can be increased by increasing the number of turns in the coils.

79. (a) : We know that the mutual inductance depends (directly proportional) on the permeability of the medium surrounding the coils. When the permeability of the medium is increased by inserting a sheet of iron, then the mutual inductance between the coils also increases.

80. (c)

81. (a) : The inductance in a coil plays the same role as inertia in mechanics.

82. (b) : Here, $I = 2.5$ A, $L = 5$ H

Magnetic flux linked with the coil is
$\phi_B = LI = (5\text{ H})(2.5\text{ A}) = 12.5$ Wb

83. (c) : The inductance of a solenoid is $L = \mu_0 n^2 Al$ where *A* is the area of cross-section of the solenoid, *l* its length and *n* is the number of turns per unit length.
As $A = \pi R^2$, where *R* is the radius of the solenoid.
$\therefore$ $L = \mu_0 n^2 \pi R^2 l \Rightarrow L \propto R^2$

84. (c) : The magnitude of induced emf is

$|\varepsilon| = L\frac{dI}{dt} \Rightarrow L = \frac{|\varepsilon|dt}{dI}$

or, $L = \frac{\text{volt}\times\text{second}}{\text{ampere}} = \text{ohm second}$

85. (b) : Here $L = 10$ henry $I_1 = 9$ A, $I_2 = 4$ A
and $\Delta t = 0.2$ second
Then induced e.m.f.

$$\varepsilon_1 = -L\frac{dI}{dt} = -L\frac{(I_2 - I_1)}{\Delta t} = \frac{-10\times(4-9)}{0.2} = \frac{50}{0.2} = 250\text{ V}$$

86. (d) : E.m.f. induces, when there is change in magnetic flux. The magnitude of induced e.m.f. depends upon the rate at which the magnetic flux changes. When magnetic flux is steady or constant no e.m.f. is induced. Faraday did experiment in which, there is relative motion between the coil and magnet, the flux linked with the coil changes and e.m.f. induces.

87. (d) : According to Faraday's law, the induced e.m.f. (*E*) is given by $E = \frac{-d(N\phi)}{dt} = -\frac{d(NBA)}{dt} = -NA\frac{dB}{dt}$.
Thus the induced e.m.f. depends on the rate of change of magnetic flux, number of turns of coil and area of the coil. If any of these factor increases (or decreases) then induced e.m.f. also increases (or decreases).

88. (b) : According to Lenz's law when magnet is moved towards the coil, the direction of the induced current is such that the coil repels magnet and when the magnet moves away from the coil, the coil attracts the magnet.

89. (a) : The coefficient of self inductance of the coil is given by $L = \frac{\mu_0 N^2 A}{l}$

where *N* is number of turns, *l* is length of the coil and *A* is area of coil, so $L \propto N^2$.

90. (c) : The coil in the resistance boxes are made from double wire. Due to this current in two wires flows in opposite directions, *i.e.*, magnetic flux linked with the each coil cancel each other. Thus, no e.m.f. is induced in the resistance.

91. (d) : When an alternating current is sent through the coil then effective resistance of the coil will be $\sqrt{R^2 + (\omega L)^2}$

while it was only R for direct current *i.e.*, effective resistance of coil will increases for A.C.

92. (a) : When the magnet falls, the magnetic flux through the copper ring increases and induced e.m.f. is produced in the ring. The induced emf so produced, opposes the motion of falling magnet. Therefore, the acceleration of the falling magnet will be less than that due to gravity.

93. (c) : When the satellite move in inclined plane with equatorial plane the value of magnetic field will change both in magnitude and direction. Due to this, the magnetic flux through the satellite will change and hence induced currents will be produced in the metal of the satellite. But no current will induce if satellite orbits in the equatorial plane because the magnetic flux does not change through the metal of the satellite in this plane.

94. (a) : Self-inductance of a coil is its property by virtue of which the coil opposes any change in the current flowing through it. It is because, the induced emf produced opposes the change in current. For this reason, self induction is called inertia of electricity.

95. (a) : As the aircraft flies, magnetic flux changes through its wings due to the vertical component of the earth's magnetic field. Due to this, induced emf is produced across the wings of the aircraft.

96. (c) : The manner in which the two coils are oriented, determines the coefficient of coupling between them *i.e.*,

$$K = \sqrt{\frac{M}{L_1L_2}}$$

where L_1 and L_2 are self inductance of two coils. When the two coils are wound on each other, the coefficient of coupling is maximum and hence mutual inductance between the coil is maximum.

97. (a) : An induced current develop in a conductor cannot moved in a direction parallel to magnetic field. This is because when the conductor moved in a direction parallel to magnetic field, amount of flux linked with the conductor does not change. Thus the induced current develops only when conductor cuts the lines of magnetic force. The direction of flow of induced current can also be found by applying Fleming's right hand rule, when the direction of motion of conductor inside the magnetic field and the direction of magnetic field action on it are known.

98. (a) : When we pull a copper plate out of the magnetic field or push it into the magnetic field, magnetic flux linked with the plate changes. As a result of this eddy currents are produced in the plate which oppose its motion (according to Lenz's law).

99. (b) : E.m.f. induces, when there is change in magnetic flux. The magnitude of induced e.m.f. depends upon the rate at which the magnetic flux changes. When magnetic flux is steady or constant no e.m.f. is induced. Faraday did experiment in which, there is relative motion between the coil and magnet, the flux linked with the coil changes and e.m.f. induces.

100.(a) : The inductance coils made of copper will have very small ohmic resistance. Due to change in magnetic flux a large induced current will be produced in such an inductance, which will offer appreciable opposition to the flow of current.

☺☺☺

CHAPTER 7

Alternating Current

Recap Notes

- **Alternating current :** It is that current which changes continuously in magnitude and periodically in direction. It can be represented by a sine curve or a cosine curve
$$I = I_0 \sin \omega t \quad \text{or} \quad I = I_0 \cos \omega t$$
Here, I_0 is peak value of current and is known as amplitude of ac, I is instantaneous value of alternating current. $\omega = 2\pi/T = 2\pi\upsilon$ where T is period of ac and υ is frequency of ac.

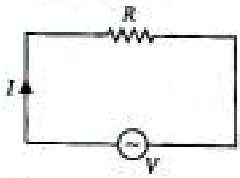
- **Mean or average value of alternating current or voltage over one complete cycle :** The mean or average value of alternating current or voltage over one complete cycle is zero.
$$I_m \text{ or } \bar{I} \text{ or } I_{av} = \frac{\int_0^T I_0 \sin\omega t \, dt}{\int_0^T dt} = 0$$
$$V_m \text{ or } \bar{V} \text{ or } V_{av} = \frac{\int_0^T V_0 \sin\omega t \, dt}{\int_0^T dt} = 0$$

- **Mean value or average value of alternating current over any half cycle :** It is that value of steady current, which would send the same amount of charge through a circuit in the time of half cycle *i.e.*, $T/2$ as is sent by ac through the same circuit in the same time.
$$I_{av} = \frac{2I_0}{\pi} = 0.637\, I_0$$

- Similarly, for alternating voltage
$$V_{av} = \frac{2I_0}{\pi} = 0.637\, V_0$$

- **Root mean square (rms) value of alternating current :** It is defined as that value of steady current, which would generate the same amount of heat in a given resistance in a given time, as is done by the alternating current, when passed through the same resistance for the same time. The rms value of ac is also known as effective value or virtual value of ac. It is represented by I_{rms}, I_{eff} or I_v.
$$I_{rms} \text{ or } I_v = \frac{I_0}{\sqrt{2}} = 0.707\, I_0$$
Similarly, for alternating voltage
$$V_{rms} = \frac{V_0}{\sqrt{2}} = 0.707\, V_0$$

- **AC circuit containing pure resistance only :**

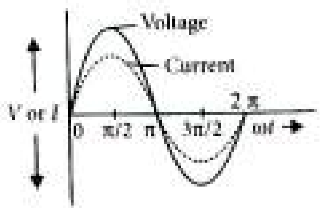


Let $V = V_0 \sin\omega t$

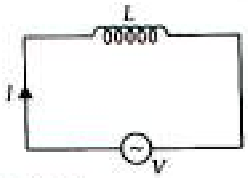
Then, $I = \frac{V}{R} = \frac{V_0}{R} \sin \omega t = I_0 \sin\omega t$

Here the alternating voltage is in phase with current, when ac flows through a resistor.

The instantaneous value of alternating current and alternating voltage in the circuit containing R, follow that both are in same phase as shown in figure.



- **AC circuit containing pure inductor only :**

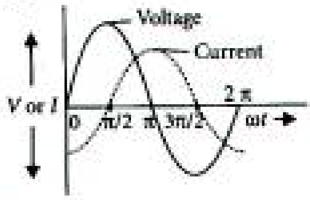


- Let $V = V_0 \sin\omega t$

  Then, $I = I_0 \sin\left(\omega t - \frac{\pi}{2}\right)$

  where $I_0 = \frac{V_0}{\omega L}$

  Thus, the alternating current lags behind the alternating voltage by a phase angle of $\frac{\pi}{2}$ when ac flows through an inductor as shown in figure.

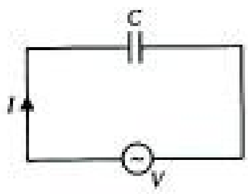


  ▸ **Inductive reactance :** It is the opposition offered by the inductor to the flow of alternating current through it.

  $X_L = \omega L = 2\pi\upsilon L$

  The inductive reactance is zero for dc ($\upsilon = 0$) and has a finite value for ac.

- **AC circuit containing pure capacitor only :**

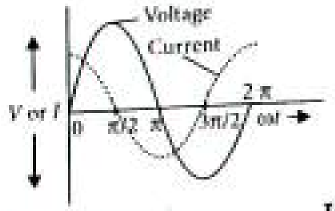


  Let $V = V_0 \sin\omega t$

  $I = I_0 \sin\left(\omega t + \frac{\pi}{2}\right)$

  where $I_0 = (\omega C)V_0$.

  Thus, the alternating current leads the voltage by a phase angle of $\frac{\pi}{2}$, when ac flows through a capacitor.

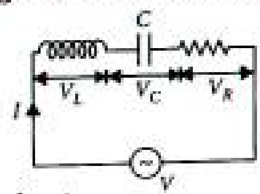


▸ **Capacitive reactance :** It is the opposition offered by the capacitor to the flow of alternating current through it.

$X_C = \frac{1}{\omega C} = \frac{1}{2\pi\upsilon C}$

The capacitive reactance is infinite for dc ($\upsilon = 0$) and has a finite value for ac.

- **AC through *LCR*-series circuit :**

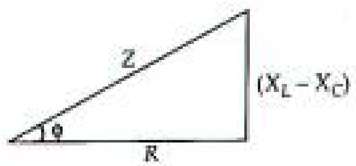


Let $V = V_0 \sin\omega t$

Then, $I = I_0 \sin(\omega t - \phi)$

where $I_0 = \frac{V_0}{Z}$

Here Z is the impedance of the series LCR circuit.



$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$

▸ The alternating current lags behind the voltage by a phase angle ϕ

$$\tan\phi = \frac{X_L - X_C}{R}$$

- When $X_L > X_C$, $\tan\phi$ is positive. Therefore, ϕ is positive. Hence current lags behind the voltage by a phase angle ϕ. The ac circuit is inductance dominated circuit.
- When $X_L < X_C$, $\tan\phi$ is negative. Therefore, ϕ is negative. Hence current leads the voltage by a phase angle ϕ. The ac circuit is capacitance dominated circuit.

- **Resonant series *LCR* circuit :** When the frequency of ac supply is such that the inductive reactance and capacitive reactance become equal ($X_L = X_C$), the impedance of the series LCR circuit is equal to the ohmic resistance in the circuit. As such, the current in the circuit becomes maximum. Such a series LCR circuit is known as resonant series LCR circuit and the frequency of the ac supply is known as resonant frequency (υ_r). The resonant frequency is

$$\upsilon_r = \frac{1}{2\pi\sqrt{LC}}, \quad \omega_r = \frac{1}{\sqrt{LC}}$$

- The series resonance circuit is known as acceptor circuit. It is used in radio and TV receivers sets for tuning a particular radio station/TV channel.
- Resonance phenomenon is exhibited by a circuit only if both L and C are present in the circuit. Then only voltages across L and C cancel each other. We cannot have resonance in a RL or RC circuit.
- **Quality factor :** It is a measure of sharpness of resonance. It is defined as the ratio of reactance of either the inductance or capacitance at the resonant angular frequency to the total resistance of the circuit.

$$Q = \frac{X_L}{R} = \frac{\omega_r L}{R}$$

$$Q = \frac{X_C}{R} = \frac{1}{\omega_r CR}$$

$$\therefore\ Q = \frac{1}{R}\sqrt{\frac{L}{C}}$$

Quality factor is also expressed in terms of bandwidth.

$$Q = \frac{\text{Resonant frequency}}{\text{Bandwidth}}$$

- **Power in an ac circuit :** In an ac circuit we may define three types of power.
  - **Instantaneous power :** The power in the ac circuit at any instant of time is known as instantaneous power. It is equal to the product of values of alternating voltage and alternating current at that time.
  - **Average power (P_{av}) :** The power averaged over one full cycle of ac is known as average power. It is also known as true power or average power.

$$P_{av} = V_{rms}\, I_{rms}\, \frac{R}{Z} = \frac{V_0 I_0}{2}\frac{R}{Z}$$

Here, R is resistance and Z is impedance.

  - **Apparent power :** The product of virtual voltage (V_{rms}) and virtual current (I_{rms}) in the circuit is known as virtual power or apparent power.

$$P_v = V_{rms}\, I_{rms} = \frac{V_0 I_0}{2}$$

- **LC-Oscillations :** When a charged capacitor is allowed to discharge through a non-resistive inductor, electrical oscillations of constant amplitude and frequency are produced, these oscillations are called LC-oscillations.
- **Transformer :** It is a device used for converting a low alternating voltage to a high alternating voltage and vice versa. It is based on phenomenon of mutual induction.

For ideal transformer, $\dfrac{V_S}{V_P} = \dfrac{I_P}{I_S} = \dfrac{N_S}{N_P} = k$.

where k is called transformation ratio.

  - For a step-up transformer, $k > 1$, *i.e.*, $V_S > V_P$, $I_S < I_P$ and $N_S > N_P$.
  - For a step-down transformer, $k < 1$, *i.e.*, $V_S < V_P$, $I_S > I_P$ and $N_S < N_P$.
  - Efficiency of a transformer,

$$\eta = \frac{\text{output power}}{\text{input power}} = \frac{V_S I_S}{V_P I_P}.$$

- **AC Generator :** A generator produces electrical energy from mechanical work, just the opposite of what a motor does.
  - An AC generator is based on the phenomena of electromagnetic induction, which states that whenever magnetic flux linked with a conductor (or coil) changes, an emf is induced in the coil.
  Here ε is the emf induced in the coil, then
  $\varepsilon = NBA\omega \sin \omega t$ or $\varepsilon = \varepsilon_0 \sin \omega t$
  where $\varepsilon_0 = NBA\omega$ is the maximum or peak value of induced emf.
  The instantaneous emf ε produced in coil varies sinusoidally with time and hence is also known as alternating emf.
  where, N = number of turns in the coil, B = strength of magnetic field, A = Area of each turns of the coil and ω = angular velocity of rotation.

Practice Time

Multiple Choice Questions (MCQs)

1. A light bulb is rated at 100 W for a 220 V ac supply. The resistance of the bulb is
(a) 284 Ω (b) 384 Ω
(c) 484 Ω (d) 584 Ω

2. In an ac circuit, V and I are given by
$V = 150\sin(150t)$ volt and $I = 150\sin\left(150t + \frac{\pi}{3}\right)$ ampere. The apparent power in the circuit is
(a) 106 W (b) 150 W
(c) 11250 W (d) zero

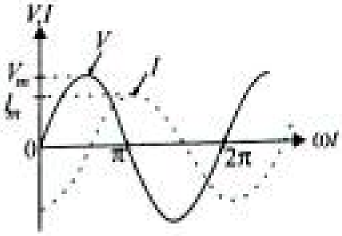
3. In the case of an inductor
(a) voltage lags the current by $\frac{\pi}{2}$
(b) voltage leads the current by $\frac{\pi}{2}$
(c) voltage leads the current by $\frac{\pi}{3}$
(d) voltage leads the current by $\frac{\pi}{4}$.

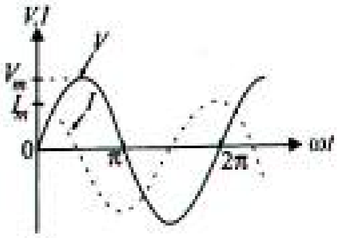
4. An inductor of 30 mH is connected to a 220 V, 100 Hz ac source. The inductive reactance is
(a) 10.58 Ω (b) 12.64 Ω
(c) 18.85 Ω (d) 22.67 Ω

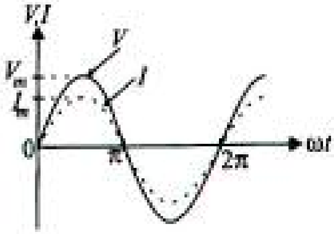
5. A fully charged capacitor C with initial charge Q_0 is connected to a coil of self inductance L at $t = 0$. The time at which the energy is stored equally between the electric and the magnetic field is
(a) $\frac{\pi}{4}\sqrt{LC}$ (b) $2\pi\sqrt{LC}$
(c) $\sqrt{LC}$ (d) $\pi\sqrt{LC}$

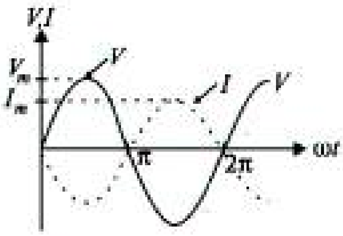
6. An LCR series circuit is under resonance. If I_m is current amplitude, V_m is voltage amplitude, R is the resistance, Z is the impedance, X_L is the inductive reactance and X_C is the capacitive reactance, then
(a) $I_m = \frac{Z}{V_m}$ (b) $I_m = \frac{V_m}{X_L}$
(c) $I_m = \frac{V_m}{X_C}$ (d) $I_m = \frac{V_m}{R}$

7. The phase relationship between current and voltage in a pure resistive circuit is best represented by

(a)


(b)


(c)


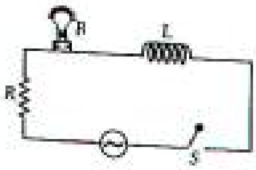
(d)


8. At resonant frequency the current amplitude in series LCR circuit is
(a) maximum (b) minimum
(c) zero (d) infinity.

9. A 0.2 kΩ resistor and 15 μF capacitor are connected in series to a 220 V, 50 Hz ac source. The impedance of the circuit is
(a) 250 Ω (b) 268 Ω
(c) 29.15 Ω (d) 291.5 Ω

10. A sinusoidal voltage of peak value 293 V and frequency 50 Hz is applied to a series LCR circuit in which $R = 6$ Ω, $L = 25$ mH and $C = 750$ μF. The impedance of the circuit is
(a) 7.0 Ω (b) 8.9 Ω
(c) 9.9 Ω (d) 10.0 Ω

11. Switch S is closed at $t = 0$. After sufficiently long time, an iron rod is inserted into the inductor L.
Then, the light bulb

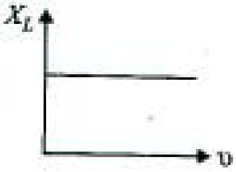


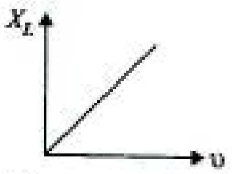
(a) glows more brightly
(b) gets dimmer
(c) glows with the same brightness
(d) gets momentarily dimmer and then glows more brightly.

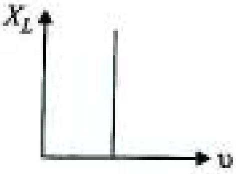
12. In a series LCR circuit having $L = 30$ mH, $R = 8\ \Omega$ and the resonant frequency is 50 Hz. The quality factor of the circuit is
(a) 0.118 (b) 11.8
(c) 118 (d) 1.18

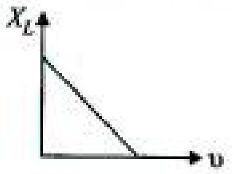
13. Alternating voltage (V) is represented by the equation
(a) $V(t) = V_m e^{\omega t}$ (b) $V(t) = V_m \sin\omega t$
(c) $V(t) = V_m \cot\omega t$ (d) $V(t) = V_m \tan\omega t$
where V_m is the peak voltage.

14. Which of the following graphs represents the correct variation of inductive reactance X_L with frequency υ?

(a)


(b)


(c)


(d)


15. A 44 mH inductor is connected to 220 V, 50 Hz ac supply. The rms value of the current in the circuit is
(a) 12.8 A (b) 13.6 A
(c) 15.9 A (d) 19.5 A

16. The output of a step-down transformer is measured to be 24 V when connected to a 12 watt light bulb. The value of the peak current is
(a) $\frac{1}{\sqrt{2}}$ A (b) $\sqrt{2}$ A
(c) 2 A (d) $2\sqrt{2}$ A

17. Which of the following combinations should be selected for better tuning of an LCR circuit used for communication?
(a) $R = 20\ \Omega$, $L = 1.5$ H, $C = 35\ \mu$F
(b) $R = 25\ \Omega$, $L = 2.5$ H, $C = 45\ \mu$F
(c) $R = 15\ \Omega$, $L = 3.5$ H, $C = 30\ \mu$F
(d) $R = 25\ \Omega$, $L = 1.5$ H, $C = 45\ \mu$F

18. A 30 μF capacitor is connected to a 150 V, 60 Hz ac supply. The rms value of current in the circuit is
(a) 17 A (b) 1.7 A
(c) 1.7 mA (d) 2.7 A

19. The rms value of current in an ac circuit is 25 A, then peak current is
(a) 35.36 mA (b) 35.36 A
(c) 3.536 A (d) 49.38 A

20. The resonant frequency of a series LCR circuit with $L = 2.0$ H, $C = 32\ \mu$F and $R = 10\ \Omega$ is
(a) 20 Hz (b) 30 Hz
(c) 40 Hz (d) 50 Hz

21. A 60 μF capacitor is connected to a 110 V (rms), 60 Hz ac supply. The rms value of current in the circuit is
(a) 1.49 A (b) 14.9 A
(c) 2.49 A (d) 24.9 A

22. When a voltage measuring device is connected to ac mains, the meter shows the steady input voltage of 220 V. This means
(a) input voltage cannot be ac voltage, but a dc voltage
(b) maximum input voltage is 220 V
(c) the meter reads not V but $<V^2>$ and is calibrated to read $\sqrt{<V^2>}$.
(d) the pointer of the meter is stuck by some mechanical defect.

23. In series LCR circuit, the phase angle between supply voltage and current is
(a) $\tan\phi = \frac{X_L - X_C}{R}$ (b) $\tan\phi = \frac{R}{X_L - X_C}$
(c) $\tan\phi = \frac{R}{X_L + X_C}$ (d) $\tan\phi = \frac{X_L + X_C}{R}$

24. A series LCR circuit with $R = 22\ \Omega$, $L = 1.5$ H and $C = 40\ \mu$F is connected to a variable frequency 220 V ac supply. When the frequency of the supply equals the natural frequency of the circuit, what is the average power transferred to the circuit in one complete cycle?
(a) 2000 W (b) 2200 W
(c) 2400 W (d) 2500 W

25. In an alternating current circuit consisting of elements in series, the current increases on increasing the frequency of supply. Which of the following elements are likely to constitute the circuit?

(a) Only resistor.
(b) Resistor and an inductor.
(c) Resistor and a capacitor.
(d) Only an inductor.

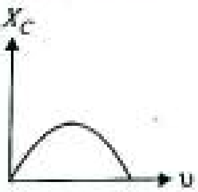
26. When an ac voltage of 220 V is applied to the capacitor C, then
(a) the maximum voltage between plates is 220 V
(b) the current is in phase with the applied voltage
(c) the charge on the plate is not in phase with the applied voltage
(d) the current developed leads the applied voltage by a phase angle of 90°.

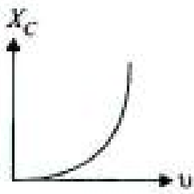
27. The LC parallel resonant circuit
(a) has a very high impedance
(b) has a very high current
(c) acts as resistance of very low value
(d) has zero impedance

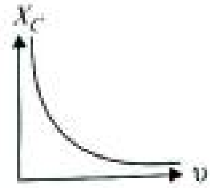
28. A capacitor and an inductance coil are connected in separate AC circuits with a bulb glowing in both the circuits. The bulb glows more brightly when
(a) an iron rod is introduced into the inductance coil
(b) the number of turns in the inductance coil is increased
(c) separation between the plates of the capacitor is increased.
(d) a dielectric is introduced into the gap between the plates of the capacitor.

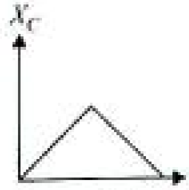
29. Quantity that remains unchanged in a transformer is
(a) voltage
(b) current
(c) frequency
(d) none of these.

30. Which of the following graphs represents the correct variation of capacitive reactance X_C with frequency υ ?

(a) 

(b) 

(c) 

(d) 

31. The loss of energy in the form of heat in the iron core of a transformer is
(a) iron loss
(b) copper loss
(c) mechanical loss
(d) none of these

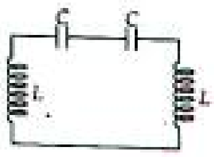
32. An alternating current generator has an internal resistance R_g and an internal reactance X_g. It is used to supply power to a passive load consisting of a resistance R_g and a reactance X_L. For maximum power to be delivered from the generator to the load, the value of X_L should be equal to
(a) zero (b) X_g
(c) $-X_g$ (d) R_g

33. An inductor of reactance 1 Ω and a resistor of 2 Ω are connected in series to the terminals of a 6 V (rms) ac source. The average power in the circuit is
(a) 8 W (b) 12 W
(c) 14.4 W (d) 18 W

34. A charged 30 μF capacitor is connected to a 27 mH inductor. The angular frequency of free oscillations of the circuit is
(a) 1.1×10^3 rad s^{-1}
(b) 2.1×10^3 rad s^{-1}
(c) 3.1×10^3 rad s^{-1}
(d) 4.1×10^3 rad s^{-1}

35. The Q factor of a series LCR circuit with $L = 2$ H, $C = 32$ μF and $R = 10$ Ω is
(a) 15 (b) 20
(c) 25 (d) 30

36. The natural frequency of the circuit shown in figure is



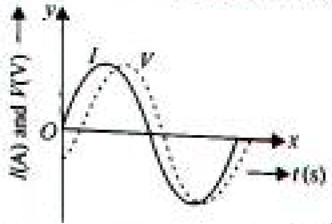
(a) $\frac{1}{2\pi\sqrt{LC}}$ (b) $\frac{1}{2\pi\sqrt{2LC}}$
(c) $\frac{2}{2\pi\sqrt{LC}}$ (d) zero

37. A circuit is made up of a resistance 1 Ω and inductance 0.01 H. An alternating voltage of 200 V at 50 Hz is connected, then the phase difference between the current and the voltage in the circuit is

(a) $\tan^{-1}(\pi)$ (b) $\tan^{-1}\left(\frac{\pi}{2}\right)$

(c) $\tan^{-1}\left(\frac{\pi}{4}\right)$ (d) $\tan^{-1}\left(\frac{\pi}{3}\right)$

38. When an ac source of voltage $V = V_0 \sin 100t$ is connected across a circuit, the phase difference between the voltage V and current I in the circuit is observed to be $\pi/4$, as shown in figure. If the circuit consists possibly only of RC or RL or LC in series, find possible values of two elements.



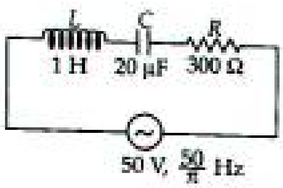
(a) $R = 1\ k\Omega$, $C = 10\ \mu F$

(b) $R = 1\ k\Omega$, $C = 1\ \mu F$

(c) $R = 1\ k\Omega$, $L = 10\ mH$

(d) $R = 10\ k\Omega$, $L = 10\ mH$

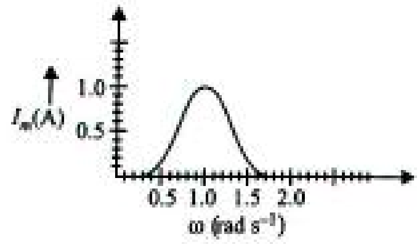
39. In the series LCR circuit shown, the impedance is



(a) 200 Ω (b) 100 Ω

(c) 300 Ω (d) 500 Ω

40. In a series LCR circuit, the plot of I_m versus ω is shown in the figure. The bandwidth of this plot will be



(a) zero (b) 0.1 rad s^{-1}

(c) 0.2 rad s^{-1} (d) 0.4 rad s^{-1}

41. The line that draws power supply to your house from street has

(a) $220\sqrt{2}$ V average voltage.

(b) 220 V average voltage.

(c) voltage and current out of phase by $\pi/2$.

(d) voltage and current possibly differing in phase φ such that $|\phi| < \frac{\pi}{2}$.

42. An alternating current of rms value 10 A is passed through a 12 Ω resistor. The maximum potential difference across the resistor is

(a) 20 V (b) 90 V

(c) 169.68 V (d) none of these

43. 200 V ac source is fed to series LCR circuit having $X_L = 50\ \Omega$, $X_C = 50\ \Omega$ and $R = 25\ \Omega$. Potential drop across the inductor is

(a) 100 V (b) 200 V

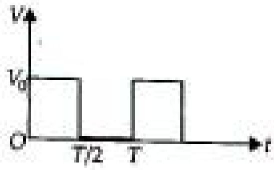
(c) 400 V (d) 10 V

44. A 100 μF capacitor in series with a 40 Ω resistor is connected to a 100 V, 60 Hz supply. The maximum current in the circuit is

(a) 2.65 A (b) 2.75 A

(c) 2.85 A (d) 2.95 A

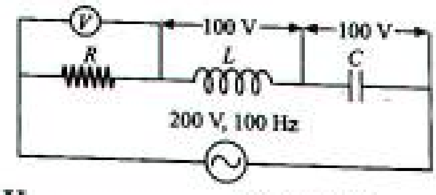
45. The rms value of potential difference V shown in the figure is



(a) $\frac{V_0}{\sqrt{3}}$ (b) V_0

(c) $\frac{V_0}{\sqrt{2}}$ (d) $\frac{V_0}{2}$

46. In the circuit shown in figure, what will be the reading of the voltmeter?



(a) 300 V (b) 900 V

(c) 200 V (d) 400 V

47. A transformer is used to light 140 W, 24 V lamp from a 240 V ac mains. If the main current is 0.7 A, the efficiency of the transformer is

(a) 63.8% (b) 74%

(c) 83.3% (d) 48%

48. The 220 V AC line voltage that we receive in our homes is

(a) rms value (b) peak value

(c) average value (d) none of these

49. An alternating current in a circuit is given by $I = 20 \sin(100\pi t + 0.05\pi)$ A. The rms value and the frequency of current respectively are
(a) 10 A and 100 Hz (b) 10 A and 50 Hz
(c) $10\sqrt{2}$ A and 50 Hz (d) $10\sqrt{2}$ A and 100 Hz

50. A bulb of resistance 280 Ω is supplied with a 200 V AC supply. What is peak current?
(a) Nearly 1 A (b) Nearly 2 A
(c) Nearly 1.4 A (d) Nearly 2.8 A

51. A capacitor of capacity C has reactance X. If the capacitance and frequency become double, then reactance will be
(a) $4X$ (b) $\frac{X}{2}$
(c) $\frac{X}{4}$ (d) $2X$

52. When the frequency of the AC voltage applied to a series LCR circuit is gradually increased from a low value, the impedance of the circuit
(a) monotonically increases
(b) first increases and then decreases
(c) first decreases and then increases
(d) monotonically decreases

53. A series LCR circuit is connected to an AC source and is showing resonance. Then
(a) $V_R = 0$ (b) $V_L = V_R$
(c) $V_C = V_R$ (d) $V_L = V_C$

54. An LCR circuit contains $R = 50\ \Omega$, $L = 1$ mH and $C = 0.1\ \mu$F. The impedance of the circuit will be minimum for a frequency of
(a) $\frac{10^5}{2\pi}$ Hz (b) $\frac{10^6}{2\pi}$ Hz
(c) $2\pi \times 10^5$ Hz (d) $2\pi \times 10^6$ Hz

55. A 50 volt AC is applied across an RC (series) network. The rms voltage across the resistance is 40 volt, then the potential across the capacitance would be
(a) 10 V (b) 20 V
(c) 30 V (d) 40 V

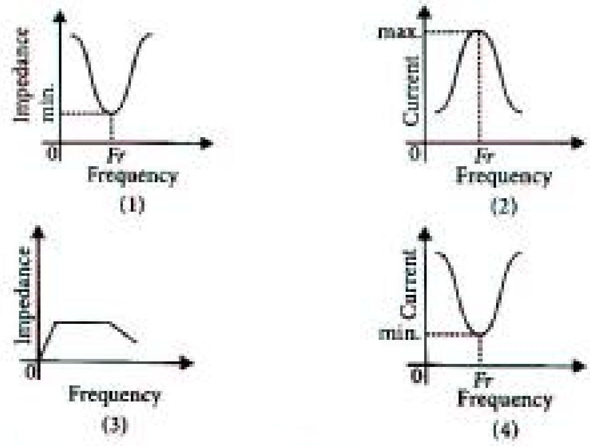
56. The turn ratio of a transformer is 1 : 2. An electrolytic DC cell of emf 2 volt is connected to its primary. The output voltage is
(a) 2 V (b) 0 V
(c) 1 V (d) 3 V

57. In step-up transformer, relation between number of turns in primary (N_P) and number of turns in secondary (N_S) coils is
(a) N_S is greater than N_P
(b) N_P is greater than N_S
(c) N_S is equal to N_P
(d) $N_P = 2N_S$

58. A charged capacitor $C = 30\ \mu$F is connected to an inductor $L = 27$ mH. The angular frequency of their oscillations is
(a) 9.1×10^3 (b) 3.0×10^3
(c) 1.1×10^3 (d) 0.3×10^3

59. The resonance frequency of the tank circuit of an oscillator when $L = \frac{10}{\pi^2}$ mH and $C = 0.04\ \mu$F are connected in parallel is
(a) 250 kHz (b) 25 kHz
(c) 2.5 kHz (d) 25 MHz

60. Out of the following graphs, which graph shows the correct relation (graphical representation) for LC parallel resonant circuit?



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

Case Based MCQs

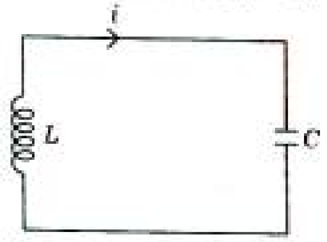
Case I : Read the passage given below and answer the following questions from 61 to 65.

LC Circuit

An LC circuit also called a resonant circuit, tank circuit or tuned circuit is an electric circuit consisting of an inductor represented by the letter L and a capacitor, represented by the letter C connected together. An LC circuit is an idealized model since it assumes there is no dissipation of energy due to resistance.

An LC circuit contains a 20 mH inductor and a 50 μF capacitor with an initial charge of 10 mC.

The resistance of the circuit is negligible. Let the instant the circuit is closed be $t = 0$.



61. The total energy stored initially is
(a) 5 J (b) 3 J
(c) 10 J (d) 1 J

62. The natural frequency of the circuit is
(a) 159.24 Hz (b) 200.12 Hz
(c) 110.25 Hz (d) 95 Hz

63. At what time is the energy stored completely electrical?
(a) $T, 5T, 9T$ (b) $\frac{T}{2}, \frac{5T}{2}, \frac{9T}{2}$
(c) $0, T, 2T, 3T$ (d) $0, \frac{T}{2}, T, \frac{3T}{2}$

64. At what time is the energy stored completely magnetic?
(a) $\frac{T}{2}, \frac{3T}{2}, \frac{T}{4}$ (b) $\frac{T}{3}, \frac{T}{9}, \frac{T}{12}$
(c) $0, 2T, 3T$ (d) $\frac{T}{4}, \frac{3T}{4}, \frac{5T}{4}$

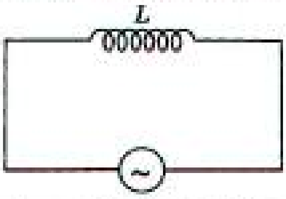
65. The value of X_L is
(a) 20 Ω (b) 40 Ω
(c) 60 Ω (d) 50 Ω

Case II : Read the passage given below and answer the following questions from 66 to 70.

AC Voltage Applied to an Inductor

Let a source of alternating e.m.f. $E = E_0 \sin\omega t$ be connected to a circuit containing a pure inductance L. If I is the value of instantaneous current in the circuit, then $I = I_0 \sin\left(\omega t - \frac{\pi}{2}\right)$.

The inductive reactance limits the current in a purely inductive circuit and is given by $X_L = \omega L$.



66. A 100 hertz a.c. is flowing in a 14 mH coil. The reactance is
(a) 15 Ω (b) 7.5 Ω
(c) 8.8 Ω (d) 10 Ω

67. In a pure inductive circuit, resistance to the flow of current is offered by
(a) resistor
(b) inductor
(c) capacitor
(d) resistor and inductor.

68. In a inductive circuit, by what value of phase angle does alternating current lags behind e.m.f.?
(a) 45° (b) 90°
(c) 120° (d) 75°

69. How much inductance should be connected to 200 V, 50 Hz a.c. supply so that a maximum current of 0.9 A flows through it?
(a) 5 H (b) 1 H
(c) 10 H (d) 4.5 H

70. The maximum value of current when inductance of 2 H is connected to 150 volt, 50 Hz supply is
(a) 0.337 A (b) 0.721 A
(c) 1.521 A (d) 2.522 A

Case III : Read the passage given below and answer the following questions from 71 to 75.

Transformer

A transformer is essentially an a.c. device. It cannot work on d.c. It changes alternating voltages or currents. It does not affect the frequency of a.c. It is based on the phenomenon of mutual induction. A transformer essentially consists of two coils of insulated copper wire having different number of turns and wound on the same soft iron core.

The number of turns in the primary and secondary coils of an ideal transformer are 2000 and 50 respectively. The primary coil is connected to a main supply of 120 V and secondary coil is connected to a bulb of resistance 0.6 Ω.

71. The value of voltage across the secondary coil is
(a) 5 V (b) 2 V
(c) 3 V (d) 10 V

72. The value of current in the bulb is
(a) 7 A (b) 15 A
(c) 3 A (d) 5 A

73. The value of current in primary coil is
(a) 0.125 A (b) 2.52 A
(c) 1.51 A (d) 3.52 A

74. Power in primary coil is

(a) 20 W (b) 5 W

(c) 10 W (d) 15 W

75. Power in secondary coil is

(a) 15 W (b) 20 W

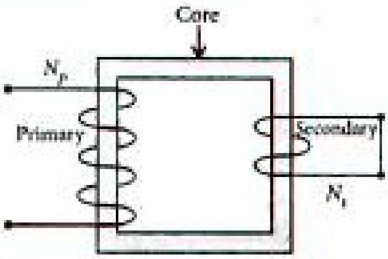
(c) 7 W (d) 8 W

Case IV : Read the passage given below and answer the following questions from 76 to 80.

Step-down Transformer in the Transmission of Electric Power

Step-down transformers are used to decrease or step-down voltages. These are used when voltages need to be lowered for use in homes and factories.

A small town with a demand of 800 kW of electric power at 220 V is situated 15 km away from an electric plant generating power at 440 V. The resistance of the two wire line carrying power is 0.5 Ω per km. The town gets power from the line through a 4000 - 220 V step-down transformer at a sub-station in the town.



76. The value of total resistance of the wires is

(a) 25 Ω (b) 30 Ω

(c) 35 Ω (d) 15 Ω

77. The line power loss in the form of heat is

(a) 550 kW (b) 650 kW

(c) 600 kW (d) 700 kW

78. How much power must the plant supply, assuming there is negligible power loss due to leakage?

(a) 600 kW (b) 1600 kW

(c) 500 W (d) 1400 kW

79. The voltage drop in the power line is

(a) 1700 V (b) 3000 V

(c) 2000 V (d) 2800 V

80. The total value of voltage transmitted from the plant is

(a) 500 V (b) 4000 V

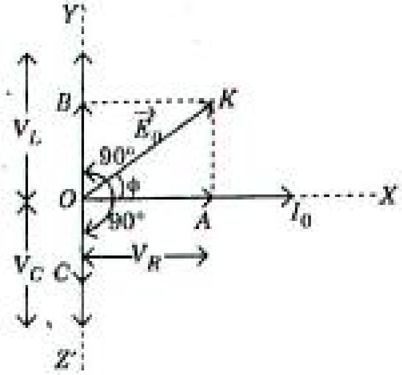
(c) 3000 V (d) 7000 V

Case V : Read the passage given below and answer the following questions from 81 to 85.

LCR Circuit

When a pure resistance R, pure inductor L and an ideal capacitor of capacitance C is connected in series to a source of alternating e.m.f., then current at any instant through the three elements has the same amplitude and is represented as $I = I_0 \sin\omega t$. However, voltage across each element has a different phase relationship with the current as shown in graph.

The effective resistance of RLC circuit is called impedance (Z) of the circuit and the voltage leads the current by a phase angle ϕ.



A resistor of 12 Ω, a capacitor of reactance 14 Ω and a pure inductor of inductance 0.1 H are joined in series and placed across 200 V, 50 Hz a.c. supply.

81. The value of inductive reactance is

(a) 15 Ω (b) 31.4 Ω

(c) 20 Ω (d) 30 Ω

82. The value of impedance is

(a) 20 Ω (b) 15 Ω

(c) 30 Ω (d) 21.13 Ω

83. What is the value of current in the circuit?

(a) 5 A (b) 15 A

(c) 10 A (d) 9.46 A

84. What is the value of the phase angle between current and voltage?

(a) 53°9′ (b) 63°9′

(c) 55°4′ (d) 50°

85. From graph, which one is true from following?

(a) $V_L \geq V_C$ (b) $V_L < V_C$

(c) $V_L > V_C$ (d) $V_L = V_C$

Assertion & Reasoning Based MCQs

For question numbers 86-100, two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.

(a) *Both A and R are true and R is the correct explanation of A*

(b) *Both A and R are true but R is NOT the correct explanation of A*

(c) *A is true but R is false*

(d) *A is false and R is also false*

86. **Assertion (A) :** Long distance transmission of A.C. is carried out at extremely high voltage.

Reason (R) : For large distance, voltage has to be large.

87. **Assertion (A) :** An electric lamp connected in series with a variable capacitor and A.C. source, its brightness increases with increase in capacitance.

Reason (R) : Capacitive reactance decreases with increase in capacitance of capacitor.

88. **Assertion (A) :** A transformer cannot work on D.C. supply.

Reason (R) : D.C. changes neither in magnitude nor in direction.

89. **Assertion (A) :** Step-down transformer increases the current.

Reason (R) : Transformer obeys the law of conservation of energy.

90. **Assertion (A) :** Soft iron is used as a core of transformer.

Reason (R) : Area of hysteresis loop for soft iron is small.

91. **Assertion (A) :** The core of transformer is made laminated in order to increase the eddy currents.

Reason (R) : The sensitivity of transformer increases with increase in the eddy currents.

92. **Assertion (A) :** The alternating current lags behind the e.m.f. by a phase angle of $\pi/2$, when A.C. flows through an inductor.

Reason (R) : The inductive reactance increases as the frequency of A.C. source decreases.

93. **Assertion (A) :** Capacitor serves as a block for D.C. and offers an easy path to A.C.

Reason (R) : Capacitive reactance is inversely proportional to frequency.

94. **Assertion (A) :** When capacitive reactance is smaller than the inductive reactance in *LCR* series circuit, e.m.f. leads the current.

Reason (R) : The phase angle is the angle between the alternating e.m.f. and alternating current of the circuit.

95. **Assertion (A) :** At resonance, *LCR* series circuit have a maximum current.

Reason (R) : At resonance, in *LCR* series circuit, the current and e.m.f are in phase with each other.

96. **Assertion (A) :** A bulb connected in series with a solenoid is connected to A.C. source. If a soft iron core is introduced in the solenoid, the bulb will glow brighter.

Reason (R) : On introducing soft iron core in the solenoid, the inductance decreases.

97. **Assertion (A) :** An electric heater is heated first by direct and then by alternating currents. For both the currents, the potential difference across the ends of the heater is the same. The rate of production of heat will be different in two cases.

Reason (R) : The resistance of a coil in alternating current will be more than the resistance of a coil in direct current, hence heat produced in case of direct current will be low.

98. **Assertion (A) :** An alternating current shows magnetic effect.

Reason (R) : Magnitude of alternating current varies with time.

99. **Assertion (A) :** We use a thick wire in the secondary coil of a step down transformer to reduce the production of heat.

Reason (R) : When the plane of the armature is parallel to the line of force of magnetic field, the magnitude of induced e.m.f. is maximum.

100. **Assertion (A) :** An inductance and a resistance are connected in series with an A.C. circuit. In this circuit the current and the potential difference across the resistance lags behind potential difference across the inductance by an angle $\pi/2$.

Reason (R) : In *L-R* circuit voltage leads the current by phase angle which depends on the value of inductance and resistance both.

ANSWERS

1. **(c)** : Here, $P = 100$ W, $V_{rms} = 220$ V
Resistance of the bulb is

$$R = \frac{V^2_{rms}}{P} = \frac{(220)^2}{100} = 484\ \Omega$$

2. **(c)** : Compare $V = 150\sin(150t)$ with $V = V_0\sin\omega t$, we get
$V_0 = 150$ V

Compare $I = 150\sin\left(150t + \frac{\pi}{3}\right)$ with

$I = I_0\sin(\omega t + \phi)$, we get $I_0 = 150$ A

Apparent power,

$$P = V_{rms}I_{rms} = \frac{1}{2}V_0 I_0 = \frac{1}{2}\times 150\times 150$$

$= 11250$ W

3. **(b)** : In an inductor voltage leads the current by $\frac{\pi}{2}$ or current lags the voltage by $\frac{\pi}{2}$.

4. **(c)** : Here, $L = 30$ mH $= 30\times 10^{-3}$ H
$V_{rms} = 220$ V, $\upsilon = 100$ Hz
Inductive reactance,
$X_L = 2\pi\upsilon L$
$= 2\times 3.14\times 100\times 30\times 10^{-3} = 18.85\ \Omega$

5. **(a)** : As $\omega^2 = \frac{1}{LC}$ or $\omega = \frac{1}{\sqrt{LC}}$

Maximum energy stored in capacitor $= \frac{1}{2}\frac{Q_0^2}{C}$

Let at any instant t, the energy be stored equally between electric and magnetic field. Then energy stored in electric field at instant t is

$$\frac{1}{2}\frac{Q^2}{C} = \frac{1}{2}\left[\frac{1}{2}\frac{Q_0^2}{C}\right]$$

or $\quad Q^2 = \frac{Q_0^2}{2}$ or $Q = \frac{Q_0}{\sqrt{2}}$ or $Q_0\cos\omega t = \frac{Q_0}{\sqrt{2}}$

or $\quad \omega t = \frac{\pi}{4}$ or $t = \frac{\pi}{4\omega} = \frac{\pi}{4\times(1/\sqrt{LC})} = \frac{\pi\sqrt{LC}}{4}$

6. **(d)** : Impedance of the circuit,

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

At resonance, $X_L = X_C$

$\therefore\ Z = R$

$\therefore\ I_m = \frac{V_m}{Z} = \frac{V_m}{R}$.

7. **(c)** : In the pure resistive circuit current and voltage both are in phase. Hence graph (c) is correct.

8. **(a)**

9. **(d)** : Here, $R = 0.2$ k$\Omega = 200\ \Omega$
$C = 15\ \mu$F $= 15\times 10^{-6}$ F
$V_{rms} = 220$ V, $\upsilon = 50$ Hz

Capacitive reactance, $X_c = \frac{1}{2\pi\upsilon C}$

$$= \frac{1}{2\times 3.14\times 50\times 15\times 10^{-6}} = 212\ \Omega$$

The impedance of the RC circuit is

$$Z = \sqrt{R^2 + X_C^2}$$

$$= \sqrt{(200)^2 + (212)^2} = 291.5\ \Omega$$

10. **(a)** : Here, $R = 6\ \Omega$, $L = 25$ mH $= 25\times 10^{-3}$ H,
$C = 750\ \mu$F $= 750\times 10^{-6}$ F, $\upsilon = 50$ Hz

$X_L = 2\pi\upsilon L = 2\times 3.14\times 50\times 25\times 10^{-3} = 7.85\ \Omega$

$$X_C = \frac{1}{2\pi\upsilon C} = \frac{1}{2\times 3.14\times 50\times 750\times 10^{-6}} = 4.25\ \Omega$$

$\therefore\ X_L - X_C = 7.85 - 4.25 = 3.6\ \Omega$

Impedence of the series LCR circuit is

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

$\therefore\ Z = \sqrt{(6)^2 + (3.6)^2} = \sqrt{36 + 12.96} = 7.0\ \Omega$

11. **(b)** : As the rod is inserted, inductance increases and hence the voltage across inductor increases. This causes a drop in the voltage across the bulb and hence it gets dimmer.

12. **(d)** : Here, $L = 30$ mH $= 30\times 10^{-3}$ H, $R = 8\ \Omega$, $\upsilon_r = 50$ Hz
As $\omega_r = 2\pi\upsilon_r = 2\times 3.14\times 50 = 314$ Hz

$\therefore\ $ Quality factor, $Q = \frac{\omega_r L}{R} = \frac{314\times 30\times 10^{-3}}{8} = 1.18$

13. **(b)** : The equation of alternating voltage is
$V(t) = V_m\sin\omega t$

14. **(b)** : Inductive reactance, $X_L = \omega L = 2\pi\upsilon L$
$\Rightarrow\ X_L \propto \upsilon$
Hence, inductive reactance increases linearly with frequency.

15. **(c)** : Here, $L = 44$ mH $= 44\times 10^{-3}$ H
$V_{rms} = 220$ V, $\upsilon = 50$ Hz
The inductive reactance is
$X_L = \omega L = 2\pi\upsilon L = 2\times 3.14\times 50\times 44\times 10^{-3} = 13.82\ \Omega$

$$\therefore\ I_{rms} = \frac{V_{rms}}{X_L} = \frac{220}{13.82} = 15.9\ \text{A}$$

16. **(a)** : Here, $V_s = 24$ V, $P_s = 12$ W

$$I_s = \frac{P_s}{V_s} = \frac{12}{24} = 0.5\ \text{A}$$

$$I_m = \sqrt{2}\,I_s = \sqrt{2}\times 0.5 = \frac{1}{\sqrt{2}}\ \text{A}$$

17. (c) : For better tuning of an LCR circuit used for communication the circuit should possess high quality factor of resonance.

i.e., $Q = \frac{1}{R}\sqrt{\frac{L}{C}}$ should be high.

For it R should be low, L should be high and C should be low, therefore combination in option (c) is correct.

18. (b) : Here, $C = 30\ \mu F = 30 \times 10^{-6}$ F

$V_{rms} = 150$ V, $\upsilon = 60$ Hz

Capacitive reactance

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi\upsilon C} = \frac{1}{2\times3.14\times60\times30\times10^{-6}} = 88.46\ \Omega$$

$$I_{rms} = \frac{V_{rms}}{X_C} = \frac{150}{88.46} = 1.7\ \text{A}$$

19. (b) : Here, $I_{rms} = 25$ A

$\therefore\quad I_0 = \sqrt{2}\, I_{rms} = \sqrt{2}\times 25 = 35.36$ A.

20. (a) : Here, $L = 2$ H, $C = 32\ \mu F = 32 \times 10^{-6}$ F

$R = 10\ \Omega$

$$\therefore\quad \omega_r = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{2\times32\times10^{-6}}}$$

$$= \frac{10^3}{\sqrt{64}} = \frac{10^3}{8} = 125\ \text{rad s}^{-1}$$

$$\upsilon_r = \frac{\omega_r}{2\pi} = \frac{125}{2\times3.14} = 20\ \text{Hz}$$

21. (c) : Here, $C = 60\ \mu F = 60 \times 10^{-6}$ F

$V_{rms} = 110$ V, $\upsilon = 60$ Hz

$$\therefore\quad I_{rms} = \frac{V_{rms}}{X_C} = \frac{V_{rms}}{1/2\pi\upsilon C}$$

$$= 2\pi\upsilon C\, V_{rms}$$

$$= 2 \times 3.14 \times 60 \times 60 \times 10^{-6} \times 110 = 2.49\ \text{A}$$

22. (c) : The voltmeter connected to ac mains is calibrated to read root mean square value or virtual value of ac voltage.

23. (a)

24. (b) : When the frequency of the supply equals to the natural frequency of circuit, resonance occurs.

$\therefore\quad Z = R = 22\ \Omega$

and $I_{rms} = \frac{V_{rms}}{Z} = \frac{220}{22} = 10$ A

Average power transferred per cycle,

$$P = V_{rms}\, I_{rms}\, \frac{R}{Z} = 220 \times 10 \times 1 = 2200\ \text{W}$$

25. (c) : Reactance of a capacitor, $X_C = \frac{1}{\omega C} = \frac{1}{2\pi\upsilon C}$

As frequency increases, X_C decreases and therefore current increases. As R does not vary with frequency, therefore, likely elements constituting the circuit may be capacitor and resistor.

26. (d) : When an ac voltage of 220 V is applied to a capacitor C, the charge on the plates is in phase with the applied voltage.

As the circuit is pure capacitive so, the current developed leads the applied voltage by a phase angle of 90°.

27. (a) : The LC parallel resonant circuit has a very high impedance, hence a very low current.

28. (d)

29. (c) : A transformer does not change the frequency of ac.

30. (c) : Capacitive reactance, $X_C = \frac{1}{\omega C} = \frac{1}{2\pi\upsilon C}$

$\Rightarrow\quad X_C \propto \frac{1}{\upsilon}$

With increase in frequency, X_C decreases.

Hence, option (c) represents the correct graph.

31. (a) : Iron loss is the energy loss in the form of heat due to the formation of eddy currents in the iron core of the transformer.

32. (c) : For maximum power to be delivered from the generator to the load, the total reactance must vanish.

i.e., $X_L + X_g = 0$ or $X_L = -X_g$

33. (c) : Here, $X_L = 1\ \Omega$, $R = 2\ \Omega$, $V_{rms} = 6$ V

Impedance of the circuit

$$Z = \sqrt{X_L^2 + R^2} = \sqrt{(1)^2 + (2)^2} = \sqrt{5}\ \Omega$$

$$I_{rms} = \frac{V_{rms}}{Z} = \frac{6}{\sqrt{5}}\ \text{A}$$

Average power, $P = V_{rms} I_{rms} \frac{R}{Z}$

$$= 6 \times \frac{6}{\sqrt{5}} \times \frac{2}{\sqrt{5}} = \frac{72}{5} = 14.4\ \text{W}$$

34. (a) : Here, $C = 30\ \mu F = 30 \times 10^{-6}$ F

$L = 27$ mH $= 27 \times 10^{-3}$ H

$$\therefore\quad \omega = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{27\times10^{-3}\times30\times10^{-6}}} = \frac{1}{\sqrt{81\times10^{-8}}}$$

$$= \frac{10^4}{9} = 1.1\times10^3\ \text{rad s}^{-1}$$

35. (c) : Here, $L = 2$ H, $C = 32\ \mu F = 32 \times 10^{-6}$ F, $R = 10\ \Omega$

$\therefore$ Resonance frequency, $\omega_r = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{2\times32\times10^{-6}}}$

$$= \frac{10^3}{8}\ \text{rad s}^{-1}$$

Quality factor $= \frac{\omega_r L}{R} = \frac{10^3\times2}{8\times10} = 25$

36. (a) : In the given circuit, two capacitors are in series and so are the two inductors. So, their equivalent capacitance and inductance are

$$\frac{1}{C_s} = \frac{1}{C} + \frac{1}{C} = \frac{2}{C} \text{ or } C_s = \frac{C}{2} \text{ and } L_s = L + L = 2L$$

$\therefore$ The natural frequency of the circuit is

$$\upsilon = \frac{1}{2\pi\sqrt{L_s C_s}} = \frac{1}{2\pi\sqrt{(2L)\left(\frac{C}{2}\right)}} = \frac{1}{2\pi\sqrt{LC}}$$

37. **(a)** : $\tan\phi = \left(\frac{X_L}{R}\right)$

$X_L = \omega L = (2\pi\upsilon L) = (2\pi)(50)(0.01) = \pi\ \Omega$

Also, $R = 1\ \Omega$

$\therefore \quad \phi = \tan^{-1}(\pi)$

38. **(a)** : Figure given in the question shows that current I leads the voltage V by a phase angle $\pi/4$. Therefore, the circuit can be RC circuit alone.

$$\tan\phi = \frac{X_C}{R} = \frac{1}{\omega CR} \qquad \left(\because X_C = \frac{1}{\omega C}\right)$$

$$\tan\frac{\pi}{4} = \frac{1}{\omega CR}$$

$$1 = \frac{1}{\omega CR} \qquad \text{...(i)}$$

From $V = V_0 \sin 100t$, we get

$\omega = 100$ rad s^{-1}

$\therefore \ CR = \frac{1}{\omega} = \frac{1}{100}$ (Using (i))

When $R = 1\ k\Omega = 10^3\ \Omega$

$C = \frac{1}{10^5} = 10^{-5}\ \text{F} = 10\ \mu\text{F}$

39. **(d)** : Here, $L = 1$ H, $C = 20\ \mu$F $= 20 \times 10^{-6}$ F

$R = 300\ \Omega,\ \upsilon = \frac{50}{\pi}$ Hz

The inductive reactance is

$X_L = 2\pi\upsilon L = 2 \times \pi \times \frac{50}{\pi} \times 1 = 100\ \Omega$

The capacitive reactance is

$X_C = \frac{1}{2\pi\upsilon C} = \frac{1}{2 \times \pi \times \frac{50}{\pi} \times 20 \times 10^{-6}} = 500\ \Omega$

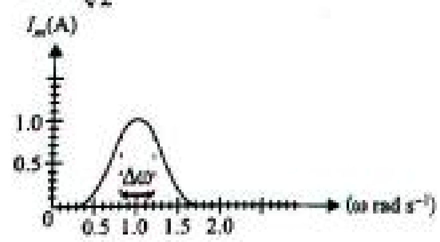
The impedance of the series LCR circuit is

$$Z = \sqrt{R^2 + (X_C - X_L)^2}$$

$$= \sqrt{(300)^2 + (500 - 100)^2}$$

$$= \sqrt{(300)^2 + (400)^2} = 500\ \Omega$$

40. **(d)** : Bandwidth is the frequency range at which current amplitude $I_m = \frac{1}{\sqrt{2}} I_{max} = 0.7 I_{max}$.



From figure,
Band width $\Delta\omega = 1.2 - 0.8 = 0.4$ rad s^{-1}

41. **(d)** : As the line has some resistance ($R \neq 0$), voltage and current differ in phase ϕ such that $|\phi| < \frac{\pi}{2}$.

42. **(c)** : Here, $I_{rms} = 10$ A, $R = 12\ \Omega$

The maximum current $I_m = \sqrt{2} I_{rms} = \sqrt{2}(10) = 10\sqrt{2}$ A

Maximum potential difference is $V_m = I_m R$

$= 10\sqrt{2} \times 12 = 169.68$ V

43. **(c)** : Here, $V_{rms} = 200$ V

$X_L = 50\ \Omega,\ X_C = 50\ \Omega,\ R = 25\ \Omega$

Impedance of the circuit,

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{25^2 + (50 - 50)^2} = 25\ \Omega$$

Current in the circuit,

$$I_{rms} = \frac{V_{rms}}{Z} = \frac{200\ \text{V}}{25\ \Omega} = 8\ \text{A}$$

Voltage drop across the inductor is

$V_L = I_{rms} X_L = 8\ \text{A} \times 50\ \Omega = 400$ V

44. **(d)** : Here, $C = 100\ \mu\text{F} = 100 \times 10^{-6}\ \text{F} = 10^{-4}$ F,

$R = 40\ \Omega$,

$V_{rms} = 100$ V, $\upsilon = 60$ Hz

$\therefore \quad V_0 = \sqrt{2}\, V_{rms} = 100\sqrt{2}$ V

In series RC circuit,

$$Z = \sqrt{R^2 + X_C^2} = \sqrt{R^2 + \frac{1}{\omega^2 C^2}}$$

$$= \frac{1}{\sqrt{R^2 + \frac{1}{4\pi^2\upsilon^2 C^2}}} \qquad [\because \omega = 2\pi\upsilon]$$

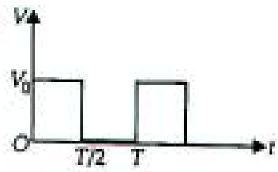
Maximum current in the circuit,

$$I_0 = \frac{V_0}{Z} = \frac{V_0}{\sqrt{R^2 + \frac{1}{4\pi^2\upsilon^2 C^2}}}$$

$$= \frac{100\sqrt{2}}{\sqrt{(40)^2 + \frac{1}{4 \times (3.14)^2 \times (60)^2 \times (10^{-4})^2}}}$$

$$= \frac{100\sqrt{2}}{48} = 2.95\ \text{A}$$

45. **(c)** :



$V = V_0$ for $0 \le t \le \frac{T}{2}$

$V = 0$ for $\frac{T}{2} \le t \le T$

$$V_{rms} = \left[\frac{\int_0^T V^2\,dt}{\int_0^T dt}\right]^{1/2} = \left[\frac{\int_0^{T/2} V_0^2\,dt + \int_{T/2}^{T} (0)\,dt}{\int_0^T dt}\right]^{1/2}$$

$$= \left[\frac{V_0^2}{T}[t]_0^{T/2}\right]^{1/2} = \left[\frac{V_0^2}{T}\left(\frac{T}{2}\right)\right]^{1/2} = \left[\frac{V_0^2}{2}\right]^{1/2}$$

$$V_{rms} = \frac{V_0}{\sqrt{2}}$$

46. (c) : Here, $V_L = V_C = 100$ V, $V = 200$ V

As $V = \sqrt{V_R^2 + (V_L - V_C)^2}$

$\therefore \quad 200 = \sqrt{V_R^2 + (100-100)^2} = V_R$

or $\quad V_R = 200$ V

47. (c) : Output power = 140 W
Input power = 240 × 0.7 = 168 W

$$\text{Efficiency} = \frac{\text{output power}}{\text{input power}} \times 100 = \frac{140}{168} \times 100 = 83.3\%$$

48. (a) : The 220 V, ac line voltage that we receive in our homes is an rms value.

49. (c) : Given, $I = 20\sin(100\pi t + 0.05\pi)$ A
Comparing with standard equation, we get
$I_0 = 20$ A and $\omega = 100\pi$ rad s^{-1}

$\therefore \quad I_{rms} = \frac{I_0}{\sqrt{2}} = \frac{20}{\sqrt{2}} = 10\sqrt{2}$ A

Now $\omega = 100\pi$, $2\pi\upsilon = 100\pi$, $\upsilon = 50$ Hz

50. (a) : Here, $R = 280\ \Omega$, $V_{rms} = 200$ V

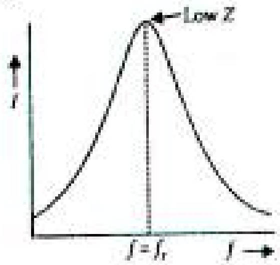
Peak voltage, $V_0 = V_{rms}\sqrt{2} = 200\sqrt{2}$

Peak current, $I_0 = \frac{V_0}{R} = \frac{200\sqrt{2}\text{ V}}{280\ \Omega} \approx 1$ A

51. (c) : $X_C = \frac{1}{\omega C} = \frac{1}{(2\pi\upsilon)C}$

$\therefore \quad \frac{X_{C_2}}{X_{C_1}} = \frac{\upsilon_1 C_1}{\upsilon_2 C_2} = \frac{1}{2}\cdot\frac{1}{2} = \frac{1}{4} \quad \therefore\ 2X_{C_2} = \frac{X_{C_1}}{4} = \frac{X}{4}$

52. (c) : From the graph, we concluded that with the increase in frequency, the current increases, attains a maximum value ($f = f_r$) and then decreases. It implies that the impedance first decreases, becomes minimum for maximum value of current and then increases.



53. (d) : At resonance, voltage across inductor = voltage across capacitor *i.e.*, $V_L = V_C$.

54. (a) : The impedance of the LCR circuit will be minimum for a resonant frequency υ_r.

$$\upsilon_r = \frac{1}{2\pi\sqrt{LC}}$$

Here, $L = 1$ mH $= 1 \times 10^{-3}$ H, $C = 0.1\ \mu$F $= 0.1 \times 10^{-6}$ F

$$\therefore \quad \upsilon_r = \frac{1}{2\pi\sqrt{(1\times10^{-3}\text{ H})(0.1\times10^{-6}\text{ F})}} = \frac{10^5}{2\pi}\text{Hz}$$

55. (c) : $V_{RC} = \sqrt{V_R^2 + V_C^2} \quad \therefore\ 50 = \sqrt{40^2 + V_C^2}$

$50^2 = 40^2 + V_C^2 \Rightarrow V_C^2 = 50^2 - 40^2 = 900$

$\therefore \quad V_C = 30$ V

56. (b)

57. (a)

58. (c) : Here, $C = 30\ \mu$F $= 30 \times 10^{-6}$ F,
$L = 27$ mH $= 27 \times 10^{-3}$ H

The angular frequency, $\omega = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{27\times10^{-3}\times30\times10^{-6}}}$

$$= \frac{1}{9\times10^{-4}} = 1.1\times10^3\ \text{rad s}^{-1}$$

59. (b) : $f = \frac{1}{2\pi}\sqrt{\frac{1}{LC}} = 25\times10^3$ Hz

60. (d) : At parallel resonance, L and C are connected in parallel combination and current is minimum.

61. (d) : Energy, $E = \frac{1}{2}\frac{Q^2}{C} = \frac{(10\times10^{-3})^2}{2\times50\times10^{-6}} = 1$ J

62. (a) : Frequency, $\upsilon = \frac{1}{2\pi\sqrt{LC}}$

$$= \frac{1}{2\pi\sqrt{20\times10^{-3}\times50\times10^{-6}}} = \frac{10^3}{2\pi} = 159.24\text{ Hz}$$

63. (d) : Total time period, $T = \frac{1}{\upsilon} = \frac{1}{159.24} = 6.28$ ms

Total charge on capacitor at time t, $Q' = Q\cos\frac{2\pi}{T}t$

For energy stored is electrical, we can write $Q' = \pm Q$.
Hence, energy stored in the capacitor is completely electrical at, $t = 0, \frac{T}{2}, T, \frac{3T}{2}, ...$

64. (d) : Magnetic energy is maximum when electrical energy is equal to zero.

Hence $\quad t = \frac{T}{4}, \frac{3T}{4}, \frac{5T}{4}, ...$

65. (a) : $X_L = \omega L = 2\pi\upsilon L = 2 \times 3.14 \times 159.24 \times 20 \times 10^{-3}$
$\Rightarrow \quad X_L = 20\ \Omega$

66. (c) : Inductive reactance,
$X_L = \omega L = 2\pi\upsilon L = 2\pi \times 100 \times 14 \times 10^{-3}$
$X_L = 8.8\ \Omega$

67. (b)

68. (b) : In an inductor voltage leads the current by $\frac{\pi}{2}$ or current lags the voltage by $\frac{\pi}{2}$.

69. (b) : The current in the inductor coil is given by

$$I_0 = \frac{E_0}{X_L} = \frac{\sqrt{2}E_v}{2\pi\upsilon L}$$

$$L = \frac{\sqrt{2}E_v}{2\pi\upsilon I_0} = \frac{1.414 \times 200}{2 \times 3.14 \times 50 \times 0.9} = 1\ \text{H}$$

70. (a) : Inductive reactance,
$X_L = \omega L = 2\pi\upsilon L = 2 \times 3.14 \times 50 \times 2 = 628\ \Omega$

$$I_0 = \frac{E_0}{X_L} \Rightarrow I_0 = \frac{\sqrt{2} \times E_v}{X_L} = \frac{\sqrt{2} \times 150}{628} = 0.337\ \text{A}$$

71. (c) : As $\frac{E_s}{E_p} = \frac{n_s}{n_p} \Rightarrow E_s = E_p \cdot \frac{n_s}{n_p}$

$$= \frac{120 \times 50}{2000} = 3\ \text{V}$$

72. (d) : $I_s = \frac{E_s}{R} \Rightarrow I_s = \frac{3}{0.6} = 5\ \text{A}$

73. (a) : As $\frac{I_p}{I_s} = \frac{E_s}{E_p}$

$$\Rightarrow I_p = \frac{E_s}{E_p} \times I_s = \frac{3}{120} \times 5 = 0.125\ \text{A}$$

74. (d) : Power in primary, $P_p = E_p \times I_p = 120 \times 0.125 = 15\ \text{W}$

75. (a) : Power in secondary coil, $P_s = E_s \times I_s = 3 \times 5 = 15\ \text{W}$

76. (d) : Resistance of the two wire lines carrying power = 0.5 Ω/km
Total resistance = (15 + 15)0.5 = 15 Ω

77. (c) : Line power loss = I^2R
RMS current in the coil,

$$I = \frac{P}{V_1} = \frac{800 \times 10^3}{4000} = 200\ \text{A}$$

$\therefore$ Power loss = $(200)^2 \times 15 = 600$ kW

78. (d) : Assuming that the power loss is negligible due to the leakage of the current.
The total power supplied by the plant
= 800 kW + 600 kW = 1400 kW

79. (b) : Voltage drop in the power line = IR
= 200 × 15 = 3000 V

80. (d) : Total voltage transmitted from the plant
= 3000 V + 4000 V = 7000 V

81. (b) : Given : $R = 12\ \Omega$, $X_C = 14\ \Omega$, $L = 0.1$ H
$X_L = \omega L = 2\pi\upsilon L = 2 \times 3.14 \times 50 \times 0.1 = 31.4\ \Omega$

82. (d) : Impedance, $Z = \sqrt{R^2 + (X_L - X_C)^2}$

$$= \sqrt{(12)^2 + (31.4 - 14)^2} = 21.13\ \Omega$$

83. (d) : $I_v = \frac{E_v}{Z} = \frac{200\ \text{V}}{21.13} = 9.46\ \text{A}$

84. (c) : $\tan\phi = \frac{X_L - X_C}{R} = \frac{31.4 - 14}{12} = 1.45$

$\phi = \tan^{-1}(1.45) = 55°4'$

85. (c)

86. (c) : The transmission is done at high voltage due to which current through the wire is reduced. By reduction in current corresponding dissipation of energy is also reduced (as $H \propto I^2R$). If transmission is done at low voltage then we have to use thick wire in order to reduce the dissipation of energy. This increase the cost of transmission lines wires. In order to reduce both energy dissipation and cost of transmission wire, transmission is done at high voltage by using step-up transformers.

87. (a) : Capacitive reactance $X_C = \frac{1}{\omega C}$. When capacitance C increases, the capacitive reactance decreases. Due to decrease in its values, the current in the circuit will increase $\left(I = \frac{E}{\sqrt{R^2 + X_C^2}}\right)$ and hence brightness of source (or electric lamp) will also increases.

88. (a) : Transformer works on the principle of mutual induction *i.e.*, if two coils are inductively coupled and when current or magnetic flux is changed through one of the two coils, then induced e.m.f. is produced in the other coil. So whenever there is change in current or magnetic flux, only then e.m.f. is induced. But in case of D.C. current or voltage, e.m.f. is not induced because it remain constant throughout and never changes its direction and magnitude. Therefore transformer cannot work when D.C. is applied.

89. (b) : If there is no loss of energy in transformer, then instantaneous output power is equal to instantaneous input power. From this we get $\frac{e_s}{e_p} = \frac{I_p}{I_s}$.

So in step up transformer voltage increases by decreasing the current. Similarly, step-down transformer decreases the voltage by increasing current. Therefore transformer simply transforms the voltage and current, obeying the law of conservation of energy.

90. (a) : The alternating current flowing through the coils, magnetises and demagnetises the iron core again and again over complete cycles. During each cycle of magnetisation, some energy is lost due to hysteresis, the energy lost during a cycle of magnetisation being equal to area of hysteresis loop (in magnitude). Energy loss can be reduce by selecting the material core, which has narrow hysteresis loop, that is why soft iron core is used.

91. (d) : Eddy current is produced in the iron core due to induced e.m.f. Since resistance of the iron core is quite small, the magnitude of eddy currents is quite large. As a result, large amount of heat is produced. To avoid it, a laminated core is used in a transformer. In laminated core iron stripes are quite thin and each strip possesses very large resistance, the magnitude of eddy currents produced is quite small and hence only a small amount of heat is produced.

92. (c) : When pure inductor is connected to source of an alternating emf, then instantaneous value of alternating emf is given by $E = E_0 \sin\omega t$, and corresponding alternating current is given by $I = I_0 \sin(\omega t - \pi/2)$. From these two equations, it follows that alternating current lags behind e.m.f. by a phase angle of $\pi/2$. The inductive reactance,

$X_L = \omega L = 2\pi f L$, so when frequency increases correspondingly inductive reactance also increases.

93. (a) : The capacitive reactance of capacitor is given by

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}.$$

So this is infinite for D.C. ($f = 0$) and has a finite value for ... refore a capacitor blocks D.C. and offers an easy pa... .C.

94. (b) ...he phase angle for the LCR series circuit is given by $\tan\theta = \frac{X_L - X_C}{R} = \frac{\omega L - 1/\omega C}{R}$

where X_L, X_C are inductive reactance a... reactance respectively. When $X_L > X_C$ then ta... i.e. θ is positive (between 0 and $\pi/2$). Hence em... the current.

95. (b) : At resonance $X_L = X_C$ or $\omega L = \frac{1}{\omega C}$. Because of this impedance of LCR series circuit become equal to resistance of circuit $\left(Z = \sqrt{R^2 + (X_L - X_C)^2}\right)$. Therefore from $I = \frac{E}{Z} = \frac{E}{R}$, at resonance, current in LCR series circuit is maximum. Correspondingly phase angle is also equal to zero. Therefore emf and current are in phase in LCR series circuit.

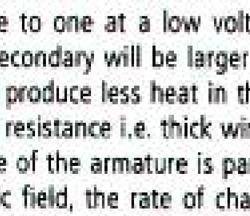
96. (d) : On introducing soft iron core, the bulb will glow dimmer. This is because on introducing soft iron core in the solenoid, its inductance L increases, the inductive reactance, $X_L = \omega L$ increases and hence the current through the bulb decreases.

97. (a) : The element of the heater is in the form of a coil so that it has inductance L also besides the resistance R. So, for the alternating current, the effective resistance of the heater would be $\sqrt{R^2 + (\omega L)^2}$ which is larger than the resistance R for the direct current. Hence on heating by alternating current, heat produced per second would be less.
($H = V^2/R$ and V is same in both the cases).

98. (b) : Like direct current, an alternating current also produces magnetic field. But the magnitude and direction of the field goes on changing continuously with time.

99. (b) : A step-down transformer converts electrical energy from a high voltage to one at a low voltage. Accordingly the current in the secondary will be larger than that in the primary. In order to produce less heat in the secondary, we use a wire of lesser resistance i.e. thick wire. We also know that when the plane of the armature is parallel to the lines of force of magnetic field, the rate of change of magnetic flux linked with it is maximum. Therefore the e.m.f. induced in the armature in this orientation is maximum.

100. (b) : As both the inductance and resistance are joined in series, hence current through both will be same. But in case of resistance, both the current and potential vary simultaneously, hence they are in same phase. While in case of an inductance when current is zero, potential difference across it is maximum and when current reaches maximum (at $\omega t = \pi/2$), potential difference across it becomes zero *i.e.*, potential difference leads the current by $\pi/2$ or current lags behind the potential difference by $\pi/2$. Phase angle in case of LR circuit is given as $\phi = \tan^{-1}\left(\frac{\omega L}{R}\right)$.



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