PHYSICS

VOULME I

QUESTION BANK

CHAPTER 1

ELECTROSTATICS

Points to ponder

✓ **Electrostatics:** The branch of electricity which deals with stationary charges is called Electrostatics.

✓ Charging the objects through rubbing is called **triboelectric charging.**

✓ **Basic properties of charges**

- **(I) Conservation of charges: The total electric charge in the universe is constant and charge can neither be created nor be destroyed. In any physical process, the net change in charge will always be zero.**
- **(ii) Quantisation of charges :** The charge q on any object is equal to an integral multiple of this fundamental unit of charge e. ie. $q = ne$, here n is any integer (0, ±1, ±2,). $e = 1.6 \times 10^{-19}$ C.
- The number of electrons in 1 coulomb of charge is 6.25×10^{18}.

✓ **COULOMB'S LAW:** Coulomb force between two-point charges directly proportional to product of charge and inversely proportionally square of the distance between them. It's a vector quantity.

$F \propto \frac{Q_1 Q_2}{r^2}$

✓ **One Coulomb** is defined as the quantity of charge, which when placed at a distance of 1 metre in air or vacuum from an equal and similar charge, experiences a repulsive force of 9×10^9 N.

✓ The gravitational force is **always attractive** but Coulomb force can be **attractive or repulsive**, depending on the nature of charges.

✓ The strength of the force between the two charges in the medium is reduced compared to the force between the same two charges in vacuum.

✓ In a system of n charges, the total force acting on a given charge is equal to the vector sum of forces exerted on it by all the other charges.. i.e. $\vec{F}_1 = \vec{F}_{12} + \vec{F}_{13} + \ldots\ldots\ldots\ldots \vec{F}_{1n}$

✓ **Electric line of force** is an imaginary straight or curved path along which a unit positive charge tends to move in an electric field.

Properties of lines of forces:

- Lines of force start from positive charge and terminate at negative charge.
- Lines of force never intersect.

- The tangent to a line of force at any point gives the direction of the electric field (E) at that point.
- The number of lines per unit area, through a plane at right angles to the lines, is proportional to the magnitude of E. This means that, where the lines of force are close together, E is large and where they are far apart, E is small.
- The electric field at a point is given force experienced by unit charge $E = F/q_o$

✓ There are two kinds of the electric field:

- Uniform (constant) electric field: Uniform electric field will have the same direction and constant magnitude at all points in space.
- Non-uniform electric field: Non-uniform electric field will have different directions or different magnitudes or both at different points in space.

✓ Electric field due to the system of point charges: The electric field at an arbitrary point due to a collection of point charges is simply equal to the vector sum of the electric fields created by the individual point charges. This is called superposition of electric fields.

✓ Electric dipole : Two equal and opposite charges separated by a small distance constitute an electric dipole. The magnitude of the **dipole moment** is given by the product of the magnitude of the one of the charges and the distance between them.

∴ Electric dipole moment, $p = q2d$ *or* $2qd$.

It is a vector quantity and acts from –q to +q. The unit of dipole moment is C m.

✓ ***Electric field due to an electric dipole at a point on its axial line* -** E acts in the direction of dipole moment.

✓ ***Electric field due to an electric dipole at a point on the equatorial line* -** The direction of E is parallel to the axis of the dipole and directed opposite to the direction of dipole moment.

✓ If the dipole is placed in a uniform electric field at an angle θ, it experiences only a torque.

✓ If the dipole is placed in a non−uniform electric field at an angle θ, it experiences both torque and force.

✓ If the dipole is placed in an electric field and aligned in the direction of electric field, it neither experiences torque nor a force.

✓ Electrostatic potential: Then the electric potential at a point P is equal to the work done by an external force to bring a unit positive charge with constant velocity from infinity to the point P in the region of the external electric field.

✓ According to the superposition principle: The total electric potential at a point is equal to the sum of the potentials due to each charge at that point.

✓ Relation between electric field and potential $dV = -E.dx$ or $E = -dV/dx$

✓ **Equi-potential Surface : An equipotential surface is a surface on which all the points are at the same potential.**

✓ The **electric potential energy** of two point charges is equal to the work done to assemble the charges or work done in bringing each charge or work done in bringing a charge from infinite distance.

✓ If all the points of a surface are at the same electric potential, then the surface is called an **equipotential surface**. If the charge is to be moved between any two points on an equipotential surface through any path, the work done is zero. The electric field must always be normal to equipotential surface.

✓ The **electric flux** is defined as the total number of electric lines of force, crossing through the given area. The electric flux dφ through the $d\varphi = \vec{E}.\overrightarrow{ds}$=E dscosθ. Its unit is N m^2 C^{-1}

✓ **Electrostatic potential energy of a dipole in a uniform electric field:** It is maximum when the dipole is aligned anti-parallel ($\theta = \pi$) to the external electric field and minimum when the dipole is aligned parallel ($\theta = 0$) to the external electric field.

✓ **Gauss's law :** The law states that the total flux of the electric field E over any closed surface is equal to $^1/\varepsilon_0$ times the net charge enclosed by the surface. $\varphi = q/\varepsilon_0$.

- Properties of Gauss's law; The charges present outside the surface will not contribute to the flux. The total electric flux is independent of the location of the charges inside the closed surface. Gauss law is another form of Coulomb's law and it is also applicable to the charges in motion.

✓ The electric field is zero everywhere inside the conductor. There is no net charge inside the conductors. The charges must reside only on the surface of the conductors. The electric field outside the conductor is perpendicular to the surface of the conductor.

✓ **Electrostatic shielding :** It is the process of isolating a certain region of space from external field. It is based on the fact that electric field inside a conductor is zero.

✓ **During** a thunder accompanied by **lightning**, it is **safer to sit inside a bus** than in open ground or under a tree. The metal body of the bus provides electrostatic shielding, where the electric field is zero. During lightning the electric discharge passes through the body of the bus.

✓ It is possible to obtain charges without any contact with another charge. They are known as induced charges and the phenomenon of producing induced charges is known as **electrostatic induction**. It is used in electrostatic machines like Van de Graaff generator and capacitors.

✓ **Dielectrics or insulators** A dielectric is a non-conducting material and has no free electrons. Ebonite, glass and mica are some examples of dielectrics.

- **Non-polar molecules** A non-polar molecule is one in which centers of positive and negative charges coincide. As a result, it has no permanent dipole moment. Examples of non-polar molecules are hydrogen (H_2), oxygen (O_2), and carbon dioxide (CO_2) etc.
- **Polar molecules** in polar molecules, the centers of the positive and negative charges are separated even in the absence of an external electric field. They have a permanent dipole moment. Examples of polar molecules are H_2O, N_2O, HCl, NH_3.
- **Polarisation** In the presence of an external electric field, the dipole moment is induced in the dielectric material. **Polarisation is defined as the total dipole moment per unit volume of the dielectric.**
- The magnitude of the induced dipole moment p is directly proportional to the external electric field E.

∴ $p \alpha E$ or $p = \alpha E$, where α is the constant of proportionality and is called **molecular polarisability**.

- Dielectric strength: When the external electric field applied to a dielectric is very large, it tears the atoms apart so that the bound charges become free charges. Then the dielectric starts to conduct electricity. This is called dielectric breakdown. The maximum electric field the dielectric can withstand before it breakdowns is dielectric strength
- Capacitance. The capacitance C of a capacitor is defined as the ratio of the magnitude of charge on either of the conductor plates to the potential difference existing between the conductors.
- The energy stored per unit volume of space is defined as energy density
- **Applications of capacitors**
  - (a) In digital camera the flash which comes from the camera is due to the energy released from the capacitor, called a flash capacitor
  - (b) During cardiac arrest, a device called heart defibrillator is used to give a sudden surge of a large amount of electrical energy
  - (c) Capacitors are used in the ignition system of automobile engines to eliminate sparking.
  - (d) Capacitors are used to reduce power fluctuations in power supplies and to increase the efficiency of power transmission.

- **Effect of dielectrics in capacitors** Since $\varepsilon r > 1$, we have $C > Co$. Thus, insertion of the dielectric constant εr increases the capacitance.

S. No	Dielectric is inserted	Charge Q	Voltage V	Electric field E	Capacitance C	Energy U
1	When the battery is disconnected	Constant	decreases	Decreases	Increases	Decreases
2	When the battery is connected	Increases	Constant	Constant	Increases	Increases

✓ The leakage of electric charges from the sharp points on the charged conductor is known as **action of points or corona discharge**. Uses - electrostatic machines for collecting charges and in lightning arresters

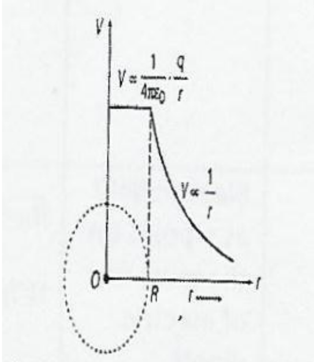
✓ **Van de Graaff Generator:** It is use to produces a large amount of electrostatic potential difference, up to several million volts (107 V). This Van de Graff generator works on the principle of electrostatic induction and action at points. The high voltage produced in this Van de Graaff generator is used to accelerate positive ions (protons and deuterons) for nuclear disintegrations and other applications.

Important formulas

S.No	APPLICATION	FORMULA	Terms	Unit	Figure
1	Electric Charge	$q=\pm ne$; Where n = 1,2,3,…. And $e=1.6\text{x}10^{-19}$ C	q=electric charge; Sl unit Coloumb n=integer $e=1.6\text{x}10^{-19}$ C		
2.	Electrostatic Force	$F=\frac{1}{4\pi\epsilon 0}\times\frac{q1q2}{r2}$ => $F=K\frac{q1q2}{r2}$ Where $\frac{1}{4\pi\epsilon 0}$ = K = 9 X 10^9 Nm^2/C^2 And ϵ_0 = permittivity of free space = 8.85 x 10^{-2} C^2/Nm^2	F=Electrostatic force Sl unit: newton(N) $Q_1=q_2$ = electric charge D=distance between charges		

3	Coulomb's law	$F=\frac{1}{4\pi\epsilon m}\ \frac{q1q2}{r2}$	F=Electrostatic force between charges in a medium
4	Resultant electrostatic force	$F=\sqrt{F1+F2+2F1\ F2}\ \cos Ø$	F=resultant electrostatic force Ø=angle between F_1 and F_2
5	Electrostatic force in an external electric field	F=qE For positive charge electrostatic force (F) on charge(q) is in the direction of external electric field, but for negative charge F is in opposite direction to that of E	F=electrostatic force on a charge (q) in external electric field (E)
6	Electric field strength due to a charge	$E=\frac{1}{4\pi\epsilon 0}\ \frac{q}{r2}=\ E=K\ \frac{q}{r2}$	E=electrostatic field due to a point charge (q) D=distance from point charge Sl unit of electric field is N/s (or) V/m
7	Electric dipole moment	P=q(2a)	P=electric dipole moment **Sl unit of electric dipole moment (P) is Cm** Q=charge 2a = distance between Charges of electric dipole
8	Electric field at a point on the axial line of electric dipole	$E_a=\frac{1}{4\pi\epsilon 0}\ \frac{2pr}{(r2-a2)2}$ When r >> a, Then $E_a=\frac{1}{4\pi\epsilon 0}\ \frac{2p}{(r3)}$	E = electric field at a point on axial line E = electric field at a point on equatorial line P= q(2a) =electric dipole moment r=radius of circular loop a=distance of a point on axial line of electric dipole
9	Electric field at a point on the equatorial line of electric dipole	$E_e=-\frac{1}{4\pi\epsilon 0}\ \frac{p}{(r2+a2)3/2}$ When r >> a, Then $E_e=-\frac{1}{4\pi\epsilon 0}\ \frac{P}{(r3)}$	
10	Torque on an electric dipole in	ī = PESinǾ	ī =torque acting on electric dipole in external electric field

	external magnetic field	$=\vec{P}\times\vec{E}$; Where Ó is angle between $\vec{P}$ and E	$\vec{P}$=electric dipole moment SI unit of torque is Nm
11	Electric flux	$Ó_E$ = E.S Cos Ó = $\vec{E}.\vec{S}$ Where Ó is angle between $\vec{E}$ and $\vec{S}$	Φ $_E$ = electric flux SI unit of electric flux is Nm^2 / C
12	Gauss Theorem for electrostatics	Φ $_E$ = ∮ $\vec{E}.d\vec{S}$ =E.ds Cos Ó = $\frac{q}{\epsilon_0}$	Φ $_E$ = electric flux dS=elementary area
13	Charge density	1.Linear charge density = λ = $\frac{q}{l}$= $\frac{dq}{dl}$	SI unit of linear charge density C/m
14		2.Surface ace charge density = σ = $\frac{q}{s}$= $\frac{dq}{ds}$	Surface charge density Ơ = C/m^2
15		3.Volume charge density = p = $\frac{q}{v}$= $\frac{dq}{dv}$	Volume charge density p=C/m^3
16	Electric flux density	Electric flux density = $\frac{Electric\ flux}{Area}$ = $\frac{Ó_E}{s}$	
17	Electric field of a charge wire	E $_e$ = $\frac{1}{4\pi\epsilon_0}\frac{2\lambda}{r}$	λ=linear charge density r=distance from charged wire
18	Electric field of an infinite place charged sheet	E = $\frac{\sigma}{2\epsilon_0}$	Ơ=surface charged density
19		Electric field outsite charged sheet = E o= $\pm\frac{\sigma_1+\sigma_2}{2\epsilon_0}$ Where $\sigma_1 > \sigma_2 > 0$	
20		Electric field in between charged sheet = E_i = $\frac{\sigma_1-\sigma_2}{2\epsilon_0}$ Where $\sigma_1 > \sigma_2 > 0$	
21		Electric field between two equal oppositely charged plates E_i = $\frac{\sigma}{\epsilon_0}$	

		Electric field outside equal and oppositely charged sheet = 0		
22	Electric field due to a charged spherical shell	$E_o = -\frac{1}{4\pi\epsilon_0}\frac{q}{r^2}$ Where E_o is electric field out side spherical shell and r > R	 Variation of potential due to charged shell with distance r from its centre	
23		$E_s = -\frac{1}{4\pi\epsilon_0}\frac{q}{R^2}$ Where is E_s electric field on the surface of spherical shell		
		$E_i = 0$ Where is E_i electric field on the surface of spherical shell		
24	Electric potential	$V = \frac{W}{q}$	V=electric Potential W=work Q=charge	Sl unit of electric potential is Volt (V)
25	Electric potential due to point charge	$V = \frac{1}{4\pi\epsilon_0}\frac{q}{r} = V = K\frac{q}{r}$	V=electric potential Q=charge R=distance from charge	
26	Electric potential of electric dipole	$V = \frac{1}{4\pi\epsilon_0}\frac{PCos\varnothing}{r^2} = V = K\frac{\vec{p}.\vec{r}}{r^3}$	P=electric dipole moment V=electric potential R=position vector of a point Ø = angle between p and r	
27	Electric potential of electric dipole at a point on axial line	$V_a = \frac{1}{4\pi\epsilon_0}\frac{P}{r^2}$	V_a =electric potential on axil line of electric dipole P=dipole moment R=distance from a point	
28	Electric potential of electric dipole at a point on equatorial line	$V_e = 0$		

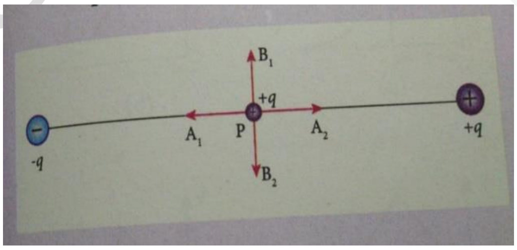
29	Relation electric field and electric potential	$E=-\frac{V}{d}=-\frac{dV}{dr}$	E=electric field; sl unit is N/c or Vm V=electric potential; Sl unit is Volt	
30	Relation electric field and electric potential	$V = -\int_{\infty}^{r} \vec{E}.\vec{dr}$	V=electric potential	E=electric field
31	Electrostatic potential energy between two charges	$U=\frac{1}{4\pi\epsilon_0}\frac{q1\,q2}{r}=K\frac{q1\,q2}{r}$	U=electrostatic potential energy	Joule (J) or eV 1eV = $1.6\text{x}10^{-19}$ C
32	Electrostatic potential energy of electric dipole in external electric field	U= -PE (Cos $Ó_f$ – cos $Ó_i$)	P=electric dipole moment E=electric field U=potential energy	
33		U= -PE Cos Ó = $-\vec{P}.\vec{E}$		
34		1.PE (U) of electric dipole is minimum when P // E and U= $-\vec{P}.\vec{E}$; Ó= 0^0 and dipole is stable equilibrium 2. PE (U) of electric dipole is minimum when P ǂ E and U= $\vec{P}.\vec{E}$; Ó= 180^0 and dipole is stable equilibrium. 3. PE (U) of electric dipole is zero when $\vec{P}$ ⊥// $\vec{E}$ and U = 0; Ó= 90^0		
35	Capacitance of capacitor	$C=\frac{q}{v}$	C=capacitance Sl unit of capacitance is Farad (F) q=charge V=electric potential	

36	Electric field between plates of capacitor	$E = \frac{\sigma}{\epsilon 0} = \frac{V}{d}$	
37	Capacitance of capacitor without dielectric	$C_o = \frac{\varepsilon o\ A}{d}$	C_o = capacitance of without dielectric A=area of plates of capacitor D=distance between plates of capacitor
38	Capacitance of capacitor with dielectric	$C = \frac{K\varepsilon o\ A}{d} = KC_o$	K=dielectric constant
39	Total capacitance (C_s) in series combination of capacitors	$\frac{1}{Cs} = \frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3} + \ldots \ldots \ldots$ When $C_1 = C_2 = C_3 \ldots \ldots = C$; When $C_s = \frac{C}{n}$	n=number of identical capacitors
40	Total capacitance (C_p) in parallel combination of capacitors	$C_p = C_1 =+ C_2 + C_3 + \ldots. \ldots.$ When $C_1 = C_2 = C_3 \ldots \ldots = C$; Then $C_p = nC$	n=number of identical capacitors
41	Ratio of total capacitance in series and parallel combination	When $C_1 = C_2 = C_3 \ldots \ldots = C$; then $C_s = \frac{Cs}{Cp} = \frac{1}{n\ 2}$	
42	Capacitance of sphere	$C=4\pi\epsilon_0 R$	C=capacitance R=radius of sphere
43	Electrostatic energy stored in capacitor	$U=\frac{CV2}{2} = \frac{q2}{2C} = \frac{qV}{2}$	U=electrostatic energy stored in capacitor V=electric potential

			q=electric charge
44.	Electrostatic energy density stored in capacitor	$U=\frac{U}{2Ad}=\frac{EoE2}{2}$	u=energy density = energy / volume E=electric field A=area of plates D=distance between plates
	Effect of dielectric introduced	**Capacitor disconnected from battery**	**Capacitor connected to battery**
45.	Charge	$q=q_0V_0$	$q=Kq_0$
46.	Capacitance	$C=KC_o$	$C=KC_0$
47.	Electric potential	$V=\frac{V0}{K}$	$V=V_0$
48.	Electric field	$E=\frac{E0}{K}$	$E=E_0$
49.	Electrostatic energy	$V=\frac{U0}{K}$	$U=KC_0$

Multiple Choice Question

1. Two identical point charges of magnitude –q all fixed as shown in the figure below. A third change +q is placed midway between the two charges at the pint P. suppose this charge +q is displaced a small distance from the point p in which direction (s) will +q be stable with respect to the displacement?



(a) A_1 and A_2 (b) B_1 and B_2

(c) Both directions (d) No stable

Solution :

If the displacement of the charge +q is equatorial line +q will be stable

∴(b) B_1 and B_2

2. Which charge configuration produces a uniform electric field?

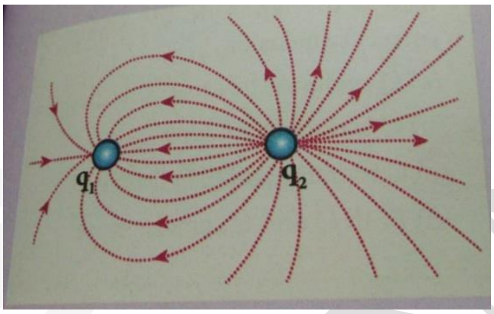
(a) Point charge (b) Infinite uniform line charge

(c) Uniformly charged infinite plane (d) Uniformly charged spherical shell.

Solution

(c) Uniformly charged infinite plane

3. What is the ratio of the charges $\left|\frac{q_1}{q_2}\right|$ for the following electric field line pattern?



(a) $\frac{1}{5}$ (b) $\frac{25}{11}$ (c) 5 (d) $\frac{11}{25}$

Solution

From q_2 to q_1, II lines of forces from q_2, 25 lines forces $\therefore \left|\frac{q_1}{q_2}\right| = \frac{11}{25}$

Ans : (d) $\frac{11}{25}$

4. An electric diploe is placed at an alignment angle of 30° with an electric field of 2×10^5 NC^{-1}. It experiences of torque equal to 8NM. The charge on the dipole if the dipole length is 1 cm is

(a) 4MC (b) 8 MC (c) 5 MC (d) 7MC

Solution :

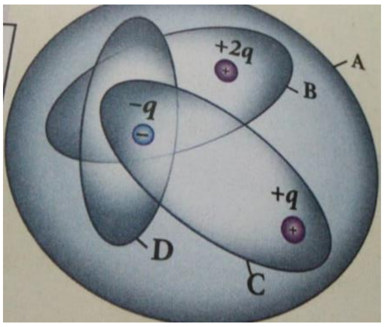
$$\tau = Eq\times 2d\ \ \text{Sin}\,\theta \qquad \therefore q = \frac{\tau}{Eq\times 2d\ \ \text{Sin}\,\theta}$$

$$Q = \frac{8}{2\times10^5\times10^{-2}\times\sin 30^o} \qquad = \frac{8}{1\times10^5\times10^{-2}\times\frac{1}{2}}$$

$$\omega = 8\times10^{-3}C$$

Ans : (b) 8MC

5. Four Gaussian surfaces are given below with charges inside each Gaussian surface. Rank the electric thux through each Gaussian surface in increasing



(a) D < C < B < A (b) A < B = C < D

(c) C < A = B < D (d) D > C > B > A

Solution :

Net charge in G.S. 'A'= 29

Net charge in G.S. 'B'= q

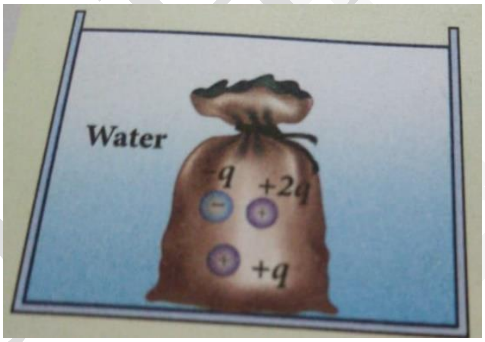
Net charge in G.S. 'C'= 0

Net charge in G.S. 'D'= -q

$$\phi_A = \frac{2_q}{\varepsilon_0}; \phi_B = \frac{q}{\varepsilon_0}; \phi_c = 0; \phi_D = \frac{q}{\varepsilon_0}$$

$\therefore$ *Ans. (a) D<C<B<A*

6. The total electric thux for the following closed surface which is kept inside water.



(a) $\frac{80_q}{\varepsilon_0}$ (b) $\frac{q}{40\varepsilon_0}$ (c) $\frac{q}{80\varepsilon_0}$ (d) $\frac{q}{160\varepsilon_0}$

Solution :

$$\phi = \frac{q}{\varepsilon} = \frac{q}{\varepsilon_0 \varepsilon_r} \quad [\therefore \varepsilon_0 = 80]$$

$$\phi = \frac{2_q}{\varepsilon_0 \times 80 =} = \frac{q}{4\varepsilon_0} \qquad \textit{Ans (b)} = \frac{q}{4\varepsilon_0}$$

7. Two identical conducting balls having +ve charge q_1 and q_2 are separated by a centre to centre distance r. if they are made to touch each other and then separated to the same distance. The force between them will be

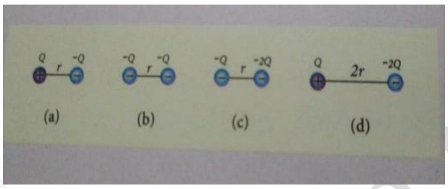
(a) Less than force (b) Same as before (c) More than before (d) zero

Solution :

$f \alpha q_1 q_2$; after contact $f \alpha q^2$ In nature $q^2 > q_1 q_2$

$\therefore f' > f$ *Ans : (c) more than before.*

8. Rank the electrostatic potential energies for the given system of charges in increasing order



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

Solution :

$$U_1 \alpha \frac{Q^2}{\gamma} \; ; \; U_2 \alpha \frac{Q^2}{\gamma} \; ; \; U_3 \alpha \frac{Q^2}{\gamma}$$

$$U_4 \alpha \frac{-2Q^2}{2\gamma} \; \alpha Q^2/\gamma \quad \therefore U_1 = U_4$$

Ans. (a) 1=4 <2<3

9. An electric field $\vec{E} = 10x\hat{i}$ exists in a certain region of space. Then the potential difference V = V_0-V_A, where V_0 is the potential at the origin and V_A is the potential at *x*=2 m is

(a) 10J (b) – 20 J (c) + 20J (d) – 10 J

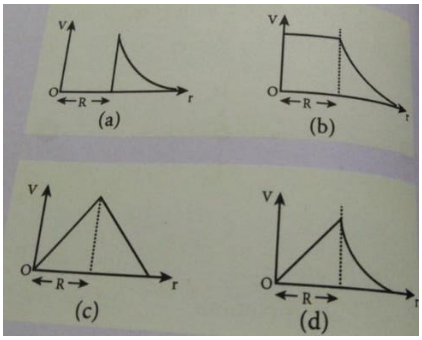
Solution :

$$\int_{VA}^{VO} dv = V_0 - V_A = -\int_2^0 E\,dx$$

$$V_0 - V_A = \int_2^0 10\times C/x = -10\left[\frac{x2}{2}\right]_2^0 = \frac{10}{2}[0-4]$$

V_0-V_A= + 20J

10. A thin conducting spherical shell of radius R has a charge Q which is uniformly distributed on its surface. The correct plot for electrostatic potential due to this spherical shell is



Solution (b)

11. Two points A and B are maintained at a potential of 7V and -4V respectively. The work done in moving 50 electrons from A to B is

(a) 8.80×10^{-7} J (b) -8.80×10^{-17}J (c) 4.40×10^{-7}J (d) 5.80×10^{-17}J

Solution :

$\phi = 50e = -50\times1{,}6\times10^{-19}$

$\Delta V\text{-}V_A\text{-}V_A\text{-}4\text{-}7 = -11V$

$W = \phi.\ \Delta V = -50\times1.6\times10^{-19}\times-11$

$W = 850\times10^{-19}C$ $\therefore$ (a) $8.8\times10^{-17}J$

12. If voltage applied on a capacitor is increased from V to 2V, choose the correct conclusion.

(a) Q remain the same, C is doubled (b) Q is doubled, C doubled

(c) C remain same, Q doubled (d) Both Q and C remain same

Solution :

If $V=2V,\ Q \Rightarrow 2Q$ $\therefore C = {}^{q}\!/\!_{v}\quad C' = \frac{2_q}{2_v} = C$

$\therefore$*Ans (c) remains same, Q doubled.*

13. A parallel plate capacitor stores a charge Q at a voltage V. suppose the area of the parallel plate capacitor and the distance between the plates are each doubled then which is the quantity that will change?

(a) capacitance (b) charge (c) voltage (d) Energy density

Solution :

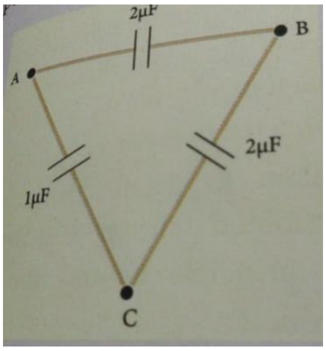
$A \rightarrow 2A\ ;\ d \rightarrow 2d$

$$C = \frac{\varepsilon_0 A}{d}; V = \frac{\sigma d}{\varepsilon_0} = \frac{Qd}{A\varepsilon_0}; Q = CV$$

Hence $A\ \varepsilon\ D$ *doubled* $C,V\ \varepsilon\ Q$

$\therefore$ *(d) Energy density*

14. Three capacitors are connected in triangle shown in the figure. The equivalent capacitance between the point A and C is



(a) 1μF (b) 2μf (c) 3 μf (d) ¼ μf

$C_P = C_1+C_s=1+1 = 2\mu f$ Ans : (b) 2μf

15. Two metallic sphere of radii 1cm and 3 cm are given charges of -1×10^{-2}C and 5×10^{-2}C respectively. If there are connected by a conducting wire, the final charge on the bigger sphere is

(a) 3×10^{-2}C (b) 4×10^{-2}C (c) 3 μf1×10^{-2}C (d) 2×10^{-2}C

Solution

$$\frac{q_1}{r_1} = \frac{q_2}{r_2} = \frac{\phi}{r_1 + r_2}; \phi = \text{Total charge}$$

$$Q=q_1+q_2=-1\times10^{-2}+5\times10^{-2}=4\times10^{-2}C$$

$$\therefore q_2 = \frac{r_2}{r_1 + r_2} \qquad Q = \frac{3\times10^{-2}}{4\times10^{-2}} \times 4\times10^{-2}$$

$$q_2 = 3\times10^{-2}\,C$$

I. Very Short Answer Questions from text book

1. What is meant by quantisation of charges? [Page No. 4]
2. Write down Coulomb's law in vector form and mention what each term represents. [Page No. 4]
3. Write a short note on superposition principle of force. [Page No.9]
4. Define 'Electric field'. [Page No.11]
5. What is mean by 'Electric field lines'? [Page No.18]
6. The electric field lines never intersect. Justify. [Page No.20]
7. Define 'Electric dipole' [Page No. 21]
8. What is the general definition of electric dipole moment? [Page No.22]

9. Define 'electrostatic potential". [Page No.28]
10. What is an equipotential surface? [Page No. 32]
11. What are the properties of an equipotential surface? [Page No. 33]
12. Give the relation between electric field and electric potential. [Page No.33,34]
13. Define 'electrostatic potential energy'. [Page No. 34,35]
14. Define 'electric flux' [Page No.38]
15. What is meant by electrostatic energy density? [Page No.55]
16. What is Polarisation? [Page No.54]
17. What is dielectric strength? [Page No.55]
18. Define 'capacitance'. Give its unit. [Page No.56]
19. What is corona discharge? [Page No.67]

Additional questions

20. What is frictional electricity or triboelectric charging? [Page No.3]
21. Briefly describe the electronic theory of frictional electricity.

Answer: During rubbing, electrons are transferred from one object to another. The object with excess of electrons develops a negative charge, while the object with deficit of electrons develops a positive charge.

22. What is electric charge? Is it a scalar or vector? Give its unit. [Page No.3]
23. What is meant by quantization of electric charge? What is its cause? [Page No.4]
24. State the law of conservation of charge. [Page No.3]
25. How an electrically charged particle does affect its mass?

Answer: According to the special theory of relativity, the mass of a body increases with its speed in accordance with the relation: $\frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$ where, m_o = rest mass of the body, c = speed of light, and m= mass of the body when moving with speed **υ**. As **υ**< c, therefore, m> m_0. In contrast to mass, the charge on a body remains constant and does not change as the speed of the body changes.

26. Define electric field intensity. What is its SI unit? What is relation between electric field and force? [Page No.11,12]
27. Derive an expression for electric field intensity at a point at distance r from a point charge q. [Page No.12]
28. A charge q is enclosed by a spherical surface of radius R, if the radius is reduced to half, how would the electric flux through the surface change.

Answer: The flux is independent of enclosed surface. It depends only on the charge enclosed. Therefore, flux remains constant.

29. An ebonite rod is rubbed with wool or fur. What type of charges do they acquire? [Page No.2]

30. A glass rod is rubbed with silk. What type of charges do they acquire? [Page No.3]

31. Consider three charged bodies P,Q and R. If P and Q repel each other and P attracts R, what is the nature of the force between Q and R? [Q and R attract, so unlike charges]

32. A positively charged glass rod is brought near an uncharged pith ball pendulum. What happens to the pith ball?

Answer: The pith ball is attracted towards the rod, touches it and thrown away.

33. Name any two basic properties of electric charges. [Page No.3,4]

34. Two insulated charged copper spheres A and B of identical size have the charges q_A and q_B respectively. A third sphere C of the same size but uncharged is brought in contact with the first and then with the second and finally removed from both. What are the new charges on A and B?

Answer: New charge on sphere A

$Q_A = \frac{q_A}{2}$

New charge on sphere B

$Q_B = \frac{q_B + \frac{q_A}{2}}{2} = \frac{2q_B + q_A}{4}$

35. Obtain the SI unit of electrical permittivity of free space. [Page No.5]

36. Deduce the dimensional formula for the proportionality constant k in Coulomb's law. [Page No.5]

37. Define dielectric constant of a medium in terms of force between electric charges.

Answer: The dielectric constant of a medium is the ratio of the force between two charges placed some distance apart in vacuum to the force between the same two charges when they are placed the same distance apart in the given medium.

38. How many electrons are present in 1 coulomb of charge? [Page No.4]

39. Define volume charge density at a point. Write its SI unit. [Page No.17]

40. Define surface charge density at a point. Write its SI unit. [Page No.17]

41. Define line charge density at a point. Write its SI unit. [Page No.17]

42. Draw the pattern of electric field around a point charge (i) $q > 0$ and (ii) $q<0$. [Page No.20]

43. Sketch the lines of force due to two equal positive charges placed near each other. [Page No.21]

44. Draw the lines of force of an electric dipole. [Page No.22]

45. Distinguish between electric potential and potential energy and write the relation between them. [Page No.27,28]

46. Give three differences between the nature of electric potential of a single point charge and an electric dipole. [Page No.28,31]

47. Show that the amount of work done in moving a test charge over an equipotential surface is zero. [Page No.33]

48. Show that the direction of the electric field is normal to the equipotential surface at every point. [Page No.33]

49. Sketch equipotential surfaces for (i) a point charge (ii) for uniform electric field. [Page No.33]

50. What is electrostatic shielding? Mention its two applications. [Page No.50]

51. Distinguish between polar and non-polar dielectrics. Give one example of each. [Page No.53]

52. Van-de-Graaff generator working principle. [Page No.68]

II. Short Answer Questions Text book questions

1. What are the differences between Coulomb force and gravitational force? [Page No.5]

2. Write a short note on 'electrostatic shielding'. [Page No.50]

3. Derive an expression for the torque experienced by a dipole due to a uniform electric field. [Page No.25]

4. Derive an expression for electrostatic potential due to a point charge. [Page No.28]

5. Obtain an expression for potential energy due to a collection of three-point charges which are separated by finite distances. [Page No.34]

6. Derive an expression for electrostatic potential energy of the dipole in a uniform electric field.

7. Explain the process of electrostatic induction. [Page No.51]

8. Obtain Gauss law from Coulomb's law. [Page No.41]

9. Obtain the expression for capacitance for a parallel plate capacitor. [Page No.56]

10. Obtain the expression for energy stored in the parallel plate capacitor. [Page No.58]

Additional questions

11. State the principle of superposition and use it to obtain the expression for the total force exerted on a point charge due to an assembly of (N-1) discrete point charges. [Page No.9]

12. Consider s system of charges q_1, q_2, ………., q_n with position vectors $\vec{r}_1$, $\vec{r}_2$, $\vec{r}_3$, ………., $\vec{r}_n$ relative to some origin 'O". Deduce the expression for the net electric field $\vec{E}$ at a point P with position vector $\vec{r}_P$, due to this system of charges. [Page No.15]

13. State Coulomb's Law of force between two electric charges and state its limitations. Also define the SI unit of electric charge. [Page No.4,5]

14. State Coulomb's Law in vector form and prove that $\vec{F}_{21} = -\vec{F}_{12}$ where letters have their usual meanings. [Page No.4,5]

15. In a non-uniform electric field, is there any torque or force acting on a dipole held parallel or anti-parallel to the field. If yes, show them by suitable diagrams. [Page No.26]

16. Briefly explain how does a comb run through dry hair attract small pieces of paper.

Answer: A comb runs through dry hair attracts small pieces of paper: As the comb runs through hair, it acquires charge due to friction. When the charged comb is brought closer to an uncharged piece of paper, it polarises the piece of paper i.e., induces a net dipole field due to the comb on the piece of paper is not uniform. It exerts a force in the direction of increasing field i.e., the piece of paper gets attracted towards the comb.

17. Define an electric field line. Draw the pattern of the field lines around a system of two equal positive charges separated by a small distance. [Page No.18,19]

18. Define electric line of force and give its properties. [Page No. 18,20]

19. What do electric lines of force represent? Explain attraction between two unlike charges on their basis. [Page No.18]

20. Prove that $1/r^2$ dependence of electric field of a point charge is consistent with the concept of the electric field lines. [Page No.19,20]

21. Use Gauss's law to derive the expression for the electric field between two uniformly charged large parallel sheets with surface charge densities σ and –σ respectively. [Page No. 45]

22. Define electric potential. Derive an expression for the electric potential at a distance r from a charge q. [Page No.27]

23. Show that the electric field at any point is equal to the negative of the potential gradient at that point. [Page No.28]

24. An electric dipole is held in a uniform electric field $\vec{E}$. (a) Show that the net force acting on it is zero. (b) The dipole is aligned with its dipole moment $\vec{p}$ parallel to the field $\vec{E}$, then find (i) the work done in turning the dipole till its dipole moment points in the direction opposite to $\vec{E}$. (ii) the orientation of the dipole for which the torque acting on it becomes maximum. [Page No.25,26]

25. Using Gauss's law, show that electric field inside a conductor is zero. [Page No.48]

26. Just outside a conductor electric field is perpendicular to the surface. Give reason [Page No.49].

27. Show that the excess charge on a conductor resides only on its surface. [Page No.48]

28. Show that the electric field at the surface of a charged conductor is given by $\vec{E} = \frac{\sigma}{\varepsilon 0}\hat{n}$, where σ is the surface charge density and $\hat{n}$ is a unit vector normal to the surface in the outward direction.{OR} Derive an expression for the electric field at the surface of a charged conductor. [Page No.49,50]

29. Explain why the polarization of a dielectric reduces the electric field inside the dielectric. [Page No.54]

30. A capacitor is charged with a battery and then its plate separation is increased without disconnecting. Discus (a) charge stored in the capacitor? (b) energy stored in the capacitor? (c) potential difference across the plates of the capacitor?

Answer: $C = \varepsilon_0 A/ d$. When d is increased, C decreases. (a) q = CV decreases due to the decreases in the value of C. (b) $U = ½ CV^2$ decreases due to the decreases in the value of C. (c) V remains unchanged because the battery remains connected.

31. Briefly describe discharging action of sharp points (or corona discharge). [Page No 67]

III. Long Answer questions

1. Discuss the basic properties of electric charges. [Page No.3-4]
2. Explain in detail Coulomb's law and its various aspects. [Page No.4-5]
3. Define 'Electric field' and discuss its various aspects. [Page No.11-13]
4. How do we determine the electric field due to a continuous charge distribution? Explain. [Page No.16-17]
5. Calculate the electric field due to a dipole on its axial line. [Page No.23-24]
6. Calculate the electric field due to a dipole on its equatorial plane. [Page No.24-25]
7. Derive an expression for electrostatic potential due to an electric dipole. [Page No.30-32]
8. Obtain the expression for electric field due to an infinitely long charged wire. [Page No.43-44]
9. Obtain the expression for electric field due to a charged infinite plane sheet. [Page No.44-45-46]
10. Obtain the expression for electric field due to a uniformly charged spherical shell. [Page No. 46-47]
11. Discuss the various properties of conductors in electrostatic equilibrium. [Page No.48-50]
12. Explain dielectrics in detail and how an electric field is induced inside a dielectric. [Page No.53-55]
13. Explain in detail the effect of a dielectric placed in a parallel plate capacitor. When the capacitor is disconnected from battery. [Page No.59-60]
14. Explain in detail the effect of a dielectric placed in a parallel plate capacitor. When the battery remains connected to the capacitor. [Page No.60-61]
15. Derive the expression for resultant capacitance, when capacitors are connected in series and in parallel. [Page No.62-64]

16. Explain in detail how charges are distributed in a conductor, and the principle behind the lightning conductor. [Page No.65-68]

17. Explain in detail the construction and working of a Van de Graaff generator. [Page No.68]

Additional questions

18. Obtain an expression for the electric field at any point due to a continuous charge distribution. Hence extend it for the electric field of a general source charge distribution. [Page No.16-17]

19. State Gauss's law in electrostatics. Using this theorem, show mathematically that for any point outside the shell, the field due to uniformly charged thin spherical shell is the same as if entire charge of the shell is concentrated at the centre. Why do you expect the electric field inside the shell to be zero according to this theorem? [Page No.40-41,46-47]

Numerical Problems

1. When two objects are rubbed with each other, approximately a charge of 50 nC can be produced in each object. Calculate the number of electrons that must be transferred to produce this charge.

Ans: 31.25×10^{10} electrons

Solution:

$$n = \frac{q}{e} = \frac{50\times10^{-9}}{1.6\times10^{-19}}$$

$$= \frac{50}{1.6} \times 10^{10}$$

$$= \frac{50}{16}\times10^{11}$$

$= 3.125\times10^{11}$

(or) 31.25×10^{10} electrons.

2. The total number of electrons in the human body is typically in the order of 10^{28}. Suppose, due to some reason, you and your friend lost 1% of this number of electrons. Calculate the electrostatic force between you and your friend separated at a distance of 1m. Compare this with your weight. Assume mass of each person is 60kg and use point charge approximation.

Ans: $F_e = 9 \times10^{61}$, N, W = 588 N

$$Fe = K\frac{q_1q_2}{r^2}$$

$1\% of 10^{28}$

$$= \frac{1}{100} \times 10^{28}$$

$= 10^{26}$

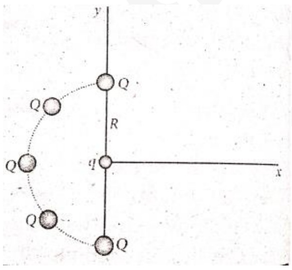
$$= \frac{9\times10^{9}\times10^{26}\times10^{26}}{(1)^{2}}$$

$= 9\times10^{61}N$

W= mg

$= 60\times9.8 = 588N$

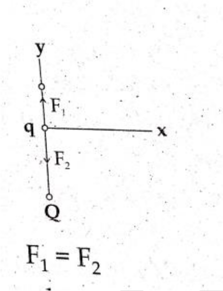
3. Five identical charges Q are placed equidistant on a semicircle as shown in the figure. Another point charge q is kept at the center of the circle of radius R. Calculate the electrostatic force experienced by the charge q.



$$Ans: \vec{F} = \frac{1}{4\pi\varepsilon_0}\frac{qQ}{R^2}(1+\sqrt{2})\hat{\imath}N$$

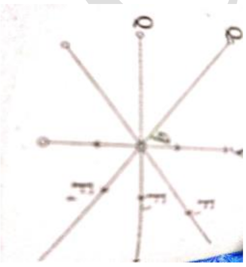
Solution:

Step 1:-

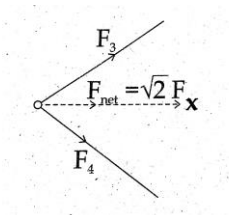


They cancel each other as they act opposite to each other

Step 2:-



step 3:- Opposite to each other



$F_3 = F_4$ and they act right angles to each other.

$$F_{net} = \sqrt{2}F$$

Step 4: -

$F_{resultant} = F_3 + F_{net}$

$$= K\frac{Qq}{R^2} + \sqrt{2}\frac{KQq}{R^2}$$

$$= K\frac{Qq}{R^2}(1+\sqrt{2})\,\text{along x} - \text{axis}$$

$$F_{resultent} = \frac{1}{4\pi\varepsilon_0}\frac{Qq}{R^2}(1+\sqrt{2})\hat{i}$$

4. Suppose a charge +q on Earth's surface and another +q charge is placed on the surface of the Moon.

(a) Calculate the value of q required to balance the gravitational attraction between Earth and Moon

(b) Suppose the distance between the Moon and Earth is halved, would the charge q change?

(Take m_E=5.9×10^{24}kg, Mm = 7.9×10^{22} (kg))

Ans: (a) q ≈+5.64×10^{13} C

(b) no change

$$Fe = K\frac{q^2}{R^2}\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$F_G = G\frac{m_e m_m}{R^2}\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$F_e = F_G$$

$$K\frac{q^2}{R^2} = \frac{Gm_e m_m}{R^2}$$

$$q^2 = \frac{Gm_e m_m}{K}$$

$$q^2 = \frac{6.6\times10^{-11}\times509\times10^{24}\times7.9\times10^{22}}{9\times10^{9}}$$

$$= \frac{307.6}{9}\times10^{26}$$

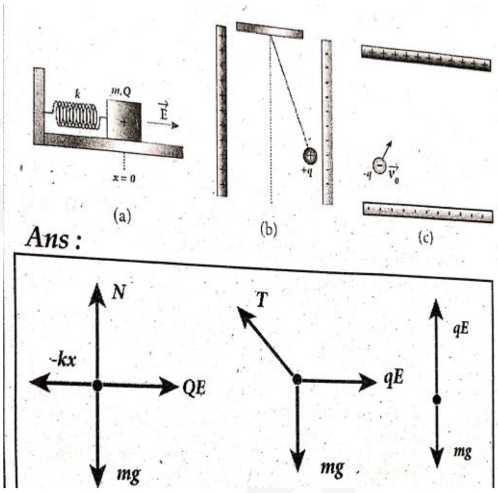
$$= 34.1\times10^{26}$$

$$q = \sqrt{34.1\times10^{26}}$$

$$q = 5.84 \times 10^{13} C$$

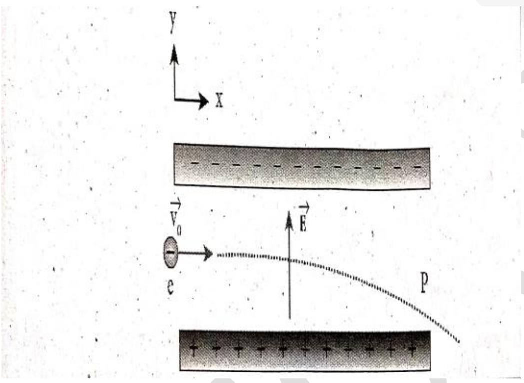
b) distance independent hence ‘q’ value does not change.

5. Draw the free body diagram for the following charges as shown in the figure (a), (b) and (c).



Ans:

6. Consider an electron travelling with a speed V0 and entering into a uniform electric field, $\vec{E}$ which is perpendicular to $\vec{V}_0$, as shown in the Figure . Ignoring gravity, obtain the electron’s acceleration, velocity and position as functions of time.



Ans: $\vec{a} = -\frac{eE}{m}\hat{j}$, $\vec{v} = v_0\hat{i} - \frac{eE}{m}t\hat{j}$

$\vec{r} = v_0 t\hat{i} - \frac{1}{2}\frac{eE}{m}t^2\hat{j}$

Solution:-

i) $a = \frac{F}{m}$

$$= \frac{eE}{m}(alongnegativey - axis)$$

$$\vec{a} = -\frac{eE}{m}\hat{j}$$

ii) Velocity acts along positive x– axis

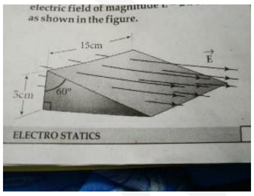
$$\vec{v} = v_o\hat{\imath} - \frac{eE}{m}t\hat{\jmath}$$

iii) $S = ut + \frac{1}{2}at^2$

$$\vec{r} = v_o t\hat{\imath} - \frac{1}{2}\frac{eE}{m}t^2\hat{\jmath}$$

is the equation of their position with the function of time.

7. A closed triangular box is kept in an electric field of magnitude E-2×10^3 NC^{-1} as shown in the figure.



Calculate the electric flux through the (a) vertical rectangular surface (b)slanted surface and (c) entire surface,

Ans:

(a)$15Nm^2C^{-1}$ (b) $15Nm^2C^{-1}$ (c) Zero0

Solution:

i) $\phi = Eds\cos\theta$

$$\phi_{(vertical)} = 2x10^3 x5x10^{-2} x15x10^{-2} x\ \cos 90^o$$

$$= 15Nm^2C^{-1}$$

ii) $\phi = E.ds.\cos\theta$ (slanted surface)

$$= 2x10^3 x5x10^{-2} x15x10^{-2} x\ \cos 90^o$$

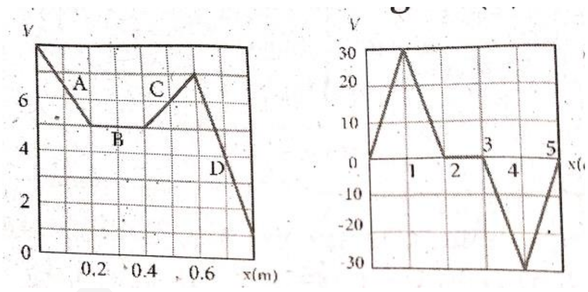
$$= 15Nm^2C^{-1}$$

iii) $\phi = Eds\cos\theta$ (entire surface)

$\theta = 0^o$

$\phi = 0$

8. The electrostatic potential is given as a function of x in figure (a) and (b). Calculate the corresponding electric fields in regions A, B. and D. Plot the electric field as a function of x for the figure (b).



Ans:

(a)E× = 15 Vm^{-1} (region A)

E× = -10 Vm^{-1} (region C)

E× =0 (region B)

E× = 30 Vm^{-1} (region D)

Solutions: Figure (a)

$$\vec{E} = \frac{dv}{dx}\hat{i}$$

From 0 to o.2m,

$$E_x = \frac{dv}{dx} = \frac{3}{0.2} = \frac{30}{2} = 15Vm^{-1}(\text{region A})$$

$Ex = \frac{dv}{dx} = 0$ Since the potential is constant (region B)

$$Ex = \frac{dv}{dx} = \frac{-2}{0.2} = \frac{-20}{2} = -10Vm^{-1}(regionc)$$

$$Ex = \frac{dv}{dx} = \frac{6}{0.2} = \frac{60}{2}$$

$$= 30Vm^{-1}(regiond)$$

Figure (b)

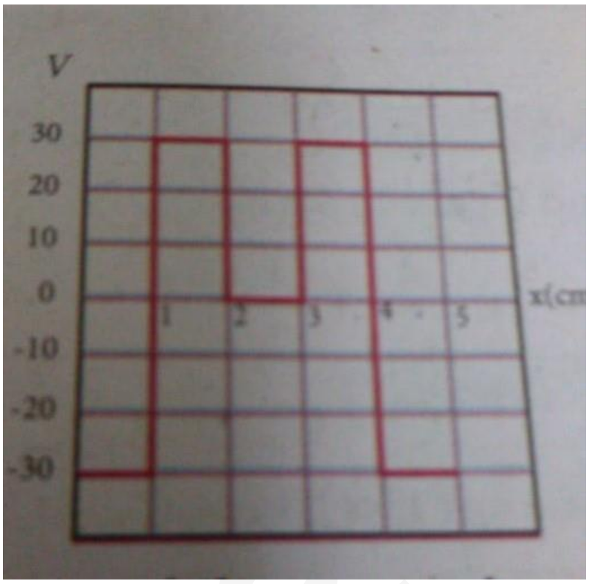
$$E_x = \frac{dv}{dx} - 30Vm^{-1}(\text{region } 0-1\text{cm})$$

$$E_x = \frac{dv}{dx} - 30Vm^{-1}(\text{region } 1-2\text{cm})$$

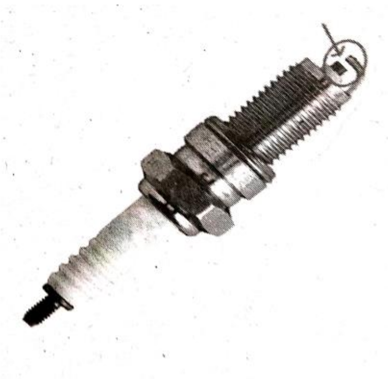
$$E_x = \frac{dv}{dx} = 0 \qquad (\text{region } 2-3\text{cm})$$

$$E_x = \frac{dv}{dx} - 30Vm^{-1}(\text{region } 3-4\text{cm})$$

$$E_x = \frac{dv}{dx} - 30Vm^{-1}(\text{region } 4-5\text{cm})$$



9. A spark plug in a bike or a car is used to ignite the air – fuel mixture in the engine. It consists of two electrodes separated by a gap of around 0.6mm gap as shown in the figure.



To create the spark, an electric field of magnitude $3 \times 10\ Vm^{-1}$ is required. (a) What potential difference must be applied to produce the spark? (b) If the gap is increased, does the potential difference increase, decrease or remains the same? (c) find the potential difference if the gap is 1mm.

Ans : (a) 1800 V, (b) increases (c) 3000 V

Solution :

a) $V = E \times d$

$= 3 \times 10^6 \times 0.6 \times 10^{-3}$

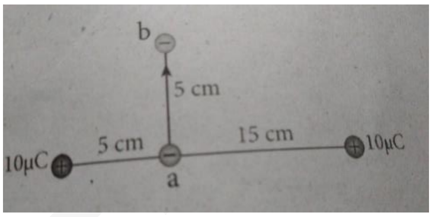
$= 1800v$

b) If the distance between the plate increased, then its capacitance will decrease which gives rise to increase in potential.

c) $V = E \times d$

$= 3 \times 10^6 \times 1 \times 10^{-3} = 3000\ v$

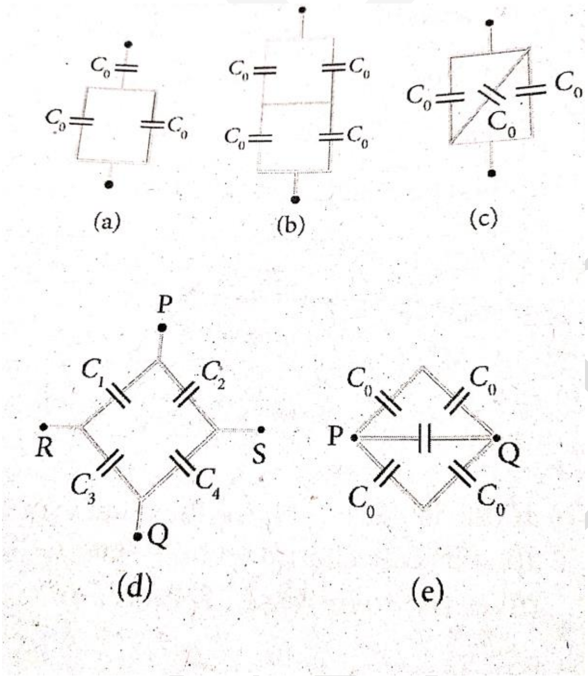
10. A point charge of +10μC is placed at a distance of 20cm from another identical point charge of + 10μC. A point charge of -2μC is moved from point a to b as shown in the figure. Calculate the change in potential energy of the system? Interpret your result.



Ans:

△U = 3.246 J, negative sign implies that to move the charge -2μC no external work is required. System speeds its stored Energy to move the charge from point to point b.

11. Calculate the resultant, capacitances for each of the following combinations of capacitors.



Ans:

(a) $\frac{2}{3}C_o$ (b) C_o (c) $3C_o$

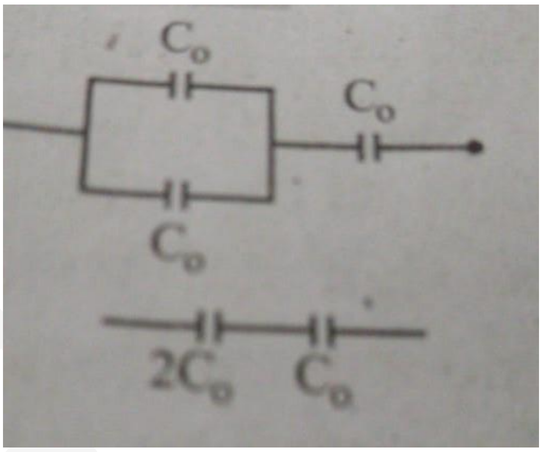
(d) across PQ.

$$\frac{C_1C_2C_3+C_2C_3C_4+C_1C_2C_4+C_1C_3C_4}{(C_1+C_2)(C_3+C_4)}$$

(e) across PQ : 2 Co across RS :

$$\frac{C_1C_2C_3+C_2C_3C_4+C_1C_2C_4+C_1C_3C_4}{(C_1+C_2)(C_3+C_4)}$$

Solution:



a)

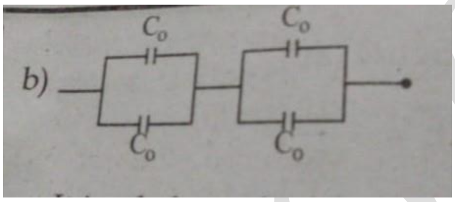
$$C_p = C = 2C_0$$

$$C_s = \frac{2C_0 x C_0}{2C_0 + C_0}$$

$$= \frac{2C_2^0}{3C_0}$$

$$C_s = \frac{2C_0}{3}$$

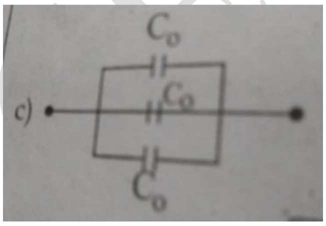
b)



It is a balanced wheatstone Network

$C_{net} = C_0$

c)

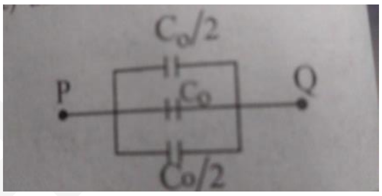


$C_{net} = 3C_0$

$$\text{d) } C_{eq} = \left(\frac{C_1C_2}{C_1 + C_2}\right) + \left(\frac{C_3C_4}{C_3 + C_4}\right)$$

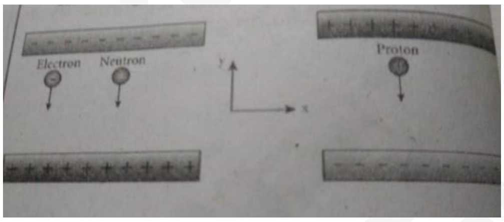
$$C_{eq}\ \frac{C_1C_2C_3+C_2C_3C_4+C_1C_2C_4+C_1C_3C_4}{(C_1+C_2)(C_3+C_4)}$$

e) Across PQ :



$C_{PQ} = 2C_0$

12.An electron and a proton are allowed to fall through the separation between the plates of a parallel plate capacitor of voltage 5V and separation distance h-1mm as shown in the figure.



a) Calculate the time of flight for both electron and proton (b) Suppose if a neutron is allowed to fall, what is the time of flight? c) Among the three, which one will reach the bottom first? (Take $m_p = 1.6 \times 10^{-27}$ kg, $m_e = 9.1 \times 10^{-31}$ kg and $g = 10\ ms^{-2}$)

Ans

(a) $t_e = \sqrt{\frac{2hm_e}{eE}} \simeq 1.5$ ns (ignoring the gravity)

$t_p = \sqrt{\frac{2hm_e}{eE}} \simeq 63$ns (ignoring the gravity)

b) $t_n = \sqrt{\frac{2h}{g}} \sim \underline{14.1\text{ ms}}$

c) electron will reach first.

Solution:

$$E = \frac{V}{d} = \frac{5}{10^{-3}} = 5 \times 10^3\,Vm^{-1}$$

$$\text{(a) } t_e = \sqrt{\frac{2hme}{eE}} = \sqrt{\frac{2\times10^{-3}\times9.1\times10^{-31}}{1.6\times10^{-19}\times5\times10^{3}}}$$

$$= \sqrt{\frac{18.2\times10^{-34}}{8\times10^{-16}}}$$

$$= \sqrt{2.275\times10^{-18}}$$

$$= 1.5\times10^{-9}\text{S}$$

$$\text{(b) } t_p = \sqrt{\frac{2hm_p}{eE}} = \sqrt{\frac{2\times10^{-3}\times\cancel{1.6}\times10^{-27}}{\cancel{1.6}\times10^{-19}\times5\times10^{3}}}$$

$$= \sqrt{\frac{2}{5}\text{x}10^{-14}}$$

$$= \sqrt{0.4\times10^{-7}} = 0.632\times10^{-7}$$

$$= 63.2\times10^{-9}\text{S} \quad \cong 63\text{ns}$$

$$\text{(c) } t_n = \sqrt{\frac{2h}{g}}$$

$$= \sqrt{\frac{2\text{x}10^{-3}}{9.8}}$$

$$= \sqrt{0.204\times10^{-3}} = \sqrt{2}\times10^{-2}$$

$$= 1.414\times10^{-3}$$

$$= 14.1\times10^{-3} \quad \cong 14.1\text{ms}$$

(d) hence electron will reach the bottom first.

13.During a thunder storm, the movement of water molecules within the clouds creates friction, partially causing the bottom part of the clouds to become negatively charged. This implies that the bottom of the cloud and the ground act as a parallel plate capacitor. If the electric field between the cloud and ground exceeds the dielectric breakdown of the air (3×10_{6} Vm$_{-1}$). Lightning will occur.

a) If the bottom part of the cloud is 1000m above the ground, determine the electric potential difference that exists between the cloud and ground.

b) In a typical lightning phenomenon, around 25C of electrons are transferred from cloud to ground. How much electrostatic potential energy is transferred to the ground?

Ans : a) V= 3×10^{9}V, b) U=75×10^{9} J

Solution :

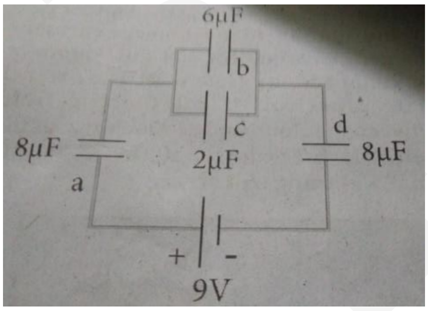
a) $E = \frac{dv}{dx}$ b) $U = \frac{QV}{2}$

$V = E.x$ $= \frac{23 \times 3 \times 10^9}{2}$

$= 3 \times 10^6 \times 10^3$ $= 37.5J$

$= 3 \times 10^9 V$

14.For the given capacitor configuration a) Find the charges on each capacitor b) potential difference across them c) energy stored in each capacitor.



Ans : Q_a = 24 μC, Q_b = 18μc

Q_c= 6μc, Q_d = 24μc

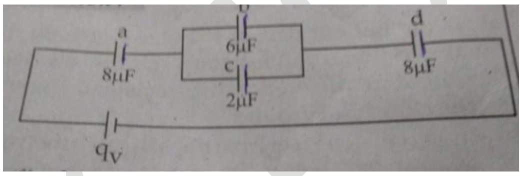
V_a = 3V, V_b =3V

V_c = 3V, V_d =3V

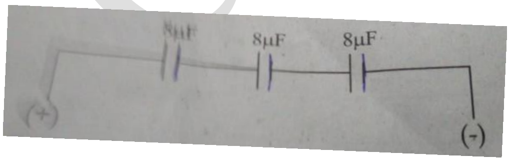
U_a =36μJ, U_b =27μJ

U_c= 9μJ, U_d =36μJ

Solution :



To find total capacitance.



$Cs = \frac{C}{n} = \frac{8}{3} = 2.6\mu F$

Total charge $q = CV = \frac{8}{3}\times10^{-6}\times9$

$= 24\times10^{-6}C$

$Qa \; = C_aV_a$

$= 8\times10^{-6}3$

$= 24\times10^{-6C}$

$Q_c \; = C_cV_c$

$= 2\times10^{-6}\,3$

$= 6\times10^{-6}\,C$

$Q_b \; = C_bV_b$

$= 6\times10^{-6}3$

$= 18\times10^{-6}C$

$\therefore$ Va=3V as 9V is connected in three equal capacitors

$Q_d = 24\times10^{-6}C$

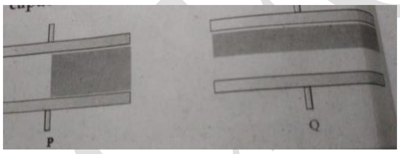
$$U_a = \frac{q^2}{2C} = \frac{24\times10^{-6}\times24\times10^{-6}}{8\times10^{-6}\times2} = 36\times10^{-6}J$$

$$U_b = \frac{q^2}{2C} = \frac{18\times10^{-6}\times18\times10^{-6}}{2\times6\times10^{-6}} = 27\times10^{-6}J$$

$$U_c = \frac{q^2}{2C} = \frac{6\times10^{-6}\times6\times10^{-6}}{2\times2\times10^{-6}} = 9\times10^{-6}J$$

$$U_d = \frac{q^2}{2C} = \frac{24\times10^{-6}\times24\times10^{-6}}{2\times8\times10^{-6}} = 36\times10^{-6}J$$

15.Capcitors P and Q have identical cross-sectional areas A and separation d. The space between the capacitors is filled with a dielectric of dielectric constant ε_r as shown in the figure. Calculate the capacitance of capacitors P and Q.



Ans:

$$C_P = \frac{\varepsilon_o A}{2d}(1+\varepsilon_r)$$

$$C_Q = \frac{2\varepsilon_o A}{2d}\left(\frac{\varepsilon_r}{(1+\varepsilon_r)}\right)$$

Solution:

i) The arrangement can be supposed to be a parallel combination of two capacitors each with plate area A /2 and separation d.

Total capacitance $C_P = C_{air} + C_{dielectric}$

$$= \frac{\varepsilon_0 (A/2)}{d} + \frac{\varepsilon_0 (A/2)\varepsilon r}{d}$$

$$C_P = \frac{\varepsilon_o A}{2d}(1+\varepsilon_r)$$

ii) The arrangement can be supposed to be a series combination of two capacitors, each with plate area A and separation d/2.

Total capacitance $C_Q = \frac{C_1 C_2}{C_1 + C_2}$

$$= \frac{\frac{2\varepsilon_o A}{d} \times \frac{2\varepsilon_r \varepsilon_o A}{d}}{\frac{2\varepsilon_o A}{d} + \frac{2\varepsilon_r \varepsilon_o A}{d}}$$

$$= \frac{4\varepsilon_r \left(\frac{\varepsilon_o A}{d}\right)^2}{\frac{2\varepsilon_o A}{d}(1+\varepsilon_r)}$$

$$= \frac{2\varepsilon_r \frac{\varepsilon_o A}{d}}{(1+\varepsilon_r)}$$

$$C_Q = \frac{2\varepsilon_o A}{d}\left(\frac{\varepsilon_r}{(1+\varepsilon_r)}\right)$$

CHAPTER 2

CURRENT ELECTRICITY

Points to Ponder:

- ✓ Substances which have abundance of free electrons are conductors.
- ✓ The instantaneous current is the limit of the average current, as $\Delta t \rightarrow 0$

$$I = \lim_{\Delta t \to 0} \frac{\Delta Q}{\Delta t} = \frac{dQ}{dt}$$

- ✓ Current is a scalar and current density is a vector.
- ✓ The graph between I versus V is a straight line.

Slope= $\frac{1}{R}$

- ✓ The value of equivalent resistance in series connection will be greater than each individual resistance.
- ✓ The value of equivalent resistance in parallel connection will be lesser than each individual resistance.
- ✓ All household appliances are connected in parallel.
- ✓ Multi meter is used to measure voltage, current, resistance and capacitance.
- ✓ $\propto$ for conductors is positive.
- ✓ $\propto$ for semiconductors is negative.
- ✓ Semiconductor with negative temperature co-efficient of resistance is a thermistor.
- ✓ Electrical power is the rate at which the electrical potential energy is delivered.
- ✓ An electrical cell converts chemical energy into electrical energy to produce electricity.
- ✓ Electromotive force determines the amount of work a battery does to move a certain amount of charge around the circuit.
- ✓ A battery or cell is the source of emf.
- ✓ The emf of the cell is directly proportional to the balancing length, is the principle of potentiometer.
- ✓ Nichrome has a very high specific resistance and can be heated to very high temperature without oxidation.
- ✓ Molybdenum – Nichrome wire is used to produce temperature upto 1500°C .
- ✓ Carbon arc furnaces produce temperature up to 3000°C.
- ✓ The melting point of tungsten is 3380°C.
- ✓ Only 5% of electrical energy is converted into light in incandescent electrical lamps.
- ✓ Two dissimilar metals connected to form two junctions is a thermocouple.

Important Formulas

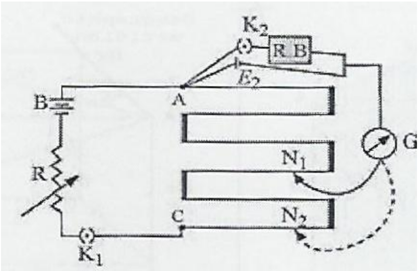
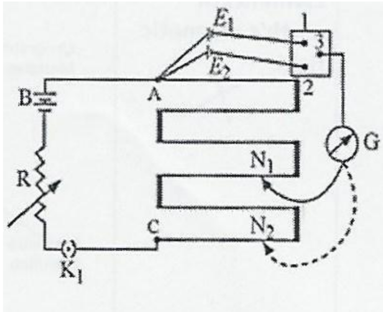
S No	Application	Formula	Terms/unit	figure
1	Electric current	I $=\frac{q}{t}=\frac{\pm ne}{t}=\frac{dq}{dt}$	Q=electric charge	
2	Electric potential	V= $\frac{W}{q}$	W = work V = electric potential Q = electric charge	
3	Ohm's law	V=IR	V=electric potential; Sl unit of electric potential is Volt (V) l=electric current; Sl unit of electric current is Ampere(A) R= electrical resistance; Sl unit of electrical resistance is ohm (Ω)	
4	Current density	j= $\frac{I}{A}$	j=current density ; Sl unit of current density is Am^{-2} l=electric current A=area	
5		$I=\vec{J}.\ \vec{A}$ = jAcosθ		
6	Electric resistance	R= $\frac{pl}{A}=\frac{pl^2}{V}$	P=electric resistivity; Sl unit : Ωm A=area of cross section L=length V=volume R=electric resistance; Sl unit; ohm(Ω)	
7	Conductance	G= $\frac{1}{R}$	G=conductance; Unit is mho (or) siemens	
8	Conductivity	σ= $\frac{1}{p}$	P=resistivity σ=conductivity	

9	Vector form of ohm's law	$\vec{E} = \vec{PJ}$ $\vec{J} = \sigma \vec{E}$	E=electric field J=current density P=resistivity σ=conductivity
10	Drift velocity	ϋ$_d$ = $\frac{eEЃ}{m}$ = - $\frac{eVЃ}{ml}$	ϋ$_d$ = drift velocity e=charge of electron m=mass of electron e=electric field V=electric potential Ѓ=relaxation time
11	Relation between current and drift velocity	I = neAv$_d$	n=number density of charges e=electric charge m=mass of electron l=length of conductor Ѓ=relaxation time J=current density
12	Relation between current density and drift velocity	$\vec{J}$ = ne $\vec{v}$d	
13	Relation between electric resistance and drift relaxation time	R= $\frac{ml}{ne2ЃA}$	A=area of cross section L=electric current E=electric field V$_d$ = drift velocity
14	Relation between electric resistivity and drift relaxation time	p= $\frac{m}{ne^{2}Ѓ}$	

15	Mobility of charges	$\mu=\frac{vd}{E}$	
16	Electric resistance at a temperature	$R_t = R_0\,(1+a\Delta t)$	a=temperature coefficient of resistance
17	Total resistance (R_s) in series combination of resistors	$R_s = R_1 + R_2 + R_3 \ldots.$ If $R_1 = R_2 = \ldots.\ R_n = R$; Then $R_s = nR$	R_1 ; R_2 ; R_3 . . . . difference electrical resistors
18	Total resistance (R_s) in parallel combination of resistors	$\frac{1}{Rp} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \ldots \ldots \ldots$ If $R_1 = R_2 = \ldots.\ R_n = R$; Then $R_p = R_p = \frac{R}{n}$	$R_s : R_p = n^2 :1$
19	Electromotive force (OR) emf (ε)	$\varepsilon=\frac{W}{q}$	ε=electromotive force (emf); SI unit of emf is Volt(V) r=internal resistance; SI unit ohm (Ω) V=terminal potential difference R=external resistance I=electric current
20	Electromotive force or emf during discharging of cell	$\varepsilon= V+Ir = I(R+r)$	
21	Terminal p.d during discharging of cell	$V= \varepsilon - Ir$	
22	Terminal p.d during charging of cell	$V= \varepsilon + Ir$	

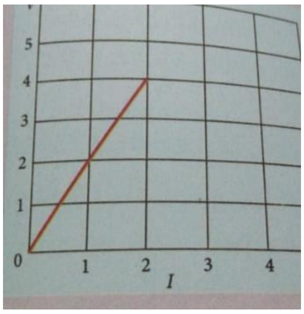
23	Internal resistance of an electric cell	$R = R(\frac{\varepsilon - v}{V})$	
24	Cells in series	$\varepsilon_s = \varepsilon_1 + \varepsilon_2 + \varepsilon_3 \ldots. + \varepsilon_n$ $r_s = r_1 + r_2 + r_3 \ldots\ldots r_n$	E_{eq} = total emf r_{eq} = total internal resistance of cells n=number of rows R=external electric resistance
25		$I = \frac{ne}{R+nr}$ 1.When R>> nr then $I = \frac{ne}{R}$ 2.When R<< nr then $I = \frac{\varepsilon}{r}$ 3.When R>> nr then cells must be connected In series to get maximum current	
26	Cells in parallel	$\frac{\varepsilon eq}{Req} = \frac{\varepsilon 1}{R1} + \frac{\varepsilon 2}{R2} + \ldots\ldots \frac{\varepsilon n}{Rn}$ $\frac{1}{Req} = \frac{1}{R1} + \frac{2}{R2} + \ldots\ldots \frac{1}{Rn}$	E_{eq}= total emf R_{eq} = total internal resistance of cells n=number of rows R=external electric resistance
		$I = \frac{n\varepsilon}{nR+r}$ 1.When R>> $\frac{r}{n}$ then $I = \frac{\varepsilon}{R}$ 2.When R<< $\frac{r}{n}$ then $I = \frac{ne}{r}$ 3.When R>> $\frac{r}{n}$ then cells must be connected	

		In parallel to get maximum current	
28	Series and parallel grouping of cells	$I = \frac{nm\varepsilon}{nR+nr}$	n=number of cells in a row m=number of row in parallel R=electric resistance r=internal resistance
29		For maximum current R= r (or) $I = \frac{nr}{m}$	
30	Electrical heat energy	$H=VIt=I^2 Rt = \frac{V2t}{R}$	H=heat energy V=electric potential I=electric current R=electric resistance T=time P=power; SI unit of power is Watt (W) 1hp = 746 W 1kWh=3.6 x 10^{6}J
	Electric power	$P=VI= I^2 R = \frac{V2}{R}$	
31	Electric power in series combination (P_p)	$\frac{1}{Ps} = \frac{1}{P1} + \frac{1}{P2} + \frac{1}{P3} + \ldots \ldots \frac{1}{Pn}$	SI unit of power is watt (W)
32	Electric power in parallel combination (P_p)	$P_p = P_1 + P_2 + P_3 \ldots + P_n$	
33	Kirchhoff's laws	$\sum I = 0$ (junction rule) $\sum IR = \sum \varepsilon$ (loop rule)	I = electric current R=electric resistance ε=emf
34	Wheatstone bridge	$\frac{P}{Q} = \frac{R}{S}$	PQR and S are resistors

35	Meter bridge	$\frac{X}{R} = \frac{100-l}{l}$		
36	Potentiometer $K=\frac{V}{l}$			
37	$\frac{\varepsilon X}{\varepsilon} = \frac{l1}{l2}$			
38	$r=R\left(\frac{l1-l2}{l2}\right)$			

Multiple Choice Questions

1) The following graph shows current versus voltage values of some unknown conductor. What is the resistance of this conductor?



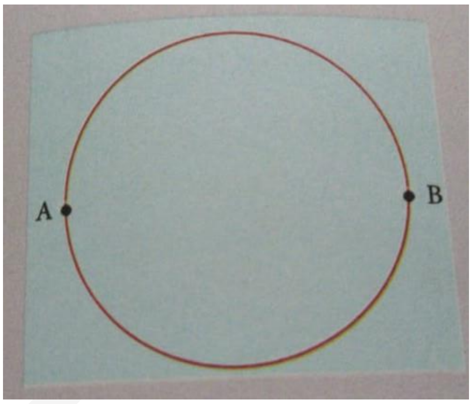
(a) 2 Ohm (b) 4 Ohm (c) 8 Ohm (d) 1 Ohm

Solution

$$\textit{Resistance}\ \ R = \text{slope} = \frac{\Delta V}{\Delta J} = \frac{4}{2} = 1\Omega$$

Ans : (d) 1 Ohm

2) A wire of resistance 2 Ohms per meter is bent to form a circle of radius 1m. The equivalent resistance between its two diametrically opposite points, A and B as shown in the figure is



(a) $\pi\Omega$ (b) $\frac{\text{II}}{2}\Omega$ (c) $2\pi\Omega$ (d) $\frac{\text{II}}{4}\Omega$

Solution :

Length, d = 2nγ *γ=1m*

$\therefore l = 2\pi$ Total resistance, $R = 2\pi, x$

$R = 2\pi \times 2 = 4\pi\Omega$

$$\therefore R_P = R/P = \frac{2\pi}{2} = \pi\Omega$$

Ans : (a) πΩ

3. A roaster operating at 240 v has a resistance of 120Ω. The power is

(a) 400 W (b) 2W (c) 480 W (d) 240 W

Solution : 2

$$P = \frac{V^2}{R} = \frac{240 \times 240}{120} = 480W$$

Ans : (c) 480 W

4. A carbon resistor of (47 ± 4.7) kΩ to be marked with rings of different colours for its identification the colour code sequence will be

(a) Yellow - Green - Violet- Gold

(b) Yellow - Violet - Orange- Silver

(c) Violet - Yellow - Orange - Silver

(d) Green - Orange - Violet -Gold

Solution :

$R = (47 \pm 4.7)\ k\Omega = 47 \pm 10\%\ K\Omega$

$R = \underset{Y}{4}\ \underset{V}{7} \times \underset{O}{10^3}\ \underset{S}{\pm 10\%}$

Ans (b) Yellow-Violet-Orange - Silver

5. What is the value of resistance of the following resistor?

(a) 100 kΩ (b) 10KΩ (c) IKΩ (d) 1000 KΩ

Solution

Brown - Black - Yellow

1 0 10^4

$10 \times 10^4 = 100\ k\Omega$

Ans : (a) 100 kΩ

6. Two wires of A and B with circular cross section made up of the same material with equal lengths. Suppose RA – $3R_B$, then what is the ratio of radius of wire A to that of B?

(a) 3 (b) $\sqrt{3}$ (c) $\frac{1}{\sqrt{3}}$ (d) $\frac{1}{3}$

Solution

R_A-$3R_B$

$$\frac{R_A}{R_B} = \frac{A_2}{A_1} = \frac{\pi r_2^2}{\pi r_1^2}$$

$$\frac{r_1}{r_2} = \sqrt{\frac{R_B}{R_A}} = \sqrt{\frac{R_B}{3R_B}} = \frac{1}{\sqrt{3}}$$

Ans : (c) $\frac{1}{\sqrt{3}}$

7. A wire connected to a power supply of 230 V has power dissipation P_1. Suppose the wire is cut into two equal pieces and connected parallel to the same power supply. In this case power dissipation is P_2. The ratio $\frac{P_2}{P_1}$ is

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

Solution :

Initial resistance $\therefore P \alpha \frac{1}{R}$

After cutting final resistance

$$\Rightarrow R/4 = R'$$

$$\frac{P_2}{P_1} = \frac{R}{R'} = \frac{R \times 4}{R} \qquad \therefore \frac{P_2}{P_1} = 4$$

Ans : (d) 4

8. In India electricity is supplied for domestic use of 220 V. It is supplied at 110 V in USA. If the resistance of a 60W bulb for use in India is R, the resistance of a 60W bulb for use in USA will be

(a) R (b) 2R (c) $\frac{R}{4}$ (d) $\frac{R}{2}$

Solution

$$\frac{V_1^{\ 2}}{R_1} = \frac{V_2^{\ 2}}{R_2} \qquad \therefore R_2 \frac{V_1^{\ 2}}{V_2^{\ 2}} \times R_1$$

$$R_2 = \frac{110 \times 110}{220 \times 220} \times R \qquad \therefore R_2 = R/4$$

Ans : (c) $\frac{R}{4}$

9. In a large building there are 13 bulbs of 40W, 5 bulbs of 100W, 2 Fans of 80W and 1 heater of 1KW are connected. The voltage of electric mains is 220V. The minimum capacity of the main fuse of the building will be

(a) 14A (b) 8A (c) 10A (d) 12A

Solution

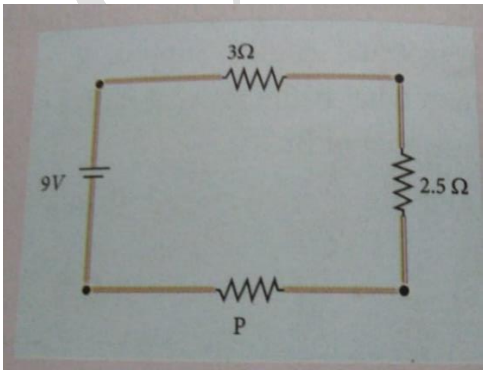
Total power = (15×40)+(5×100)+ (5×80)+(1×1000)

P = 600+500+400+1000 = 2500W

$$I = \frac{P}{V} = \frac{2500}{220} = 11.36 \approx 12A$$

Ans : (d) 12A.

10. There is a current of 1.0 A in the circuit shown below. What is the resistance of



(a) 1.5Ω (b) 2.5Ω (c) 3.5Ω (d) 14.5Ω

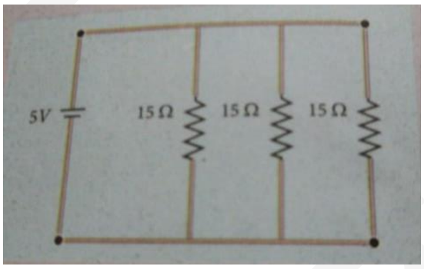
Solution :

3I + 2.5I + P.I = 9 (∴ *I = 1A*)

∴ *3+2. 5+P= 9* ⇒ *P=9-5.5=3.5Ω*

Ans : (c) 3.5Ω

11. What is the current out of the battery?



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

Solution :

$$I=\frac{V}{R_{eff}} \quad R_{eff}=\frac{R}{n}=\frac{15}{3}=5\Omega$$

$$\therefore\ I=\frac{5}{5}=1A$$

Ans : (a) 1A

12. The temperature co-efficient of resistance of a wire is 0.00125 per °C. At Book, its resistance is 1Ω. The resistance of the wire will be 2 Ω at

(a) 1154K (b) 1100K (c) 1440K (d) 1127K

Solution :

$$\alpha=\frac{R_2-R_1}{R_1(T_2-T_1)}=T_2-T_1=\frac{R_2-R_1}{R_1\alpha_1}$$

$$T_2-27^o=\frac{2-1}{1\times 0.00125}=\frac{1}{0.00126}$$

T_2=800+27=827°C

T_2= 827+273=1100K

Ans : (b) 1100K

13. The internal resistance of a 2.1 V cell which gives a current of 0.2A through a resistance of 10Ω is

(a) 0.2Ω (b) 0.5Ω (c) 0.8Ω (d) 1.0Ω

Solution :

$$r\frac{\varepsilon - V}{I} \qquad V = IR = 0.2\times 10 = 2$$

$$\therefore r = \frac{2.1-2}{0.2} = \frac{0.1}{0.2} = 0.5\Omega$$ *Ans: (b) 0.5Ω*

14. A piece of copper and another of germanium are cooled from room temperature to 80K. The resistance of

(a) each of them increase

(b) each of them decrease

(c) copper increase and germanium decrease

(d) copper decrease and germanium increase

Solution :

Resistivity α Temperature for conductor

$\therefore$ *Copper $\rightarrow$ decreases*

Resistivity α 1/ temp for semi conductor

$\therefore$ *Germanium – increases.*

Ans : (d) copper decrease and germanium increase.

15. In Joule's heating law, when I and t are constant. If the H is taken along the Y axis and I^2 along the X axis, the graph is

(a) straight line (b) parabola (c) circle (d) ellipses

Solution : $H \alpha I^2$ *Ans : (a) Straight line*

Very short answer questions

1. Why current is a scalar? P-88
2. Distinguish between drift velocity and mobility. P-85,86
3. State microscopic form of Ohm's law.(J = σ E) P-87
4. State macroscopic form of Ohm's law. (V=IR) P-89
5. What are ohmic and non ohmic devices? P-89
6. Define electrical resistivity. P-90
7. Define temperature coefficient of resistance. P-97
8. What is superconductivity? P--99
9. What is electric power and electric energy? P-99,100
10. Define current density. P-87

11. Derive the expression for power P-VI in electrical circuit. P-100
12. Write down the various forms of expression for power in electrical circuit.P-100
13. State Kirchhoff's current rule. P-107
14. State Kirchhoff's voltage rule. P-108
15. State the principle of potentiometer. P-112
16. What do you mean by internal resistance of a cell? P-103
17. State Joule's law of heating P-115
18. What is Seebeck effect? P-117
19. What is Thomson effect? P-118
20. What is Peltier effect? P-118
21. State the applications of Seebeck effect. P-117

Additional questions

1. Define electric current. P-84
2. Define the SI unit of electric current. P-84
3. Distinguish between conventional current and flow of electrons in a circuit. P-84
4. Define the term relaxation time. P-86
5. Derive relation between electric current and drift velocity. P-87
6. Derive relationship between quantities current density and electric field. P-87
7. Derive Ohm's law from current density. P- 88,89
8. Define resistance and give its SI unit. P-89
9. Draw a graph between current and voltage for ohmic and non ohmic materials. P- 89
10. Define conductivity of a material. P-88
11. How can we classify solids on the basis of their resistivity? P-90
12. When are the resistance said to be connected in series? P-92
13. When are the resistance said to be connected in parallel? P-93
14. What are carbon resistors? P-96
15. Describe the colour code used for Carbon resistors. P-96
16. State the commercial unit of electrical energy. P-100
17. Define the term electromotive force. P- 103
18. What is internal resistance of a cell? P- 103
19. What do you mean by a series combination of cells? P-104
20. What do you mean by parallel combination of cells? P-106
21. What is a potentiometer? P- 112

22. What is joule's heating effect of current. P-114

23. Obtain an expression for the heat developed in a resistor by the passage of an electric current through it. Hence state joule's law of heating. P-115

24. Discuss some of the following practical applications of the Joule's heating effect of current. (i) Electric heaters (ii) Electric fuses (iii) Electric furnace (iv) Electric lamp. P-115,116,117

25. What is known as thermoelectric effect. P-117

26. What is Thomson effect? Explain with an example what is positive Thomson effect and negative Thomson effect. P- 118

Concept related questions

27. What are other factors which determines the current in a conductor?

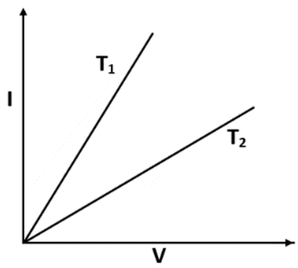
(i) number of free electrons per unit volume n

(ii) charge of the electron e

(iii) area of cross section of the conductor A

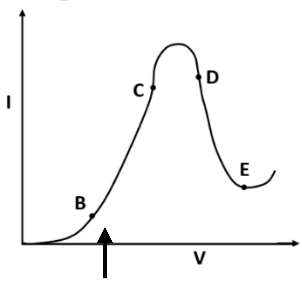
(iv) drift velocity of the electron v_d

28. Current (I) – Voltage (V) graph for a metallic wire at 2 different temperatures T_1 and T_2 is as shown in the figure below. Which of the two temperature is lower and why?



From the graph, The slope of line 1 > The slope of line 2, $\therefore R_1 < R_2$, W.K.T resistance α temperature. Therefore $T_2 > T_1$

29. Graph showing the variation of Current vs Voltage for a material of GaAs. Identify the region of (i) negative resistance. (ii) where ohm's l aw is obeyed.



(i) DE is the region, of negative resistance because the slope of curve in this part is negative.

(ii) BC is the region, where Ohm's law is obeyed because in this part, the current varies linearly with voltage.

30. The temperature of two materials Silicon and Copper are reduced from 250 K to 50 K. What will be the effect on their resistivity?

In Silicon, the resistivity increases with decrease in temperature.

In Copper, the resistivity decreases with decrease in temperature,

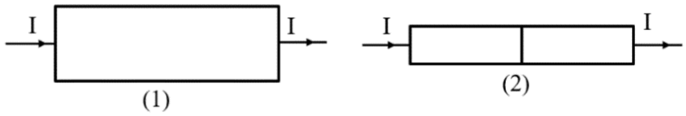
31. The relaxation time τ is nearly independent of the applied electric field E, where as it changes significantly with temperature T. First that is responsible for Ohm's law, whereas the second fact leads to the variation of resistivity ρ with temperature. Elaborate why?

Relaxation time is inversely proportional to the velocities of electrons and ions. The applied electric field produces the insignificant change in the velocity of electron at the order of 1 mm/s . Where is the change in temperature T affects velocity at the order of 10^2 m/s?

This decreases the relaxation time considerably in metals and consequently resistivity of metal or conductor increases as

$$\rho = \frac{1}{\sigma} = \frac{m}{n\,e^2\,\tau}$$

32. A metal rod of square cross-sectional area A, having length l has current I flowing through it, when a potential difference of V volt is applied across its end. Fig I Now, the rod is cut parallel to its length into two identical pieces and joined as shown in the figure II. What potential difference must be maintained across the length of 2l, so that the current in the rod is still I?



Ohm's law, V = IR,

$$V_1 = I\rho\,\frac{l}{A}$$

$$V_2 = I\rho\,\frac{2l}{A/2}$$

$V_2 = 4\,V_1$

33. A wire of resistivity ρ is stretched to three times of its length. What will be its new resistivity?

Resistivity is a property of the material it does not depend on the dimensions of the wire. Thus, when the wire is stretched, then its resistivity remains same.

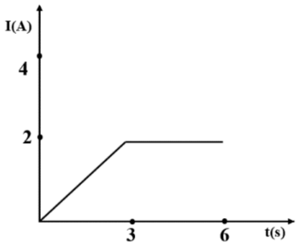
34. In what manner do the relaxation time in the good conductor change when its temperature increases?

$$\rho = \frac{m}{n\,e^2\,\tau}$$

The resistivity of the material is inversely proportional to the average relaxation time of free electron in the conductor. As the value of τ depends on the temperature of the conductor. So, resistivity of the conductor changes with the temperature, as temperature increases, τ decreases, hence ρ increases.

35. Draw a graph showing the variation of resistivity of a (i) conductor and (ii) semiconductor, with the increase in temperature. how does one explain this behaviour in terms of number density of charge carriers and relaxation time? P-98,99

36. Figure shows a graph of current I flowing through the cross section of a wire versus the time t. Use the graph to find the charge flowing in 6 seconds through the wire.



Area under I-t curve gives the charge flowing through the conductor.

$$Q = \left(\frac{1}{2} \times 3\ \times 2\right) + (\,3\ \times 2\,) = 9\,C$$

37. A conductor of length l is connected to a DC source of emf E. if the length of the conductor is doubled by stretching it, keeping E constant, explain how its drift velocity would be affected?

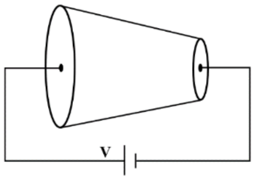
$$v_d\ \alpha\ E$$

$$\frac{v_{d2}}{v_{d1}} = \frac{E_2}{E_1} = \frac{\frac{E_i}{2l}}{\frac{E_i}{l}} = \frac{1}{2}$$

$$v_{d2} = \frac{v_{d1}}{2}$$

38. A wire whose cross-sectional area is decreasing linearly from its one end to other, is connected across a battery of V volts. Which of the following quantities remains constant in the wire? (a) drift speed (b) current density (c) electric current (d) electric field Justify your answer.

The setup is shown in the figure. Here, electric current remains constant throughout the length of the wire. Electric field also remains constant which is equal to V / l. Current density and then drift speed changes.



39. A 60 W, 220 V bulb is connected to a supply of 110 volt. What will be the power dissipated in the bulb ?

P = VI

For 60 W bulb, 60 = 220 × I

$$I = \frac{60}{220}$$

The power dissipated by 60 W bulb will be $P = V \times I = 110 \times \frac{60}{220} = 30\ W$

40. Two bulbs of 60 W and 100 W are connected to 220 V line. What will be the ratio of the resistance?

$$P = \frac{V^2}{R}$$

$$\frac{R_1}{R_2} = \frac{P_2}{P_1} = \frac{100}{60} = \frac{5}{3}$$

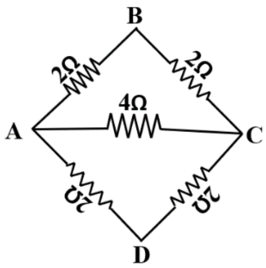
41. A washing machine of 500 W is used for 4 hours, then what is the value of the unit expense of electricity?

Electrical energy = power × time in hours = 500 W × 4 h = 2000 Wh = 2 KWh

1 KWh = 1 commercial unit of electricity

Electrical energy consumed = 2 unit of electricity

42. In the following diagram equivalent resistance between A and D is



Path ABC, $R_{s1} = R_1 + R_2 = 2 + 2 = 4\ \Omega$

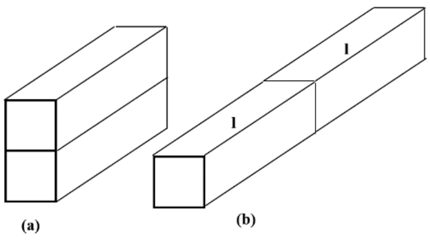
Path ADC, $R_{s2} = 2 + 2 = 4\ \Omega$

Between A and C

$$\frac{1}{R_p} = \frac{1}{R_{s1}} + \frac{1}{R_5} + \frac{1}{R_{s2}}$$

$$R_p = \frac{4}{3}\ \Omega$$

43. Two identical slabs of a given metal, are joined together, in two different ways shown in the figure (a) and (b). What is the ratio of the resistance of these two combinations?



For (a)

$$\frac{1}{R_p} = \frac{1}{R} + \frac{1}{R}$$

$$R_p = \frac{R}{2}$$

For (b) $R_s = R + R = 2R$

$$\frac{R_p}{R_s} = \frac{1}{4}$$

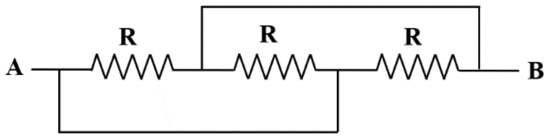
44. A wire of 20 Ω is half and the two pieces are joined in parallel. Find its resistance.

When the wire of 20 Ω is halved, then each part has a resistance of 10 Ω. When they are connected in parallel, then the equivalent resistance = 5 Ω.

45. The potential difference applied across a given resistor is altered, so that the heat produced per second increases by a factor of 16. By what factor does the applied potential difference change?

Heat produced per second $=V^2/R$ So, when voltage is made 4 times, then he produced increases 16 times for same R.

46. Find the equivalent resistance between points A and B of the circuit given below.



All the resistors are in parallel

$$\frac{1}{R_p} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R}$$

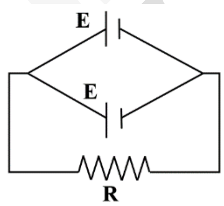
$$R_p = \frac{R}{3}$$

47. The current through a resistor 10 Ω is 3 A. If another resistor of 10 Ω is connected in parallel with it, then what will be the amount of current flowing through the first resistance?

As the two resistances are connected in parallel, the current of 10 A is divided among the resistance, the value of the resistances are equal, current through each of them = 1.5 A

48. Two identical cells, each of emf E , having negligible internal resistance are connected in parallel with each other across an external resistance R. What is the current through this resistance?

The cells or arranged as shown in the circuit diagram



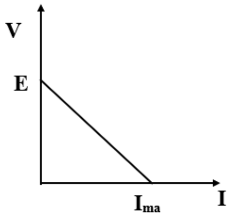
As the internal resistance negligible, show total resistance of the circuit = R, so current through the resistance, I= E/R

(In parallel combination, potential is same as the single cell)

49. A cell of emf E and internal resistance R is connected across a variable resistor R. Plot a graph showing variation of terminal voltage V of the cell versus the current I. Using the graph show, how the emf of the cell and its internal resistance can be determined.

W.K.T, V = E -Ir

The graph between v and I is a straight line of positive intercept and negative slope as shown



(i) The value of the potential difference corresponding to zero current gives the emf of the cell. (E)

(ii) Maximum current is drawn, when terminal voltage is zero, so

V = E – Ir

0 = E – I_{max} r

$$r = \frac{E}{I_{max}}$$

50. What is the difference between the values of potential difference across the terminals of a cell in an open circuit and closed circuit?

The potential difference across the terminal of a cell is given by V = E-Ir.

In an open circuit, there is no current. i.e., I=0

Therefore E=V

In a closed-circuit V< E, the difference between the two values of potential difference = Ir, which is called the lost voltage.

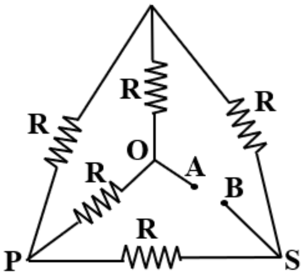
51. Which type of combination of cells is used in the following two cases. (i) if the external resistance is much larger than the total internal resistance? (ii) if the external resistance is much smaller than the total internal resistance?

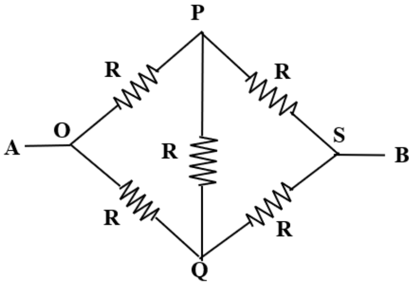
(i) series combination of cells. (ii) parallel combination of cells.

52. Under what condition will the terminal potential difference of a cell be greater than its emf?

The Terminal potential difference of the cell becomes greater than the emf of the cell during charging of the cell. In this process, current flows from positive electrode to negative electrode of the cell. Hence, V = E + Ir

53. If each of the resistance in the network in figure is R, the equivalent resistance between terminals A and B is





The resistance in the arm PQ is ineffective as the network satisfy the Wheatstone network condition.

Therefore, path OPS, $R_{s1} = R + R = 2R$,

Path OQS, $R_{s2} = R + R = 2R$,

R_{s1} and R_{s2} are in parallel

$$\frac{1}{R_p} = \frac{1}{2R} + \frac{1}{2R}$$

$R_p = R\ \Omega$

54. In an experiment of metre bridge, the balancing length of the wire is l. What would be its value, if the radius of the metre bridge wire is doubled? Justify your answer.

The balancing length remains same as per relation

$$\frac{R}{S} = \frac{l}{100 - l}$$

The balancing length is independent of radius of bridge wire provided that it is uniform throughout.

55. Sometimes balance point may not be obtained on the potentiometer wire. Why?

The balance point may not be obtained on the potentiometer wire, because the emf of the axillary battery is less than the emf of the cell to be measured.

56. Two conducting wires P and Q of the same length and area of cross section but of different material or joined in series across a battery. If the number density of electrons in P is twice then that in Q. Find the ratio of drift velocity of electrons in two wires.

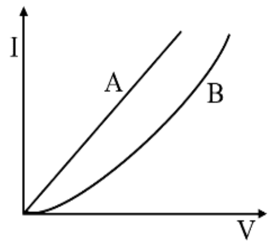
As A and B are in series, the current through them is same,

$I_P = I_Q$

$(nev_dA)_P = (nev_dA)_Q$

$$\frac{(v_d)_P}{(v_d)_Q} = \frac{n_Q}{n_P} = \frac{1}{2}$$

57. Figure below shows a plot of current vs voltage for two different materials A and B. Which of the two material satisfies Ohm's law? Explain.



The graph of V verses I is a straight line for materials that obey Ohm's law. So A is ohmic material

58. Differentiate between emf and terminal potential difference of a cell.

Emf	Terminal potential difference
The EMF of a cell is the maximum potential difference between the two electrodes of a cell, when the cell is in the open circuit.	The Terminal potential difference of a cell is the potential difference between the two terminals of the cell in a closed circuit.
It is independent of the resistance of the circuit and depends upon the nature of the electrode and electrolyte of the cell.	It depends upon the resistance of the circuit and current flowing through it.
The term emf is used for the source of electric current.	the potential difference is measured between any two points of the electric circuit.
The emf is a cause	The potential difference is an effect.

59. Differentiate between potentiometer and voltmeter.

Potentiometer	Voltmeter
It is based on null deflection method	It is based on deflection method
It measures the emf of a cell very accurately	It measures the emf of a cell approximately
While measuring emf,it does not draw any current from the source of known emf	While measuring emf, it draws some current from the source of emf
When measuring emf, the resistance of the potentiometer becomes infinite	While measuring emf, the resistance of voltmeter is high but finite
It can be used for various purposes	It can be used only to measure emf or potential difference
Its sensitivity is high	Its sensitivity is low

60. Resistivity of copper, constantan, silver or 1.7 into 10 power minus 8 ohm metre, 39.1 into 10 power minus 8 ohm metre and 1.6 into 10 power minus 8 ohm metre respectively. Which has the best conductivity?

Conductivity = 1/ resistivity.

As silver has the lowest resistivity, so it has the best conductivity.

61. Two wires of equal lengths, one of copper and the other of manganin have the same resistance. Which wire will be thicker?

$$R = \rho \frac{l}{A}$$

$$A = \rho \frac{l}{R}$$

For both wires R and l are same,

$$\rho_{copper} < \rho_{manganin}$$

$$A_{copper} < A_{manganin}$$

Manganin wire is thicker than copper wire.

62. Two wires of equal cross-sectional area, one of copper and other of manganin have the same resistance. Which one will be longer?

$$R = \rho \frac{l}{A}$$

$$l = \frac{RA}{\rho}$$

For both wires R and l are same,

$$\rho_{copper} < \rho_{manganin}$$

$$l_{copper} > l_{manganin}$$

Copper wire longer than manganin wire

63. The current flowing through a conductor is 2 mA at 250 V and 3 mA at 60 volt. Is it an ohmic or non ohmic conductor?

$$R = \frac{V}{I}$$

Case (i)

$$R_1 = \frac{50}{2 \times 10^{-3}} = 25000\ \Omega$$

Case (i)

$$R_2 = \frac{60}{3 \times 10^{-3}} = 20000\ \Omega$$

As the resistance changes with current, so the given conductor is non-ohmic.

64. If potential difference V applied across a conductor is increased to 2 V, how will the drift velocity of the electron change?

$$v_d \frac{e\,E\,\tau}{m} = \frac{e\,V\,\tau}{m\,l}$$

When V is increased to 2 V, drift velocity also gets doubled.

65. When a motor car is started, the car lights become slightly dim. Why?

When a motor car is started, its starter takes a high current from the battery, so a large potential drop occurs at the terminals of the battery and the bulb gets dim.

66. Why does the conductivity of a semiconductor increase with rise of temperature?

As temperature increases, covalent bonds begin to break in the semiconductor, setting free more and more electrons. So the conductivity increases.

67. Can we use copper wire as a potentiometer wire?

Resistivity of copper is small, so there will not be and appreciable potential drop across the ends of the potentiometer wire. Also temperature coefficient of resistance of copper is large.

68. What is the end error in metre bridge?

The end error in a metre bridge is due to the following reasons.

(i) the zero mark of the scale provided along the wire may not start from the position where the bridge why are leaves the copper strips and hundred centimetre mark of the scale may not end at position where the wire touches the copper strip.

(ii) resistance of copper wire and copper strips of metre bridge has not been taken into account.

69. Three resistors of resistance 2 Ω, 3 Ω and 4 Ω. If they are connected to the same battery in turn, in which case the power dissipated will be maximum?

$$P = \frac{V^2}{R}$$

For a given V, $P \, \alpha \, \frac{1}{R}$

So the power dissipation will be maximum at 2 Ω resistor.

70. Three bulbs 40 W, 60 W and 100 W are connected to 220 V mains. Which bulb will glow brightly, if they are connected in series?

In the series circuit, the same current flows through each bulb. But the 40 W bulb has the highest resistance ($R = \frac{V^2}{P}$) . The 40 W bulb produces maximum heat per second ($P = I^2 R$). So, it will glow more brightly than the other bulbs.

71. A 100 W and a 500 W bulb or joined in parallel to the mains. Which bulb will glow brighter?

In parallel, same voltage V is applied to both the bulbs. But 500 W bulb has a smaller resistance ($R = \frac{V^2}{P}$), so it will produce more heat per second ($P = \frac{V^2}{R}$) and It will glow brighter than 100 W bulb.

72. Two 120 V light bulbs, one of 25 W and other of 200 W where connected in series across a 240 V line. One bulb burnt out almost instantaneously. Which one was burnt and why?

As $R = \frac{V^2}{P}$, so 25 W bulb has more resistance. In the same circuit, same current flows through both the bulbs. The 25 W bulb develops more heat ($H = I^2 R t$) and hence burns out almost instantaneously.

73. The electron drift speed is so small, how can we still obtain large amount of current in a conductor?

The current in a conductor is given by

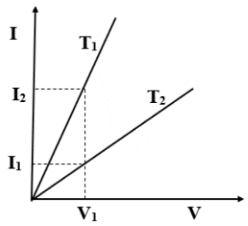
$I = e n A v_d$

Although the electrons charge e and drift speed v_d are very small quantities, yet we can obtain a large amount of current in a conductor. This is because the free electron density of a conductor is large approximately 10^{29} m^{-3}, the drift of a very large number of free electrons are added to cause a large current inside the conductor.

74. It is easier to start a car engine on a warm day then on a chilly day. Why?

The internal resistance of a car battery decreases with increase in temperature. Therefore, on your warm day a car battery gives large current which helps in starting the car engine.

75. The current voltage graphs for a given metallic wire at different temperatures T_1 and T_2 are shown in the graph. Which of the temperatures T_1 and T_2 is greater?



For the same V_1,

Resistance at T_1,

$$R_1 = \frac{V_1}{I_1}$$

Resistance at T_2,

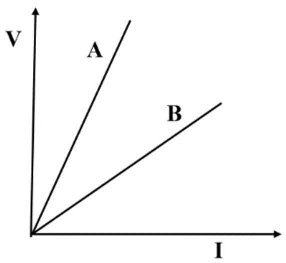
$$R_2 = \frac{V_1}{I_2}$$

Since $I_2 < I_1$ Therefore $R_2 > R_1$

w.k.t , R α T ,

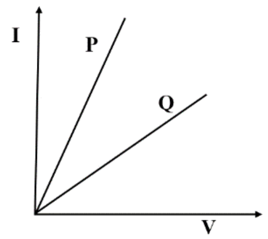
$T_2 > T_1$

76. V- I graphs for parallel and series combination of two metallic resistors are as shown in the graph. Which graph represents parallel combination? Justify your answer.



As $R = \frac{V}{I}$. Clearly, slope of V-I graph gives resistance R. Here graph A has a greater slow than B, so graph A represents series combination (higher resistance) and graph B represents parallel combination. (Lower resistance)

77. The voltage current variation of two metallic wires A and B at constant temperature are as shown. Assume that the wires have the same length and the same the diameter, explain which of the two wires will have larger resistivity.



Slope of I-V line of wire P > slope of I-V line for wire Q

Therefore, conductance of wire P > conductance of wire Q

Resistance of wire P < resistance of wire Q

$$\rho_P \frac{l}{A} = \rho_Q \frac{l}{A}$$

$$\rho_P < \rho_Q$$

Thus, wire Q has a larger resistivity.

78. Explain how electron mobility changes for a good conductor when (i) the temperature of the conductor is decreased at constant potential difference and (ii) applied potential difference is doubled at constant temperature.

Electron mobility of a conductor,

$$\mu = \frac{e\,\tau}{m}$$

(i) when the temperature of the conductor decreases, relaxation time τ of the free electron decreases, so mobility μ decreases.

(ii) mobility μ is independent of applied potential difference.

79. Three materials A, B and C have electrical resistivities σ, 2σ and 2σ respectively. Their number densities of free electrons are n, 2n and n respectively. For which material, is the average collusion time of free electrons maximum?

Conductivity, $\sigma = \frac{n\,e^2\,\tau}{m}$

Therefore, Relaxation time, $\tau = \frac{\sigma\, m}{n\, e^2}$

For metal A, $\tau_A = \frac{\sigma\, m}{n\, e^2}$

For metal B, $\tau_B = \frac{2\, \sigma\, m}{2\, n\, e^2} = \frac{\sigma\, m}{n\, e^2}$

For metal C, $\tau_C = \frac{2\, \sigma\, m}{n\, e^2}$

It is clear that, $\tau_C > \tau_B = \tau_A$

Short Answer Questions

1. Describe the microscopic model of current and obtain general form of Ohm's law. P-87,88
2. Obtain the microscopic form of Ohm's law from its microscopic form and discuss and discuss its limitations. P-89
3. Explain the equivalent resistance of a series and parallel resistor network. P-92,93
4. Explain the determination of the internal resistance of the cell using voltmeter. P-103
5. State and explain Kirchhoff's rules. P-107,108
6. Obtain the condition for bridge balance in Wheatstone's bridge. P-109
7. Explain the determination of unknown resistance using meter bridge. P-111
8. How the emf of two cells are compared using potentiometer? P-113

Additional questions

1. Derive an expression for resistivity in terms of number density of free electrons and relaxation time. Show that resistivity is independent of the dimensions of the conductor. P-87,88
2. Find an expression for the equivalent resistance of a number of resistance connected in series. P-92
3. Find the equivalent resistance of a number of resistance connected in parallel. P-93
4. Explain the variation of resistivity of conductors, semiconductors with the change in temperature. P-97
5. Derive the condition for obtaining maximum current through and external resistance connected across a series combination of cells. P-105
6. Derive the condition for obtaining maximum current through an external resistance connected to a parallel combination of cells. P-106

Long Answer Questions

1. State and explain Kirchhoff's laws by giving suitable illustrations. Also state the sign convention used. P-107,108
2. With the help of a circuit diagram, explain how potentiometer can be used to measure the internal resistance of a primary cell. P-114

Creative questions

1. A wire is carrying a current. Is it charged?

Ans. No. 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 electron is equal and opposite to that of proton. Hence net charge on the wire is zero.

2. Is current density a vector or a scalar quantity? How does the current density, in a conductor vary with –
   - a) increase in potential gradient?
   - b) increase in temperature?
   - c) increase in length?
   - d) increase in area of cross-section?

Ans. Current density is a vector quantity.

Current, $I = nA ev_d = eE / m$

Current density $J = I/A = nev_d = ne \times eE/m$

- a) With increase in potential gradient (V/l), J increases
- b) With increase in temperature, τ decreases, so J decreases.
- c) With increase in length J decreases
- d) With increase in area, J remains unchanged as J is independent of A.

3. Why the resistance of the conductor increases with the rise in temperature.

Ans. With the rise of temperature of conductor, the resistance of a conductor increases because the frequency of collision of electrons with ions/atoms of the conductor increases, resulting decreases in relaxation time (τ) of electrons.

4. If the temperature of a good conductor increases, how does the relaxation time of electrons in the conductor change?

Ans. With the increase in temperature, the free electrons collide more frequently with the ions/atoms of conductor, resulting decrease in relaxation time.

5. Two wires of equal length one of copper and other of manganin have the same resistance. Which wire is thicker?

Ans. $R = \rho l/A$ or $A \propto \rho$ if i and R are constant. Since ρ is greater for manganin than for copper, hence manganin wire is thicker than copper wire.

6. On increasing the current drawn from a cell, the potential difference of its terminals is lowered. Why?

Ans. This is due to internal resistance r of the cell. We know that terminal potential difference $V = \xi - Ir$. If I is increased V will be lowered.

7. Can the terminal potential difference of a cell exceed its e.m.f.?

Ans. Yes. When cell itself is being charged, because terminal potential difference

8. The V – I graph for a conductor makes angle θ with V –axis. Here V denotes voltage and I denotes current. What is the resistance of this conductor?

Ans. V-I graph for a conductor is a straight line, inclined to voltage axis, according to Ohm's Law. If θ is the angle which V-I graph makes with V-axis, then slope of the graph,

$$\tan\theta = I/V = 1/R \quad \text{or} \quad R = \frac{1}{\tan\theta} = \cot\theta$$

9. Lights of a car become dim when the starter is operated. Why ?

Ans. When the motor starter of a car is operated, it drawn more current from the battery for the operation of car. Therefore, the voltage across the light bulb is lowered, hence the right of a car is dimmed.

10. For what basic purpose the cells are connected (i) in series (ii) in parallel and (iii) in mixed grouping?

Ans. The cells are connected (i) in series, to get maximum voltage (ii) in parallel, to get maximum current and (iii) in mixed grouping, to get maximum power.

11. What happens to the balance point if the position of the cell and the galvanometer are inter-changed in balanced Wheatstone bridge?

Ans. There will be no deflection in the galvanometer as the condition of balanced bridge will still hold good.

12. Why do we prefer a potentiometer to measure emf of a cell rather than a voltmeter?

Ans. At null point, a potentiometer does not draw any current from the cell whose emf is to be determined, whereas the voltmeter always draws some little current. Therefore, emf measured by voltmeter is slightly less than actual value of emf of the cell.

13. If the length of the wire be (i) doubled and (ii) halved, what will be effect on the position of zero deflection in a potentiometer? Explain.

Ans. (i) When length of the wire is doubled, the potential gradient across the potentiometer wire will decrease. Due to it, the position of zero deflection will occur at longer length. (ii) The reverse will be true when length is halved.

14. If the current flowing in the wire of the potentiometer be decreased, what will be effect on the position of zero deflection in potentiometer? Explain.

Ans. If the current in the wire of potentiometer is decreased, the potential gradient will decrease and hence the position of zero deflection will occur at longer length.

15. A wire connected to a bulb does not glow, whereas the filament of the bulb glows when same current flows through them. Why?

Sol. Filament of bulb and supply wires are connected in series. Therefore, the same current flows through them. Since the resistance of connecting wires is negligibly small as compared to the resistance of filament and heat produced due to given current is directly proportional to its resistance (from Joule's law of heating), therefore, the heat produced in the filament is very large. Hence the bulb glows, but the connecting wires remain practically unheated.

16. Nichrome and copper wires of same length and area of cross-section are connected in series, current is passed through them. Why does the nichrome wire get heated first?

Ans. Since resistivity of nichrome is greater than that of copper, hence heat produced in nichrome wire will be more than that of copper wire.

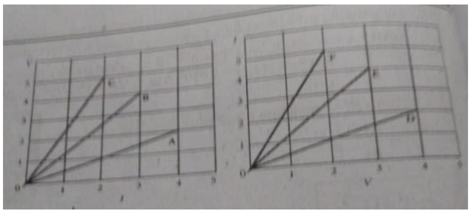
17. Why the brightness of light emitted by a bulb decreases gradually with its period of use

Ans. When the bulb is used, the evaporation of the metal from the filament of bulb takes place with time which deposits on the inner side of the glass wall as black substance. Due to it, the filament of the bulb becomes thinner and thinner with use. This in turn increases the resistance of the bulb. So brightness of bulb decreases gradually with its period of use.

Numerical Problems:

1. The following graphs represent the current versus voltage and voltage versus current for the six conductors A,B,C,D,E and F. Which conductor has least resistance and which has maximum resistance?

(Ans: Least R_F=0.4Ω, maximum R_C=2.5Ω)



Solution :

By Ohm's law, V= IR

$$R = \frac{V}{1}$$

From graph, slope $R = \frac{\Delta V}{\Delta I}$

$$R_A = \frac{2}{4} = \frac{1}{2} = 0.5\Omega$$

$$R_B = \frac{4}{3} 1.33\Omega$$

$$R_C = \frac{5}{2} 2.5\Omega$$

From the above values,

The least resistance is $R_F = 0.4\Omega$

The maximum resistance is $R_C = 2.5\Omega$

From graph, $\frac{1}{\text{slope}} R = \frac{\Delta V}{\Delta I}$

$$R_D = \frac{4}{2} = 2\Omega$$

$$R_E = \frac{3}{4} = 0.75\Omega$$

$$R_F = \frac{2}{5} = 0.4\Omega$$

2. Lightning is very good example of natural current. In typical lightning, there is 10^9J energy transfer across the potential difference of 5 $\times 10^7$V during a time interval of 0.2s. Using this information, estimate the following quantities (a) total amount of charge transferred between cloud and ground (b) the current in the lighting bolt (c) the power delivery in 0.2s.

(Ans :Charge =20C, I =100A, P=5 GW)

Given data :

$E=10^9$J, $V=5\times10^7$V, t=0.2s

Solution :

a)Total amount of charge

$$W = qv \Rightarrow q\frac{W}{V} = \frac{E}{V} = \frac{10^9}{5\times10^7} = 0.2\times10^2$$

q = 20C

$$\text{b) current, } I = \frac{q}{t} = \frac{20}{0.2} = \frac{200}{2} = 100$$

I = 100 A

c) power, P=VI =5× 10^7×100 = 5×10^9

P=5GW

Ans : Q=20C

I=100A

P=5GW

3. A copper wire of 10^{-6} m^2 area of cross section, carries a current of 2A. If the number of electrons per cubic meter is 8×10^{28}, calculate the current density and average drift velocity (Answers : J=2×10^6 Am^{-2}; Vd -15.6×10^{-5} ms^{-1})

Given data : A=10^{-6} m^2, I =2A, n = 8 × 10^{28}

Formula :

$$\text{Current density, } J = \frac{I}{A}$$

$$\text{Drift velocity, } V_d = \frac{J}{ne}$$

Solution :

$$J = \frac{I}{A} = \frac{2}{10^{-6}} = 2\times10^6$$

J = 2 × $10^6 Am^{-2}$

$$V_d = \frac{J}{ne} = \frac{2\times10^6}{8\times10^{28}\times1.6\times10^{-19}}$$

$$V_d = 15.6\times10^{-5} ms^{-1}$$

Ans : J =2 × $10^6 Am^{-2}$

V_d = 15.6 × 10^{-5} ms^{-1}

4. The resistance of a nichrome wire at 0°C is 10Ω. If its temperature coefficient of resistance is 0.004/°C, find is resistance at boiling point of water. Comment on the result.

(Ans : R_T =14Ω)

Given data :

T_1 = 10°C, R_0 =10

Boiling point of water T_2 = 100°C

α = 0.004/°C

R_T =?

Formula :

$R_T = R_o [1+\alpha(T-T_o)]$

$R_T=10[1+0.004(100-0)]$

$= 10 (1+0.4)$

$=10(1.4)$

$R_T=14\Omega$

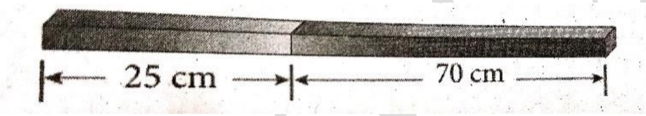
Ans : R_T = 14Ω

As the temperature increase the resistance of the wire also increase.

5. The rod given in the figure is made up of two different materials.

Both the have square cross sections of 3mm side. The resistivity of the first material is 4 × 10^{-3}Ω and it 25 cm long while second material has resistivity of 5×10^{-3}Ω and is of 70cm long. What is the resistivity of rod between its ends?

(Ans: 500Ω)



Given data :

$e_1 = 4\times10^{-3}\Omega m,\ \ l_1 = 25cm = 25\times10^{-2}m$

$e_2 = 5\times10^{-3}\Omega m,\ \ l_2 = 70cm = 70\times10^{-2}m$

Formula :

$$e = \frac{A.R}{l}$$

To find Area (A)

Area of square = $a^2 = (3\times10^{-3})^2 = 9\times10^{-6}m^2$

Solution :

$$R = \frac{\rho_1 l_1}{A_1}$$

$$R_1 = \frac{\rho_1 l_1}{A_1} = \frac{4\times10^{-3}\times25\times10^{-2}}{9\times10^{-6}m^2} = 111.11\Omega$$

$$R_2 = \frac{\rho_2 l_2}{A_1} = \frac{5\times10^{-3}\times70\times10^{-2}}{9\times10^{-6}m^2} = 388.88\Omega$$

Resistance of the rod between its ends =

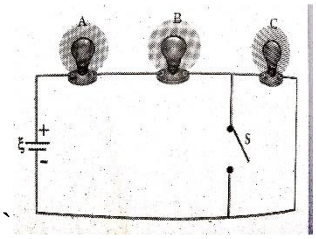
$R_1 + R_2 = 111.11 + 388.88$

$R \quad = 499.99 = 500\Omega 0$

Ans : R =500Ω

6. Three identical lamps each having a resistance R are connected to the battery of emf as shown in the figure.

Suddenly the switch S is closed. (a) Calculate the current in the circuit when S is open and closed (b) What happens to the intensities of the bulbs A, B and C. (c) Calculate the voltage across the three bulbs when S is open and closed (d) Calculate the power delivered to the circuit when S is opened and closed (e) Does the power delivered to the circuit decreases, increases or remain same?

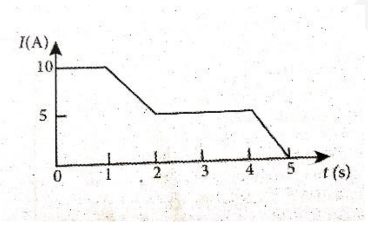


Ans

Electrical quantities	Switch S is open	Switch S is closed
Current	$\frac{\xi}{3R}$	$\frac{\xi}{2R}$
Voltage	$V_A = \frac{\xi}{3R}$, $V_B = \frac{\xi}{3R}$, $V_C = \frac{\xi}{3R}$	$V_A = \frac{\xi}{2R}$, $V_B = \frac{\xi}{2R}$, $V_C = 0$

Power	$P_A = \frac{\xi^2}{9R}$, $P_B = \frac{\xi^2}{9R}$, $P_C = \frac{\xi^2}{9R}$	$P_A = \frac{\xi^2}{4R}$, $P_B = \frac{\xi^2}{4R}$, $P_C = 0$ Total power increases
Intensity	All the bulbs glow with equal intensity	The intensities of the bulbs A and B equally increase. Bulb C will not glow since no current pass through it.

7. The current through an element is shown in the figure. Determine the total charge that pass through the element at a) t = 0s, b) t= 2s, c) t=5s.



Ans : At t =0s, dq =0C

At 1 = 2s, dq=10C,

At t =5s, dq =0C

Solution :

Charge, q = It

From graph :

a) At t =0s, I =10A,

q = It = 10 ×0=0 $\therefore$ q = 0C

b) At t =2s, I =5A,

q = It = 5 ×2=10 $\therefore$ q =10C

c) At t =5s, I =0A,

q = It = 0 ×5=0 $\therefore$ q =0C

Ans : a) dq =0C at t =0s

b) dq =10C at t =2s

c) dq =0C at t =5s

8. **An electronics hobbyist is building a radio which requires 150Ω in her circuit, but she has only 220 Ω, 79 Ω and 92 Ω resistors available. How can she connect the available resistors to get desired value of resistance?**

(Ans : Parallel combination of 220Ω and 79Ω in series with 92Ω)

Solution :

Required resistance =150Ω

Available resistances =220Ω, 79Ω, 92Ω

Case I

If 3 resistors are connected in series, then

$R_S = R_1 + R_2 + R_3 = 220+79+92 = 391\Omega$

This value is greater than the required resistance so it is not possible.

Case II

If 3 resistors are connected in parallel, then

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\frac{1}{R_P} + \frac{1}{220} + \frac{1}{79} + \frac{1}{92} = 0.0279$$

$R_P = 35.84\ \Omega$

This does not meet the requirement.

Case III

If R_1& R_2 are connected in parallel and R3 in series.

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{220} + \frac{1}{79}$$

$$= 0.0172 \Rightarrow R_P = 58.14\Omega$$

$$R_S = R_P + R_3 = 58.14 + 92 = 150.13\Omega$$

$$\therefore R = 150\Omega$$

This meets the requirement.

9. A cell supplies a current of 0.9 A through a 2 Ω resistor and a current of 0.3 A through a 7 Ω resistor. Calculate the internal resistance of the cell.

Solution :

(Ans: 0.5 Ω)

With the 2 Ω resistor

$$I = \frac{\xi}{R + r}$$

$$0.9 = \frac{\xi}{2 + r}$$

$$\xi = 0.9(2 + r)$$

with the 7Ω resistor :

$$I = \frac{\xi}{R + r}$$

$$0.9 = \frac{\xi}{7 + r}$$

$$\xi = 0.3(7 + r)$$

Since ‘ξ’ is constant,

$$0.9(2 + r) = 0.3(7 + r)$$

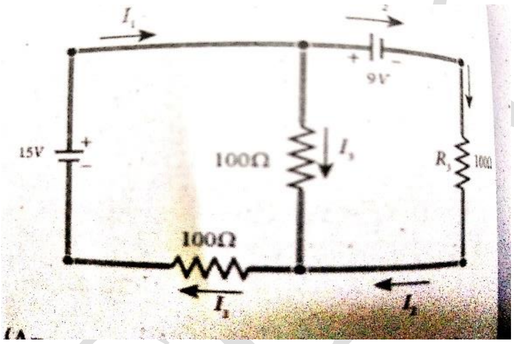
$$1.8 + 0.9r = 2.1 + 0.3r$$

$$0.6r = 0.3$$

$$r = \frac{0.3}{0.6}$$

$$r = \frac{1}{2} = 0.5\Omega$$

10.Calculate the currents in the following circuit.



Solutions :

(Ans : $I_1 = 0.070A$, $I_2 = -0.010A$ $I_3 = 0.080A$)

At junction B, applying current law,

$I_1 - I_2 - I_3 = 0$

$I_1 = I_2 + I_3$ ------------(1)

Kirchhoff’s voltage law in loop ABEFA

$100I_3 + 100I_1 = 15$

Using (1), we get,

$100I_3 + 100(I_2+I_3) = 15$

$100I_3 + 100I_2 + 100I_3 = 15$

Voltage law in loop BCDEB

$100I_2 - 100I_3 + 9 = 0$

$100I_3 - 100I_2 = 9$ ---------------(3)

Adding (1) & (2), we et

$200I_3 + \cancel{100I_2} = 15$

$\underline{100I_3 - \cancel{100I_2} = 9}$

$300I_3 = 29$

$$I_3 = \frac{24}{300} = 0.08$$

$$\therefore I_3 = 0.08A$$

(3) $\Rightarrow 100I_3 - 100I_2 = 9$

Substituting the value of I_3, we get

$100 \times 0.08 - 100I_2 = 9$

$8 - 100I_2 = 9$

$-100_2 = 1$

$$\Rightarrow I_2 = \frac{-1}{100} = -0.01A$$

$$I_2 = -0.01A$$

From (1),

$I_1 = I_2 + I_3$

$= -0.01 + 0.08$

$I_1 = 0.07A$

$I_1 = 0.07A$

$I_2 = -0.01A$

$I_3 = 0.08A$

11.A potentiometer wire has a length of 4m and resistance of 20Ω. It is connected in series with resistance of 2890 Ω and a cell of emf 4 V. Calculate the potential along the wire.

(Ans : Potential = 0.65×10^{-2} Vm^{-1})

Given data :

L=4m of R = 20Ω

In series with $R' = 2980\Omega$

E=4V

Formula :

Ohm's Law V = IR

Solution :

Since 20 is in series with 2980

R_{eff} = 20+2980 =300

$$\text{current } I = \frac{V}{R_{eff}} = \frac{4}{300} = 1.3\times10^{-3}\,A$$

$$I = 1.3\times10^{-3}\,A$$

Potential along the wire of 4m length is,

$$\frac{V}{l} = \frac{IR}{l}\ I = \frac{1.3\times10^{-3}\times20}{4}$$

$$= \frac{26\times10^{-3}}{4}$$

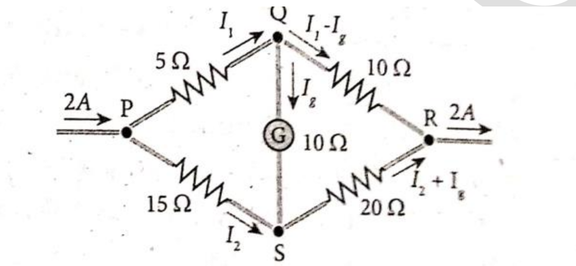
$$= 6.5\times10^{-3}\,Vm-1$$

$$\frac{V}{l} = 0.65\times10^{-2}\,Vm-1$$

$$\text{Potential} = 0.65\times10^{-2}\,Vm^{-1}$$

12.Determine the current flowing through the galvanometer (G) as shown in the figure

(Ans : $I_g = \frac{1}{11}$ A)



Solution :

$I_2 = I - I_1$

Circuit flowing the current I =2A Applying Kirchhoff's II law to PQSP

$5I_1+10I_g -15 I_2 =0$

$5I_1+10I_g -15 (I-I_1) =0$

$5I_1+10I_g -15I + 15I_1 =0$

$20 I_1 + 10I_g = 15 \times 1$

$20 I_1 + 10I_g = 30$

$2I_1 + I_g = 3$ ……………….(1)

Applying Kirchhoff's II law to QRSQ

$10(I_1 - I_g) - 20(I_2 + I_g) - 10 I_g = 0$

$10 I_1 - 10 I_g - 20(I - I_1 + I_g) - 10 I_g = O$

$10 I_1 - 10 I_g - 20 I + 20 I_1 - 20 I_g - 10 I_g = O$

$30 I_1 - 40 I_g = 20 I$

$30 I_1 - 40 I_g = 20 \times 2$

$3 I_1 - 4 I_g = 4$ …………… (2)

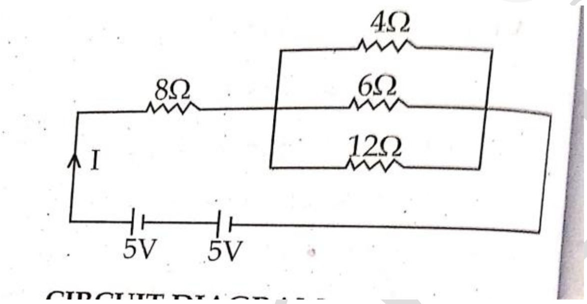
$(1) \times 3$ $6 I_1 + 3 I_g = 9$ ………… (3)

$(21) \times 2$ $6 I_1 + 8 I_g = 8$ ………… (4)

Solving (3) & (4)

$$+11 I_g = 1 \; ; \; I_g = \frac{1}{11} A$$

13.Two cells each of 5V are connected in series across a 8 Ω resistor and three parallel resistors of 4Ω, 6Ω, and 12 Ω. Draw a circuit diagram for the above arrangement. Calculate i) the current drawn from the cell (ii) current through each resistor.



Ans :

$$\text{The Current at } 4\Omega, I = \frac{2}{4} = 0.5A$$

$$\text{The Current at } 6\Omega, I = \frac{2}{6} = 0.33A$$

$$\text{The Current at } 12\Omega, I = \frac{2}{12} = 0.17A$$

Solution :

CIRCUIT DIAGRAM :

i) Current drawn from the cell

$E_{eq} = 5 + 5 = 10V$

$R_{eff} = R^{*}S + R_{P}$

$R_S = 8\Omega$

$$\frac{1}{R_P} = \frac{1}{4} + \frac{1}{6} + \frac{1}{12} = \frac{18+12+6}{72} = \frac{36}{72}$$

$$\therefore R_P = \frac{72}{36} \qquad = 2\Omega$$

$$R_{eff} = 8 + 2 \qquad = 10\Omega$$

$$1 = \frac{E_{eq}}{R_{eff}} = \frac{10}{10} \qquad = 1A$$

$\therefore I = 1A$

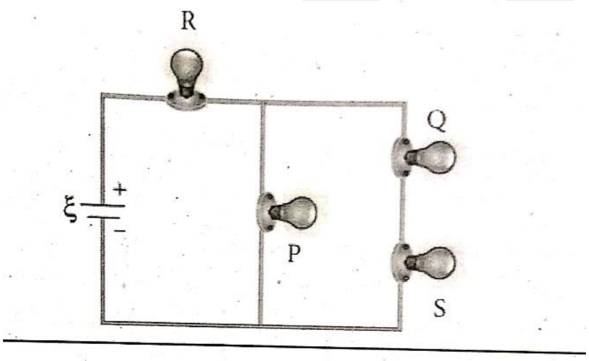
$\text{Voltage drop } V = IR = 1 \times 2 = 2V$

14.Four light bulbs P, Q, R, S are connected in a circuit of unknown arrangement. When each bulb is removed one at a time and replaced, the following behavior is observed.

	P	**Q**	**R**	**S**
P removed	*	on	on	on
Q removed	on	*	on	off
R removed	off	off	*	off
S removed	on	off	on	*

Draw the circuit diagram for the bulbs

Answer :



15. In a potentiometer arrangement, a cell of emf 1.25 V gives a balance point at 35cm length of the wire. If the cell is replaced by another cell and the balance point shifts to 63cm, what is the emf of the second cell?

(Ans : emf of the second cell is 2.25V)

Given data :

$E_1 = 1.25V$ $\quad$ $l_1 = 35cm$ $\quad$ $E_2 = ?$

Formula :

$$\frac{\xi_1}{\xi_2} = \frac{l_1}{l_2}$$

$$\xi_2 = \xi_1 \frac{l_2}{l_1}$$

$$= 1.25 \times \frac{63 \times 10^{-2}}{35 \times 10^{-2}}$$

$$l_2 = 63\text{cm}$$

$$\xi_2 = \frac{78.75}{35} = 2.25\text{V}$$

$$\xi_2 = 2.25\text{V}$$

Ans : Emf of the second cell is 2.25V

CHAPTER 3

MAGNETISM AND MAGNETIC EFFECTS OF ELECTRIC CURRENT

Points to ponder

- ✓ A magnet is a piece of material that has both attractive and directive properties. It attracts small pieces of iron, nickel, cobalt etc
- ✓ The word lodestone means a leading stone. It represents the directive behaviour of a magnet
- ✓ A magnetic dipole is an arrangement of two equal and opposite magnetic poles separated by a certain distance. A bar magnet is a magnetic dipole
- ✓ The magnetic dipole moment of a magnet is the product of its pole strength and magnetic length 2l.
- ✓ SI unit of magnetic moment is ampere metre
- ✓ magnetic moment is a vector, its direction is from south pole to north pole of the magnet,
- ✓ The SI unit of magnetic moment is Ampere meter^2 or joule/tesla
- ✓ The direction of magnetic moments from S-pole to N-pole of the magnet.
- ✓ Torque, T= mB sin θ
- ✓ Torque is maximum when magnet perpendicular to the direction of the magnetic field.
- ✓ Torque is minimum (zero) when the magnet lies along the direction of the field.
- ✓ The P.E. of a magnetic dipole is minimum when its dipole moment is parallel to the magnetic B
- ✓ The P.E. of a magnetic dipole is zero, when its dipole moment m is perpendicular to the field B
- ✓ The pole strength of a magnet depends on (I) its area of cross-section (ii) nature of its material and (iii) its state of magnetisation.
- ✓ Magnetic moment of a current loop, M= IA.
- ✓ Bohr magneton is the minimum value of atomic dipole moment and is defined as the magnetic dipole moment associated with the electron revolving in the first orbit of hydrogen atom.
- ✓ The straight line passing through the magnetic north and south poles of the earth is called magnetic axis of the earth.
- ✓ The vertical plane passing through the geographical north and south poles is called geographic meridian.

- ✓ The elements of earth's magnetic tiled are(I) Declination (ii) Dip (iii) Horizontal component of earth's magnetic field.
- ✓ The angle between the geographic meridian and the magnetic meridian at a place is called the magnetic declination at that place.
- ✓ The angle made by the earth's total magnetic with the horizontal direction is called angle of dip or magnetic inclination at that place
- ✓ Angle of dip at the equator, I = 0.
- ✓ Angle of dip at magnetic poles, I = 90
- ✓ Dip angle increases from 0° to 90° as one moves from magnetic equator to poles.
- ✓ A compass needle is free to rotate about a vertical axis in a horizontal plane while a dip needle is free to rotate about a horizontal axis in a vertical plane.
- ✓ Curie point is the temperature above which ferromagnetic substance becomes paramagnetic.
- ✓ The material used for making an electromagnet(i) high permeability (ii) low retentivity.
- ✓ The phenomenon of lagging of magnetic induction behind the magnetising field in a magnetic material is called hysteresis,
- ✓ The area of the hysteresis loop gives the energy wasted in a sample when it is taken through a cycle of magnetisation • Relative permeability for diamagnetic substance is less than 1 relative permeability for paramagnetic substances is greater than 1 relative permeability for ferromagnetic substances is much greater than 1
- ✓ Ampere's circuital law can be derived from the Biot-Savart law.
- ✓ Ampere's circuital law and Biot-Savart law relate magnetic field to the electric current.
- ✓ Ampere's circuital law holds for steady currents which do not change with time.
- ✓ The magnetic field inside a toroidal solenoid is independent of its radius and depends only on the current and the number of turns per unit length.
- ✓ The field inside the toroid has constant magnitude and tangential direction at every point.
- ✓ A static charge is a source of electric field only.
- ✓ A moving charge is source of both electric and magnetic fields.
- ✓ No force is exerted on stationary charge in a magnetic field.
- ✓ A charge moving parallel or antiparallel to the direction of the magnetic field experience magnetic Lorentz force.
- ✓ Electric field, the force experienced by a moving charge depends on the strength of the field and not on the velocity of the charge.
- ✓ Magnetic field, the force experienced by a moving charge depends not only on the strength of the field but also on the velocity of the charge.

- ✓ As the magnetic force on a charged particle acts perpendicular to the velocity. So, it does not do any work on the particle. Therefore, the kinetic energy or the speed of the particle does not change.
- ✓ When a charged particle is projected into a uniform magnetic field with its initial velocity perpendicular to the field, make the particle move in a circle in a plane perpendicular to the magnetic field.
- ✓ When a charged particle moves perpendicular to a uniform magnetic field. the radius of the circular path is proportional to is momentum,
- ✓ The force acting on the particle is independent of the radius of the circular orbit but proportional to its speed
- ✓ The period of revolution of the charged particles independent of its speed and the radius of its circular orbit.
- ✓ When a charged particle IS projected into a uniform magnetic field at an arbitrary angle with the field, the particle will follow a helical path with its axis parallel to the field.
- ✓ In a cyclotron, the electric field accelerates the charged particles. The magnetic field makes the charge to move it along a circular path.
- ✓ The torque on a planar current loop depends on current, strength of magnetic field and area of the loop. It is independent of the shape of the loop.
- ✓ Fora given perimeter, a circle has maximum area. So it experiences maximum torque than any other planar shape.
- ✓ The torque on a current loop in a magnetic field is the principle of the electric motor and galvanometers.
- ✓ In a uniform magnetic field, the net magnetic force on a current loop is zero but torque acting on it may be zero or non-zero.
- ✓ In a non-uniform magnetic field, the net magnetic force on a current is non-zero but torque acting on it may be zero or non-zero.
- ✓ The radial field present in a moving coil galvanometer, makes current proportion to delflection there by the scale is linear
- ✓ Phosphor-bronze is used for suspension or hair springs because of the following reasons (i) it is a good conductor of electricity (ii) It does not oxidise easily (iii) It is perfectly elastic (iv) It is non-magnetic (v) it has the minimum value for restoring torque per unit twist i.e., smallest torsion constant.
- ✓ Ammeter resistance is less than the shunt so it is placed in a series circuit and does not practically change the current in the circuit to be measured.
- ✓ The resistance of an ideal ammeter is zero
- ✓ The range of an ammeter can be increased but it cannot be decreased.

✓ Voltmeter resistance is much higher than that of the galvanometer

✓ The resistance of an ideal voltmeter is infinite.

✓ A voltmeter is placed in parallel with the circuit, so it draws a very small current and therefore the potential difference across the element remains practically same.

✓ The range of voltmeter can be both increased or decreased.

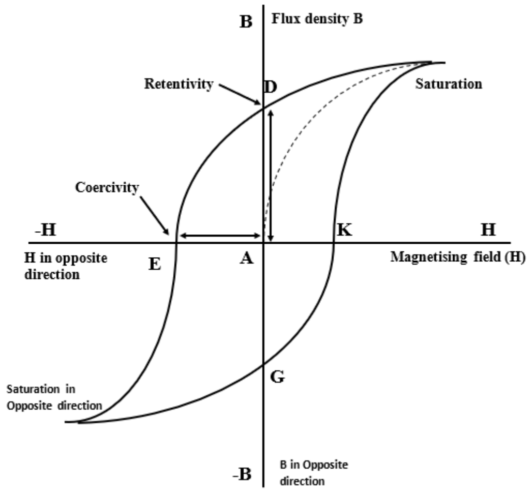
Important formulas

S No	Application	Formula	Terms/Units	Figure
1	Magnetic dipole moment of electric current coil	$p_m = NAI$	p_m =magnetic dipole moment SI unit is Am^2 N=total number of turns I=electric current A=area of electric coil	
2	Magnetic dipole moment of a bar magnet	$p_m = q_m(2l)$	p_m=magnetic dipole moment SI unit is Am^2 2l=length of magnet q_m = magnetic pole strength	
3	Magnetic field at a point of axial line	$\vec{B}_{axial} = \frac{\mu_0}{4\pi}\left[\frac{2\,r\,p_m}{(r^2 - l^2)^2}\right]\hat{\imath}$ When d >> >> l then $\vec{B}_{axial} = \frac{\mu_0}{4\pi}\left[\frac{2\,p_m}{r^3}\right]\hat{\imath}$	$\vec{B}_{axial}$ =magnetic field at a point on axial line of bar magnet B_e=magnetic field at a point on equatorial line of bar magnet m=magnetic dipole moment r =distance of point on axil line from center of magnet 2l=length of bar magnet	
4	Magnetic dipole moment at a point on equatorial line	$\vec{B}_{equatorial} = -\frac{\mu_0}{4\pi}\left[\frac{p_m}{(r^2 + l^2)^{\frac{3}{2}}}\right]\hat{\imath}$ When d >> >> l then $\vec{B}_{equatorial} = -\frac{\mu_0}{4\pi}\left[\frac{p_m}{r^3}\right]\hat{\imath}$		

5	Torque(τ) on magnet or electric coil in external magnetic field (B)	$\tau = p_m\, B\, \sin\theta$ When $\theta = 0$ then $\tau = 0$ = minimum When $\theta = 90^0$ then $\tau = p_m\, B$	
6	Potential energy of (U) magnet or electric coil in external magnetic field (B)	$U = -p_m\, B(\cos\theta - \cos\theta')$ When $\theta' = 90°$ and $\theta = 0$ then U = - p_m B Cos 0 = - p_m.B	
		1.PE (U) of magnetic dipole is minimum when p_m is parallel B and U= - p_mB; $\theta = 0^0$ and dipole is stable equilibrium.	
		2. PE (U) of magnetic dipole is minimum when p_m is antiparallel to B and U= + p_mB; $\theta = 180^0$ and dipole is stable equilibrium.	
		3. PE (U) of magnetic dipole is zero when p_m is perpendicular to B and U = 0; $\theta = 90^0$	
7	Gauss law for magnetism	$\int \vec{B}\,.\,\vec{dS} = 0$	$\vec{B}$ =magnetic field $\vec{dS}$ = elementary area vector
8	Horizontal component of earth's total magnetic field	$B_H = B \cos I$	B_H =horizontal component of earth's magnetic field B_v = vertical component of earth's magnetic field B = total earth's magnetic field I = angle of dip
9	Vertical component of	$B_v = B \sin I$	

	earth's total magnetic field		
10	Relation between horizontal vertical components of earth's magnetic field and angle of dip	$\frac{B_V}{B_H} = \tan I$	
11	Total earth's magnetic field	$B = \sqrt{B_H^2 + B_V^2}$	B=total earth's magnetic field B_H = horizontal component of earth's magnetic field B_v = vertical component of earth's magnetic field
12	**Magnetizing field (B_0)**	The magnetic field in vacuum and induce magnetism is called **magnetizing field (B_0)** $B_0 = \mu_0 n I$ (magnetizing field due to current carrying solenoid)	
13	**Magnetizing field intensity (H)**	Magnetizing field intensity (H) is the ability of magnetizing field to magnetize a material medium. It is also defined as number of ampere turns (nl) required to produce given magnetizing field H = nl $H == \frac{B_0}{\mu_0} = \frac{\mu_0 n I}{\mu_0} = n I$	

14	Intensity of magnetization (M)	Intensity of magnetization (M) or magnetization is the magnetic dipole moment developed per unit volume $\vec{M} = \frac{1}{V}\vec{p_m} = \frac{q_m\, 2l}{2l\, A} = \frac{q_m}{A}$	
15	Magnetic induction or Total magnetic field (B)	$B = B_0 + B_m$ $B = \mu_0 (H + M)$	
16	Magnetic Permeability (μ)	Magnetic permeability (μ) is the ratio of magnetic induction(B) to magnetic intensity (H) $\mu = \frac{B}{H}$	
17	Relative magnetic permeability	$\mu_r = \frac{\mu}{\mu_0}$	μ_r = relative magnetic permeability μ = magnetic permeability of medium χ_m = magnetic susceptibility
18	Magnetic susceptibility	$\chi_m = \frac{M}{H}$	
19	Relation between magnetic permeability and magnetic susceptibility	$\mu_r = 1 + \chi_m$	
20	Curie law	$\chi_m = \frac{C}{T}$	T=absolute temperature C=curie constant
21	Curie law for ferromagnetic materials	$\chi_m = \frac{C}{T - T_C}$	χ_m = magnetic susceptibility C=curie constant T_c = critical temperature

22	Hysteresis Curve			
23	Electrostatic force	$F_E = q\,E$	q=electric field	E=electric field
24	Magnetic force on moving charged particle	$F_B = B\,q\,Sin\,\theta = q\,(\vec{v} \times \vec{B})$	**B=magnetic field;** **Sl unit of magnetic field is Tesla (T)** **CGS unit of magnetic field is Gauss (T)** **1Tesla = 10 Gauss** q=charged particle V=velocity of charged particle θ=angle between velocity (v) and magnetic field (B) E=electric field	
25	Lorentz force	$\vec{F} = q\,(\vec{E} + \vec{v} \times \vec{B})$		
26	Velocity selector	$F_E = F_B$ $v = \dfrac{E}{B}$	V=velocity of charged particle E=electric field B=magnetic field	
27	Motion of charge particle in magnetic field	1.When v of ± q parallel or anti parallel to B then ± q moves in St.line in the	3.When v is perpendicular to B, charged particle move in circular path 4.When angle between v and B is θ charged particle move in helical path	

28	Cyclotron – motion of particle perpendicular to magnetic field	$F_B = F_C$ $B\,q\,v = \frac{m\,v^2}{r}$	m=mass of charged particle v=velocity of charged particle p=momentum of charged particle	
29	Radius (r) of circular path	$r = \frac{m\,v}{B\,q} = \frac{p}{B\,q}$		
30	Velocity (v) of charged particle	$v = \frac{B\,q\,r}{m}$		
31	Time period (T) of charged particle	$T = \frac{2\,\pi\,m}{B\,q}$	B=magnetic field q=charge of charged particle k=kinetic energy of charged particle	
32	Frequency of charged particle	$\upsilon = \frac{1}{T} = \frac{B\,q}{2\,\pi\,m}$		
33	Kinetic energy (k) of charged particle	$KE = \frac{q^2\,B^2\,r^2}{2\,m}$		
34	Radius of helical path	$r = \frac{m\,v\sin\theta}{B\,q}$	m=mass of charged particle v=velocity of charged particle	B=magnetic field q=charge of charged particle Ó=angle between velocity and magnetic field

35	Velocity of charged particle accelerated through electric potential (V)	$\frac{1}{2} m v^2 = q V$ $v = \sqrt{\frac{2 q V}{m}}$	M=mass of charged particle V=velocity of charged particle	q=charge of charged particle v=electric potential
36	Magnetic force (F_B) on electric conductor in magnetic field(B)	$F_B = I\vec{l} \times \vec{B} = B I l \sin\theta$	B=magnetic field I=electric current	
37	Biot – Savart law	$dB = \frac{\mu_0}{4\pi} \frac{I\, dl \sin\theta}{r^2}$ $d\vec{B} = \frac{\mu_0}{4\pi} \frac{I\, d\vec{l} \times \hat{r}}{r^2}$ vector form $\frac{\mu_0}{4\pi} = 10^{-7}\, TmA^{-1}$	l=electric current dl=current element r=distance of a point from dl θ = angle between I and dL = current element	
38	Magnetic field due to finite long electric wire	$B = \frac{\mu_0 I}{4\pi a}(\sin\theta_1 + \sin\theta_2)$	I= electric current a = perpendicular distance from electric wire	
39	Magnetic field due to infinite long electric wire	$B = \frac{\mu_0 I}{2\pi a}$		

40	Magnetic field at a point on the axial line of electric coil (N=1)	$$\vec{B} = \frac{\mu_0\ I}{2} \frac{R^2}{(R^2 + Z^2)^{\frac{3}{2}}}\ \hat{k}$$ $$\vec{B} = \frac{\mu_0\ I}{2\ \pi} \frac{\pi R^2}{(R^2 + Z^2)^{\frac{3}{2}}}\ \hat{k}$$ $$\vec{B} = \frac{\mu_0}{2\ \pi} \frac{p_m}{(R^2 + Z^2)^{\frac{3}{2}}}\ \hat{k}$$ Where, $p_m = I\ A$ =magnetic dipole moment	B = magnetic field at a point on axial line $p_m = I\ A$ magnetic dipole moment Z =distance of a point on the axial line from center of circular electric coil R=radius of electric coil
		When Z >> >> R then B $$\vec{B} = \frac{\mu_0}{2\ \pi} \frac{I\ A}{Z^3}\ \hat{k}$$	
		When R = 0 i,e at centre $$\vec{B} = \frac{\mu_0}{2\ \pi} \frac{I\ A}{R^3}\ \hat{k}$$	
41	Magnetic dipole moment of current carrying coil(N=1)	$$p_m = I\ A$$	p_m=magnetic dipole moment of an electric loop or coil A = Area of the coil I=electric current in each turn
42	Ampere circuital law	$$\oint_C \vec{B}.\ d\vec{l} = \mu_0\ I_{enclosed}$$	B=magnetic field dl=current element I=electric current
43	Magnetic field due to current carrying solenoid	$$B = \mu_0\, n\, I$$ (for air core solenoid) $$B = \mu_m\, n\, I = B = \mu_r\, \mu_0\, n\, I$$	B = magnetic field inside solenoid or toroid I=electric current n=number of turns per unit length

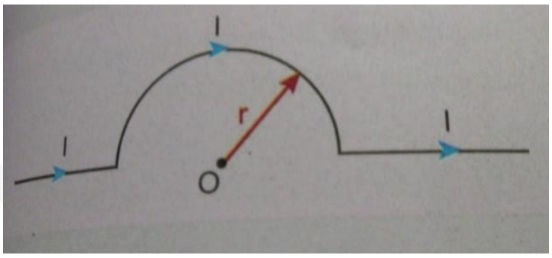
		(for medium core solenoid) B = 0 (out side solenoid)	N=nl=total number of turns μ_r=relative permeability μ_m=permeability of medium μ_0= permeability of free space	
44	Relation between speed of light, permeability and permittivity of free space	$c = \frac{1}{\sqrt{\epsilon_0\ \mu_0}}$	c=speed of light in vacuum	ε_0 = permittivity of free space μ_0 = permeability of free space
45	Force per unit length between two parallel electric current carrying wires	$\frac{\vec{F}}{l} = -\frac{\mu_0\, I_1 I_2}{2\,\pi\, r}\ \hat{\jmath}$ Parallel electric currents attract each other Antiparallel electric currents repel each other	F = magnetic force I_1 and I2 are electric current in parallel wires r = dependicular distance between parallel wires	
46	Torque on electric loop in magnetic field	$\overrightarrow{\tau_{net}} = I\, ab\, B \sin\theta\ \hat{\jmath}$ $= I\ A\ B \sin\theta\ \hat{\jmath}$ $\overrightarrow{\tau_{net}} = p_m\ B \sin\theta\ \hat{\jmath}\ = \overrightarrow{p_m} \times \vec{B}$	I= current B=magnetic field K=torsional constant A=area of coil R=resistance T =torque $p_m = I\ A$ = magnetic dipole moment of electric coil or loop	
47	Galvanometer constant or figure of merit	$G = \frac{K}{N\ A\ B}$		

	of galvanometer		
48	Current Sensitivity of galvanometer	$$I_S = \frac{\theta}{I} = \frac{N\ A\ B}{K} = \frac{1}{G}$$	
49	Voltage Sensitivity of galvanometer	$$V_S = \frac{\theta}{V} = \frac{N\ A\ B}{K\ R_g} = \frac{I_S}{R_g}$$	
50	Shunt resistance to convert galvanometer in to ammeter	$$S = \frac{I_g}{I - I_g} R_g$$	S = shunt resistance R_g = resistance of galvanometer R_a =resistance of ammeter I_g = current through galvanometer
51	Resistance of ammeter (R_A)	$$R_a = \frac{R_g\ S}{R_g + S}$$	
52	High resistance to be connected in series to covert galvanometer to voltmeter	$$R_h = \frac{V}{I_g} - R_g$$	
53	Resistance of voltmeter	$$R_V = R_g + R_h$$	R_h = high shunt resistant R_g = resistance of galvanometer R_v = resistance of voltmeter V_g = voltage across galvanometer V_i = initial range of voltage V_f = final range of voltage

54	To increase the range of an ammeter n times, the value of S to be connected parallel ammeter	$S = \frac{G}{n-1}$	
	To increase the range of voltmeter n times the value of R to be connected in series	$R = (n-1)\,G$	
55	Orbital magnetic moment of electron	$\mu_L = -\frac{e\,v\,R}{2}$	n=principal quantum number = 1,2,3…… h=planks constant e=charge of electron m = mass of electron
56	Bohr magnetron	When n = 1; $\mu_B = \frac{e\,h}{4\,\pi\,m}$ $\mu_B = 9.27 \times 10^{-24} Am^2$	
65	Gyromagnetic ratio of electron $\frac{\mu i}{I}$	$\frac{\mu_L}{L} = \frac{e}{2\ m} = 8.18 \times 10^{10}\ Ckg^{-1}$	e=charge of electron m=mass of electron

Multiple choice question

1. The magnetic field at the center O of the following current loop is



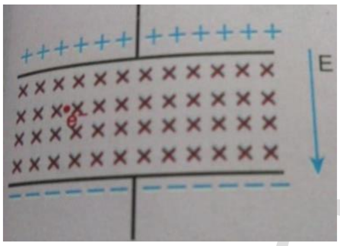
(a) $\frac{\mu_0 I}{4r}$ (b) $\frac{\mu_0 I}{4r}$ (c) $\frac{\mu_0 I}{2r}$ (d) $\frac{\mu_0 I}{2r}$

$B = \int dB = \int_0^{\pi r} \frac{\mu_0}{4\pi}\frac{Idl}{r^2} = \frac{\mu_0}{4\pi}\frac{I}{r^2}[l]_0^{\pi r}$

$B = \frac{\mu 0}{4\pi}\frac{I}{r^2} \times \pi r = \frac{\mu_0 I}{4r}$ *The direction of magnetic field B is perpendicular to plane of paper acting inward.*

[Ans : (a)]

2. An electron moves straight inside a charged parallel plate capacitor of uniform charge density σ .The time taken by the electron to cross the parallel plate capacitor when the plates of the capacitor are kept under constant magnetic build of induction $\vec{B}$ is



(a) $\varepsilon_0 \frac{\text{el B}}{\sigma}$ (b) $\varepsilon_0 \frac{\text{el B}}{\sigma \text{l}}$

(c) $\varepsilon_0 \frac{\text{l B}}{\sigma \text{l}}$ (d) $\varepsilon_0 \frac{\text{l B}}{\sigma}$

$$V = \frac{E}{B} \Rightarrow \frac{l}{t} = \frac{\sigma}{\varepsilon_0 B}\left[\therefore E = \frac{\sigma}{\varepsilon_0}\right]$$

$\therefore t = \frac{\varepsilon_0 lB}{\sigma}$ *[Ans : (d)]*

3. The force experienced by a particle having mass m and charge q accelerated through a potential difference V when it is kept under perpendicular magnetic field $\vec{B}$ is

(a) $\sqrt{\frac{2q^3BV}{m}}$ (b) $\sqrt{\frac{q^3B^2V}{2m}}$

(c) $\sqrt{\dfrac{2q_3B^2V}{m}}$ (d) $\sqrt{\dfrac{2q^3BV}{m^3}}$

$\frac{1}{2}mv^2 = qV \therefore v^2 = \frac{2qV}{m}$

$\therefore F = B.q.v = B.q.\sqrt{\frac{2qv}{m}} \quad \therefore v = \sqrt{\frac{2qV}{m}}$

$\therefore F = \sqrt{\frac{2q^3B^2v}{m}}$ *[Ans : (c)]*

4. A circular coil of radius 5 cm and 50 turns carries a current of 3 ampere. The magnetic dipole moment of the coil is

(a) 1.0 amp $-m^2$ (b) 1.2 amp $-m^2$

(c) 0.5 amp $-m^2$ (d) 0.8 amp $-m^2$

$M = N.i.A = N.i.\pi r^2 = 50\times3\times\pi\times(5\times10^{-2})^2$

$= 50\times3\times3.14\times25\times10^{-4}$

$= 11775\times10^{-4} = 1.17 \text{ or } 1.2\ Am^2$

[Ans : (b)]

5. A thin insulated wire forms a plane spiral of N = 100 tight turns carrying a current I = 8m A (milli ampere). The radial of inside and outside turns are a = 50 mm and b = 100mm respectively The magnetic induction at the center of the spiral is

(a) 5μT (b) 7μT

(c) 8μT (d) 10μT

$B = \frac{\mu_o IN}{2(b-a)} l_n \frac{b}{a}$

$= \dfrac{4\pi\times10^{-7}\times8\times10^{-3}\times10^2}{2(100-50)\times10^{-3}} l_n \dfrac{100\times10^{-3}}{50\times10^{-3}}$

$= \frac{4\pi\times10^{-7}\times10^2\times8}{2\times50} l_n 2 \quad = 4\times 3.14 \times 10^{-7} \times 2.303 \times \log_{10} 2$

$= 4 \times 3.14 \times 10^{-7} \times 8 \times 2.303 \times 0.3010$

$= B = 69.65 \times 10^{-7} \approx 7\mu T$

[Ans : (b)]

6. Three wires of equal lengths are bent in the farm of loops. One of the loop is circle, another is a semi – circle and the third one is a square. They are placed in a uniform magnetic field and same

electric current is passed through them which of the following loop configuration will experience greater torque?

(a) Circle (b) Semi – circle

(c) Square (d) all of them

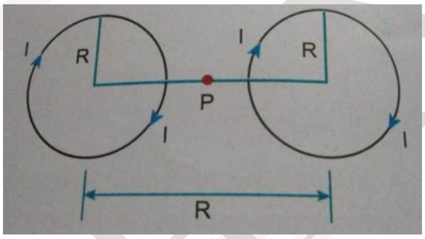
$\tau \,\alpha\, A$ *(Area)*

$A_{\text{Circle}} > A_{\text{Square}} > A_{\text{Semi Circle}}$ *(circumference same)*

$\tau_{\text{Circle}} > \tau_{\text{Square}} > \tau_{\text{Semi Circle}}$

[Ans : (a)]

7. Two identical coils, each with N turns and radius R are placed coaxially at a distance R as shown in the figure. If I is the current passing through the loops in the same direction, then the magnetic filed at a paint P which is at exactly at $\frac{R}{2}$ distance between two coils is



(a) $\frac{8N\mu_0 I}{R\sqrt{5}}$ (b) $\frac{8N\mu_2 I}{5^{\frac{3}{2}}R}$

(c) $\frac{8N\mu_0 I}{5R}$ (d) S $\frac{4N\mu_0 I}{\sqrt{5R}}$

$B_1 = \frac{n\mu_0 I R^2}{2(R^2+r^2)^{3/2}}$ Here $r = \frac{R}{2}$

$\therefore B_1 = \frac{n\mu_0 I R^2}{2\left(R^2+\frac{R^2}{4}\right)^{\frac{3}{2}}} = \frac{n\mu_0 I R^2}{2\left(\frac{5R^2}{4}\right)^{3/2}}$

$B_1 = \frac{n\mu_0 I R^2}{\frac{5^{3/2}}{4}R^3} = \frac{4n\mu_0 I}{5^{3/2}R} = B_2$

$B_T = B_1 + B_2 = \frac{8n\mu_0 I}{5^{3/2}R}$ *[Ans : (b)]*

8. A write of length l carries a current I along the Y direction and magnetic field is given by $\vec{B} = \frac{\beta}{\sqrt{3}}(\hat{\imath}+\hat{\jmath}+\hat{k})T$ The magnitude of Lorentz τ force acting on the wire is

(a) $\sqrt{\frac{2}{3}} I\, l\, \beta_0$ (b) $\sqrt{\frac{1}{\sqrt{3}}} \beta I l$ (c) $\sqrt{2}\ \beta I l$ (d) $\sqrt{\frac{1}{2}} \beta I l$

$$\vec{F} = \left(I\vec{l} \times \vec{B}\right)$$

$$\vec{F} = Il\hat{j} \times \frac{\beta}{\sqrt{3}}(\hat{\imath} + \hat{\jmath} + \hat{k})$$

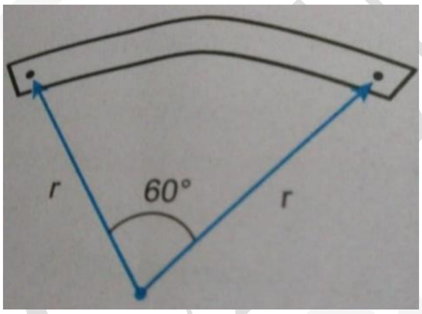
$$= \frac{Il\beta}{\sqrt{3}}[(\hat{\jmath} \times \hat{\imath}) + (\hat{\jmath} \times \hat{\jmath}) + (\hat{\jmath} \times \hat{k})]$$

$$= \frac{Il\beta}{\sqrt{3}}[-\hat{k} + 0 + \hat{\imath}]$$

$$= \frac{Il\beta}{\sqrt{3}}\sqrt{(1)^2 + (-1)^2}$$

$$= \frac{Il\beta}{\sqrt{3}} \times \sqrt{2} = \sqrt{\frac{2}{3}} I\, l\beta$$

9. A bar magnet of length l and magnetic moment M is bent in the form of an arc as shown in figure. The new magnetic dipole moment will be



(a) M (b) $\frac{3}{\pi}M$

(c) $\frac{2}{\pi}M$ (d) $\frac{1}{2}M$

for straight magnet

$M = q_m \times l$

New magnet $M' = q_m \times l'$

$l' = 2r Sin\, 30 = 2r \times \frac{1}{2} = r$

$\frac{\ell}{r} = \frac{\pi}{3} \therefore r = \frac{3\ell}{\pi}$

$M' = qm \times r = qm \times \frac{3\ell}{\pi} = \frac{3}{\pi}M$ ∴ [Ans : (b)]

10. A non – conducting charged ring of charge q, mass mand radius r is rotated with constant angular speed ω. Find the ratio of its magnetic moment with angular momentum is

(a) $\frac{q}{m}$ (b) $\frac{2q}{m}$

(c) $\frac{q}{2m}$ (d) $\frac{q}{4m}$

$$\mu_l = I.A = \frac{q}{T}.\pi r^2$$

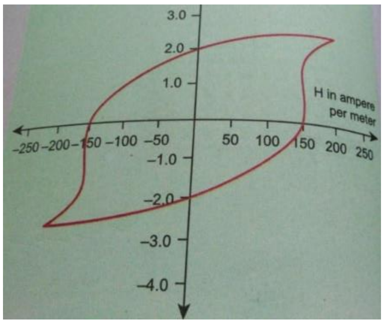
$$= \frac{q.\omega}{2\pi}\pi r^2$$

Angular momentum $I = mr^2\omega$

$$\frac{\mu_L}{L} = \frac{q.\omega.\pi r^2}{2\pi.mr^2\omega} = \frac{q}{2m}$$

$\therefore$ *[Ans : (c)]*

11. The BH curve for a ferromagnetic material is shown in the figure. The material is placed inside a long Solenoid which contains 1000 turns / cm. The current that should be passed in the Solenoid to demagnetize the ferromagnet completely is



(a) 1.00 mA (milli ampere) (b) 1.25 mA

(c) 1.50 mA (d) 1.75 mA

$H = nI$ $\therefore I = H/n$

$$I = \frac{150\times10^{-2}}{1000} = 1.5\times10^{-3}\,A$$ *[Ans = (c)]*

12. Two shunt bar magnets have magnetic moments 1.20 Am^2 and 1.00 Am^2 respectfully. They are kept on a horizontal table parallel to each other with their north poles painting towards the South. They have a common magnetic equator and are separated by a distance of 20.0 cm. The value of the result horizontal magnetic induction at the mid point O of the line joining their centers is (Horizontal) components of Earth's magnetic induction is 3.6 X 10-5 wb m^{-2})

(a) 3.60×10^{-5} Wbm^{-2} (b) 3.5×10^{-5} Wbm^{-2}

(c) 2.56×10^{-4} Wbm^{-2} (d) 2.2×10^{-4} Wbm^{-2}

Resultant Magnetic field

$$B = B_1 + B_2 + B_H$$

$$B = \frac{\mu_0}{4\pi}\frac{M_1}{r^3} + \frac{\mu_0}{4\pi}\frac{M_2}{r^3} + BH$$

$$= \frac{\mu_0}{4\pi r^3}(M_1 + M_2) + B_H$$

$$= \frac{10^{-7}}{(0.1)^3}[1.2+1] + 3.6\times10^{-5}$$

$$B = 2.2\times10^{-4} + 3.6\times10^{-5}$$

$$B = 2.56\times10^{-4}\text{T}$$ *[Ans : (C)]*

13. The vertical component of Earth's magnetic field at a palace is equal to the horizontal component what is the value of angle of dip at this place?

(a) 30° (b) 45°

(c) 60° (d) 90°

$$B_V = B_H \therefore \ tan\theta = \frac{B_r}{B_H} = 1$$

$$\therefore \theta = \tan^{-1} 1 = 45^\circ$$

14. A flat dielectric disc of radius R carries a excess charge on its surface. The surface charge density is σ. The disc rotates about an axis perpendicular to its plane passing through the center with angular velocity W. Find the magnitude of the torque on the disc if it is placed in a uniform magnetic field whose strength is which is directed perpendicular to the axis of rotation.

(a) $\frac{1}{4}\sigma\omega\pi BR$ (b) $\frac{1}{4}\sigma\omega\pi BR^2$

(c) $\frac{1}{4}\sigma\omega\pi BR^3$ (d) $\frac{1}{4}\sigma\omega\pi BR^4$

$$i = \frac{d_q}{t} = \frac{d_q}{2\pi} \times \omega \qquad \sigma = \frac{d_q}{2\pi r dr}$$

$$= \frac{2\pi\, r\, dr\, \sigma\, \omega}{2\pi} = \sigma\, \omega\, rdr$$

$$p_{m} = iA = \sigma\, \omega\, rdr \times \pi r^2 = \sigma\, \omega\pi\, r^3 dr$$

$$d\tau = p_m B \sin 90$$

$$= \sigma\, \omega\pi\, r^3 drB$$

$$\tau = \sigma\, \omega\pi\, B \int_0^r r^3\ dr$$

$=\frac{\sigma\omega\pi BR^4}{4}$

Ans (d)

15. A simple pendulum with charged bob is Oscillating with time period T and let θ be the angular displacement. If the uniform magnetic field is switched ON in a direction perpendicular to the plane of Oscillation then

(a) time period will decrease but θ will remain constant.

(b) time period remain constant but θ will decrease.

(c) both T and θ will remain the same.

(d) both T and θ will remain the same.

Ans: (c) both T and θ will remain the same.

Very short answers

1. What is meant by magnetic induction? P-137
2. Define magnetic flux. P-136
3. Define magnetic dipole moment. P - 132
4. State Coulomb's inverse law. P-139
5. What is magnetic susceptibility? P-151
6. State Biot-Savart's law. P-162
7. What is magnetic permeability? P-149
8. State Ampere's circuital law. P-169
9. Compare dia, para and ferro- magnetism. P-152
10. What is meant by hysteresis? P-156

Additional questions

1. In what way the behaviour of a diamagnetic material different from that of a paramagnetic, when kept in an external magnetic field?

When a paramagnetic material is placed in external magnetic field, there are feebly magnetised in the direction of the applied external magnetic field whereas in case of diamagnetic materials, these are feebly magnetised opposite in that of applied external magnetic field.

2. Relative permeability of a material = 0.5. identify the nature of the magnetic material and write its relation of magnetic susceptibility.

The nature of magnetic material is diamagnetic. The relation between relative permeability and magnetic susceptibility is

$$\mu_r = 1 + \chi_m$$

3. What is the angle of dip at a place where the horizontal and vertical components of the earth's magnetic field are equal?

$$I = \tan^{-1}\left(\frac{B_V}{B_H}\right) = \tan^{-1}(1) = 45°$$

4. A magnetic needle free to rotate in a vertical plane Orients itself vertically at a certain place on the earth. What are the values of (i)horizontal component of the earth's magnetic field and (ii) angle of dip at this place?

(i) The coil is free to move in vertical plane. It means that there is no component of the earth's magnetic field in horizontal direction, so the horizontal component of the earth's magnetic field is zero.

(ii) The angle of dip = 90°

5. The susceptibility of a magnetic material is - 4.2×10^{-6} name the type of magnetic material, it represents.

Negative susceptibility represents diamagnetic substance.

6. Write two characteristics of a material used for making permanent magnets?

Two characteristics of materials used for making permanent magnets are (a) high coercivity (b) high retentivity and high hysteresis loss.

7. Why is the core of an electromagnet made of ferro magnetic materials?

Core of electromagnet made of ferromagnetic material because of its (a) low coercivity (b) low hysteresis loss

8. State briefly and efficient way of making a permanent magnet.

Permanent magnet can be made by putting a steel rod inside the solenoid and a strong current is allowed to pass through the solenoid. The strong magnetic field inside the solenoid magnetise the rod.

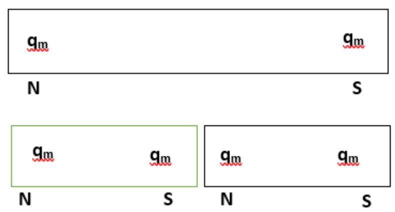
9. Out of the following, identify the materials which can be classified as (i) paramagnetic (ii) diamagnetic

(a) aluminium (b) Bismuth (c) copper (d) sodium

(i) paramagnetic substance: aluminium, sodium

(ii) diamagnetic substance: Bismuth, copper

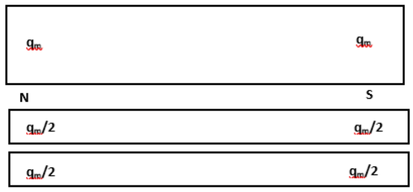
10. How does the (i) pole strength and(ii) magnetic moment of each part of a bar magnet change if it is cut into two equal pieces transverse to its length?



(1) Pole strength of each part remains same as that of the original magnet.

(ii) Magnetic moment of each part is half of that of the original magnet because length of each part is halved

11. How does the (i) pole strength and (ii) magnetic moment of each part of a bar magnet change if it is cut into two equal pieces along its length?



(1) Pole strength of each part becomes half of the original pole strength.

(ii) Magnetic moment of each part becomes half of the original magnetic moment.

12. What should be the orientation of a magnetic dipole in a uniform magnetic field so that its potential energy is maximum?

The potential energy of a magnetic dipole will be maximum when its dipole moment m is antiparallel to the magnetic field B'.

Umax = - mB cos 180° = + mB.

13. What do you mean by the statement that "susceptibility of iron is more than that of copper"?

Susceptibility of iron is more than copper. this indicates that iron can be magnetized more easily than copper.

14. Is earth's magnetic field inside an exports iron box place or more than that outside it?

Earth's magnetic field inside a closed iron box is less than that outside it.

15. What is the importance of magnetic permeability in magnetic recording?

High permeability of iron is useful in magnetic recording. The tape is provided with traces of iron. When it is in front of recording head, it develops magnetization in proportion to the strength of current fed to recording head.

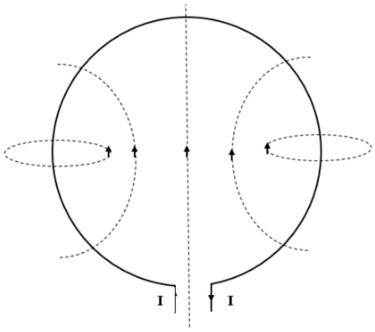
16. Why is the core of transformer made of material (e.g., iron) of high permeability?

High permeability of the core material makes the magnetic lines of force due to current in the coil mostly confined to the core. This prevents stray currents from being induced in conductors lying around. This minimises power loss and flux leakage. Efficiency of the transformer increases.

17. Two identical looking iron bars A and B are given, one of which is definitely known to be magnetized. (We do not know which one). How would one ascertain whether or not both or magnetized? If only one is magnetized, how does one assert time which one? (Use nothing else but the two boss A and B).

If on bringing different ends of two bars closer to one another, repulsions occur in any one situation, then both the iron rods are magnetized. If the force is always attractive, then one of them is magnetized. To check whether A or B is magnetized, place the bar B on a table. Hold the bar A in hand and lower its one end on the middle of bar B. If there is attraction, then bar A is magnetised otherwise the bar B is magnetized.

18. Draw the magnetic field lines due to a current carrying loop.



19. What is the force on a charge moving along the direction of the magnetic field?

Force on a charge moving along the direction of the magnetic field is zero.

F = by sin O° =0

20. An electron beam is moving vertically downwards. if it passes through a magnetic field which is directed from South to North in a horizontal plane, then in which direction the beam would be deflected?

Towards West

21. What will be the path of a charged particle moving perpendicular to the uniform magnetic field?

Circular path.

22. What will be the path of a charged particle moving perpendicular to the uniform magnetic field?

Circular path.

23. What will be the path of a charged particle moving along the direction of uniform magnetic field?

The charged particle will move along a straight-line path.

24. Under what condition does an electron moving through a magnetic field experiences maximum force?

The electron moving perpendicular to a magnetic field experiences a maximum force.

25. An electron and a proton moving with the same speed enter the same magnetic field region at right angles to the direction of the field. For which of the two particles will the radius of the circular path be smaller?

$$r = \frac{m\,v}{e\,B}$$

r proportional to m

As electron has smaller mass than proton, so it will circulate in a circular path of smaller radius.

26. A charged particle moving in a uniform magnetic field penetrates a layer of lead and thereby loses one half of its kinetic energy how does the radius of curvature of its path change?

$$r = \frac{m\,v}{q\,B} = \frac{m}{q\,B}\sqrt{\frac{2K}{m}} = \frac{\sqrt{2mK}}{qB}$$

$$r \;\; \alpha \; \sqrt{K}$$

If the kinetic energy is halved, radius of curvature is reduced to $\sqrt{K}$

27. An electron and a proton having equal moment, enter uniform magnetic field at right angles to the field lines. What will be the ratio of curvature of their trajectories?

$$r = \frac{m\,v}{e\,B}$$

r proportional to mv

$r_e : r_p = 1 : 1$

28. An alpha particle and a proton are moving in the plane of the paper in a region back there is a uniform magnetic field (B) directed normal to the plane of the paper. If two particles have equal linear momenta, what will be the ratio of the radii of their trajectories in the field?

$$r = \frac{m\,v}{q\,B} = \frac{p}{q\,B}$$

For same p and B

$$\frac{r_\alpha}{r_p} = \frac{q_p}{q_\alpha} = \frac{e}{2e} = \frac{1}{2}$$

29. How can it be shown that an electric current in a wire produces a magnetic field around it?

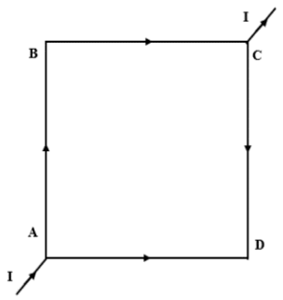
Bring a magnetic needle near the current carrying wire the magnetic field produced by the electric current will deflect the magnetic needle from equilibrium position in the north south direction.

30. How will the magnetic field intensity at the centre of a circular coil carrying current change, if the current through the coil is double and the radius of the coil of halved?

$$B = \frac{\mu_0\,N\,I}{2R}$$

$$B' = \frac{\mu_0\,N\,2I}{2\left(R/_2\right)} = 4B$$

31. Diagram shows a square loop made from here uniform wire. If a battery is connected between the points A and C, what will be the magnetic field at the centre of the square?



Consider I divide equally at A magnetic fields due to currents in the wire AD and BC will be equal and opposite also the fields due to current in the wire AB and BC will be equal and opposite. Hence the resultant field at the centre will be zero.

32. What happens to speed and kinetic energy of a charge placed in (i) electric field (ii) magnetic field.

(i) There is a change in speed and kinetic energy of a charge placed in an electric field.

(ii) There is a no change in speed and kinetic energy of a charge placed in a magnetic field.

33. An electron moving with the velocity of 10^7 m/s enters a uniform magnetic field of 1T, along a direction parallel to the field. What would be its trajectory in this field?

The electron will continue to follow its straight-line path because a parallel magnetic field does not exert any force on electron.

34. Which one of the following will experience maximum force when projected with the same velocity v perpendicular to the magnetic field (i) α particle (ii) β particle

F = by sin θ = by

For α particle; q = 2e; F_α = 2evB

For β particle; q = e; F_β = evB

$F_\alpha > F_\beta$

35. Which one of the following will describe the smallest circle when projected with the same velocity v perpendicular to the magnetic field (i) α particle (ii) β particle.

$$r = \frac{m\,v}{q\,B} \qquad r_\alpha = \frac{m_\alpha\,v}{q_\alpha\,B} \qquad r_\beta = \frac{m_\beta\,v}{q_\beta\,B} \qquad \frac{r_\alpha}{r_\beta} = \frac{m_\alpha}{q_\alpha}\frac{q_\beta}{m_\beta}$$

$$\frac{r_\alpha}{r_\beta} = \frac{4m_p}{2\,e}\frac{e}{m_e} \qquad \frac{r_\alpha}{r_\beta} = \frac{2\times 1836m_e}{e}\frac{e}{m_e} \qquad \frac{r_\alpha}{r_\beta} = \frac{3672}{1} \qquad r_\alpha > r_\beta$$

36. A beam of proton on passing through a region in space is deflected sideways. How would you be able to tell which of the two fields (electric or magnetic) has caused the deflection?

If the part of the proton beam is parabolic, the deflection is due to electric field. If the path is circular or helical, the deflection is due to magnetic field.

37. Stream of proton is moving parallel to a stream of electrons. Do that to stream tend to come closer or move apart?

The behaviour of the two streams depends on their speed.

If they move with less speed, they attract each other because the electrostatic force is greater than magnetic force. If they move with more speed, they repel each other because magnetic force is greater than electrical force.

38. An electron beam moving with uniform velocity is gradually diverging. As it is accelerated to a high velocity, it starts converging does it happened so?

For answer refer previous question

39. Why does a solenoid contract when a current is passed through it?

The current in the adjacent turns of the solenoid flows in the same direction. Show different patterns at right one another and the solenoid contracts.

40. What is permittivity?

Electric permittivity ε_0 is the physical quantity that determines the degree of interaction of electric field with the medium.

41. What is permeability?

Magnetic permeability μ_0 is the physical quantity that measure the ability of the substance to acquire magnetization in the magnetic field i.e. the degree of penetration of matter by B.

42. What is the relation between permittivity ε_0 and permeability μ_0

$$\varepsilon_0\mu_0 = 4\pi\varepsilon_0 \times \frac{\mu_0}{4\pi} \qquad \varepsilon_0\mu_0 = \frac{1}{9 \times 10^9} \times 1 \times 10^{-7}$$

$$\varepsilon_0\mu_0 = \frac{1}{(3 \times 10^8)^2} \qquad \varepsilon_0\mu_0 = \frac{1}{c^2} \qquad c = \frac{1}{\sqrt{\varepsilon_0\mu_0}}$$

43. An electron passes through the region of crossed electric and magnetic fields of intensity E and B respectively. For what value of electron speed will the beam remain and deflected?

v = (E/B)

44. What are the three quantities required to specify the magnetic field of earth on its surface? Or What are the elements of earth's magnetic field? P-130

45. Define declination at a place. P- 131

46. Define angle of dip are magnetic inclination at a place. P- 131

47. Diagrammatically represents uniform magnetic field and non-uniform magnetic field. P-138

48. State tangent law of magnetism. P-147

49. What are the precautions to be followed while using tangent galvanometer in experiment? P-147

50. Define magnetic field and give its SI unit. P-149

51. Define relative permeability. P-149

52. Define intensity of magnetisation. P-150

53. why are the diamagnetic substances repelled by magnets? P-152

54. State Curie's law of magnetism. Draw a graph between magnetic susceptibility and temperature. P-153, 154

55. How does Curie's law get modified for ferromagnetic substances? Or state Curie - Weiss law. P-155

56. How is the relative permeability of a material related to susceptibility? P-151

57. What are diamagnetic substances? Give two examples of diamagnetic substances. P-152

58. State Meissner effect. P-152

59. What are paramagnetic substances? Give two examples of paramagnetic substances. P-153

60. What is a ferromagnetic substance? Give two examples of ferromagnetic substances. P- 154

61. Define Curie temperature. P-155

62. Define the term remanence or retentivity of a ferromagnetic substance. P-157

63. Define the term coercivity. P-157

64. What does the area of hysteresis loop indicate? P-157

65. Define right hand thumb rule. P-161

66. Maxwell's right hand corkscrew rule. P-161

67. State and explain Biot savart law for magnetic field produced by a current element. P-162

68. What is Lorentz force? Write an expression for it. P- 175

69. Give the limitations of cyclotron. P-183

70. State Fleming's left-hand rule. P-184

Short answer questions

1. The horizontal component of earth's magnetic field at a place is B and the angle of dip is 60 °. what is the value of the vertical component of the earth's magnetic field at equator?

$$B_H = B_E \cos 60 = B$$

$$B_E \times \frac{1}{2} = B$$

$$B_E = 2B$$

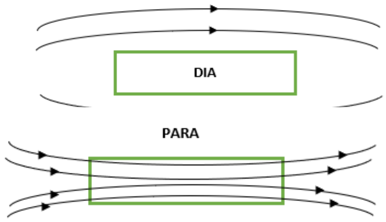
$$B_V = B_E \cos 60$$

$$B_V = 2\,B \times \frac{\sqrt{3}}{2}$$

$$B_V = \sqrt{3}\,B$$

2. Draw magnetic field lines when a (i) diamagnetic, (ii) para magnetic substance is placed in an external magnetic field. Which magnetic property distinguishes this behaviour of field lines due to the two substances?

(i) behaviour of magnetic lines when diamagnetic substance is placed in an external field



Behaviour of magnetic field lines when paramagnetic substance is placed in an external field

Magnetic susceptibility distinguishes the behaviour of the field lines due to diamagnetic and paramagnetic substance.

3. (i) how an electromagnet different from a permanent magnet? (ii) write two properties of a material which makes it suitable for making electromagnet.

An electromagnet consists of here four made of ferromagnetic material placed inside a solenoid. It behaves like a strong magnet when current flows through the solenoid and effectively loses its magnetism when the current is switched off. (i) your permanent magnet is also made up of ferromagnetic material but it retains its magnetism at room temperature for a long time after being magnetized one (ii) properties of material are as below: (a) high permeability (b) low retentivity (c) low coercivity.

4. A magnetic needle free to rotate in a vertical plane parallel to the magnetic meridian has its North tip down at 60 ° with the horizontal. The horizontal component of earth's magnetic field at the place is known to be 0.4 G. Determine the magnitude of the earth's magnetic field at the place.

$$B_H = B_E \cos I$$

$$B_E = \frac{B_H}{\cos I}$$

$$B_E = \frac{0.4}{\cos 60}$$

$$B_E = \frac{0.4}{1/2}$$

$$B_E = 0.8\,G$$

5. Distinguish between diamagnetic and ferromagnetic materials in terms of (a) susceptibility and (b) their behaviour in a non-uniform magnetic field.

(i) Susceptibility for diamagnetic material: it is independent of magnetic field and temperature (except for Bismuth at low temperature).

susceptibility for ferromagnetic material: the susceptibility of ferromagnetic materials decreases steadily with increase in temperature. Act curie temperature, the paramagnetic material become paramagnetic.

(ii) behaviour in non-uniform magnetic field: diamagnets are feebly repelled, where is ferro magnets are strongly attracted by non-uniform field, that is diamagnets move in the direction of decreasing field, where is ferromagnet feels force in the direction of increasing field intensity.

6. The horizontal component of earth's magnetic field at a place is $\sqrt{3}$ times its vertical component there. Find the value of the angle of dip at that place. What is the ratio of the horizontal component to the total magnetic field of the earth at that place?

$$Tan\ I = \frac{B_V}{B_H}$$

$$Tan\ I = \frac{B_V}{\sqrt{3}B_V}$$

$$Tan\ I = \frac{1}{\sqrt{3}}$$

$$I = \pi/6$$

$$B_H = B_E \cos I$$

$$\frac{B_H}{B_V} = \cos\frac{\pi}{6} = \frac{\sqrt{3}}{2}$$

7. A wheel with 8 metallic spokes each 50 cm long is rotated with a speed of 120 Revolution per minute in a plane normal to the horizontal component of earth's magnetic field. Bias magnetic field at the place is 0.4 G and the angle of dip is 60 °. Calculate the EMF induced between the axle and the rim of wheel. How will the value of EMF be affected, if the number of spokes were increased?

$$B_H = B_E \cos I$$

$$B_H = 0.4 \times \cos 60 = 0.4 \times \frac{1}{2} = 0.2\ G = 0.2 \times 10^{-4}\ T$$

$$\varepsilon = \frac{1}{2} B_H\, l^2\, \omega = \frac{1}{2} \times 0.2 \times 10^{-4} \times (0.5)^2 \times \frac{2 \times 3014 \times 120}{60} = 3.14 \times 10^{-5}\ V$$

The value of EMF induced is independent of the number of spokes, as the EMF across the spokes are in parallel. Show the EMF will be unaffected with the increase in spokes.

8. Write down the properties of bar magnet. P-134

9. Write down the properties of magnetic lines of force. P-136

10. Derive an expression for the potential energy of a bar magnet uniform magnetic field at angle theta with it. P-145

11. Draw a graph between magnetic moment and magnetising field for dia, para, and ferromagnetic substances. P- 156
12. Differentiate between soft and hard ferromagnetic materials. P-158
13. How will you select materials for making permanent magnets, electromagnets and cores of transformers? P-158
14. Give some points of similarities and difference between Biot savart law for the magnetic field and Coulomb's law for the electric static field. P-163
15. Show that a current carrying loop behaves as a magnetic dipole. Hence write an expression for its magnetic dipole moment. P- 167
16. Derive an expression for the magnetic dipole moment of an electron revolving around the nucleus. Define for magnetron and find its value. P- 168
17. Give a qualitative discussion of a magnetic field produced by a straight solenoid. P-170
18. State the factors on which the force acting on a charge moving in a magnetic field depends. Write the expression for this force. Define one tesla. P- 175
19. Define current sensitivity and voltage instability of a galvanometer. How can we increase the sensitivity of a galvanometer? P-192

Long answer questions

1. Discuss Earth's magnetic field in detail. P- 130
2. Deduce the relation for the magnetic induction at a point due to an infinitely long straight conductor carrying current. P-164
3. Obtain a relation for the magnetic induction at a point along the axis of a circular coil carrying current. P-166
4. Compute the torque experienced by a magnetic needle in a uniform magnetic field. P-143
5. Calculate the magnetic induction at a point on the axial line of a bar magnet. P-140
6. Obtain the magnetic induction at a point on the equatorial line of a bar magnet. P-141
7. Find the magnetic induction due to a long straight conductor using Ampere's circuital law. P-169
8. Discuss the working of cyclotron in detail. P-181
9. What is tangent law? Discuss in detail. P-146
10. Explain the principle and working of a moving coil galvanometer. P-190
11. Discuss the conversion of galvanometer into an ammeter and also a voltmeter. P-193,194
12. Calculate the magnetic field inside and outside of the long solenoid using Ampere's circuital law. P-171

Additional questions

1. Describe the principle, construction, theory and working of tangent galvanometer. P-146
2. Apply ampere circuital law to find the magnetic field both inside and outside of a toroidal solenoid. P-173
3. Discuss the motion of a charged particle in a uniform magnetic field with initial velocity perpendicular to the magnetic field. P-177
4. Derive an expression for the force experienced by a current carrying conductor placed in a magnetic field. P-183
5. Derive an expression for the force per unit length between two infinitely long straight parallel current carrying wires. Hence define one ampere. P-185
6. Derive an expression for the torque acting on a current carrying loop suspended in a uniform magnetic field. P-187

Numerical Problems

1. A bar magnet having a magnetic moment $\vec{M}$ is cut into four pieces i.e, first cut in two pieces along the axis of the magnet and each piece is further cut into two pieces. Compute the magnetic moment of each piece.

Answer : $\vec{M}_{new} = \frac{1}{4}\vec{M}$

Solution :

If cut along the axis of magnet of length '*l*' into 4 pieces ,

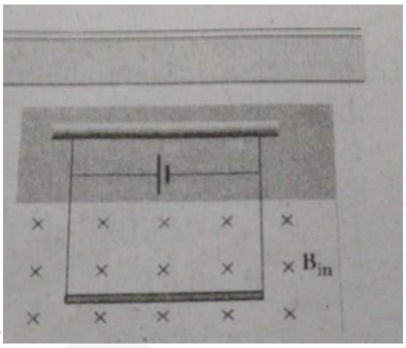
New pole strength $M' = \frac{m}{4}$

New length $1' = 1$

Magnetic moment, $M' = \frac{m}{4} \times 1$

2. A conductor of linear mass density 0.2 g m^{-1} suspended by two flexible wire as shown in figure. Suppose the tension in the supporting wires is zero when it is kept inside the magnetic field of 1 T whose direction is into the page. Compute the current inside the page. Compute the current inside the current and also the direction for the current.

Assume g =10ms^{-2}

+ 

Solution :

To have zero tension in the wires, the magnetic force per unit length must be upwards and equal to the weight per unit length.

$$\therefore \left|\frac{F_m}{L}\right| = BI = \frac{mg}{L}$$

$$I = \frac{\left(\frac{m}{L}\right)g}{B}$$

$$\frac{m}{L} = 0.2gm^{-1}$$

$$= 0.2x10^{-3}kgm^{-1}$$

$$B = IT, g = 10ms^{-2}$$

$$\therefore I = \frac{0.2x10^{-3}x10}{1}$$

$$= 2x10^{-3}A$$

$$I = 2mA$$

3. A circular coil with cross –sectional area 0.1 cm^2 is kept in a uniform magnetic field of strength 0.2 T. If the current passing in the coil is 3A and plane of the loop is perpendicular to the direction of magnetic field. Calculate

a) total torque on the coil

b) total force on the coil

c) average force on each electron in the coil due to the magnetic field of the free electron density for the material of the wire is 10^{28} m^{-3}.

Answer : (a) zero b) zero c) 0.6 × 10^{-23}N

Solution :

N =1

A = 0.1 × 10^{-4}m2

B = 0.2T

I=3A

$\theta = 0°$ [Plane is perpendicular to the field]

$n = 10^{28}\ m^{-3}$

a) Torque, τ $= NIB\ A \sin\theta$

$= 1 \times 3 \times 0.2 \times 0.1 \times 10^{-4} \times \sin 0°$

Torque = 0

b) Total force on a current loop is always zero in a magnetic field.

c) for free electron, drift velocity,

$vd = q(\vec{v} x \vec{B})$

$= qv_d B \sin 90^o$

$F = BqV_d$

$$V_d = \frac{I}{nqA}$$

$$F = Bq.\frac{I}{nqA}$$

$$= \frac{BI}{nA}$$

$$= \frac{0.2x3}{10^{28} x 0.1x10^{-4}}$$

$$= \frac{0.6}{0.1} x10^{28} x10^{4}$$

$$= 6x10^{-24}$$

Average Force, $F = 0.6 \times 10^{-23}$ N

4. A bar magnet is placed in a uniform magnetic field whose strength is 0.8 T. Suppose the bar magnet orient an angle 30° with the external field experience a torque of 0.2 Nm. Calculate:

i) the magnetic moment of the magnet

ii) the work done by an applied force in moving it from most stable configuration to the most unstable configuration and also compute the work done by the applied magnetic field in this case.

Answer : i) 0.5 A m^2 ii) W=0.8 J and $W_{mag} = -0.8$ J

Solution :

ii) $W = U_f - U_i$

$U_f = \mu_B \cos 180^o$

$U_i = -\mu B \cos 0^o$

$\therefore W = -\mu_B \cos 180^o - (-\mu_B \cos 0^o)$

$= \mu_B + \mu_B$

$W = 2\mu_B; W = 2\rho_m B$

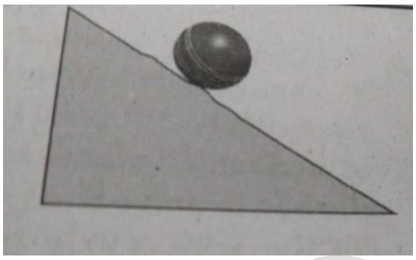
$\therefore W = 2x0.5x0.8$

$W = 0.85 J and$

$W_{mag} = -0.85 J$

5 . A non – conducting sphere has mass of 100g and radius 20cm. A flat compact coil of wire turns 5 is wrapped tightly around it with each turns concentric with the sphere. This sphere is placed on an inclined plane such that plane of coil is parallel to the inclined plane. A uniform magnetic field of 0.5 T exists in the region in vertically upward direction. Compute the current I required to rest the sphere in equilibrium.

***Answer* :** $\frac{2}{\pi} A$



Solution :

The sphere is in translational equilibrium,

$f_s - Mg \sin\theta = 0$.............(1)

The sphere is in rotational equilibrium. torque = p_m B sin θ (Produces by magnetic field clockwise)

Frictional force (anticlockwise torque) = $f_s R$

R – radius of the sphere

$f_s R - p_m B \sin\theta = 0$…………(2)

Substitute (1) in (2)

$f_s = mg \sin\theta$

$\therefore mg \sin\theta R - p_m B \sin\theta = 0$

$mg \cancel{\sin}\, \theta R - p_m B \cancel{\sin}\, \theta$

p_m B = mg R…………………..(3)

p_m = NIA

p_m = $NI\pi R^2$ …………………..(4)

$NI\pi R^2 B = mg\, R$

$$I = \frac{mgR}{BN\pi R^2}$$

$$I = \frac{mg}{BN\pi R}$$

$m = 100g = 100x10^{-3} kg = 0.1kg$

$R = 20cm = 0.2m$

$B = 0.5T$

$N = 5turns$

$g = 10m/s^2$

$$I = \frac{0.1x10}{0.5x5x\pi x0.2}$$

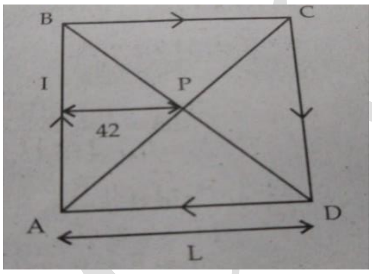
$$= \frac{1}{0.5\pi}$$

$$I = \frac{2}{\pi} A$$

6. Calculate the magnetic field at the center of a square loop which carries a current of 1.5A, length of each loop is 50cm.

Answer : 3.4×10^{-6}T

Solution :



$$BAB = \frac{\mu_o I}{4\pi a}[\sin\theta_1 + \sin\theta_2]$$

$$= \frac{\mu oI}{4\pi\left(\frac{L}{2}\right)}[\sin 45^o + \sin 45^o]$$

$$= \frac{\mu_o I}{2\pi x L}\left[\frac{1}{\sqrt{2}} + \frac{1}{\sqrt{2}}\right]$$

$$\frac{\mu_o I}{2\pi x L}\,\frac{1}{\sqrt{2}}$$

$$B_{AB} = \frac{\mu_o I}{2\pi x L}$$

III^{ly} for your sides BC, CD, DA

$$B = \frac{4\mu_o I}{\sqrt{2}\pi L}$$

Hence, $I = 1.5A$

$L = 50cm$

$L = 0.5m$

$$B = \frac{4\mu_o I}{\sqrt{2}\pi L}$$

$$B = \frac{4x4\pi x10^{-7}x1.5}{\sqrt{2}\pi x0.5}$$

$$= \frac{24x10^{-7}}{70.7x10^{-2}}$$

$$= 0.3394x10^{-7}x10^{2}$$

$$B = 3.39x10^{-6}T$$

$$B = 3.4x10^{-6}T$$

7. Show that the magnetic field at any point on the axis of the solenoid having turns per unit length is

$$B = \frac{1}{2}\mu_o nI(\cos\theta_1 - \cos\theta_2)$$

$$dB = \frac{\mu_o IR^2}{2r^3} xN$$

$$N = ndx$$

$$dB = \frac{\mu_o}{2}\frac{nIR^2}{r^3}dx$$

$$\sin\theta = \frac{R}{r}$$

$$r = R\operatorname{cosec}\theta$$

$$\tan\theta = \frac{R}{x_o - x}$$

$$x_o - x = R\cot\theta$$

$$\frac{dx}{d\theta} = R\operatorname{Cosec}^2\theta$$

$$dx = R\operatorname{cosec}^2\theta\, d\theta$$

$$dB = \frac{\mu_o nIR^2}{2R^3}\frac{\operatorname{cosec}^2\theta\, d\theta}{\operatorname{cosec}^3\theta}$$

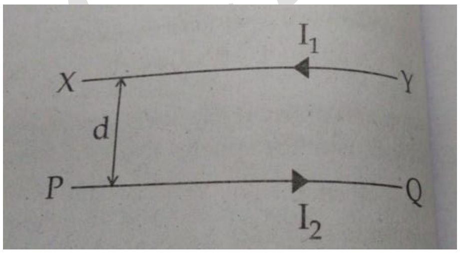
$$dB = \frac{\mu_o}{2} nI\sin\theta\; d\theta$$

$$dB = \frac{\mu_o nI}{2}\int_{\theta_1}^{\theta_2}\sin\theta\; d\theta$$

$$B = \frac{\mu_o nI}{2}[-\cos\theta]_{\theta_1}^{\theta_2}$$

$$B = \frac{\mu_o nI}{2}[\cos\theta_1 - \cos\theta_2]$$

8. Let I_1 and I_2 be the steady current passing through a long horizontal wire XY and PQ respectively. Suppose the wire PQ is fixed in horizontal plane and the wire XY is allowed to move freely in a vertical plane. Let the wire XY is in equilibrium at a height d over the parallel wire PQ as shown in figure.



Show that if the wire XY is slightly displaced and released, it executes Simple Harmonic Motion (SHM). Also, compute the time period of oscillations.

Answer: $a_y = -\omega^2 y$ (SHM) and time period

$$T = 2\pi\sqrt{\frac{d}{g}} \text{ in sec}$$

Solution

If ×y is allowed to move freely in a vertical plane

∴ Vertical oscillation of the wire ×y experience a force F = -ky

Applying Newton's second law

$$m\frac{d^2y}{dt^2} = -ky$$

$$\frac{d^2y}{dt^2} = -\frac{k}{m}y \text{..........(1)}$$

$$\text{We know that } \frac{m}{k} = \frac{l}{g}$$

$$\text{Here } l = d$$

$$\therefore \frac{m}{k} = \frac{d}{g} \text{.........(2)}$$

Sub (2) in (1)

$$\frac{d^2y}{dt^2} = \frac{-g}{d}y$$

$$ay = \frac{-g}{d}y$$

$$\therefore ay = -\omega^2 y$$

$$T = \frac{2\pi}{\omega}$$

$$\omega^2 = \frac{g}{d}$$

$$\omega = \sqrt{\frac{g}{d}}$$

$$\therefore T = \frac{2\pi}{\sqrt{\frac{g}{d}}}$$

$$T = 2\pi\sqrt{\frac{d}{g}}$$

LESSON 4

ELECTROMAGNETIC INDUCTION & ALTERNATING CURRENT

Points to ponder:

✓ Electric field produced by stationary charges is conservative

i.e $\oint \vec{E}.\vec{dl} = 0$

In E.M.I, induced electric field is non conservative

Magnetic flux density B = $\frac{d\emptyset}{dA}$

✓ Conductor is placed in varying magnetic field, an emf is induced.

✓ Induced emf is rate of change of magnetic flux.

✓ Induced emf in Faraday's Law is created from a motional emf

✓ that opposes the change in flux.

$F_E = F_B$, qE= qvB, E=vB, $\frac{\xi}{l}$ = Bv, induced emf ξ=Blv

✓ Magnetic field rotates inside a coil in a commercial generator

inducing emf ξ = N B A ω sinω t

✓ Peak emf in a generator is ξ_m = NBAω

✓ Induced current should be marked in such a way to oppose the increase or decrease of flux.

✓ If in a solenoid, coil is stretched, air gaps are created between elements of coil, magnetic flux will leak, consequently magnetic flux decreases, current increases.

✓ Current loops in moving conductor are called eddy currents. They create drag called magnetic damping.

✓ When a bar magnet is dropped into a coil, the electro magnetic induction in the coil opposes its motion, so that the magnet falls with acceleration less than that due to gravity.

✓ Inductance in the electrical circuit is equivalent to the inertia (Mass) in mechanics.

✓ Rod of length l moves perpendicular to the magnetic field B with a velocity v, then induced emf produced across it is given by –

$$\xi = \vec{B}.(\vec{v} \times \vec{l}) = vBl$$

✓ A graph between magnetic flux and current is a straight line with positive slope.

✓ A graph between induced emf and rate of change of current is a straight line inclined to X – axis.

✓ In this, if rate of change of current is constant then it is straight line parallel to X-axis.

- ✓ A loop entering a magnetic field perpendicular to it.

  Before it enters, emf is zero.

  While entering B, emf is induced.

  When the loop is completely inside B, again there is no emf.

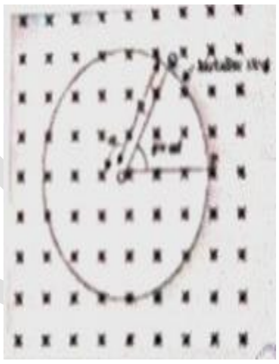
  While it is leaving, emf is induced.

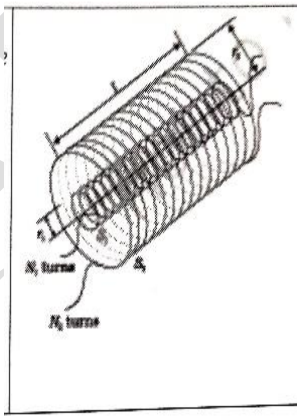
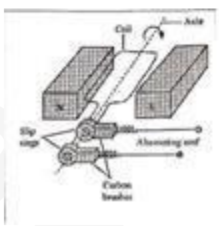
  After coming out, emf is zero.
- ✓ Behaviour of Ohmic resistance R in AC circuit is the same as in dc circuit.
- ✓ For pure inductive circuits in A.C. current lags the Voltage by $\frac{\pi}{2}$
- ✓ Average power supplied to an inductor over one complete cycle is zero.
- ✓ For pure capacitive circuit in A.C. current leads the Voltage by $\frac{\pi}{2}$
- ✓ Average power supplied to a capacitor over one complete cycle is zero.
- ✓ Inductive reactance is linked with varying magnetic field in a coil carrying current.
- ✓ Capacitive reactance is linked with varying electric field in it.
- ✓ Choke coil reduces the voltage across the fluorescent tube without wastage of power.
- ✓ In impedance triangle, base is Ohmic resistance, perpendicular is reactance, hypotenuse is impedance.
- ✓ For LCR circuit, Ø is the phase difference between current and voltage.

  Ø is positive $X_L > X_C$ Ø is negative $X_L < X_C$ Ø is zero $X_L = X_C$
- ✓ In series LCR resonance or acceptor circuit, current is maximum, impedance is minimum.
- ✓ If current is out of phase with Voltage, then power is known as apparent power.
- ✓ Power factor Cos Ø is ratio of effective power to apparent power, where Øis the phase difference between Voltage & Current.
- ✓ Quality factor Q is a dimensionless quantity that shows sharpness of the peak of Resonance circuit.
- ✓ For Q to be high, R should be low, L should be high and C should be low.
- ✓ Current flowing in a circuit without any net dissipation of power is called Wattless Current.
- ✓ Induced current $i = \frac{e}{R} = \frac{N d\emptyset / dt}{R}$

  $Idt = \frac{N d\emptyset}{R}$ (or) $q = \frac{N\emptyset}{R}$

1	Magnetic flux $\emptyset_B$	$\emptyset_B = BACos\theta = \vec{B}.\vec{A}$	$\emptyset_B$ = magnetic flux, CGS unit of magnetic flux is **maxwell** B=magnetic field; sl unit is magnetic field is **Tesla (T)** A=area CGS unit is **Gauss(G)** **1Wb = 10 maxwell** Sl unit of magnetic flux is **Weber (wb)**	
2	Magnetic flux $\emptyset_B$	$\emptyset_B = \int \vec{B}.\vec{A}$		
3	Faraday's law and lenz's law	$\xi = -N\frac{d\emptyset_B}{dt}$	$\emptyset_B$ = magnetic flux N = total number of turns ε = induced emf	
4		$\mathcal{E} = -N\frac{\Delta\emptyset B}{\Delta t}$		
5	Induced current	$i = \frac{\xi}{R}$	ε = induced emf; unit is Volt(v) i=induced current; Unit is Ampere(A) R=Resistance; Unit is Ohm(Q)	
6	Induced charge	$Q = \frac{\Delta\emptyset B}{R}$		
7	Motional emf	$\xi = Bl\,v$	ε = induced emf due to motion of a conducting rod perpendicular to magnetic field.	
8	Induced current	$i = \frac{Bl\,v}{R}$		
9	Force on conductor moving in magnetic field	$F = B^2 l^2 v / R$		
10	Electric power due to motion of conductor in magnetic field	$P = B^2 l^2 v^2 / R$	B=magnetic field; Unit tesla(I) L=length of conductor V=velocity of conductor R=resistance of conductor	
11	Heat dissipated	$H = B^2 l^2 v^2 t / R$		

			P=power H=heat energy	
12	Induced emf between ends of rods rotating perpendicular to magnetic field	$\xi = B l^2 \omega / 2 = B \pi l^2 f$	w=angular velocity of rotating conducting rod f=frequency of rotation of rod l=length of rotating rod R=resistance of rod T=time	
13	Induced current due to rotation of conductor in magnetic field	$i = B l^2 \omega / 2R$		
14	Heat dissipated	$H = B^2 l^4 \omega^2 t / 4R$		
15	Self-inductance(L)	$L = \frac{\phi_B}{I}$	L=self-inductance; Sl unit is Hendry (H) l=current e=induced emf due to self-inductance	
16	Induced emf due to self- inductance	$\xi = -L \frac{di}{dt}$		
17. ----- 18 ----- 19	Self-inductance due to a rate of change of current in a solenoid	$L = \mu_0 n^2 l A$ __________ $L = \mu_0 N^2 A / l$ __________ $L = \mu_0 \mu_r n^2 l A$ $= N^2 \times \frac{\mu_0 \mu_r A}{l}$	μ_0 = permeability of free space n=number of turns per unit length N=nl=total number of turns l=length of solenoid A=area of cross section of solenoid μ_r = relative permeability	
20	Mutual inductance (M)	$M = \frac{\phi_B}{I} = \frac{N\phi_B}{I}$	M=mutual inductance; Unit is Hendry (H) l=electric current	

21	Induced emf dur to mutual induction	$\xi = -M \frac{dI}{dt}$	$\emptyset_B$ = magnetic flux N=total number of turns
22 ____ 23	Mutual induction due to two Air core Coaxial solenoid	M= $\mu_0 n_0 n_i A l$ ________________ ____ M = $\mu_r\mu_0 n_0 n_i A l$	M=mutual inductance unit is Hendry(H) A=area of cross section l=length n_0 =number of turns per unit length of outer solenoid n=number of turns per unit length of inner solenoid 
24	Induced emf due to two current carrying coils	$\xi = -L_1 \frac{dI_1}{dt} - M_{12} \frac{dI_2}{dt}$ L1= self inductance M_{12} = mutual inductance	
25	AC generator	$\xi = \xi_m \sin \omega t$ OR $\xi = \xi_m \sin 2\pi f t$ Where $\xi_m = BAN\omega$ = ac voltage amplitude or peak voltage	ξ_m =ac voltage amplitude ξ=instantaneous induced emf w=angular frequency of ac generator B=magnetic field A=area of coil or armature N=total number of turns t=time 

ALTERNATING CURRENT

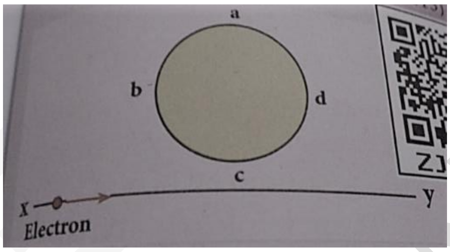
S.No.	Application	Formula	Terms	Unit	Figure
.	Instantaneous AC voltage	$\varepsilon = \varepsilon_m \sin \omega t$	ε_m= voltage amplitude		
.	Instantaneous current	$i = i_m \sin \omega t$	i_m=current amplitude		
.	Rms A.C voltage (ε_r)	$\varepsilon_r = \frac{\varepsilon_m}{\sqrt{2}}$ $= 0.707\varepsilon_m$			
.	Rms a.c current (i_r)	$i_{Tm} = \frac{i_m}{\sqrt{2}}$ $= 0.707 i_m$			
	characteristics	**Pure resistor ac circuit**	**Pure inductor** ac circuit	**Pure capacitor ac circuit**	**Series LCR ac circuit**
.	Instantaneous ac voltage (ε)	$\varepsilon = \varepsilon_m \sin \omega t$	$\varepsilon = \varepsilon_m \sin \omega t$	$\varepsilon = \varepsilon_m \sin \omega t$	$\varepsilon = \varepsilon_m \sin \omega t$
.	Instantaneous current (i)	$i = i_m \sin \omega t$	$i = i_m \sin(\omega t - \frac{\pi}{2})$	$i = i_m \sin(\omega + \frac{\pi}{2})$	$i = i_m \sin(\omega t - \phi)$
.	Phase difference between current and voltage (ϕ)	$\phi = 0$	$\phi = \frac{\pi}{2}$ current lags behind voltage by a phase angle of $\frac{\pi}{2}$	$\phi = \frac{\pi}{2}$ current leads voltage by a phase angle of $\frac{\pi}{2}$	$\tan \phi = \frac{X_L - X_C}{R}$ $Cos\, \phi \frac{R}{Z}$
.	Resistance	$R = \frac{\varepsilon_m}{i_m}$	$X_L = L\omega = 2\pi f L$ $= \frac{\varepsilon_m}{i_m}$ X_L is called inductive reactance SI unit of X_L is ohm	$X_c = \frac{1}{C\omega}$ $X_c = \frac{1}{2\pi f C} = \frac{\varepsilon_m}{i_m}$ X_c is called inductive capacitance SI unit of X_c is ohm	Z $=\sqrt{R^2 + (X_L - X_C)^2}$ Z is called Impedance SI unit of Z is ohm
.	Average Power	$< P > = \frac{i_m^2 R}{2}$			$< P > = \varepsilon_r i_r, Cos\, \phi$ $Where, Cos\, \phi = \frac{R}{Z}$ $= Powerfactor$

.	Power factor	$< P >= \varepsilon_{rms} i_{rms} \, Cos \, \phi$ $Where, Cos \, \phi = \frac{R}{Z} = Powerfactor$		
.	Resonance condition for series LCR circuit	$X_L = X_C$ $\omega_r L = \frac{1}{\omega_r C}$	X_L = inductive reactance ; unit Ω X_c = capacitive reactance ; unit Ω C = Capacitance ; Unit Farad (F) L = inductance ; unit is Henry (H) ω_t = resonance frequency	
.	Resonance frequency	$\omega_r = 2\pi f_r$ $= \frac{1}{\sqrt{LC}}$		
.	Quality factor or Q – factor Conservation of energy in LC circuit	$\frac{\omega_r}{2\Delta\omega} = \frac{\omega_r L}{R}$ $= \frac{1}{\omega_r CR}$ $= \frac{1}{R}\sqrt{\frac{L}{C}}$		
.	Total energy stored in series LC circuit	$U = UE + UB$ $U = \frac{q_m^2}{2C} = \frac{Li_m^2}{2}$	U_E= electrical energy U_S= magnetic energy L = Inductance (unit : Henry) q_m = change amplitude i_m=current amplitude	
.	Transformer equation	$\frac{N_s}{N_p} = \frac{V_s}{V_p} = \frac{l_p}{l_s}$	N_s= number of secondary coil N_p = number of turns of primary coil V_s=output voltage V_p=input voltage l_s=output current l_p=input current P_o=output power P_i=input power	

.	Equation of ideal transformer	$V_s I_s = V_p I_p$		
.	Efficiency of transformer	$\eta = \frac{P_o}{P_i} = \frac{V_s I_s}{V_p I_p}$		

Multiple choice questions

1 An electron moves on a straight line path XYas shown in the figure.The coil abcd is adjacent to the path of the electron. What will be the direction of the current if any induced in the coil ?



a) The current reverse its direction as the electron goes past the coil

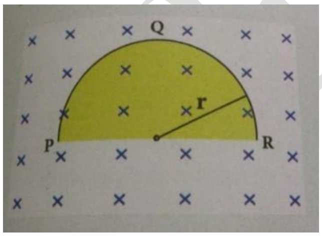
b) No current will be induced

c) abcd

d) adcb

Ans: When electron moves towards the loop flux increases ,induced current is anti clock wise (abcd)Away from the loop flux decreases induced current clockwise (adcb]Ans(a)

2. A thin semi -circular conducting ring (PQR) of radius r is falling with its plane vertical in a horizontal magnetic field B as show in the figure.



The potential difference developed across the ring when its speed v is

a) Zero

b) $\frac{Bv\pi r^2}{2}$

c) πrBv and R is at a higher potential.

d) 2rBv and R is at a higher potential.

Ans: $\xi = B.l_{eff}.v = B.2r.v$

$= 2rBv$ *and R is higher potential [ans:- d]*

3. The flux linked with a coil at instant t is given by $\phi_B = 10\,t^2 - 50t + 250$. The induced emf at t = 3s is

a) $-190\,V$ b) $-10V$ C) $10\,V$ d) $190\,V$

$\xi = -\frac{d\O}{dt} = -\frac{d}{dt}((10t^2 - 50t + 250)$

$\xi = -[20t - 50]$ $\quad t = 3s$

$\xi = -[(20.3) - 50] = -60 + 50$

$\xi = -10V$ $\quad$ *[ans:-B]*

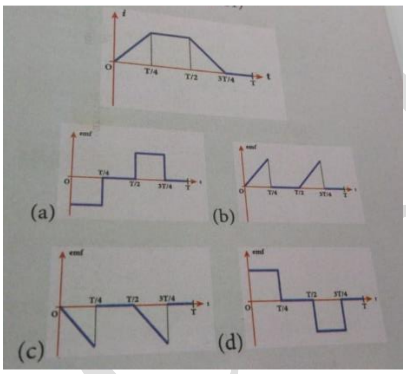
4. When the current changes from +2A to $-$ 2A in .05secs,an emf of 8V is induced in a coil , the coefficient of self -induction of the coil is.

a) 0.2H b)0.4H c) 0.8H d) 0.1H

$L = \xi/({}^{dI}/_{dt}) = \frac{8}{{}^{4}/_{0.05}} = \frac{0.4}{4}$

$L = 0.1\ H$ $\quad$ *[ans:- d]*

5. The current *i* flowing in a coil varies with time as shown in the figure . The variation of induced emf with tie would be



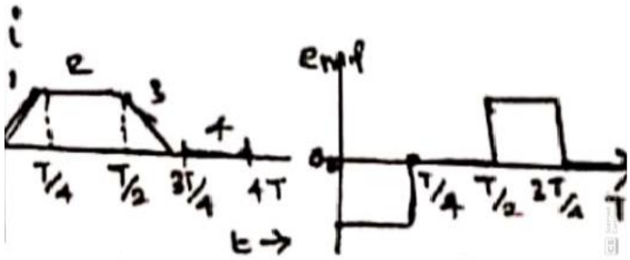
$\xi = -{}^{di}/_{dt}$ $\quad$ *[ans:a]*

i) 0 to ${}^{t}/_{4}$; $\frac{di}{dt} = +ive$; $\xi = -ive$

ii) ${}^{t}/_{4}$ to ${}^{t}/_{2}$; $\frac{di}{dt} = 0$; $\xi = 0$

iii) ${}^{t}/_{2}$ to ${}^{3t}/_{4}$; ${}^{di}/_{dt} = -\,ive$; $\xi = +ive$

$iv)\ {}^{3t}/_{4}$ *to T ;* ${}^{di}/_{dt}$=0 ξ=0



6. A circular coil with a cross sectional area 4cm^2 has 10 turns . It is placed at the centre of a long solenoid that has 15turns /cmand a cross sectional area of 10cm^2 .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 μHd) 10.54 μH

$M=\frac{\mu 0\ N1\ N2\ A2}{l1}$ $=\mu_0\ n_1 N_2\ A_2$ *(Here n_1- number of turns/Unit length)*

$\mu_0=4\pi\ X10^{-7}\times\frac{15}{10^{-2}}\times 10\times 4\times 10^{-4}$

$=7.54\times 10^{-6}\ H=7.54\mu H$ *[ans :- a]*

7. In a transformer , the number of turns in the primary and secondary are 410 and1320 respectively.If the current in primary 6A, then that in secondary coil is

a)2A b)18A c)12A d) 1A

$\frac{Is}{Ip}=\frac{Np}{Ns}$ $\therefore Is=\frac{Np}{Ns}\times Ip$

$Is=\frac{410}{1230}\times 6=2A$ *[Ans: a]*

7. A step-down transformer reduces the supply voltage from 220V to 11V and increase the current from 6A to 100 A then its efficiency is

a) 1.2 b)0 .83 c) 0.12 d) 0.9

$H=\frac{Es\times Is}{Ep\times Ip}=\frac{11\times 100}{220\times 6}=0.83$ *[Ans: b]*

8. In an electrical circuit R,L,C and AC voltage source are all connected series. When L is removed from the circuit, the phase difference between the voltage and curret in the circuit is $\frac{\pi}{3}$. Instead if C is removed from the circuit, the phase difference is again $\frac{\pi}{3}$.

The power factor of the circuit is

a) $\frac{1}{2}$ b)$\frac{1}{\sqrt{2}}$ c)1 d) $\frac{\sqrt{3}}{2}$

Ans :The phase lead by removing the inductor = the phase lag by removing the capacitor

$X_L = Xc$, $Z=R$; *power factor* $Cos\emptyset=\frac{R}{Z}$ *[Ans :c]*

9. In a series RL circuit, the resistance and the inductive reactance are the same .Then, the phase difference between the voltage and the current in the circuit is

a) $\frac{\pi}{4}$ b) $\frac{\pi}{2}$ c) $\frac{\pi}{6}$ d) zero

$R=X_L \quad tan\emptyset=\frac{XL}{R}=1$

$\emptyset=tan^{-1}1 = 45^o = \frac{\pi}{4}$

[Ans:a]

10. In a series resonant RLC circuit , the voltage across 100 Ω resistor is 40V . The resonant frequency ω is 250radian per second.If the value of C is 4 μF then the voltage across L is

a) 600V b) 4000V c)400V d)1 V

$X_L = X_c \qquad L\omega_r = \frac{1}{c\omega_r} = \frac{1}{4\times10^{-6}\times250}$

$X_L = 10^3\Omega \;;\; I = V/_R = \frac{40}{100} = 0.4A$

The voltage across $L = I\,X_L = 0.4\times10^3$ $V_L = 400V$ [Ans:c]

11. An inductor 20mH, a capacitor 50 μF and a resistor 40 Ω are connected in series across a source of emf v= 10sin340t.The power loss in AC circuit is

a) 0.76W b)0.89W c)0.46W d) 0.67W

$L = 20\times10^{-3}\times340 = 6.8\ \Omega$

$x_c = \frac{1}{c\varpi} = \frac{1}{50\times340\times10^{-6}}$

$x_L - x_c = 52\ \Omega \quad ; \quad Z = \sqrt{R^2 + (X_L - X_c)^2}$

$= \sqrt{40^2 + 52^2} = \sqrt{1600 + 2704}$

$Z = 65.6\ \Omega$

$p_{av} = Irms^2 R = (\frac{Erms^2}{Z^2}).R = \left|\frac{7.07^2}{65.6^2}\right| \times 40$

$p_{av} = 0.46W$ [Ans : c]

12. The instantaneous values of alternating current and voltage in a circuit are

$i = \frac{1}{\sqrt{2}}\sin(100\pi t)$ A and

$V = \frac{1}{\sqrt{2}}\sin(100\pi t + \frac{\pi}{3})$

The average power in watts consumed in the circuit is a) $\frac{1}{4}$ b) $\frac{\sqrt{3}}{4}$ c) $\frac{1}{2}$ d) $\frac{1}{8}$

$p_{av} = \frac{I_0 E_0}{2}cos\emptyset = \frac{1}{2}\times 1/_{\sqrt{2}} \times 1/_{\sqrt{2}} \times cos\frac{\pi}{3}$

$p_{av} = \frac{1}{2}\times\frac{1}{2}\times\frac{1}{2} = 1/_8$ [Ans :d]

13. In an oscillating LC circuit , the maximum charge on the capacitor, is Q. The charge of the capacitor when the energy is stored equally between the electric and the magnetic field is

a) $\frac{Q}{2}$ b) $\frac{Q}{\sqrt{3}}$ c) $\frac{Q}{\sqrt{2}}$ d)Q

$U_c=\frac{Q^2}{2c}$; $Uc' = \frac{Q'^2}{2c}$

Energy stored equally $Uc' = {}^{1}/_{2}\, U_c = {}^{1}/_{2}[\frac{Q^2}{2c}]$

$\frac{Q'^2}{2c} = {}^{1}/_{2}\ \frac{Q^2}{2c}$ $\qquad Q'^2 = \frac{Q^2}{2}$

$Q' = {}^{Q}/_{\sqrt{2}}$ *[Ans : c]*

14. $\frac{20}{\pi^2}$ H inductor is connected to capacitor of capacitance C.The value of C in order to impart maximum power at 50 Hz is

a) 50 μF b) 0.5 μF c) 500 μFd) 5 μF

For Maximum power $X_L = X_c$

$L\omega_r = \frac{1}{c\omega_r}$ $\qquad c=\frac{1}{L.\omega_r{}^2} = \frac{\pi^2}{20\times4\pi^2\times2500}$

$C=0.05\times10^{-4} = 5\mu F$ *[Ans : -d]*

<u>Very Short answer questions from text</u>

1. What is meant by electromagnetic induction? (Page:210)
2. State Faraday's laws of electromagnetic induction . (Page 212)
3. State Lenz's law (Page 214)
4. State Fleming's right hand rule. (Page 216)
5. How is eddy current produced? How do they flow in a conductor? (Page 221)
6. Mention the ways of producing induced emf. (Page 233)
7. What for is an inductor used ? Give examples. (Page 226)
8. What do you mean by self - induction ? (Page 225)
9. What is meant by mutual induction? (Page 229)
10. Give the principle of AC generator ? (Page 237)
11. List out the advantages of stationery armature-rotating field system of AC generator.(240)
12. What are step-up and step-down transformers . (Page 245)
13. Define average value of alternating current (Page 250)

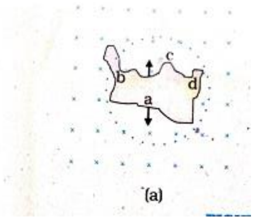
14. How will you define RMS value of an alternating current. (Page 250)
15. What are phasors ? (Page 253)
16. Define electric resonance. (Page 261)
17. What do you mean by resonant frequency? (Page 261)
18. How will you define Q-factor? (Page 263)
19. What is meant by wattles current? (Page 265)
20. Give one definition of power factor. (Page 266)
21. What are LC oscillations . (Page 267)

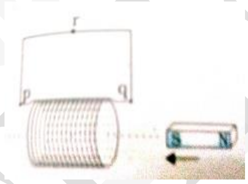
Additional Questions

1. What is magnetic flux? (Page 207)
2. When would magnetic flux linked with an area be (a) Maximum (b) Minimum?

   Answer: a) $\vec{B}$, $\vec{A}$ in same direction b) $\vec{B}$, $\vec{A}$ are perpendicular.

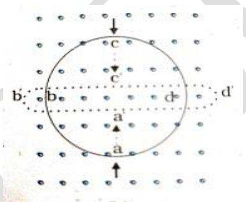
3. Predict the direction of induced current in the following situations. (H)





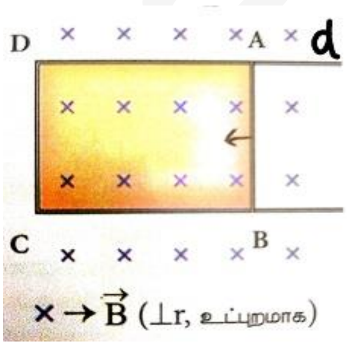
b

a irregular shape into circular shape



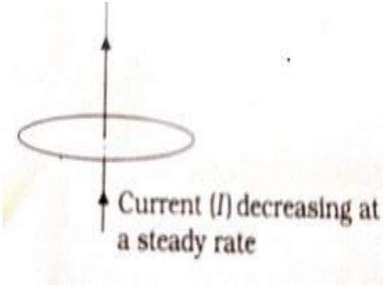
c

d



C.circular loop into a wire

e



Solution :

a) Circle has maximum area. Flux increases , Lenz law (Current in anticlockwise direction)

b) Current from p to q , clockwise at the end p.

c) Area decreases. Flux decreases. Lenz law (Anticlockwise direction)

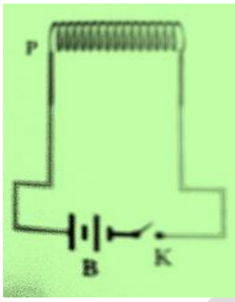
d) Area decreases. Flux decreases. Lenz law (clockwise direction)

e. Zero since $\vec{B}$ & $\vec{A}$ are at right angles)

4. If a conductor along east west direction is dropped vertically with it to be horizontal ,will there be any induced emf in it? (H)

Ans: Yes .There will be induced emf.It is moving perpendicular to horizontal component of earth's magnetic field.

5. Deflection is observed momentarily in Galvanometer only when Key K is closed or opened. Why? (H)

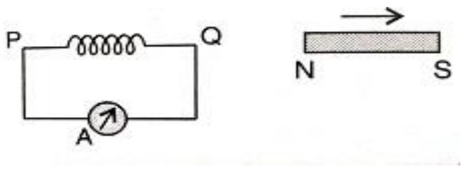


Ans: When key K is closed or opened current increases or decreases. Magnetic flux lined with the coil changes, induced current is produced.

6. What is the magnitude of induced emf.

according to Faraday's II law of Electromagnetic induction.

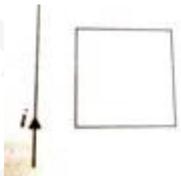
7. Magnet is moved away from coil with ends P and Q. Which end would become North pole ? (H)



Ans. (Since North pole of magnet is moving away, End Q of coil should become South pole to attract the magnet and oppose its motion

(Lenz Law) Therefore end P should be North pole.

8. If I is decreasing, find the direction of induced current in square loop of conductor. (H)



Ans: Flux through the loop is decreasing Lenz law current in clockwise direction .

9. If a metal disc is made to oscillate between poles of electromagnet, what would happen to number of oscillations made by it, when slots are cut in it. Why? (H)

Ans (With slots in disc, eddy current is reduced, no of oscillation is increased)

10. Give one drawback of eddy current and hence one method to reduce eddy current.(P 222)

11. If a spherical stone and spherical metal ball of same size and mass are dropped from same height, which would be reaching the earth's surface first? Why?

Ans: Stone would reach first. Eddy currents are produced in metal ball due to earth's magnetic field which opposes its motion.

12. Give two applications of eddy current (Page 223)

13. How is eddy current testing done? (Page 224)

14. Explain the working of induction stove. (Page 223)

15. Define self inductance (Page 226)

16. Define 1 Henry (Page 226)

17. Give the dimensional formula of self-inductance. (Page 226)

18. Which is the equivalent inertial factor of inductance in translational and rotational motion. 226)

19. Why inductance is the inertial factor in electrical circuit? (Page 226)

20. Define Mutual inductance between the given pair of coils.

21. What are the methods of producing induced emf. (Page 229)

22. Show the graphical variation of emf induced in a coil with the change in the orientation O of coil with magnetic field in which it is placed. (Page 235)

23. What is a stator? Mention its parts. (Page 238)
24. What is a rotor? (Page 238)
25. What is a salient pole rotor? (Page 238)
26. What is a cylindrical pole rotor (Page 240)
27. What is hysteresis loss? How can it be minimized? (Page 245)
28. Why are the wires of larger diameter preferred for transformer windings? (Page 245)
29. How can we minimize the flux leakage in a transformer? (Page 245)
30. Which important property of Alternating Voltage is used in long distance power transmission? How? (Page 246)
31. What is an alternating Voltage? (Page 248)
32. Draw the phasor diagram and wave diagram for AC circuit with resistance. (Page 254)
33. Differentiate inductive reactance and capacitive reactance. (Page 255,257)
34. How does inductive reactance vary with frequency of applied A.C.? (Page 256)
35. Capacitor blocks d.c. voltage, allows a.c. voltage. Why? (Page259)
36. Differentiate Active and Reactive components of I_{rms}. (Page 265)
37. Tabulate the growth and decay of charge in capacitor and current in inductor during Oscillation in an LC circuit for every 1/8 th of time period T.

Answer:

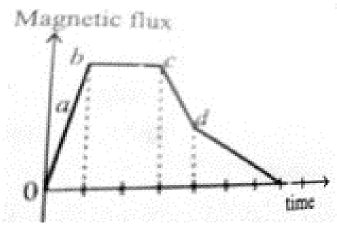
	0	T/8		3T/8	4T/8	5T/8	6T/8	7T/8	8T/8
Charge in a capacitor	Q_m	$Q_m/\sqrt{2}$	0	$Q_m/\sqrt{2}$	Q_m	$Q_m/\sqrt{2}$	0	$Q_m/\sqrt{2}$	Q_m
Current in an Inductor	0	$I_m/\sqrt{2}$	I_m	$I_m/\sqrt{2}$	0	$I_m/\sqrt{2}$	I_m	$I_m/\sqrt{2}$	0

38. Show the variation of Electrostatic potential energy and Magneto static potential energy graphically in an LC circuit. (Page 271)
39. How can we find induced emf from magnetic flux -time graph. (H)

Ans: Negative slope.

40. Arrange the regions of graph in ascending order of magnitude of induced emf.

(H)



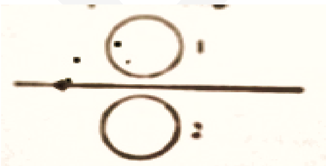
Ans: a, c, d, b.

(All the values of emf are with negative sign since flux is positive. Variation in flux in decreasing order)

a>c>d>b

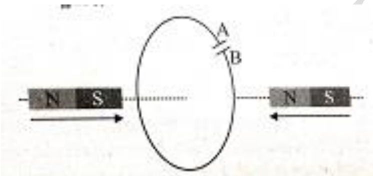
-a <-c <-d <0

41. Predict the direction of current in rings 1 & 2 if current is steadily decreasing. (H)



Ring 1 – clockwise, ring-2 Anticlockwise (Lenz's Law)

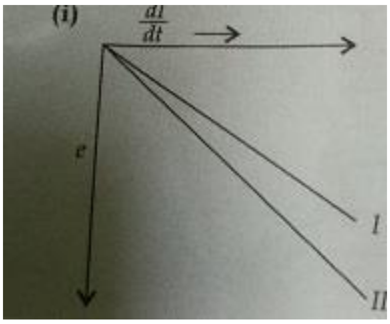
42. Find the polarity of the capacitor on A and B. (H)



Ans: South pole is approaching the coil. Left side of coil should become South pole using Cork Screw rule. Current is from A to B . A is +ve

B is –ve.

43. I, II represent the variation of emf with rate of change of current for two inductances L1 and L2. Compare L1 and L2. (H)



Ans : Slope = e / d_i /d_t = L Slope II > Slope I

L2 > L1

44. A metallic piece gets hot when surrounded by a coil carrying high frequency alternating current. Why? (H)

Ans: Due to Joule's heating effect of eddy current produced in metal piece.

45. A light bulb and a solenoid are connected in series across an A.C. source or voltage. Explain, how glow of light bulb will be affected when an iron rod is inserted in the Solenoid.

(H)

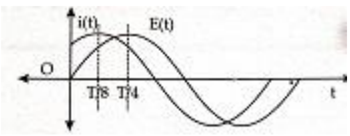
Ans: Brightness decreases. When a rod is inserted, L increases, Z increases, Current decreases.

46. Write any 4 factors on which the following depend: (Page 227)

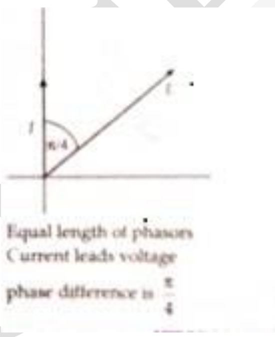
a) Self inductance b) Mutual inductance.

47. Draw the phasor diagram to show the phase relationship between (H)

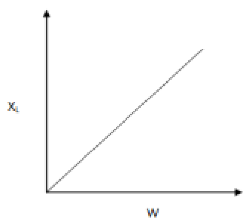
Voltage and current

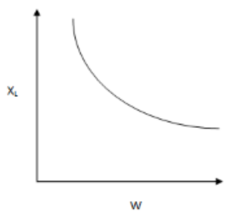


Ans



48. Show the graphical variation of X_L and X_C With frequency of applied AC voltage.





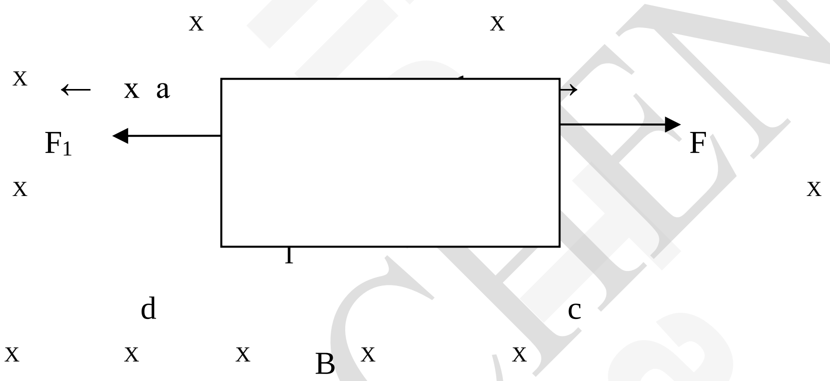
49. Discuss the frequency response curve of LCR circuit. (Page 262)

50. In LCR resonance curve what does the sharpness of the curve indicate? (Page 262)

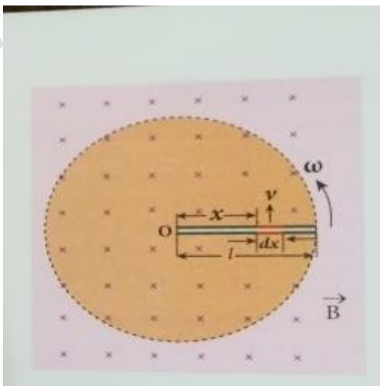
51. How is tuning achieved with LCR resonance circuit? (Page 262)

Short answer questions

1. Justify Lens Law is in accordance with Law of Conservation of energy for a system containing magnet moving with respect to coil. (Page 215)
2. Obtain motional emf from Lorentz force. (Page 217)
3. Obtain motional emf from Faraday's law. (Page 219)
4. If the coil abcd is moved by force, F towards right in magnetic field B (inward) find
   i) direction of induced current i
   ii) Magnitude of force F1 on side ad
   iii) power exerted by F if R is the resistance of coil.



5. Copper rod of length 'l' is rotating with angular velocity w in magnetic field B (H) Find the emf developed across the rod. (Page 221)



6. Obtain self inductance of solenoid. (Page 227)

7. Obtain the mutual inductance of 2 long co-axial solenoids. (Page 230)

8. Obtain expression for instantaneous induced emf in a coil rotating in a magnetic field with constant angular velocity. (Page 264)

9. List down the advantages of 3 phase Alternator. (Page 243)

10. Define average value of alternating current over positive or negative half cycle. Hence derive an expression for it. (Page 250)

11. Derive $I_{rms} = I_m / \sqrt{2}$ (Page 251)

12. Obtain expression for average power of AC over a cycle. Deduce its special cases. (P 264)

13. When LC oscillations take place in an LC circuit, tabulate the values of electrical energy and magnetic energy after every 1/8th of time period T, for 1 full oscillation.

Ans:

	0	T/8	2T/8	3T/8	4T/8	5T/8	6T/8	7T/8	8T/8
Energy In capacitor	$q_m^2/2c$	$\frac{1}{2}(q_m^2/2c)$	0	$\frac{1}{2}(q_m^2/2c)$	$q_m^2/2c$	$\frac{1}{2}(q_m^2/2c)$	0	$\frac{1}{2}(q_m^2/2c)$	$q_m^2/2c$
Energy in an Inductor	0	$\frac{1}{2}(\frac{1}{2}LI_m^2)$	$\frac{1}{2}LI_m^2$	$\frac{1}{2}(\frac{1}{2}LI_m^2)$	0	$\frac{1}{2}(\frac{1}{2}LI_m^2)$	$\frac{1}{2}LI_m^2$	$\frac{1}{2}(\frac{1}{2}LI_m^2)$	0

14. List down the various energy losses in transformer. Also suggest the methods to reduce them. (Page 245)

15. Draw a diagram to show construction of 3 phase AC. Also give the variation of emfs with orientation angle, graphically. (Page 243)

16. Current flowing through an inductor of self-inductance L is continuously increasing plot a graph to show the variation of

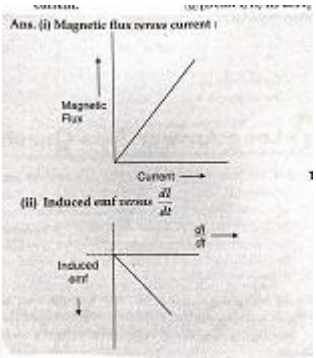
a) magnetic flux Vs current

b) Induced emf Vs di / dt

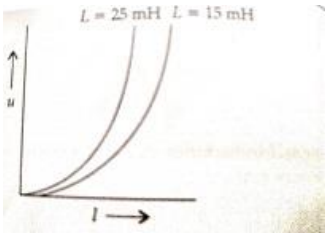
c) Magnetic potential energy Vs current

Ans :

a



b



C

17. A lamp is connected in series with a capacitor . predict your observation for dc and ac connections. What happens in each if the capacitance of the capacitor reduced ? (H)

Ans: dc source After changing no current flows .Lamp will not glow.

ac source Capacitance offers capacitive reactance. Current flows.

Bulb shines. Reducing C, X_c increases , brightness decreases.

Long Answer questions from text book

1. Establish the fact that the relative motion between the coil and the magnet induces an emf in the coil of a closed circuit. (Page 209)
2. Give an illustration of determining direction of induced current by using Lenz's law. (214)
3. Show that Lenz's law is in accordance with the law of conservation of energy. (Page 215)
4. Obtain an expression for motional emf from Lorentz force. (Page 217)
5. Using Faraday's law of electromagnetic induction, derive an equation for motional emf.
6. Give the uses of Foucault current. (Page 223)
7. Define self-inductance of a coil in terms of (i) magnetic flux and (ii) induced emf. (226)
8. How will you define the unit of inductance? (Page 2
9. What do you understand by self-inductance of a coil? Give its physical significance. (226)
10. Assuming that the length of the solenoid is large when compared to its diameter, find the equation for its inductance. (Page 227)
11. An inductor of inductance L carries an electric current. i. How much energy is stored while establishing the current in it? (Page 228)
12. Show that the mutual inductance between a pair of coils is same ($M_{12} = M_{21}$). (Page 231)

13. How will you induce an emf by changing the area enclosed by the coil? (Page 233)
14. Show that the rotation of a coil in a magnetic field over one rotation induces an alternating emf of one cycle. (Page 235)
15. Elaborate the standard construction details of AC generator. (Page 237)
16. Explain the working of a single-phase AC generator with necessary diagram. (Page 240)
17. How are the three different emfs generated in a three-phase AC generator? Show the graphical representation of these three emfs. (Page 243)
18. Explain the construction and working of transformer. (Page 244)
19. Mention the various energy loses in a transformer. (Page 245)
20. Give the advantage of AC in long distance power transmission with an example. (Page 246)
21. Find out the phase relationship between voltage and current in a pure inductive circuit.(255
22. Derive an expression for phase angle between the applied voltage and current in a series RLC circuit. (Page 260)
23. Define inductive and capacitive reactance. Give their units. (Page 255,257)

<u>Additional Long answer questions</u>

1. A circuit contains a Capacitor connected across an alternating voltage source. Find an expression for current in the circuit. Also draw phasor and wave diagram. (Page 256)
2. A circuit contains a resistor, inductor and a capacitor in series connected to an AC supply. Find an expression for (Page 260)
   a) Impedance of the circuit with special cases.
   b) Phase angle between applied voltage and current
3. Derive instantaneous power in an LCR circuit connected to an AC supply. Discuss its special cases. (Page 264)

Numerical problems:

1. A square coil of side 30 cm with 500 turns is kept in a uniform magnetic field of 0.4T. The place of the coil is inclined at an angle of 30^0 to the field. Calculate the magnetic flux through the coil.

Given data:

Area A = $30 \times 30 \times 10^{-4}$ m^2

n = 500

B = 0.4 T

θ = 90 – 30 = 60

φ = ?

Solution: φ = nBA cos θ

= $500 \times 30 \times 30 \times 10^{-4} \times 0.4 \times \cos 60^0$

φ = 9wb

2. A straight metal wire crosses a magnetic field of flux 4 m Wb in a time 0.4s. Find the magnitude of the emf induced in the wire.

Given data:

dø = 4m Wb

= 4×10^{-3} Wb

dt = 0.4 s

Induced emf ε = ?

Solution:

$$\varepsilon = +\frac{d\text{ø}}{dt}$$

$$\varepsilon = \frac{4\,x\,10^{-7}}{0.4}\times 10\times 4\times 10^{-4}$$

$$\varepsilon = \frac{40}{4}\times 10^{-3}$$

ε = 10 mV

3. The magnetic flux passing through a coil perpendicular to its place is a function of time and is given by

$\Phi B = (2\,t^3 + 4\,t^2 + 8t + 8)$ Wb. If the resistance of the coil is

5Ω determine the induced current through the coil at a time t= 3 second.

Given data:

$\Phi B = (2t^3 + 4t^2 + 8t + 8)$ wb

R = 5Ω

t = 3 second

induced current i = ?

Solution:

$$i = \frac{\varepsilon}{R}$$

$$\varepsilon = \frac{d\phi_B}{dt}$$

$$\varepsilon = \frac{d}{dt.}(2t^3 + 4t^2 + 8t + 8)$$

$\varepsilon = 6t^2 + 8t + 8$

at t = 3 second, $\varepsilon = 6 \times 3^2 \times 8 \times 3+8$

$\varepsilon = 54 + 24 + 8$

$\varepsilon = 86V$

$i = \frac{\varepsilon}{R} = \frac{86}{5} = 17.2$ A

i = 17.2 A

4. A closely wound coil of radius 0.02 m is placed perpendicular to the magnetic field.When the magnetic field is changed from 8000 T to 2000 T in 6s, an emf of 44 V is induced. Calculate the number of turns in the coil. [Ans : 35 turns]

Given data:

Radius r = 0.02 m

$Q = 0^0$

$B_1 = 8000\ T_1\ B_2 = 2000$ T

dt = 6 secs $\xi = 68$ V

n = ?

Solution:

$$\varepsilon = nA\cos\varnothing\frac{dB}{dt}$$

$$44 = n \times \pi \times 0.02 \times \cos\varnothing \times \frac{8000-2000}{6}$$

$$44 = n \times \frac{27}{7} \times 4 \times 10^{-4} \times 1 \times \frac{6000}{6}$$

$$n = \frac{44\ X\ 7\ X\ 6}{22\ X\ 4\ X\ 10^{-4}\ X\ 6000} = \frac{7}{2\ X\ 10^{-1}} = \frac{70}{2}$$

= 35 turns

5. A rectangular coil of area 6 cm^2 having 3500 turns is kept in a uniform magnetic field of 0.4 T. Initially, the place of the coil is perpendicular to the field and is then rotated through an angle of 180^0. If the resistance of the coil of 35Ω find the amount of charge following through the coil.

Given data:

Area $A = 6 \times 10^{-4}\ m^2$

n = 3500

B = 0.4 T

$\Phi_1 = 0$

$\Phi_2 = 180^0$

R = 35 Ω

Amount of charge Q = ?

Solution :

$Q = \frac{e}{R} dt = \frac{d\phi}{Rdt} \times dt$

$Q = \frac{nBA\,(cos\phi_1 - cos\phi_2)}{R}$

$Q = \frac{nBA}{R}$ [cos0 – cos 180^0]

$Q = \frac{3500 \; X \; 0.4 \; X \; 6 \; X \; 10^{-4} \; (2)}{35}$

$= 80 \times 6 \times 10^{-4}$

$= 480 \times 10^{-4}$ C = 48×10^{-3} C

6. An induced current of 2.5 mA flows through a single conductor of resistance 100 Ω. Find out the rate at which the magnetic flux is cut by the conductor. Ans : (250 mWbs^{-1})

Given data:

Induced current i = 2.5 mA

$i = 2.5 \times 10^{-3}$ A

Resistance R = 100 Ω

Solution :

$\varepsilon = \frac{d\phi_B}{dt}$

Where ε = iR

$\frac{d\phi_B}{dt} = i\,R = 2.5 \times 10^{-3} \times 100 =$

250×10^{-3}

= 250 mWbs^{-1}

7.A fan of metal blades of length 0.4 m rotates normal to a magnetic field of 4×10^{-3} T. If the induced emf between the centre and edge of the blade is 0.02 V, determine the rate of rotation of the blade. [Ans : 9.95 revolutions / second]

Given data:

Length = 0.4 m

$B = 4 \times 10^{-3}$

$\varepsilon = 0.02$ V

The rate of rotation ω = ?

Solution:

$\varepsilon = \frac{1}{2} B\omega l^2$

$\omega = \frac{2\varepsilon}{Bl^2}$ $(\omega = 2\pi\nu)$

$2\pi\nu = \frac{2\varepsilon}{Bl^2}$

$\nu = \frac{\varepsilon}{Bl^2\,\pi}$

$\nu = \frac{0.02}{4\times10^{-3} X\ 0.4\ X\ 0.4\ X\ 3.14}$

ν= 9.95 revolutions / second

8. A bicycle wheel with metal spokes of 1 m long rotates in Earth's magnetic field. The place of the wheel is perpendicular to the horizontal component of Earth's field of 4×10^{-5} T. If the emf induced across the spokes is 31.4 mV, calculate the rate of revolution of the wheel. [Ans : 250 revolutions / second]

Given data:

Length I = 1 m

B = 4 × 10-5 T

ε = 3.14 mV

= 3.14 × 10-3V

The rate of revolution = ?

Solution:

$\varepsilon = \frac{1}{2} B\omega l^2$

$\omega = \frac{2\varepsilon}{Bl^2}$

$2\pi\nu = \frac{2\varepsilon}{Bl^2}$

$\nu = \frac{2\varepsilon}{Bl^2 2\pi} = \frac{2\ X\ 31.4\ X\ 10^{-3}}{4\times10^{-5} X\ 1^1\ X\ 2\ X\ 3.14}$

$\nu = \frac{31.4\ X\ 10^2}{4\times\ 3.14} = \frac{10\ X\ 10^2}{4}$

$\nu = \frac{1000}{4}$ =250 revolutions / second

9. Determine the self-inductance of 4000 turn air – core solenoid of length 2m and diameter 0.04m. [Ans : 12.62 mH]

Given data:

n = 4000/2 =2000

I = 2 m

diameter d = 0.04 m

radius r = 0.02 m

Self inductance L = ?

Solution:

$L = \mu_0 n^2 Al$

$L = 4\pi \times 10^{-7} \times 2000 \times 2000 \times \pi \times 0.02 \times 0.02 \times 2$

$L = 16\pi \times 10^{-1} \times \pi \times 8 \times 10^{-4}$

$L = 1262 \times 10^{-5}$

$L = 12.62 \times 10^{-3}$ H

L = 12.62m H

10 A coil of 200 turns carries a current of 4 A. If the magnetic flux through the coil is 6×10^{-5} Wb, find the magnetic energy stored in the medium surrounding the coil. [Ans : 0.024J]

Given data:

N = 200 turns

i = 4A

$\Phi_B = 6 \times 10^{-5}$ wb

Magnetic energy U_B = ?

Solution:

$U_B = \frac{1}{2} Li^2$

∴ $U_B = \frac{1}{2} \frac{N\phi_B}{i} i^2$

$U_B = \frac{1}{2} N\phi_B \ i$

$= \frac{1}{2} \times 200 \times 6 \times 10^{-5} \times 4$

$U_B = 24 \times 10^{-3}$J

U_B = 0.024J

11. A 50 cm long solenoid has 400 turns per cm. The diameter of the solenoid is 0.04m. Find the , magnetic flux of a turn when it carries a current of A.

[Ans : 1.26 wb]

Given data:

l= 50 cm = 50×10^{-2} m

n= 400 turns/cm

50×10^{-2} m length lay = 400 turns

∴ n = 800 turns / m

Diameter d = 0.04m Radius r = 0.02 m

i = 1A ΦB = ?

Solution:

$L = \mu_0 n^2 Al$

$L = 4\pi \times 10^{-7} \times 800 \times 800 \times \pi \times 4 \times 10^{-1} \times 50 \times 10^{-2}$

$L = 4\pi \times 4\pi \times 64 \times 0.5 \times 10^{-7}$

$L = 5048 \times 10^{-7} = 5.04 \times 10^{-1}$ H

$N\phi_B = Li \quad \phi_B = \frac{Li}{N} = \frac{Li}{nl}$

$= \frac{5.04 X 10^{-4} X 1}{800\times 50 X 10^{-2}} = \frac{5.048 X 10^{-4}}{400}$

$= 0.0126 \times 10^{-4}$ wb

$= 1.26 \times 10^{-6}$ wb = 1.26 wb

12. A coil of 200 turns carries a current of 0.4 A. If the magnetic flux of 4m Wb is linked with the coil, find the inductance of the coil [Ans : 2H]

Given data:

Number of turns,N = 200; Current I= 0.4A

Magnetic flux linked with the coil

ϕ = 4m Wb = 4×10^{-3} Wb

SOLUTION

Induction of the coil $L = \frac{N\phi_B}{i}$

$= \frac{200 \times 4 \times 10-3}{0.4} = 2H$

13. Two air core solenoids have the same length of 80cm and he same cross sectional area $5cm^2$. Find the mutual inductance between them if the number of turns in the first coil is 1200turns and that in the second coil is 400 turns .

Given data:

Length of the solenoids l = 80cm =80×10^{-2} m

Cross sectional area of the solenoid,

$A= 5cm^2 = 5 \times 10^{-4} m^2$

Number of turns in the 1st coil = 1200

Number of turns in the 2nd coil = 400

Solution:

Mutual inductance between the two coils ,

$$M = \frac{\mu 0 \ N_1 \ A \ N_2}{l}$$

$$= \frac{4\pi \times 10-7 \times 1200 \times 400\times \ 5 \times 10-4}{80\times 10-2} = 0.38mH$$

14. A long solenoid having 400 turns per cm carries a current 2A. A 100 turns coil of cross sectional area 4cm^2 is placed co- axially inside the solenoid so that the coil is in the field produced by the solenoid .Find the emf induced in the coil if the current through the solenoid reverses its direction in 0.04 sec .

Given data:

Number of turns of long solenoid per cm = $\frac{400}{10^{-2}}$

$N_1 = 400 \times 10^2$

Number of turns inside the solenoid $=N_2 = 100$

Cross sectional area of the coil,A = 4cm^2

current through the solenoid,I = 2A

time t = 0.04 sec

Solution

Mutual inductance of the coil =

$$M = \frac{\mu 0 N1N2 \ A}{l}$$

$$M = \frac{4\pi \times 10-7\times 400\times 102\times 100\times 4\times 10-4}{1}$$

= 2mH

Current reverses

Induced emf of the coil $e = -M \frac{dI}{dt}$

$$= -2 \times 10^{-3} \times \frac{2-(-2)}{0.04}$$

e = - 0.2. V

15. A 200 turn coil of radius2cmis placed co-axially within a solenoid of 3cm radius.If the turn density of the solenoid is 90 turns per cm , calculate the mutual inductance of the coil.

Given data

Number of turns of solenoid,N_2 =200

Radius of the solenoid = r =2cm = 2×10^{-2} m

Area of the solenoid ,A = πr^2

$= 3.14 \times (2 \times 10^{-2})^2 = 1.256 \times 10^{-3}$ m^2

Turn density of the solenoid per m $=90\times 10^2$turns/m

Solution

Mutual inductance of the coil =

$M = \frac{\mu 0 N1 N2\ A}{l}$

$= \frac{4\pi \times 10^{-7} \times 90 \times 10^{2} \times 200 \times 1.256 \times 10^{-3}}{1}$

= 2.84 mH

16. The Solenoids S_1 and S_2 are wound on an iron-core of relative permeability 900. The area of their cross-section and their length are the same and are 4 cm^2 and 0.04 m respectively. If the number of turns in S_1 is 200 and that in S_2 is 800, calculate the mutal inductance between the coils. The current in solenoid 1 is increased from 2A to 8A in 0.04 second. Calculate the induced emf in solenoid 2.

[Ans : 1.81H; 271.5V]

Given data:

$\mu_r = 900$

$A_2 = 4 \times 10^{-4}\ m^2$

l = 0.04m

$n_1 = 5000,\ n_2 = 20,000$

$t_1 = 2A$ to $i_2 = 8A$

dt = 0.048

M = ? ε_2 = ?

Solution:

$M = \mu_o\ \mu_r\ n_1\ n_2\ A_2\ l$

$M = 4\pi \times 10^{-7} \times 900 \times 5000 \times 20000 \times 4 \times 10^{-4} \times 0.04$

$M = 4\pi \times 10^{-1} \times 10 \times 9 \times 4 \times 10^{-2} \times 4 \times 10^{-4}$

$M = 4\pi \times 90 \times 4 \times 4 \times 10^{-4}$

$M = 18086 \times 10^{-4}$ H

M = 1.81H

Induced emf

$\varepsilon_2 = M\frac{di}{dt}$

$\varepsilon_2 = 1.81(\frac{(8-2)}{\mathbf{0.04}})$

$\varepsilon_2 = \frac{1.81\ X6}{4\times 10^{-2}}$

$\varepsilon_2 = 271.5 \times 10^{2}$ V

$\varepsilon_2 = 271.5V$

17. A step-down transformer connected to main supply of 220 V is made to operate 11 V, 88W lamp. Calculate (i) Transformation ratio and (ii) current in the primary [Ans : 1/20 and 0.4A]

Given data:

$V_p = 220$ V, $P_s = 88$ W , $V_s = 11$ V

Solution:

Transformation ratio

$$K= \frac{Vs}{Vp}$$

$$K= \frac{11}{220} = \frac{1}{20} = 1:20 = \frac{1}{20}$$

Current in the primary Ip = ?

$P_s = V_s I_s$

$$I_s = \frac{Ps}{Vs} = \frac{88}{11} = 8A$$

$$\frac{Ip}{Is} = K$$

$$I_p = \frac{1}{20} \times 8 = \frac{2}{5} = 0.4$$

$I_p = 0.4$A

18. A 200V/120V step down transformer of 90% efficiency is connected to an induction stove of resistance 40 Ω . Find the current drawn by the primary of the transformer.

[Ans : 2A]

Given data:

$V_p = 200$ V $\quad V_s = 120$ V

$$\eta= 90\% \quad = \frac{90}{100} = 0.9s$$

Solution:

$$\eta= \frac{\text{output power}}{\text{input power}}$$

$\therefore 0.9 = \frac{VsLs}{VpLp}$

$\therefore V_s = I_s R_s$

$I_s = \frac{Vs}{Rs} = \frac{120}{40} = 3A$

$0.9 = \frac{120 X 3}{200 X Ip}$

$0.9 = \frac{120 X 3}{200 X 0.9} = \frac{120 X 3}{20 X 9}$

$I_p = 2A$

19. The 300 turn primary of a transformer has resistance 0.82Ω and the resistance of its secondary of 1200 turns is 6.2Ω. Find the voltage across the primary if the power output from the secondary at 1600 V is 32 kW. Calculate the power losses in both coils when the transformer efficienty is 80%..

[Ans : 8.2kW and 2.48kW]

Given data:

$N_p = 300$

$R_p = 0.82\Omega$

$N_s = 1200$

$R_s = 6.2\Omega$

$V_s = 1600$ V, $P_s = 32$ KW

Solution:

i) $P_s = V_s I_s$

20

$I_s = \frac{Ps}{Vs} = \frac{32000}{1600}$

$I_s = 20A$

ii) $\frac{Vp}{Vs} = \frac{Np}{Ns}$

$V_p = \frac{300}{1200} \times 1600 = 400V$

iii) $\eta = \frac{Ps}{VpLp}$

$0.9 = \frac{120 X 3}{200 X Ip}$

$\frac{80}{100} = \frac{32000}{400 X Ip}$

$I_p = \frac{32000}{320}$

$I_p = 100A$

iv) Power loss in primary

$= I^2_p \times R_p$

$= 100 \times 1000 \times 0.82$

$= 0.82 \times 1000$

$= 8.2000$

$= 8.2$ KW

v) Power loss in secondary

$= I^2_p \times R_p$

$= 20 \times 20 \times 6.2$

$= 400 \times 6.2$

$= \boxed{2480kW}$

20. Calculate the instantaneous value at 60^0, average value and RMS value of an alternating current whose peak value is 20A

[Ans: 17.32A, 12.74A, 14.14A]

Given data:

$I_m = 20A$

$\theta = 60^0$

i) Instantaneous value of current

$i = I_m \, Sin\theta$

$= 20 \times Sin60^0$

$= 20 \times \frac{\sqrt{3}}{2}$

$= 10 \times \sqrt{3} = 10 \times 1.732$

$i = 17.32A$

ii)Average value $I_{av} = 0.637$

$I_{av} = \frac{2I_m}{\pi}$

$I_{av} = 2 \times 20 \times \frac{7}{22}$

$= 12.72$

$I_{av} = 12.74A$

iii) $I_{rms} = 0.707\ I_m$

$= 0.707 \times 20$

$= 7.07 \times 2$

$I_{rms} = 14.14A$

CHAPTER 5

ELECTROMAGNETIC WAVES

Points to Ponder:

✓ Visible light is only a small portion of electromagnetic spectrum.

✓ Displacement current is the current which comes into play in the region in which the electric field and the electric flux are changing with time.

✓ Electromagnetic waves are produced by any accelerated charge.

✓ Electromagnetic waves are transverse in nature

✓ Electromagnetic waves are non-mechanical wave

✓ So electromagnetic waves do not require any medium for propagation

The average energy density $\langle U \rangle = \varepsilon_0 E^2 = \frac{1}{\mu_0} B^2$

✓ Intensity of electromagnetic wave

$$I = \frac{Power\ (P)}{Surface\ area\ (A)}$$

✓ Electromagnetic waves carry not only energy and momentum but also angular momentum

✓ The speed of electromagnetic wave is equal to t speed of light C

$$C = \frac{1}{\sqrt{\varepsilon_o \mu_o}} = 3X10^8$$

✓ The energy of electromagnetic waves comes from the energy of the oscillating charge.

✓ Electromagnetic spectrum is an orderly distribution of electromagnetic waves in terms of wave length or frequency

✓ Types of spectrum – emission and absorption

✓ When the spectrum of self luminous source is taken, we get emission spectrum

✓ When light is allowed to pass through a medium or an absorbing substance then the spectrum obtained is known as absorption spectrum.

✓ The dark lines in the solar spectrum are known as Fraunhofor lines.

Important formulas

1. Mathematical form of Faradays' law

$$\int \vec{E}.\vec{dl} = -\frac{d\phi_B}{dt} = \frac{d}{dt} \int \vec{B}.\vec{ds}$$

2. According to Maxwell's law of induction

$$\int \vec{B}.\vec{dl} = -\frac{d\phi_E}{dt} = -\frac{d}{dt} \int \vec{B}.\vec{ds}$$

3. Displacement current Id = $\varepsilon_0 \frac{d\phi_E}{dt}$

4. Maxwell modified Ampere's law as

$\int \vec{B}.\vec{dl} = \mu_{0I} = \mu_0 (I_c + I_d)$

5. Modified Ampere's circuited law known as Ampere – Maxwell's law

$\int \vec{B}.\vec{dl} = \mu_0 I$ enclosed + $\mu_0 \varepsilon_0 \frac{d}{dt} \int \vec{E}.\vec{dA}$

6. Velocity of light in vacuum or free space

$C = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} = 3^8 \times 10 \text{ ms}^{-1}$

7. The speed of electromagnetic wave in a medium

$V = \frac{c}{\mu} = \frac{C}{\sqrt{\varepsilon_r \mu_r}}$

Where ε_r = relative permittivity of the medium

μ_r = relative permittivity of the medium

8. The energy density of the electromagnetic wave is

$U = \varepsilon_0 E^2 = \frac{1}{\mu_0} B^2$

9. The average energy density for electric magnetic wave is

$\langle U \rangle = \frac{1}{2} \varepsilon_0 E^2 = \frac{1}{2} \frac{1}{\mu_0} B^2$

10. Intensity of electro magnetic wave is

$$I = \frac{total\ electromagnetic\ energy\ (U)}{Surface\ area\ (A) x\ time\ (t)}$$

$$I = \frac{Power\ (P)}{Surface\ area\ (A)}$$

11. Linear momentum of electromagnetic wave

$= \frac{\text{energy}}{\text{Speed}} = \frac{U}{C}$

12. The momentum imparted on the surface if the electromagnetic wave is completely absorbed

$P = \frac{U}{C}$

13. If the electromagnetic wave is totally reflected from the surface

$\Delta P = \frac{U}{C} - (-\frac{U}{C}) = 2 \frac{U}{C}$

14. Pointing vector for electromagnetic waves:

$\vec{s} = \frac{1}{\mu_0} (\vec{E} \times \vec{B})$

$= C^2 \varepsilon_0 (\vec{E} \times \vec{B})$

15. Propagation of electromagnetic field along z direction, the electric field vector along Y axis and magnetic field vector along x axis then the expression for electric field is

$E_y = E_0 \sin (Kz - wt)$

The expression for magnetic field is

$B = B_0 \sin (Kz - wt)$

Where E_0 and B_0 – amplitude of oscillating electric and magnetic field

K – wave number

W – angular frequency of the wave

16. The speed of electromagnetic wave in free space is

$C = \frac{E_0}{B_0}$

Multiple choice question:

1. The dimension of $\frac{1}{\mu_0 \varepsilon_0}$ is

Solution:

$C = C = \frac{1}{\sqrt{\mu 0 C 0}}$, C=velocity of light

$C^2 = \frac{1}{\mu_0 \varepsilon_0}$

$= L^2 T^{-2}$

Ans: (b) [$L^2 T^{-2}$]

2. If the amplitude of the magnetic field is 3 x 10 t, then amplitude of the electric field for a electromagnetic waves is

Solution:

$C = \frac{\varepsilon_0}{B_0}$

$E_0 = C \times B_0$

$= 3 \times 10^8 \times 3 \times 10^{-6}$

$= 900 \text{ vm}^{-1}$

Ans : (d) 900 vm^{-1}

3. Which of the following electromagnetic radiation is used for viewing objects through fog **Ans: (d) infrared**

4. Which of the following are false for electromagnetic waves

Ans: (c) longitudinal (b) mechanical waves

5. Consider an oscillator which has a charged particle and oscillates about its mean position with a frequency of 300 MHz. The wave length of electromagnetic waves produced by their oscillator is

Solution:

$C = \upsilon \lambda$

$\lambda = \frac{C}{\upsilon} = \frac{3 \times 10^8}{300 \times 10^6}$

$= \frac{3 \times 10^8}{3 \times 10^6}$

= 1 m

Ans : (a) 1m

6. The electric and the magnetic field, associated with an electromagnetic wave, propagating along x axis can be represented by

Ans : (b) $\vec{E}$ **= E_0 ^K and** $\vec{B}$ **= B^j**

7. In an electromagnetic wave in free space the rms value of the electric field is $3vm^{-1}$. The peak value of the magnetic field is

Solution:

$E = E_{rms} \times \sqrt{2}$

$= 3\sqrt{2}\ Vm^{-1}$

$B = \frac{Eo}{C} = \frac{3\sqrt{2}}{3 \times 10^8}$

$= \sqrt{2} \times 10^{-8}$

$= 1.4114 \times 10^{-8} T$

Ans: (a) 1.4114 x 10^{-8}T

8. During the propagation of electromagnetic waves in a medium:

Ans : (c) electric energy density is equal to the magnetic energy density

$U_E = U_B$

9. If the magnetic monopole exists, then which of the Maxwell's equation to be modified?

Ans : (b) $\int \vec{E}.\vec{dA}$=0

10. A radiation of energy E falls normally on a perfectly reflecting surface. The momentum transferred to the surface is

Ans : (b) 2 $\frac{2}{C}$

11. Which of the following is an electromagnetic wave?

Ans : y-rays

12. Which one of them is used to produce a propagating electromagnetic wave?

Ans : (a) an accelerating charge

13. Let $E = E_0 \sin [\ 10^6 x - wt\ ]$ be the electric field of place electromagnetic wave, the value of w is;

Solution:

$E = E_0 \sin [\ 10^6\ x - wt\ ]$

$E_x = E_0 \sin [\ kx - wt\ ]$

$K = \frac{2\pi}{\lambda} = 10^6$

$\lambda = \frac{2\pi}{10^6} =$

$\upsilon = \frac{C}{\lambda} = \frac{3\ x\ 10^8}{2\pi \times 10^{-6}}$

$= \frac{3\ x\ 10^8}{2\pi\ x\ 10^{-6}}$

$= \frac{1.5\ x\ 10^{14}}{\pi}\ H_z$

$W = 2\pi\upsilon = \frac{2\pi\ x\ 1.5\ x 10^{14}}{\pi}$

$= 3\ x\ 10^{14}\ rad\ S^{-1}$

Ans : (a) 3 x 10^{14} rad S^{-1}

14. Which of the following is not true for electric magnetic waves?

Ans : (d) in vacuum, it travels with different speeds which depend on their frequency.

15. The electric and magnetic fields of an electromagnetic wave are

Ans : (a) in phase and perpendicular to each other.

I. <u>Very Short answer questions</u>

1. What is displacement current?p286
2. Write down the mathematical statement of Faraday's law?p288
3. Write down the integral form of modified Ampere's circuital law.p286
4. Write down the equation of Ampere-Maxwell's law p288
5. What are electromagnetic waves?p288
6. What is the energy density of electromagnetic waves p290
7. What is electromagnetic spectrum? P292
8. What is meant by Fraunhofer lines? 296
9. How is radio waves produced? P292
10. How is X-rays produced? P294
11. How is microwaves produced?P292
12. What is the use of ozone layer in the atmosphere?p293
13. Why is microwave used for long distance communication?p 292

$$r_\beta = \frac{m_\beta\ v}{q_\beta\ B}$$

II Short Answer Questions

1. Explain Maxwell's law of induction? P285
2. What is intensity of electromagnetic wave?p290
3. What is radiation pressure?p291
4. What is pointing vector for electromagnetic waves? Give its unit. P291
5. List out the uses of ultraviolet radiations?p293
6. Write down the uses of microwaves? P292
7. What are the differences between radio waves and gamma rays?p292
8. The propagation of an electromagnetic wave is in the direction of Y p291

Find out

a. The ratio of the magnitudes of electric and magnetic fields
b. The direction of electric and magnetic field vectors

9. Light wave can travel in vacuum but sound wave cannot why? P291
10. How do you know that an electromagnetic wave carry energy and momentum? P291
11. Write down any three properties of electromagnetic waves? P290
12. What are emission and absorption spectra? P295
13. What are the four Maxwell's equations in electrodynamics?p287
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II. <u>Long Answer questions</u>

1. Write down Maxwell's equation in integral form p287
2. Explain the Maxwell's modification of Ampere's circuital law p286
3. Discuss briefly the experiment conducted by Hertz to produce and detect electromagnetic spectrum p288
4. Write down the properties of electromagnetic waves p288
5. Discuss the sources of electromagnetic waves p292
6. Write short notes on p293

a. Microwave b.X-ray c.Radio wave d.Infra red radiation e.Ultra violet radiation

7. What is emission spectra? Explain their typesp295
8. What is absorption spectra? Explain their types p296

Numerical problems:

1.Consider a parallel plate capacitor whose plates are closely spaced. Let R be the radius of plates and the current in the wire connected to the plates is 5 A, calculate the displacement current through the surface passing between the plates by directly calculating the rate of change of flux of electric field through the surface.

$I_d = \frac{d\theta}{dt}$

$I_d = 5A$

Answer : $I_d = I_c = 5A$

2.A transmitter consists of LC circuit with an inductance of 1 μH and a capacitance of 1μF. What is the wavelength of the electromagnetic waves it emits?

$\upsilon = \frac{1}{2\pi x \sqrt{LC}}$

$C = \upsilon\lambda$

$\lambda = \frac{C}{\upsilon}$

$= C \times 2\pi \times \sqrt{LC}$

$= 3 \times 10^8 \times 6.28 \times \sqrt{10 \times 10^{-6}}$

$= 3 \times 10^8 \times 6.28 \times 10^{-6}$

$= 18.84 \times 10^2$ m

Answer : 18.84×10^{-6} m

3. A pulse of light of duration 10^{-6}s is absorbed completely by a small object initially at rest. If the power of the pulse is 60×10^{-3} W, calculate the final momentum of the object.

$P = \frac{U}{C} = \frac{P \times t}{C} = \frac{60\, x 10^{-3}\, x 10^{-6}}{3\, x\, 10}$

$= 20 \times 10^{-7}$ kf ms^{-1}

Answer : 20×10^{-7} kf ms^{-1}

4. Let an electromagnetic wave propagate along the X direction, the magnetic field oscillates at a frequency of 10^{10} Hz and has an amplitude of 10^{-5} T, acting along the Y – direction. Then, compute the wavelength of the wave. Also write down the expression for electric field in this case.

Data : f = 10^{10} Hz

$B_0 = 10^{-5}$ T

1.Wavelength λ=?

2. Expression for electric field E_x = ?

Solution:

Velocity of Electromagnetic wave is free space $C = \frac{\varepsilon_o}{B_o}$

$E_0 = C \times B_0$

$= 3 \times 10^8 \times 10^{-5}$

$E_0 = 3 \times 10^3$ Nc^{-1}

Wave length $\lambda = \frac{c}{f}$

$= \frac{3 \times 10^8}{10^{10}} = 3 \times 10^{-2}$ m

i) wavelength of electromagnetic wave $\lambda = 3 \times 10^{-2}$ m

ii) Expression for electric field

$E_z = E_0 \sin (Kz - wt)$

Wave number $K = \frac{2\pi}{\lambda} = \frac{2\pi}{3 \times 10^{-2}} =$

$0.66\pi \times 10^2$

$K = 66\ \pi m^{-1} = 2.09 \times 10^2$

Angular frequency $w = 2\ \pi f = 2\ \pi \times 10^{10}$ rads^{-1}

$= 3 \times 10^3 \sin (2.09 \times 10^2\ z - 6.28 \times 10^{10}\ t)$

Answer: $\vec{E}(z,t)$ **$= 3 \times 10^3 \sin (2.09 \times 10^2\ z - 6.28 \times 10^{10}\ t)$ I NC^{-1}**

5. If the relative permeability and relative permittivity of the medium is 1.0 and 2.25, respectively. Find the speed of the electromagnetic wave in this medium.

Given:

Πr=1.0, εr = 2.25

Velocity of electromagnetic wave in medium v = ?

Solution:

Velocity of electromagnetic wave in medium $v = \frac{c}{\mu}$

Refractive index $\mu = \sqrt{\varepsilon_r\ \mu_r}$

$v = \frac{3 \times 10^8}{\sqrt{1 \times 2.25}} = = \frac{3 \times 10^8}{1.5} = 2 \times 10^8 ms^{-1}$

Answer : v = 2 × 10⁸ms⁻¹

Solution:

Velocity of electromagnetic wave in medium $v = \frac{c}{\mu}$

Refractive index $\mu = \sqrt{\varepsilon_r\ \mu_r}$

$v = \frac{3 \times 10^8}{\sqrt{1 \times 2.25}} = = \frac{3 \times 10^8}{1.5} = 2 \times 10^8 ms^{-1}$

Answer : v = 2 × 10⁸ms⁻¹