Crash Course for NEET

PHYSICS

Study Package-2

Aakash
Medical | IIT-JEE | Foundations
(Divisions of Aakash Educational Services Limited)

Edition : 2020

Preface

Dear NEET Aspirant,

This book has been written specifically for the students who get themselves enrolled for the crash course for medical entrance exams. which is a limited days programme. It is meant for the quick brush-up of all the important topics. All the chapters have been written by the experienced faculties who have been preparing the students for qualifying various medical entrance exams. Each chapter covers all the important and must do topics and has been written in such a way that the student can grasp the contents easily.

After the theory portion in the study package, Try Yourself have been given to make the student practice the questions similar to those asked in entrance exams. The sequence of the questions has been kept same as the sequence of theory part so that a student can solve questions as per his/her coverage of theory part. The questions asked in previous AIPMT/NEET exam have also been included. This will help the students to assess the difficulty level in the actual medical entrance exams. We have also added two sample papers of 45 questions each covering the entire content of this study package.

As the days are limited, the students should never miss a single class and must cover the syllabus in tandem with the coverage in the classroom. Once the topic is finished, you must do all the questions of same topic given in the form of Try Yourself. If there is any doubt, you can get it clarified from the faculties.

Finally, you are advised to remain focused on your target and must work hard and complete all the necessary work sincerely in a planned manner. You must stay away from all distractions including the mobile phone. All other things can wait but time never waits for anyone. So gear up your preparations to realise your dream of joining the most prestigious and respected profession.

Wishing you a brighter career!

J. C. CHAUDHRY
Managing Director

Analysis of NEET–2019

Subject-wise Report

Subject-wise Difficulty Level

S. No.	SUBJECT	EASY	MEDIUM	DIFFICULT	REMARKS
1	PHYSICS	18	25	2	Medium
2	CHEMISTRY	17	22	6	Medium
3	BOTANY	21	13	14	Easy
4	ZOOLOGY	9	25	8	Medium

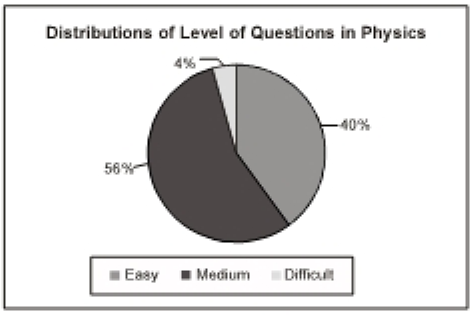
Topic-wise Credits & Difficulty Level

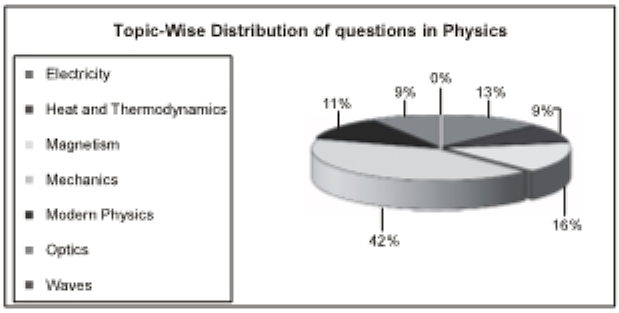
PHYSICS

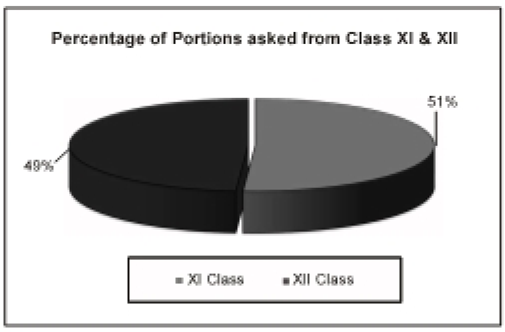
ANALYSIS OF PHYSICS PORTION OF NEET 2019

	XII	XI	XII	XI	XII	XII	XI	
	Electricity	Heat and Thermodynamics	Magnetism	Mechanics	Modern Physics	Optics	Waves	Total
Easy	3	3	2	6	2	2	0	18
Medium	3	1	5	11	3	2	0	25
Difficult	0	0	0	2	0	0	0	2
Total	6	4	7	19	5	4	0	45

XI Class	23	XII Class	22







Contents

Chapter 1

Electric Charges and Fields

Sub-topics *Electric charges and their conservation. Coulomb's law-force between two point charges, forces between multiple charges; superposition principle and continuous charge distribution. Electric field, electric field due to a point charge, electric field lines; electric dipole, electric field due to a dipole; torque on a dipole in a uniform electric field. Electric flux, statement of Gauss's theorem and its applications to find field due to infinitely long straight wire, uniformly charged infinite plane sheet and uniformly charged thin spherical shell (field inside and outside).*

Electric Charges and their Conservation

There are two kinds of electric charges viz., positive and negative. Charge is scalar. SI unit of charge is coulomb.

1 coulomb = 3×10^9 esu of charge (cgs unit)

A charge cannot exist without mass. Charge is transferable. When a glass rod is rubbed with silk, due to friction the glass rod loses some of its negative charge and it gets a small positive charge (frictional electricity). When a plastic (or ebonite) rod is rubbed with fur (or wool) the plastic gains a small negative charge as the fur or wool loses electrons. Generally electrons participate in the charge transfer. Charge is quantized.

In all interactions in nature, the total charge of an isolated system remains constant for all times. This is known as the law of "Conservation of Charge". Simultaneous creation or annihilation (destruction) of pairs of equal and opposite charges is allowed. Examples are

(a) Pair production : Gamma ray photon → Electron (e^-) + Positron (e^+)

(b) Pair annihilation : Electron (e^-) + Positron (e^+) → Two gamma ray photons

(c) Radioactive decay : ${}^{238}_{92}U \longrightarrow {}^{234}_{90}Th + {}^{4}_{2}He$

Coulomb's Law : Force between two point charges

$F = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q_1 q_2}{r^2}$ (Force on each charge due to the other when charges are kept in vacuum or air).

Points to Remember

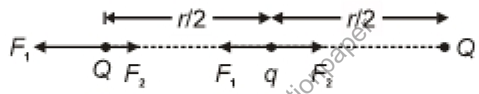
1. Force is attractive when $q_1q_2 < 0$
2. Force is repulsive when $q_1q_2 > 0$
3. Force is two body interaction. Presence of other charges doesn't affect this force.
4. If $q_1 + q_2$ = constant = Q, then force between them will be maximum when $q_1 = q_2 = \frac{Q}{2}$.
5. Minimum force between two charged particles kept in air 1m apart is possible when both are electrons.

   i.e. $F = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{1^2} = 2.303\times10^{-28}\text{N}$

Forces between multiple charges

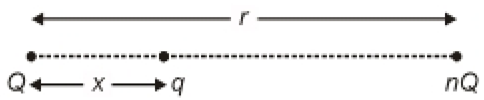
Superposition principles

(1) Two charges Q and Q are separated by a distance r.



(a) A third charge q should be placed at the centre for it to experience zero force, *i.e.*, it should be in equilibrium.

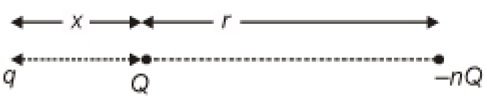
(b) For the complete system to be in equilibrium $q = \frac{-Q}{4}$. [For this find net force on Q and equate to zero]

(2) 

(where $n > 0$) [Q and nQ are of same nature]

(a) For 'q' to be in equilibrium, $x = \frac{r}{1+\sqrt{n}}$. [Remember, x is distance from Q]

(b) For the system to be in equilibrium, $q = \frac{-nQ}{(1+\sqrt{n})^2}$. [Make net force on Q equal to zero]

(3) 

(Q and nQ are of opposite nature, where $n \neq 1$ or $|nQ| > |Q|$)

(a) For q to be in equilibrium, $x = \frac{r}{\sqrt{n}-1}$ [This point is obtained closer to the charge of smaller magnitude]

(b) For the system to be in equilibrium, $q = \frac{-nQ}{(\sqrt{n}-1)^2}$.

If $n = 1$, no such position can be found. (Except at infinite distance)

Electric Field : $\vec{E} = \lim_{q_0 \to 0} \frac{\vec{F}}{q_0}$, unit : newton/coulomb

Dimensional formula : $[MLT^{-3}A^{-1}]$

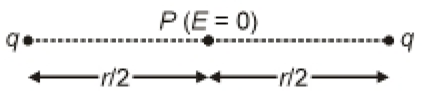
Points to Remember

1. If a charge q is placed in an electric field, it experiences a force $\vec{F} = q\vec{E}$.
2. A positive charge experiences force in the direction of electric field.
3. A negative charge experiences force opposite to direction of electric field.
4. A proton and electron, when kept in same field will experience same force in magnitude but opposite in direction. As their masses are different, their accelerations will be different.

Electric field due to a point charge : The various cases are given below

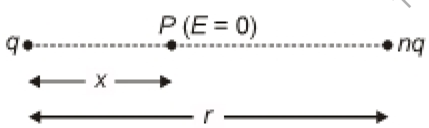
The position of point P where field due to two charges is zero.

(a)



[Both charges are equal and of same nature]

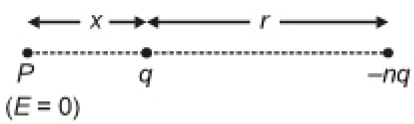
(b)



$n > 0$ [Unequal charges of same nature]

$$x = \frac{r}{1+\sqrt{n}}$$

(c)



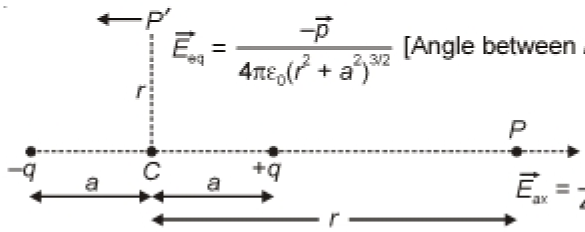
$n \neq 1$, $|nq| > |q|$ [Unequal charges of opposite nature]

$$x = \frac{r}{\sqrt{n}-1}$$

Electric dipole: (n = 1 in above case)

$p = 2aq$ is dipole moment. [Its direction is along $-q$ to $+q$, along dipole axis]

Electric field due to a dipole :



$$\vec{E}_{eq} = \frac{-\vec{p}}{4\pi\varepsilon_0(r^2 + a^2)^{3/2}}$$ [Angle between $\vec{E}$ and $\vec{p}$ = 180°]

$$\vec{E}_{ax} = \frac{1}{4\pi\varepsilon_0}\frac{2\vec{p}r}{(r^2 - a^2)^2}$$ [Angle between $\vec{E}$ and $\vec{p}$ = 0°]

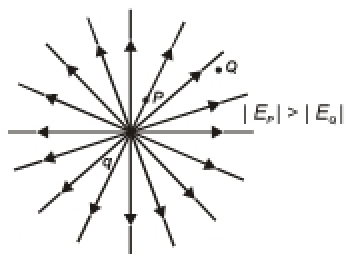
For a short dipole $\overrightarrow{E_{ax}} = \frac{2\vec{p}}{4\pi\varepsilon_0 r^3}$ [$\overrightarrow{E_{ax}}$ = Electric field at axial point/end on position/tan*A* position]

$\overrightarrow{E_{eq}} = \frac{-\vec{p}}{4\pi\varepsilon_0 r^3}$ [$\overrightarrow{E_{eq}}$ = Electric field at equatorial point/broadside on position/ tan *B* position]

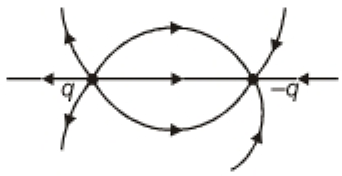
$\Rightarrow \overrightarrow{E_{ax}} = -2\overrightarrow{E_{eq}}$

Electric Field Lines :

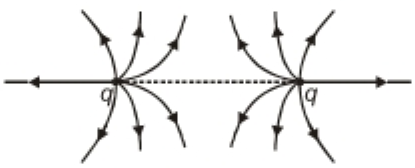
1. It is a curve or straight line, such that tangent drawn at any point gives the direction of electric field.
2. Number density of field lines in a region is proportional to the strength of electric field intensity in that region.
3. They are continuous curves starting from positive charge and terminating at negative charge.
4. Two lines of forces never intersect each other.
5. They contract longitudinally on account of attraction between unlike charges.
6. They exert lateral pressure on each other on account of repulsion between like charges.
7. If a charge particle is released from rest or with a velocity parallel to field lines (which should be straight), then it will move along field lines otherwise it will not move along them.



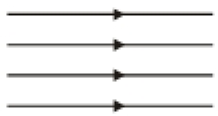
(a) Isolated point charge



(b) Equal and opposite charges

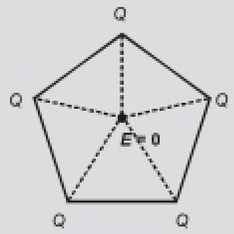


(c) Identical charges



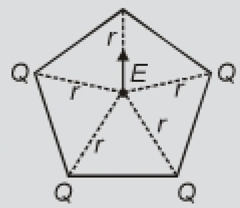
(d) Parallel, equispaced lines represent uniform electric field

***Note :** (1) For a regular polygon of n sides having indentical n point charges, 'Q' each at its vertices, E at centre is zero.*



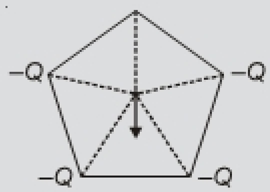
(2) If only one charge is removed, field at the centre is $\frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$ towards the empty vertex. r is distance of each vertex from centre. [Reverse is the case when charges are of negative type(away from empty vertex)]

(i) (A)

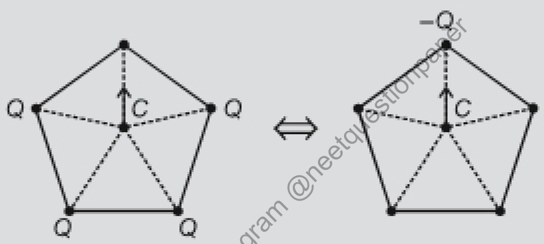


$E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$

(B)

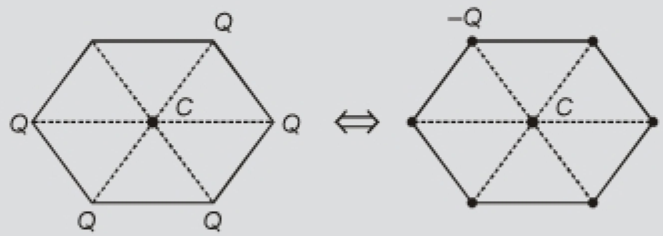


(ii)



i.e., In both cases, field at the centre will be same.

(iii)



Clearly, both arrangements will have same field at the centre.

Torque on Dipole in a Uniform Electric Field

A dipole placed in a uniform electric field at angle 'θ' between dipole moment $(\vec{p})$ and electric field $(\vec{E})$.

The net force on dipole is zero *i.e.*, $\vec{F}_{net} = 0$, Torque $\vec{\tau} = \vec{p} \times \vec{E}$

Potential energy $U = -\vec{p}.\vec{E}$ (taking zero of potential energy at θ = 90°)

(1) When $\theta = 0°$, $F = 0$, $\tau = 0$, U = minimum = $-pE$ [stable equilibrium]

(2) When $\theta = 90°$, $F = 0$, τ = maximum = pE, $U = 0$ [zero potential energy]

(3) When $\theta = 180°$, $F = 0$, $\tau = 0$, U = maximum = pE [unstable equilibrium]

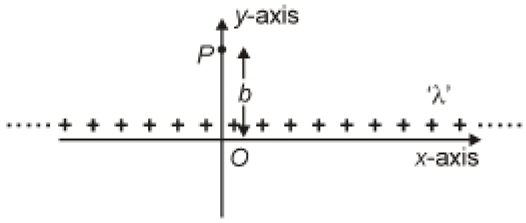
(4) Work done by external force, in rotating the dipole from initial position θ_1 to θ_2, $W = pE\,[\cos\theta_1 - \cos\theta_2]$

(5) When $\theta_1 = 0°$, $\theta_2 = 180°$, $W = 2pE$ (Work done by external force to turn a dipole from stable to unstable equilibrium)

(6) Work done means work done by external agent. Work done by electric field is negative of the work done by external agent.

Continuous Charge Distribution

Field due to Infinitely long straight wire

(a) 

$$\vec{E}_P = \frac{\lambda}{2\pi\varepsilon_0 b}\,\hat{j} \text{ (along } y\text{-axis)}$$

λ = linear charge density

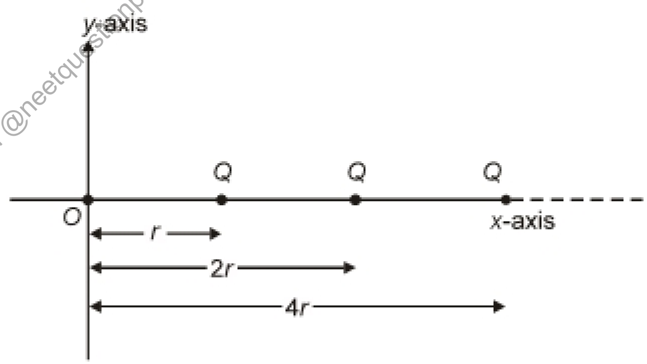
Infinite number of charges placed along x-axis

Electric field at O.

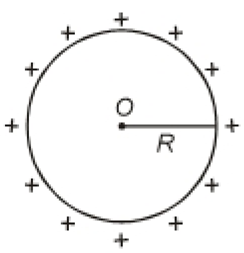
$$E_0 = \frac{Q}{4\pi\varepsilon_0 r^2}\left[\frac{1}{1^2}+\frac{1}{2^2}+\frac{1}{4^2}+\ldots\right]$$

$$= \frac{Q}{4\pi\varepsilon_0 r^2}\left[1+\frac{1}{4}+\frac{1}{16}+\ldots\right]$$

$$= \frac{Q}{4\pi\varepsilon_0 r^2}\times\frac{1}{\left(1-\frac{1}{4}\right)} = \frac{Q}{3\pi\varepsilon_0 r^2}$$



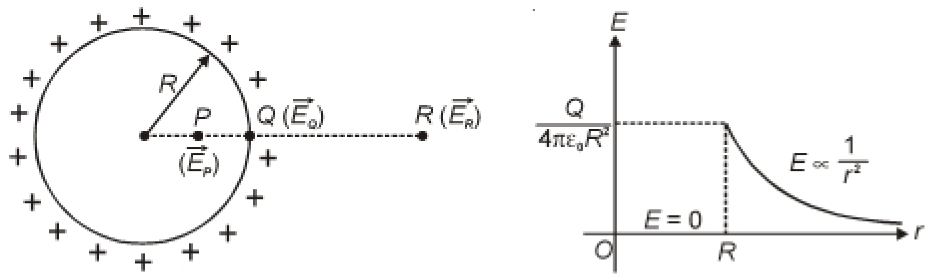
(b) A ring having uniformly distributed charge.



$E_0 = 0$

Field due to uniformly charged thin spherical shell (field inside and outside)

Metallic sphere or a hollow spherical shell with charge Q and surface charge density $\sigma = \frac{Q}{4\pi R^2}$



(a) At P, $E_P = 0$ (inside) ($r < R$)

(b) At R, $E_R = \dfrac{Q}{4\pi\varepsilon_0 r^2}$ (outside) ($r \geq R$)

(c) At Q, $E_Q = \dfrac{Q}{4\pi\varepsilon_0 R^2}$ (just near the surface, outside) ($r = R$)

or $E_Q = \dfrac{\sigma}{\varepsilon_0}$

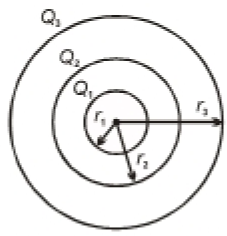
Concentric hollow shells

(a) For $r < r_1$, $E = 0$

(b) For $r_1 \leq r < r_2$, $E = \dfrac{Q_1}{4\pi\varepsilon_0 r^2}$

(c) For $r_2 \leq r < r_3$, $E = \dfrac{Q_1 + Q_2}{4\pi\varepsilon_0 r^2}$

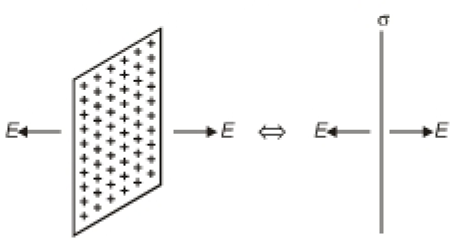
(d) For $r \geq r_3$, $E = \dfrac{Q_1 + Q_2 + Q_3}{4\pi\varepsilon_0 r^2}$



Concentric hollow shells

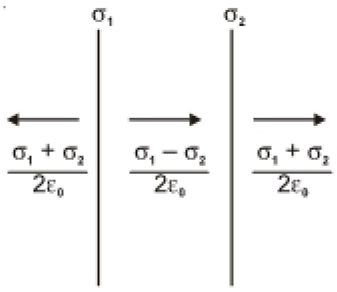
Field due to uniformly charged inifinite plane sheet

An infinite plane sheet of charge having surface charge density 'σ'.

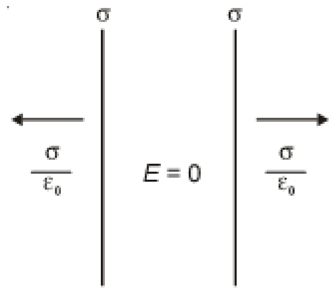


$E = \dfrac{\sigma}{2\varepsilon_0}$

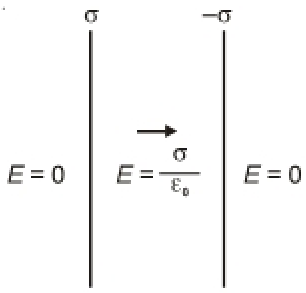
(i)



(ii) $\sigma_1 = \sigma_2 = \sigma$



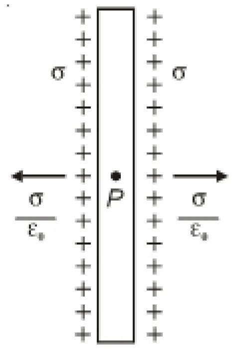
(iii)



$\sigma_1 = \sigma$

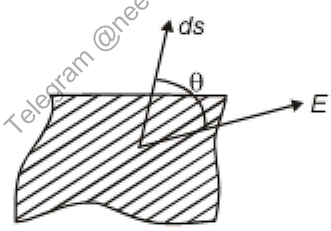
$\sigma_2 = -\sigma$

(iv) Metallic sheet



at point P, $E = 0$

Electric flux : It is the number of field lines crossing a given surface in a direction normal to it.



$$d\phi = \vec{E} \cdot \vec{ds}$$

$$\phi = \int \vec{E} \cdot \vec{ds}$$

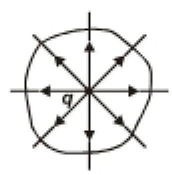
Units : Nm^2/C or Vm (volt-metre). $[ML^3T^{-3}A^{-1}]$

Statement of Gauss's Theorem

Total electric lines of force that originate from a charge q are $\frac{q}{\varepsilon_0}$.

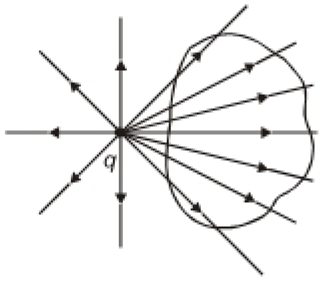
1. A closed surface has charge 'q' enclosed in it. By Gauss law, total field lines = $\frac{q}{\varepsilon_0}$

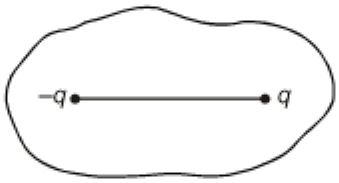
$$\therefore \quad \phi = \frac{q_{\text{enclosed}}}{\varepsilon_0}$$



2. (a) If no charge is enclosed ⇒ $\phi = 0$

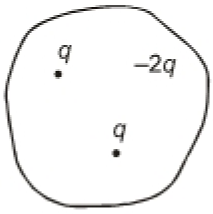
(b) Number of field lines entering the closed surface = Number of field lines leaving the closed surface. Therefore $\phi = 0$. (charge is placed outside)



3. 

$\phi = 0$

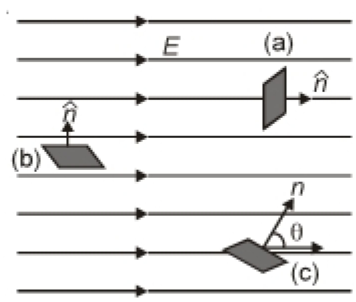
$\because \quad q_{enclosed} = 0$

4. 

$\phi = 0$

> ***Note :*** *Flux linked with a closed surface is independent of shape and size of the surface. It depends only on the charge enclosed.*

Applications



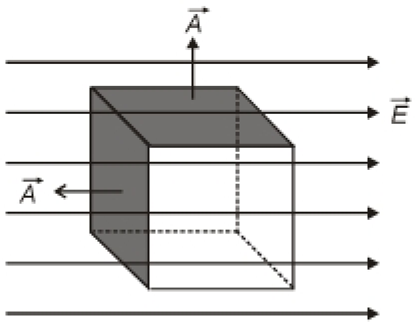
(1) E = strength of electric field

(a) $\phi = EA$

(b) $\phi = 0. \quad \because \quad \vec{E}.\vec{A} = 0$

(c) $\phi = EA \cos\theta$

(2) A cube of side '*a*' is kept in a uniform electric field $\vec{E}$.



(a) $\phi_{top} = \phi_{bottom} = 0$ [$\because$ $\theta = 90°$]

(b) $\phi_{left} = \vec{E}.\vec{A} = -Ea^2$

(c) $\phi_{right} = \vec{E}.\vec{A} = Ea^2$

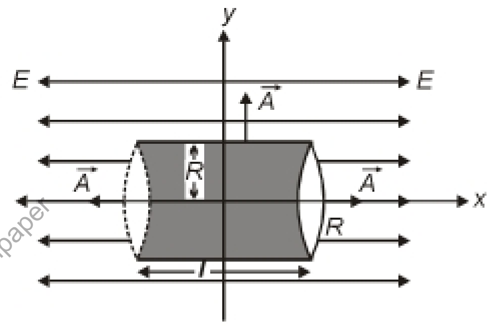
(d) $\phi_{front} = \phi_{back} = 0$ [$\because$ $\theta = 90°$]

Total flux linked with the cube $\phi = 0$

(3) In a region of space, the electric field is given by

$\vec{E} = E_0\hat{i}$ for $x > 0$

$= -E_0\hat{i}$ for $x < 0$



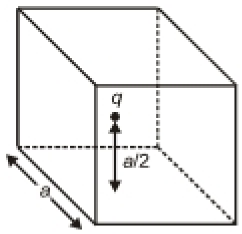
(a) $\phi_{curved} = 0$ [$\theta = 90°$]

(b) $\phi_{base\ left} = \vec{E}.\vec{A} = \pi R^2 E$ [$\theta = 0°$]

(c) $\phi_{base\ right} = \pi R^2 E$ [$\theta = 0°$]

(d) $\phi_{total} = 2\pi R^2 E = \dfrac{q_{enclosed}}{\varepsilon_0} \Rightarrow q_{enclosed} = 2\pi R^2 E\varepsilon_0$

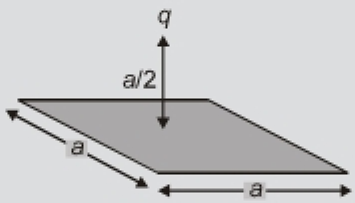
(4) A charge *q* is kept at the centre of cube.



(a) Flux linked with cube = $\dfrac{q}{\varepsilon_0}$

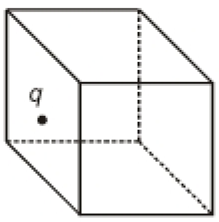
(b) Flux linked with each face = $\dfrac{q}{6\varepsilon_0}$

***Note :** Flux linked with the shown surface =* $\dfrac{q}{6\varepsilon_0}$

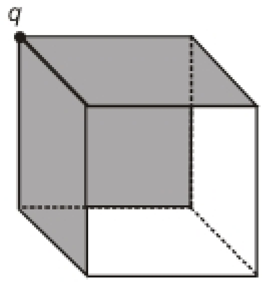


(5) *q* is kept at face centre of a cube

Flux linked with cube = $\dfrac{q}{2\varepsilon_0}$



(6) q is kept at the vertex of a cube



(a) Flux linked with the cube = $\frac{q}{8\varepsilon_0}$

(b) Flux linked with shaded faces = zero

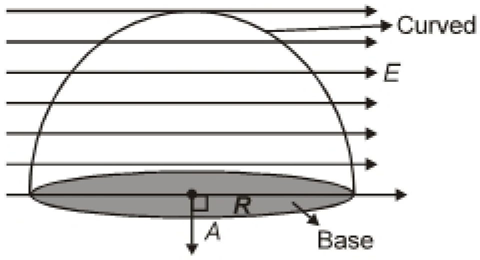
(c) Flux linked with each unshaded face = $\frac{q}{24\varepsilon_0}$

(7) A hemispherical bowl (closed) of radius R is kept in uniform electric field E.

(a) Flux linked with base = 0 [θ = 90°]

Flux linked with completed body = 0 [$q_{enclosed}$ = 0]

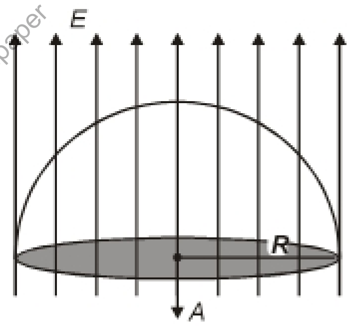
Flux linked with curved surface = 0



(b) $\phi_{base} = -E\pi R^2$ [θ = 180°]

$\phi_{total} = 0$ [$q_{enclosed}$ = 0]

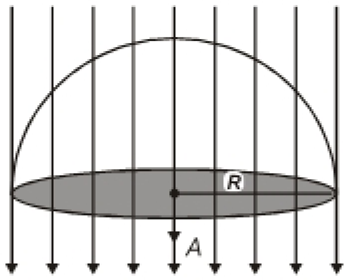
$\therefore$ $\phi_{curved} = \pi R^2 E$



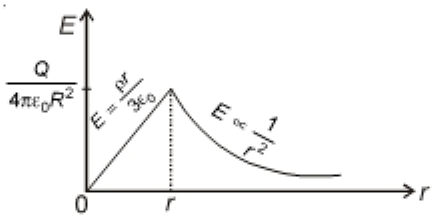
(c) $\phi_{base} = \pi R^2 E$ [θ = 0]

$\phi_{total} = 0$ [$q_{enclosed}$ = 0]

$\therefore$ $\phi_{curved} = -\pi R^2 E$



(8) Electric field due to a charge uniformly distributed in a spherical volume.



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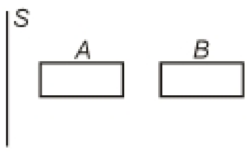
Try Yourself

SECTION - A

Objective Type Questions

1. Two identical metallic spheres X and Y have exactly equal masses. Now X is positively charged and Y is given an equal negative charge. Then after charging
   (1) Masses of X and Y are equal
   (2) Mass of Y is greater than X
   (3) Mass is not involved
   (4) Mass of X is greater than Y

2. A large non-conducting sheet S is given a uniform positive charge density. Two uncharged small metal plates A and B are placed near the sheet as shown. Which of the following is false?



   (1) S attracts A (2) S attracts B
   (3) A attracts B (4) None of these

3. Two identical metal balls with charges $2Q$ and $-Q$ are separated by some distance and exert a force F on each other. They are joined by a conducting wire, and then separated by same distance.The force between them is now
   (1) F (2) $F/2$
   (3) $F/4$ (4) $F/8$

4. A charge q_1 exerts some force on a second charge q_2. If a third charge q_3 is brought near, then the force exerted on q_2 by q_1 will
   (1) Increase in magnitude
   (2) Decrease in magnitude
   (3) Remain unchanged
   (4) Increase if q_3 is of the same sign as q_1 and will decrease if q_3 is of opposite sign

5. A charge Q is divided into two parts which are then kept at some distance apart. The force between them will be maximum, if the two parts are
   (1) $\frac{Q}{2}$ each
   (2) $\frac{Q}{4}$ and $\frac{3Q}{4}$
   (3) $\frac{Q}{3}$ and $\frac{2Q}{3}$
   (4) e and $(Q - e)$, where e is the electronic charge

6. Two point charges placed at a distance r in vacuum experience a certain force. The distance at which they will experience the same force in a medium of dielectric constant K is
   (1) $\frac{r}{K}$ (2) Kr
   (3) $\frac{r}{\sqrt{K}}$ (4) $r\sqrt{K}$

7. Three particles have charges +20 μC each. They are fixed at the corners of an equilateral triangle of side 0.5 m. The force on each of the particle has magnitude
   (1) Zero (2) 14.4 N
   (3) 28.8 N (4) $14.4\sqrt{3}$ N

8. A charge q is placed at the centre of the line joining two equal charges Q. The system of 3 charges will be in equilibrium if q is equal to
   (1) $-Q/2$ (2) $-Q/4$
   (3) $+Q/4$ (4) $+Q/2$

9. An electric dipole is placed in a uniform electric field $\vec{E}$ such that the dipole moment $\vec{p}$ makes an angle $\beta(\neq 0)$ with $\vec{E}$. The force and torque are respectively given by
   (1) $0, \vec{p}\times\vec{E}$ (2) $\vec{p}\times\vec{E}, \vec{p}\times\vec{E}$
   (3) $\vec{p}\times\vec{E}, 0$ (4) $\vec{p}\times\vec{E}, \vec{E}\times\vec{p}$

10. An electron moves with velocity $\vec{v}$ in x-direction. An electric field acts on it in +ve y-direction. The force on the electron acts along

(1) +ve direction of y-axis

(2) –ve direction of y-axis

(3) +ve direction of z-axis

(4) –ve direction of z-axis

11. The trajectory of a charged particle projected in a uniform perpendicular electric field is a

(1) Straight line (2) Ellipse

(3) Helix (4) Parabola

12. The angle between the electric dipole moment and the electric field strength due to it on the equatorial line is

(1) 0° (2) 90°

(3) 180° (4) 45°

13. A proton and an electron are placed in a uniform electric field. Which of the following is correct?

(1) The electric forces acting on them will be equal

(2) The magnitudes of electric forces acting on them will be equal

(3) Their accelerations will be equal

(4) The magnitude of their acceleration will be equal

14. The insulation property of air breaks down at 3×10^6 (volt/m). The maximum charge that can be given to a sphere of diameter 5 m is nearly

(1) 2×10^{-2} C (2) 2×10^{-3} C

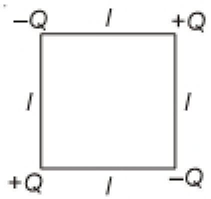
(3) 2×10^{-4} C (4) 2×10^{-5} C

15. In a regular polygon of n sides, each corner is at a distance r from the centre. Identical charges of magnitude q are placed at (n – 1) corners. The field at the centre is

(1) $\frac{Kq}{r^2}$ (2) $(n-1)\frac{Kq}{r^2}$

(3) $\frac{n}{(n-1)}\frac{Kq}{r^2}$ (4) $\frac{(n-1)}{n}\frac{Kq}{r^2}$

16. Find resultant dipole moment of system.



(1) Zero (2) 2QL

(3) $\sqrt{2}\,Ql$ (4) Ql

17. A and B are two points on the axis and the perpendicular bisector respectively of an electric dipole. A and B are far away from the dipole and at equal distances from its centre. The fields at A and B i.e. $\overrightarrow{E_A}$ and $\overrightarrow{E_B}$ are respectively such that

(1) $\overrightarrow{E_A} = \overrightarrow{E_B}$ (2) $\overrightarrow{E_A} = 2\overrightarrow{E_B}$

(3) $\overrightarrow{E_A} = -2\overrightarrow{E_B}$ (4) $\overrightarrow{E_A} = \frac{1}{2}\overrightarrow{E_B}$

18. The electric field at the centre of a uniformly charged ring is zero. What is the electric field at the centre of a half ring if the charge on it be Q and its radius be R?

(1) $\frac{1}{4\pi\varepsilon_0}\frac{Q}{\pi R^2}$ (2) $\frac{1}{4\pi\varepsilon_0}\frac{Q}{R^2}$

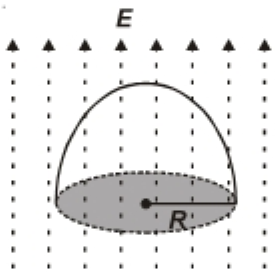
(3) $\frac{1}{4\pi\varepsilon_0}\frac{2Q}{\pi R^2}$ (4) $\frac{1}{4\pi\varepsilon_0}\frac{2Q}{R^2}$

19. A charge Q is uniformly distributed throughout the volume of a non conducting solid sphere of radius R. The dielectric constant of the material is 1. The electric field intensity at a distance r (< R) from the centre is

(1) $\frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$ (2) Zero

(3) $\frac{1}{4\pi\varepsilon_0}\frac{Qr}{R^3}$ (4) $\frac{Q}{4\pi\varepsilon_0}\left[\frac{1}{r^2}-\frac{r}{R^3}\right]$

20. Figure shows a hemispherical surface of radius R in uniform electric field $\vec{E}$. The electric flux linked with the curved surface of the hemisphere is



(1) Zero

(2) $2\pi R^2E$

(3) πR^2E

(4) $3\pi R^2E$

SECTION - B

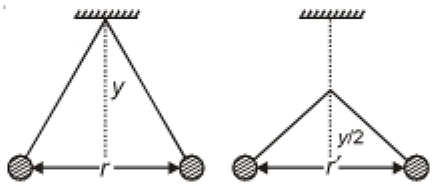
Previous Years Questions

1. What is the flux through a cube of side a if a point charge of q is at one of its corner? **[AIPMT 2012]**

(1) $\frac{q}{\varepsilon_0}$ (2) $\frac{q}{2\varepsilon_0}6a^2$

(3) $\frac{2q}{\varepsilon_0}$ (4) $\frac{q}{8\varepsilon_0}$

2. Two pith balls carrying equal charges are suspended from a common point by strings of equal length, the equilibrium separation between them is r. Now the strings are rigidly clamped at half the height. The equilibrium separation between the balls now become **[NEET-2013]**



(1) $\left(\frac{r}{\sqrt[3]{2}}\right)$ (2) $\left(\frac{2r}{\sqrt{3}}\right)$

(3) $\left(\frac{2r}{3}\right)$ (4) $\left(\frac{1}{\sqrt{2}}\right)^2$

3. Two identical charged spheres suspended from a common point by two massless strings of lengths l, are initially at a distance $d(d << l)$ apart because of their mutual repulsion. The charges begin to leak from both the spheres at a constant rate. As a result, the spheres approach each other with a velocity v. Then v varies as a function of the distance x between the spheres, as

[NEET-2016]

(1) $v \propto x^{-1}$ (2) $v \propto x^{\frac{1}{2}}$

(3) $v \propto x$ (4) $v \propto x^{-\frac{1}{2}}$

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

[NEET (Phase-2) 2016]

(1) 8 mC (2) 2 mC

(3) 5 mC (4) 7 μC

5. Suppose the charge of a proton and an electron differ slightly. One of them is $-e$, the other is $(e + \Delta e)$. If the net of electrostatic force and gravitational force between two hydrogen atoms placed at a distance d (much greater than atomic size) apart is zero, then Δe is of the order of [Given mass of hydrogen $m_h = 1.67 \times 10^{-27}$ kg]

[NEET-2017]

(1) 10^{-20} C (2) 10^{-23} C

(3) 10^{-37} C (4) 10^{-47} C

6. A toy car with charge q moves on a frictionless horizontal plane surface under the influence of a uniform electric field $\vec{E}$. Due to the force $q\vec{E}$, its velocity increases from 0 to 6 m/s in one second duration. At that instant the direction of the field is reversed. The car continues to move for two more seconds under the influence of this field. The average velocity and the average speed of the toy car between 0 to 3 seconds are respectively **[NEET-2018]**

(1) 2 m/s, 4 m/s (2) 1 m/s, 3 m/s

(3) 1.5 m/s, 3 m/s (4) 1 m/s, 3.5 m/s

7. An electron falls from rest through a vertical distance h in a uniform and vertically upward directed electric field E. The direction of electric field is now reversed, keeping its magnitude the same. A proton is allowed to fall from rest in it through the same vertical distance h. The time of fall of the electron, in comparison to the time of fall of the proton is **[NEET-2018]**

(1) Smaller (2) 5 times greater

(3) Equal (4) 10 times greater

8. A hollow metal sphere of radius R is uniformly charged. The electric field due to the sphere at a distance r from the centre **[NEET-2019]**

(1) Increases as r increases for $r < R$ and for $r > R$

(2) Zero as r increases for $r < R$, decreases as r increases for $r > R$

(3) Zero as r increases for $r < R$, increases as r increases for $r > R$

(4) Decreases as r increases for $r < R$ and for $r > R$

9. A sphere encloses an electric dipole with charges $\pm 3 \times 10^{-6}$ C. What is the total electric flux across the sphere? **[NEET-2019 (Odisha)]**

(1) 6×10^{-6} Nm²/C (2) -3×10^{-6} Nm²/C

(3) Zero (4) 3×10^{-6} Nm²/C

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Chapter 2

Electrostatic Potential and Capacitance

Sub-topics *Electric potential, potential difference, electric potential due to a point charge, a dipole and system of charges: equipotential surfaces, electrical potential energy of a system of two point charges and of electric diploes in an electrostatic field. Conductors and insulators, free charges and bound charges inside a conductor. Dielectrics and electric polarization, capacitors and capacitance, combination of capacitors in series and in parallel, capacitance of a parallel plate capacitor with and without dielectric medium between the plates, energy stored in a capacitor, Van de Graaff generator.*

Electric potential

Potential at a point, $V = -\int_{\infty}^{r} \vec{E} \cdot \vec{dr}$.

The unit of electric potential is $\frac{J}{C}$ or volt. Dimensional formula : $[ML^2T^{-3}A^{-1}]$

Potential Difference

Potential difference between two points :-

1. Close to each other, $dV = -\vec{E} \cdot \vec{dr}$

2. In general, $V_B - V_A = -\int_{r_A}^{r_B} \vec{E} \cdot \vec{dr}$

   $\vec{E} = E_x\hat{i} + E_y\hat{j} + E_z\hat{k}$, $\vec{dr} = dx\hat{i} + dy\hat{j} + dz\hat{k}$

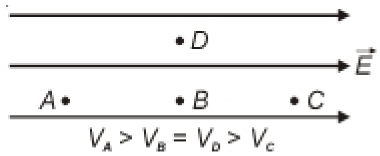
   $V_B - V_A = -\int_{x_A}^{x_B} E_x dx - \int_{y_A}^{y_B} E_y dy - \int_{z_A}^{z_B} E_z dz$

   (a) The direction of electric field is always in the direction of decreasing potential.

   (b) In a direction perpendicular to electric field, electrostatic potential is constant.

   (c) When a positive charge is free to move in a region. It will move from higher potential to lower potential.

   (d) When a negative charge is free to move in a region, it will move from lower potential to higher potential.



Electric potential due to a point charge

$dV = -\vec{E}.\vec{dr}$, if $\vec{E}$ and $\vec{dr}$ are along same direction, then $dV = -Edr \Rightarrow E = \frac{-dV}{dr}$

$\Rightarrow \quad E_x = \frac{-\partial V}{\partial x}, E_y = \frac{-\partial V}{\partial y}, E_z = \frac{-\partial V}{\partial z}$; therefore $\vec{E} = E_x(\hat{i}) + E_y(\hat{j}) + E_z(\hat{k})$

Potential is a scalar while electric field is a vector.

Potential due to a point charge is

$$V_P = \frac{Q}{4\pi\varepsilon_0 r}$$

Electric potential due to a dipole

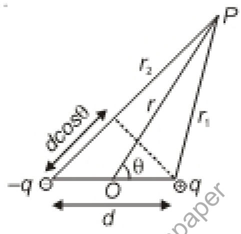


Figure shows a dipole of dipole moment $p = qd$. The line OP makes an angle θ with the dipole axis.

The potential at P due to the positive charge $(+q)$ is

$$V_1 = \frac{1}{4\pi\varepsilon_0}\frac{q}{r_1}$$

and that due to negative charge $(-q)$ is

$$V_2 = \frac{1}{4\pi\varepsilon_0}\frac{-q}{r_2}$$

$\therefore$ The net potential at P is

$$V = V_1 + V_2$$

$$= \frac{1}{4\pi\varepsilon_0}\left(\frac{q}{r_1} - \frac{q}{r_2}\right) = \frac{q}{4\pi\varepsilon_0}\left(\frac{r_2 - r_1}{r_1 r_2}\right) \quad \text{... (i)}$$

For a small dipole, we have usually $r >> d$, where d is the separation between the two charges. Under these conditions, we may write $r_2 - \boldsymbol{r}_1 \approx d\cos\theta$ and $r_1\boldsymbol{r}_2 \approx r^2$. Using these quantities in eq. (i), we get

$$V = \frac{q}{4\pi\varepsilon_0}\frac{d\cos\theta}{r^2}$$

or $V = \frac{p\cos\theta}{4\pi\varepsilon_0 r^2}$ (where $p = qd$, is the magnitude of electric dipole moment)

Electric potential due to a system of charges

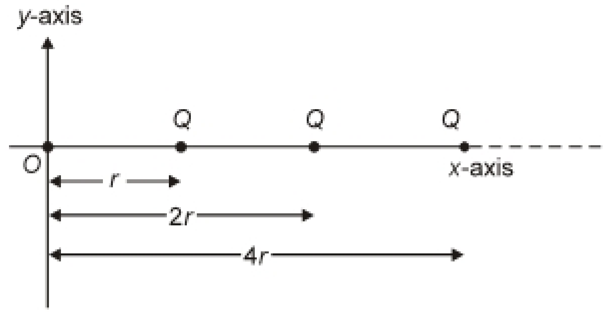
Potential due to a group of charges

(a) Infinite number of charges are placed along x-axis.

Electric potential at O,

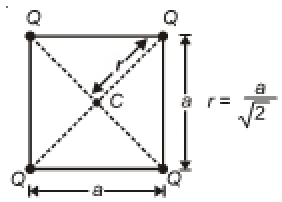
$$V_0 = \frac{Q}{4\pi\varepsilon_0 r}\left[1+\frac{1}{2}+\frac{1}{4}+....\right]$$

$$= \frac{Q}{4\pi\varepsilon_0 r}\left[\frac{1}{1-1/2}\right] = \frac{2Q}{4\pi\varepsilon_0 r}$$



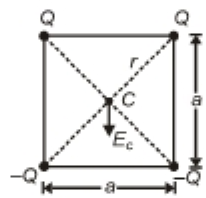
(b) $V_C = \frac{4Q}{4\pi\varepsilon_0 r}$

$E_C = 0$



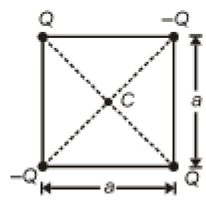
(c) $V_C = 0$

$E_C = \frac{2Q}{4\pi\varepsilon_0 r^2}\sqrt{2}$



(d) $V_C = 0$

$E_C = 0$



From the above cases it is clear that,

(1) $E = 0,\ V \neq 0$.

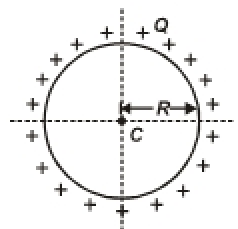
(2) $V = 0,\ E \neq 0$.

(3) $E = 0,\ V = 0$.

(4) $E \neq 0,\ V \neq 0$.

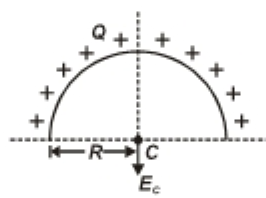
(e) $E_C = 0$

$V_C = \frac{Q}{4\pi\varepsilon_0 R}$



(f) $E_C = \frac{2Q}{4\pi\varepsilon_0 \pi R^2} = \frac{\lambda}{2\pi\varepsilon_0 R}$ (λ = charge per unit length)

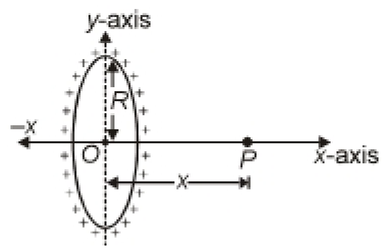
$V_C = \frac{Q}{4\pi\varepsilon_0 R}$



(g) Uniformly charged ring in y-z plane,

$$E_P = \frac{Q}{4\pi\varepsilon_0}\frac{x}{(R^2+x^2)^{3/2}} \text{ along } x\text{-axis}$$

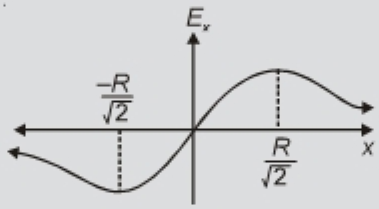
$$V_P = \frac{Q}{4\pi\varepsilon_0}\frac{1}{\sqrt{R^2+x^2}}$$



Note :

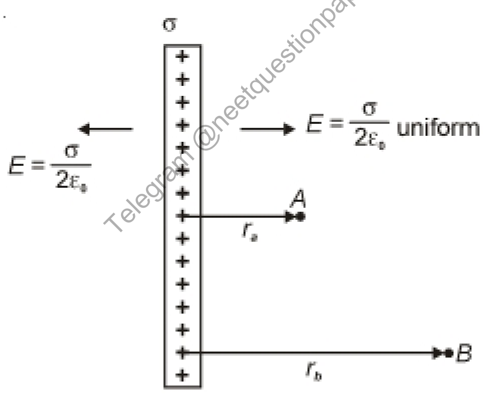
E = maximum at $x = \pm\frac{R}{\sqrt{2}}$

$$E_{max} = \frac{1}{4\pi\varepsilon_0}\frac{2Q}{3\sqrt{3}R^2}$$



(h) Thin sheet of charge

$$V_A - V_B = \frac{\sigma}{2\varepsilon_0}[r_b - r_a]$$

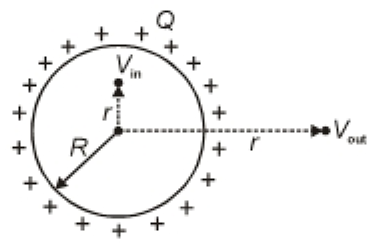


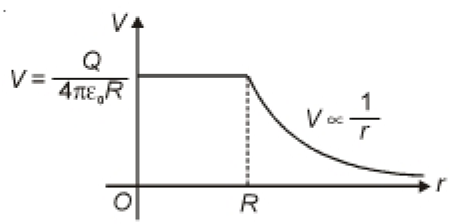
(i) Metallic sphere or hollow shell of charge Q

$$V_{out} = \frac{Q}{4\pi\varepsilon_0 r} \qquad r > R$$

V_{in} = Constant = $V_{surface}$

$$V_{in} = \frac{Q}{4\pi\varepsilon_0 R} \qquad \text{(anywhere inside)}$$





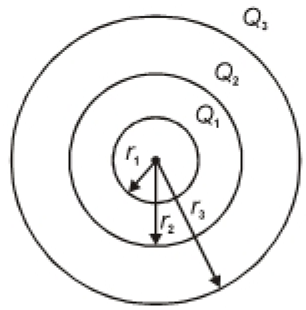
(j) Concentric metallic shells

For $r \le r_1$, $V = \dfrac{1}{4\pi\varepsilon_0}\left[\dfrac{Q_1}{r_1} + \dfrac{Q_2}{r_2} + \dfrac{Q_3}{r_3}\right]$

For $r_1 \le r < r_2$, $V = \dfrac{1}{4\pi\varepsilon_0}\left[\dfrac{Q_1}{r} + \dfrac{Q_2}{r_2} + \dfrac{Q_3}{r_3}\right]$

For $r_2 \le r < r_3$, $V = \dfrac{1}{4\pi\varepsilon_0}\left[\dfrac{Q_1 + Q_2}{r} + \dfrac{Q_3}{r_3}\right]$

For $r \ge r_3$, $V = \dfrac{Q_1 + Q_2 + Q_3}{4\pi\varepsilon_0 r}$



(k) Potential due to Volumetric Charge Distribution

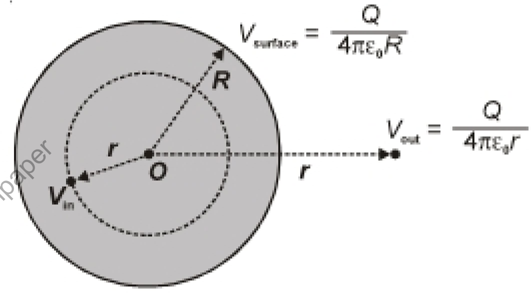
A solid sphere of charge having charge Q, radius R and made of dielectric constant K = 1.

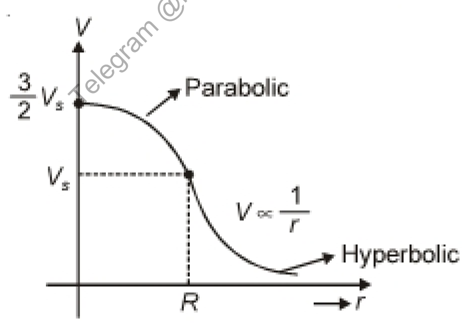
$$\rho = \frac{Q}{\frac{4}{3}\pi R^3}$$

$$V_{in} = \frac{Q}{4\pi\varepsilon_0}\left[\frac{3R^2 - r^2}{2R^3}\right]$$

At centre r = 0

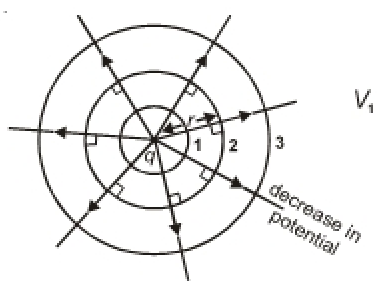
$$V_{centre} = \frac{3}{2}\frac{Q}{4\pi\varepsilon_0 R} = \frac{3}{2}V_{surface}$$





Equipotential Surface

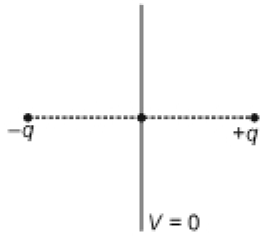
1. It is an imaginary or real surface on which every point is at the same potential.
2. $dV = 0 \Rightarrow \vec{E}.\vec{dr} = 0 \Rightarrow \vec{E} \perp \vec{dr}$. This means that electric field is always normal to equipotential surface.
3. For a point charge, equipotential surfaces are concentric spheres.



$V_1 > V_2 > V_3$ and q is positive

4. Closely spaced equipotential surfaces represent stronger electric field.

5. For a dipole, equatorial plane represents one equipotential surface (i.e. at zero volt).



$$V = \frac{kp\cos\theta}{r^2 - a^2\cos\theta}$$

6. For uniform electric field, equipotential surfaces are parallel equispaced planes perpendicular to electric lines of forces.

   (a) In the direction of electric field potential decreases $V_5 < V_4 < V_3 < V_2 < V_1$

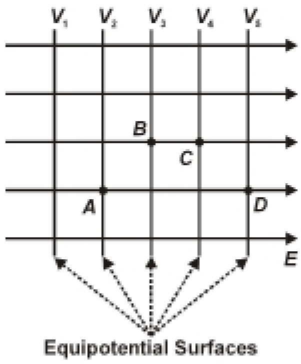
   (b) If a charge 'q' is moved from A to B

      (i) External work done

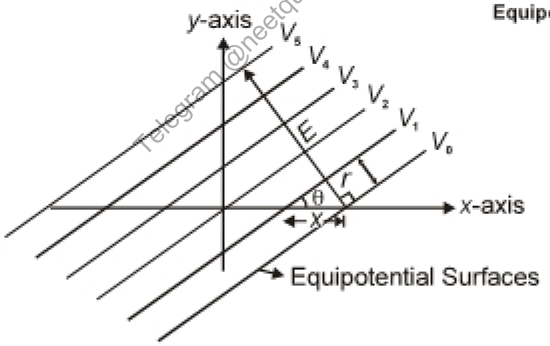
      $W_{AB} = q\,(V_3 - V_2)$

      (ii) Work done by electric field

      $W_{AB} = -q\,(V_3 - V_2)$



7. $V_5 < V_4 < V_3 < V_2 < V_1 < V_0$



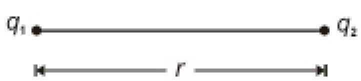
$$|E| = \frac{V_0 - V_1}{r}$$

directed at '90 + θ' with x-axis

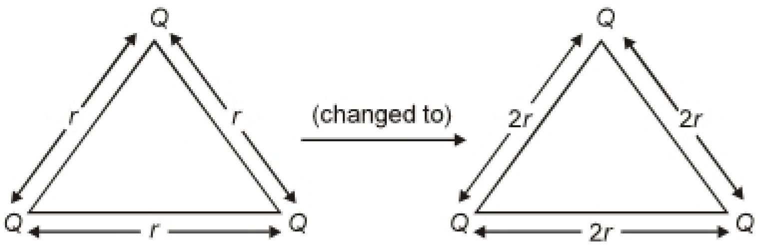
Electrostatic Potential Energy of a system of two point charges

Potential energy of a configuration of charges is the work done by an external force to bring the charges from infinity to their respective position without acceleration.

(1) $U = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r}$ $\begin{bmatrix}(a)\ q_1q_2 > 0,\ U > 0\\ (b)\ q_1q_2 < 0,\ U < 0\end{bmatrix}$



$$F = \frac{-dU}{dr} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2} \text{ [Coulomb's law]}$$

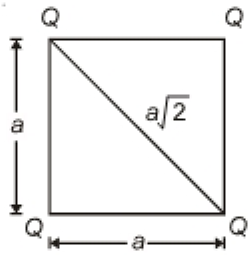
(2) If 

then,

$U_1 = \frac{3 \times Q^2}{4\pi\varepsilon_0 r}$ $\qquad$ $U_2 = \frac{3 \times Q^2}{4\pi\varepsilon_0 (2r)}$

$$W_{ext} = U_2 - U_1 = \frac{3Q^2}{4\pi\varepsilon_0}\left[\frac{1}{2r} - \frac{1}{r}\right] = \frac{-3Q^2}{4\pi\varepsilon_0 (2r)}$$

$$W_{electric\ field} = U_1 - U_2 = \frac{3Q^2}{4\pi\varepsilon_0 (2r)} = -W_{ext}$$

(3) 

$$U = 4 \times \frac{Q^2}{4\pi\varepsilon_0 a} + 2\frac{Q^2}{4\pi\varepsilon_0 (a\sqrt{2})} = \frac{Q^2}{4\pi\varepsilon_0 a}(4 + \sqrt{2}) = \text{P.E. of configuration}$$

Potential Energy of Electric Dipoles in an Electrostatic Field

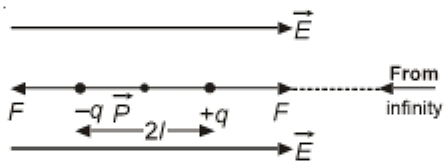
The potential energy of an electric dipole in an electric field is defined as the work done in bringing the dipole from infinity to inside the field.

An electric dipole ($+q$, $-q$) is brought from infinity to a uniform electric field $\vec{E}$ in such a way that the dipole moment $\vec{p}$ is always in the direction of the field. Due to the field $\vec{E}$, a force $\vec{F}$ (= $q\vec{E}$) acts on the charge $+q$ in the direction of the field, and force $\vec{F}$ (= $-q\vec{E}$) on the charge $-q$ in the opposite direction. Hence, in bringing the dipole in the field, work will be done on the charge $+q$ by an external agent, while work will be done by the field itself on the charge $-q$. But, as the dipole is brought from infinity into the field, the charge $-q$ covers $2l$ distance more than the charge $+q$. Therefore, the work done on $-q$ will be greater. Hence the 'net' work done in bringing the dipole from infinity into the field

= force on charge ($-q$) × additional distance moved = $-qE \times 2l = -pE$.

This work is the potential energy U_0 of the electric dipole placed in the electric field parallel to it : $U_0 = -pE$

In this position the electric dipole is in stable equilibrium inside the field.



On rotating the dipole through an angle θ work will have to be done on the dipole. This work is given by $W = pE\ (1 - \cos\theta)$.

This will result in an increase in the potential energy of the dipole. Hence, the potential energy of the dipole in the position θ will be given by

$U_\theta = U_0 + W = -pE + pE\ (1 - \cos\theta)$. or $U_\theta = -pE\cos\theta$ or, $\boxed{U_\theta = -\vec{p}\cdot\vec{E}}$

This is the general equation of the potential energy of the electric dipole.

Note : *When a conductor is placed in an electric field, the free charges present in it start moving under the action of electric field until net electric field becomes zero. Under Static Conditions*

(a) Electric field inside is zero.

(b) At the surface, electric field is normal to the surface.

(c) The surface of the conductor is equipotential surface.

(d) Electric potential is constant throughout the volume of the conductor.

(e) The interior of a conductor has no excess charge.

(f) Charge density is inversely proportional to the radius of curvature, $\sigma \propto \frac{1}{R}$.

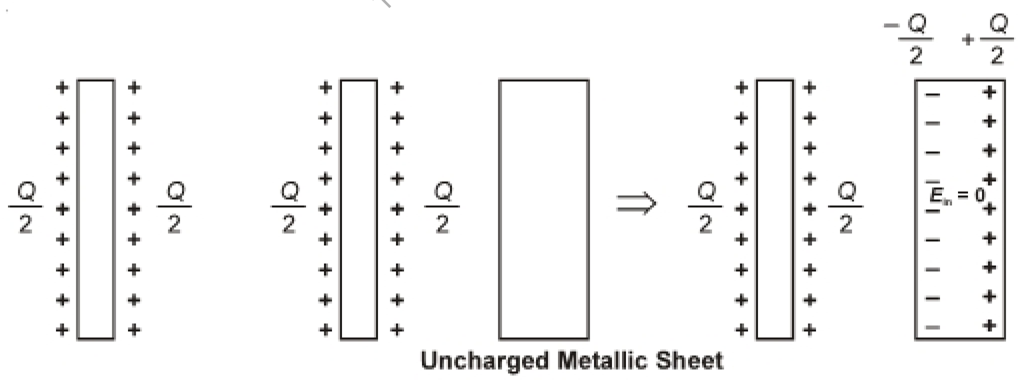
(g) When a conductor is earthed, there is a flow of charge either from earth to conductor or conductor to earth till the potential of conductor becomes zero.

Applications

(1) A metallic sheet is given a charge Q.

(a) It distributes equally on its surface.

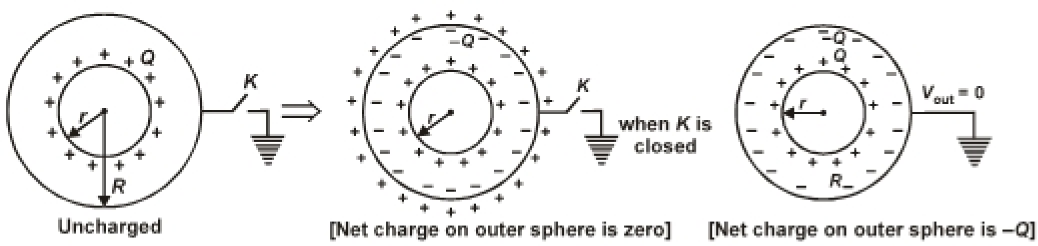
(b) Now an uncharged metallic sheet is brought near it.



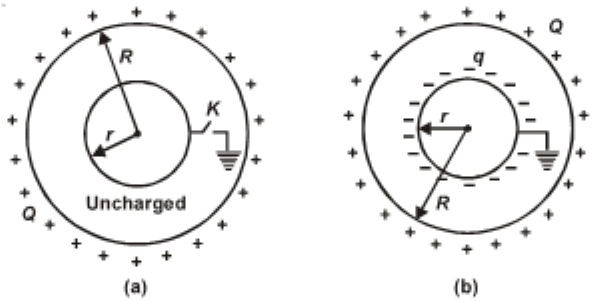
(a) (b)

(2) Two concentric conducting shells

(a)



(b)



No induced charge as $E = 0$

When 'K' is closed, $V_{in} = 0$ and a negative charge appears on its surface given by,

$$q = -\frac{Qr}{R}.$$

Conductors and Insulators

Some materials permit electric charge to move easily from one region of the material to the other. We call such materials "conductors". Metals, tap water, earth and human bodies are examples of conductors. In metals, electrons are the charge carriers but in electrolytes both positive and negative ions are the charge carriers.

Some materials do not permit electric charge to move easily from one region of the material to another. Such materials are called nonconductors or "insulators" or dielectrics. Glass, plastic, silk, fur, drywood, nylon, chemically pure water etc. are some such examples.

When a conductor is isolated, it has "free electrons" but in the presence of other charges these free charges become "bound".

Dielectrics and Electric Polarization

Dielectrics are insulator or nonconducting substances. Polar dielectrics have permanent dipole moments due to the separation between the centres of their positive and negative charges. Molecules of nonpolar dielectrics do not have any permanent dipole moment because the centre of the negative charge coincides with the centre of the positive charge of an atom or a molecule.

When a dielectric material is placed in an electric field the phenomenon of reorientation of polar molecules or the shifting of the positive and negative charge distributions in an atom or in a nonpolar molecule of the material is called the "polarization" of the atom or molecule.

Dielectric constant (K) = $\frac{\text{Electric field in vacuum}}{\text{Net electric field inside the dielectric}} = \frac{E_0}{E}$

$$\vec{D} = \varepsilon_0\vec{E} + \vec{P} = \varepsilon_0\vec{E}_0$$

where $\vec{D}$ is electric displacement and is equal to surface charge density on the capacitor plate.

Capacitors and Capacitance

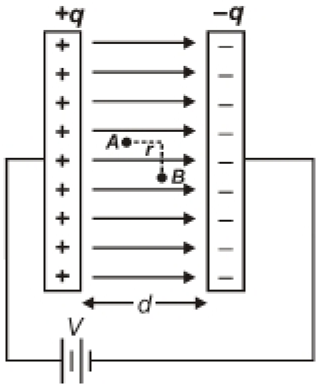
(1) An arrangement of two isolated and oppositely charged conductors is called capacitor.

(2) A capacitor is an arrangement to store electrostatic potential energy in the form of electric field.

(3) $C = \frac{q}{V}$ SI unit of capacitance is coulomb/volt = farad

(4) Energy stored in charged capacitor $U = \frac{1}{2}CV^2 = \frac{q^2}{2C} = \frac{1}{2}qV$

Parallel plate capacitor



(1) $C = \dfrac{\varepsilon_0 A}{d}$

A = Area of plates

d = Distance between them

(2) $V = \vec{E}.\vec{d}$, $V_A - V_B = \dfrac{\sigma}{\varepsilon_0}.r$

(3) $E = \dfrac{\sigma}{\varepsilon_0} = \dfrac{q}{A\varepsilon_0}$ = constant

(4) $U = \dfrac{1}{2}CV^2 = \dfrac{1}{2}\dfrac{\varepsilon_0 A}{d} \times E^2 d^2 = \dfrac{1}{2}\varepsilon_0 E^2 \times A \times d$

(5) $\dfrac{U}{\text{volume}} = \dfrac{1}{2}\varepsilon_0 E^2$ = Electric energy density

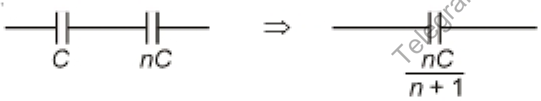
Combination of Capacitors

1. Series combination : $\dfrac{1}{C_{eq}} = \Sigma\dfrac{1}{C}$

2. Parallel combination : $C_{eq} = \Sigma C$

Applications

(1)


(2)


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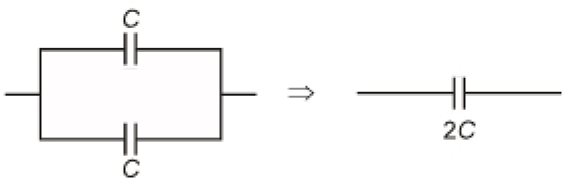
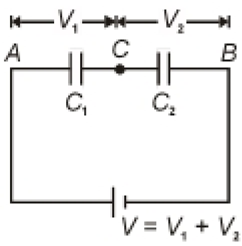


(4) (a) $V_1 = V_A - V_C$

(b) $V_2 = V_C - V_B$

(c) $V_1 = \dfrac{C_2 V}{C_1 + C_2}$, $V_2 = \dfrac{C_1 V}{C_1 + C_2}$

(d) $Q_1 = Q_2 = \dfrac{C_1 C_2}{C_1 + C_2}V$



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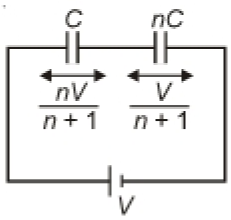
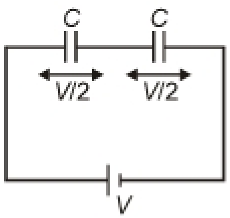
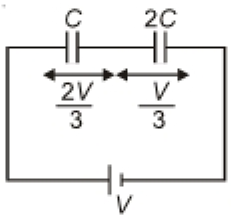
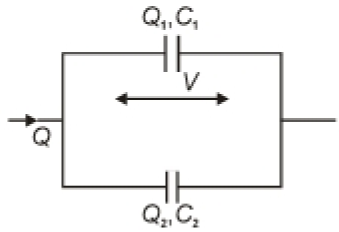


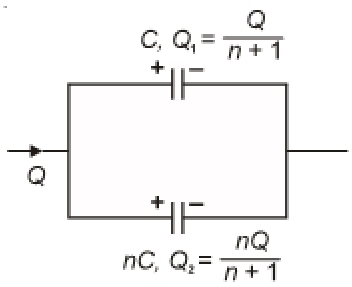
(6) 

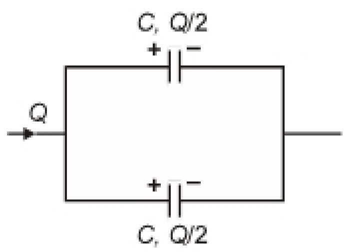
(7) 

(8) (a) $V = \frac{Q_1}{C_1} = \frac{Q_2}{C_2}$



(b) $Q_1 + Q_2 = Q$ $\Rightarrow$ $Q_1 = \frac{C_1 Q}{C_1 + C_2}$, $Q_2 = \frac{C_2 Q}{C_1 + C_2}$

(9) 

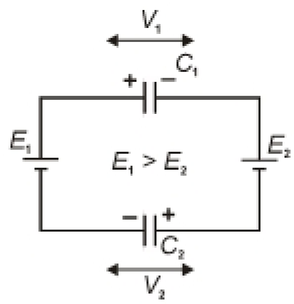
(10) 

(11) (a) $Q = \frac{(E_1 - E_2)(C_1 C_2)}{(C_1 + C_2)}$

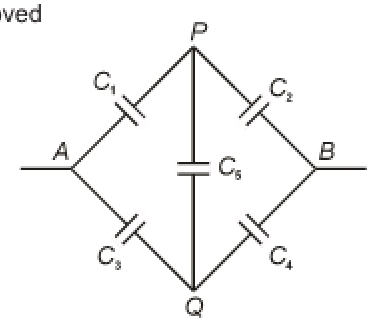
= Same on both capacitors

(b) $V_1 = \frac{C_2}{C_1 + C_2}(E_1 - E_2)$

(c) $V_2 = \frac{C_1}{C_1 + C_2}(E_1 - E_2)$



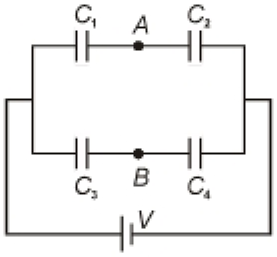
(12) When $\frac{C_1}{C_2} = \frac{C_3}{C_4}$, then $V_P = V_Q$, so C_5 can be removed



$$C_{AB} = \frac{C_1C_2}{C_1 + C_2} + \frac{C_3C_4}{C_3 + C_4}$$

$$= \frac{(C_1 + C_3)(C_2 + C_4)}{C_1 + C_2 + C_3 + C_4}$$

(13) $V_{AB} = \left[\frac{C_1C_4 - C_2C_3}{(C_1 + C_2)(C_3 + C_4)}\right]V$



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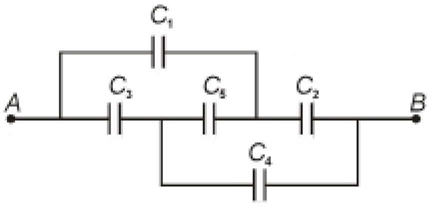

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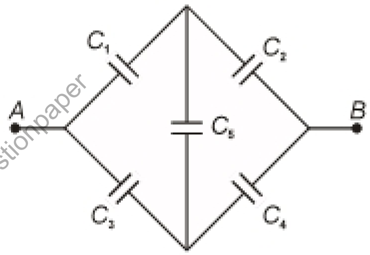

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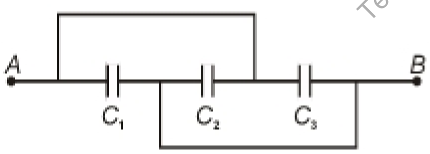

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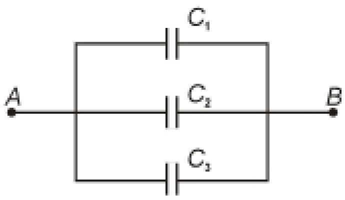
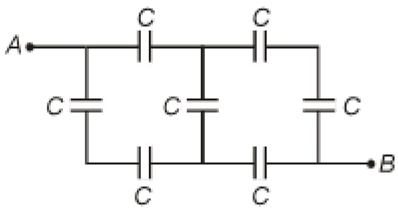


(16) $C_{AB} = \frac{5C}{7}$

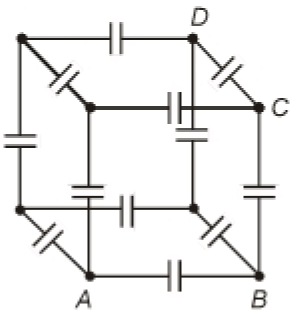


(17) 12 identical capacitors

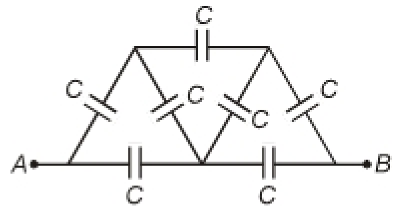
(a) $C_{AB} = \frac{12C}{7} = C_{eq}$, between adjacent corner

(b) $C_{AC} = \frac{4C}{3} = C_{eq}$, between face diagonal

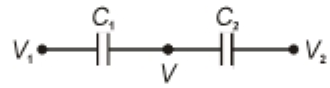
(c) $C_{AD} = \frac{6C}{5} = C_{eq}$, between body diagonal



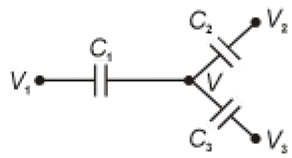
(18) $C_{AB} = \frac{7C}{8}$



(19) $V = \frac{C_1V_1 + C_2V_2}{C_1 + C_2}$

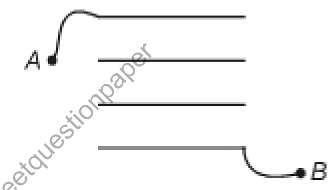


(20) $V = \frac{C_1V_1 + C_2V_2 + C_3V_3}{C_1 + C_2 + C_3}$

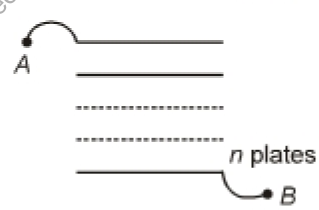


(21) Plates of area A and separation 'd' are arranged as shown

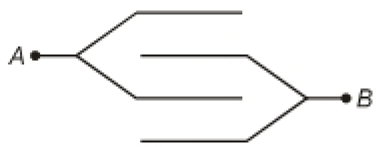
(a) $C_{AB} = \frac{\varepsilon_0 A}{3d}$



(b) $C_{AB} = \frac{\varepsilon_0 A}{(n-1)\,d}$

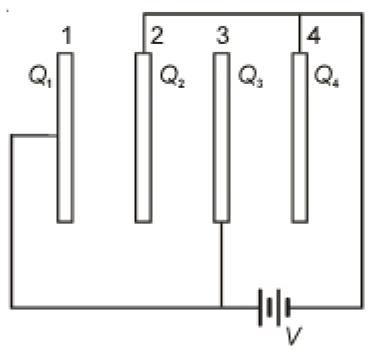


(c) $C_{AB} = \frac{3\varepsilon_0 A}{d}$



(d) n plates connected alternately $C = (n-1)\frac{\varepsilon_0 A}{d}$

(e) $C_{\text{eff}} = \frac{3\varepsilon_0 A}{d}$



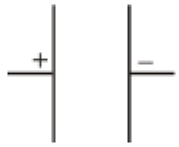
(i) $Q_{\text{total}} = C_{\text{eff}}\,V = \frac{3\varepsilon_0 AV}{d}$

(ii) $Q_1 = \frac{\varepsilon_0 AV}{d}$ (iii) $Q_2 = \frac{-2\varepsilon_0 AV}{d}$

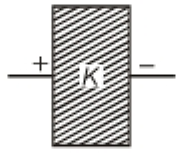
(iv) $Q_3 = \frac{2\varepsilon_0 AV}{d}$ (v) $Q_4 = \frac{-\varepsilon_0 AV}{d}$

Capacitor with Dielectric

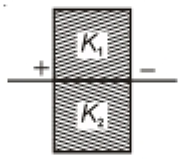
(1) $C = \dfrac{\varepsilon_0 A}{d}$



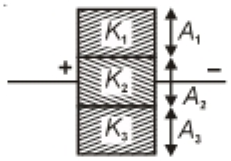
(2) $C = \dfrac{K\varepsilon_0 A}{d}$



(3) $C = \dfrac{(K_1 + K_2)\,\varepsilon_0 A}{2d} \Rightarrow K = \dfrac{K_1 + K_2}{2}$



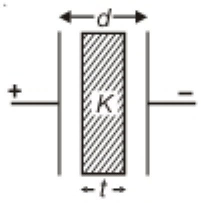
(4) $K = \dfrac{K_1A_1 + K_2A_2 + K_3A_3}{A_1 + A_2 + A_3}, C = \dfrac{K\varepsilon_0 A}{d}$



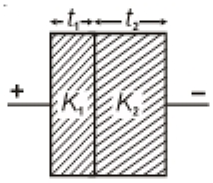
$\Rightarrow$ For n slab each of area $\dfrac{A}{n}$

$$K = \frac{K_1 + K_2 + ... + K_n}{n}$$

(5) $C = \dfrac{\varepsilon_0 A}{d - t + \dfrac{t}{K}}$



(6) $C = \dfrac{\varepsilon_0 A}{\dfrac{t_1}{K_1} + \dfrac{t_2}{K_2}}$



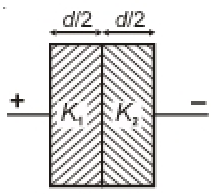
$\Rightarrow \dfrac{t_1 + t_2}{K} = \dfrac{t_1}{K_1} + \dfrac{t_2}{K_2}$

$\Rightarrow$ For n slabs of same thickness $\dfrac{d}{n}$

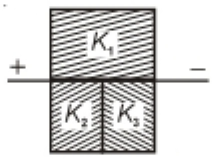
$$\frac{n}{K} = \frac{1}{K_1} + \frac{1}{K_2} + ... + \frac{1}{K_n}$$

$$C = \frac{K\varepsilon_0 A}{(t_1 + t_2)} = \frac{K\varepsilon_0 A}{d}$$

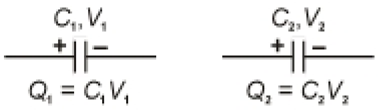
(7) $K = \dfrac{2K_1K_2}{K_1 + K_2}$



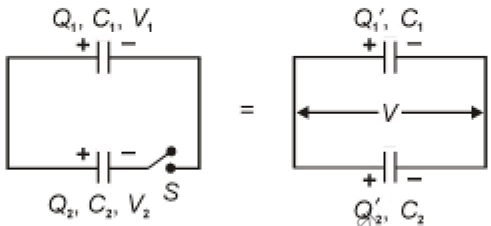
(8) $K = \dfrac{K_1 + \dfrac{2K_2K_3}{K_2 + K_3}}{2}$



Sharing of Charge and Loss of Energy : Two charged capacitors are connected to each other.

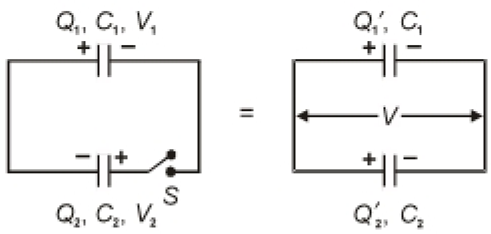


(1) $V = \dfrac{C_1V_1 + C_2V_2}{C_1 + C_2}$, $Q_1' = C_1V, Q_2' = C_2V$



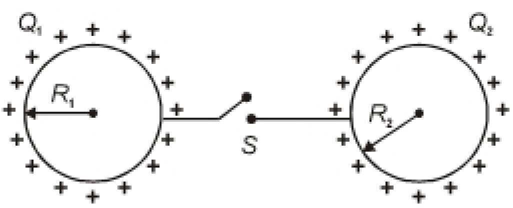
$\Delta U = \dfrac{1}{2}\dfrac{C_1C_2}{C_1 + C_2}(V_1 - V_2)^2$ (lost as heat and electromagnetic waves)

(2) $V = \dfrac{C_1V_1 - C_2V_2}{C_1 + C_2}$, $Q_1' = C_1V, Q_2' = C_2V$



$\Delta U = \dfrac{1}{2}\dfrac{C_1C_2}{C_1 + C_2}(V_1 + V_2)^2$ (Energy lost)

(3) For Spherical Capacitors,

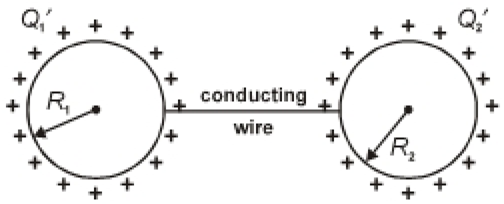


$C_1 = 4\pi\varepsilon_0 R_1$ $C_2 = 4\pi\varepsilon_0 R_2$

$V_1 = \frac{Q_1}{C_1}$ $\qquad$ $V_2 = \frac{Q_2}{C_2}$

$U_1 = \frac{Q_1^2}{8\pi\varepsilon_0 R_1}$ $\qquad$ $U_2 = \frac{Q_2^2}{8\pi\varepsilon_0 R_2}$

$\Downarrow$



(a) $V = \frac{C_1V_1 + C_2V_2}{C_1 + C_2} = \frac{Q_1 + Q_2}{4\pi\varepsilon_0[R_1 + R_2]}$

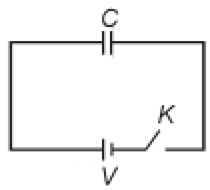
(b) $\Delta U = \frac{1}{2}\frac{C_1C_2}{C_1 + C_2}(V_1 - V_2)^2$

(c) If $V_1 = V_2$

i.e., $\frac{Q_1}{C_1} = \frac{Q_2}{C_2}$ or $\frac{Q_1}{R_1} = \frac{Q_2}{R_2}$ $\Rightarrow$ $\Delta U = 0$ (No energy loss)

Energy stored in a Capacitor

An uncharged capacitor is connected to a battery.



When the key is closed, charge flows in the circuit till capacitor becomes fully charged, such that

(1) $Q = CV$

(2) Energy stored = $\frac{1}{2}CV^2 = \frac{1}{2}QV$

(3) Energy supplied by battery = $QV = CV^2$

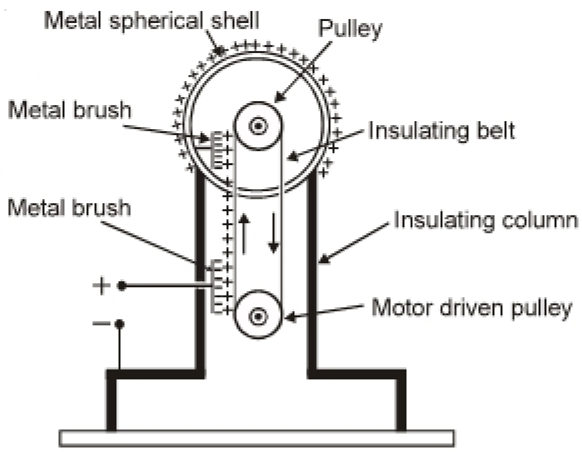
(4) Heat produced in the circuit during charging = $CV^2 - \frac{1}{2}CV^2$

$$= \frac{1}{2}CV^2 = \frac{1}{2}QV$$

Van de Graaff Generator

In 1929, Rober J. Van de Graaff designed a machine which could build up high voltages of the order of a few million volt. This machine acts on the principle of corona discharge.

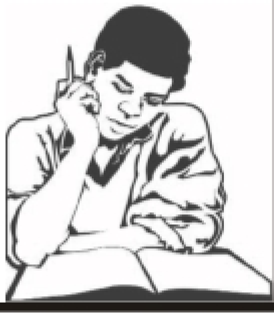
It consists of a large metal spherical shell supported on an insulating column. A long narrow belt made of insulating material passes over the two pulleys shown in the figure.



The positive charge is sprayed at the lower position of the belt through the corona discharge by the lower metal brush with sharp points. The belt is driven rapidly by the motor driving the lower pulley. When this positive charge reaches near the upper metal brush, the corona discharge takes place, and the positive charges are transferred to the metallic sphere through the metal brush. Thus, the positive charge from the electric source which supplies the charge continuously to the lower metal brush, is transferred to the outer surface of the larger sphere surrounding the upper pulley. The potential of the sphere, thus keeps on increasing till the dielectric breakdown of air surrounding the sphere.

The dielectric strength of air is 3×10^6 V/m. Hence the sphere of radius 1 m can have potential upto 3×10^6 V because $V = ER$. The potential can be raised by enclosing the sphere in a highly evacuated chamber.

❑ ❑ ❑



Try Yourself

SECTION - A

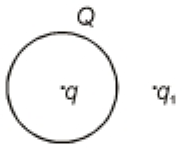
Objective Type Questions

1. The tangent at any point of an equipotential surface makes an angle θ with the electric intensity vector at that point such that

   (1) θ = 0° (2) θ = 90°

   (3) θ = 120° (4) θ = 180°

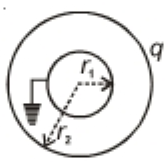
2. A thin metallic spherical shell contains a charge Q on it. A point charge q is placed at the centre of the shell and another charge q_1 is placed outside it as shown. All the three charges are positive. The net force on the charge q at the centre is



   (1) Towards left (2) Towards right

   (3) Upward (4) Zero

3. Charge on outer conducting sphere is q, and the inner sphere is grounded. Then the charge q' appearing on the inner sphere is ($r_2 > r_1$)



   (1) Zero (2) $-q$

   (3) $-\frac{r_1}{r_2}q$ (4) $-\frac{r_2}{r_1}q$

4. If a positive charge is shifted from a low potential region to a high potential region, the electric potential energy

   (1) Increases

   (2) Decreases

   (3) Remains the same

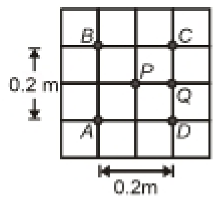
   (4) May increase or decrease

5. A, B, C, D, P and Q are points in a uniform electric field. The potentials at these points are

   $V(A)$ = 2 volt

   $V(B)$ = $V(P)$ = $V(D)$ = 5 volt, and

   $V(C)$ = 8 volt. The electric field at P is



   (1) 10 (V/m) along PQ

   (2) 5 (V/m) along PC

   (3) $15\sqrt{2}$(V/m) along PA

   (4) 5 V/m along PA

6. A hollow charged metal sphere has radius r. If the potential difference between its surface and a point, at distance $3r$ from the centre is V, then the electric field intensity at a distance $3r$ from the centre is

   (1) $\frac{V}{6r}$ (2) $\frac{V}{4r}$

   (3) $\frac{V}{3r}$ (4) $\frac{V}{2r}$

7. In a certain charge distribution, all points having zero potential can be joined by a circle C. Points inside C have positive potential. Points outside C having negative potential. A positive charge, which is free to move is placed inside C

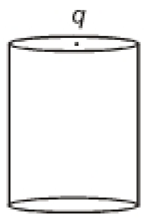
   (1) It will remain at rest

   (2) It can move inside C, but it cannot cross C

   (3) It must cross C at sometime

   (4) It may move but will ultimately return to its starting point

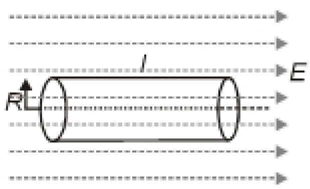
8. A charge q is placed at the centre of open end of a cylindrical vessel. The flux of the electric field through the vessel is



(1) Zero (2) $\frac{q}{\varepsilon_0}$

(3) $\frac{q}{2\varepsilon_0}$ (4) $\frac{2q}{\varepsilon_0}$

9. A cylinder of radius R and length l is placed in a uniform electric field E parallel to the cylinder axis as shown. The total flux through the cylinder is given by



(1) $2\pi R^2 E$ (2) $\pi R^2 lE$

(3) $\frac{\pi R^2 + \pi R^2}{El}$ (4) Zero

10. S_1 and S_2 are two equipotential surfaces whose potentials are not equal. Which of the following is incorrect?

(1) S_1 and S_2 can't intersect

(2) S_1 and S_2 both can't be plane surfaces

(3) The electric field between S_1 and S_2 may not be uniform

(4) A line of force from S_1 to S_2 must be perpendicular to both

11. Two conducting spheres of radii R_1 and R_2 are charged with charges Q_1 and Q_2 respectively. On bringing them in contact, there will be

(1) No change in energy of the system

(2) An increase in the energy of system if $Q_1R_1 \neq Q_2R_2$

(3) Always a decrease in energy of system

(4) A decrease in energy of system if $Q_1R_2 \neq Q_2R_1$

12. Two concentric thin metallic sphere of radii r_1 and r_2 ($r_1 > r_2$) carry charges q_1 and q_2 respectively. Then the electric potential at a distance $r(r_2 < r < r_1)$ will be $\frac{1}{4\pi\varepsilon_0}$ times

(1) $\frac{q_1 + q_2}{r}$ (2) $\frac{q_1}{r_1} + \frac{q_2}{r}$

(3) $\frac{q_1}{r} + \frac{q_2}{r_2}$ (4) $\frac{q_1}{r_1} + \frac{q_2}{r_1}$

13. Two points are at a distance a and b ($a < b$) from a long wire of charge per unit length λ. The potential difference between the points is proportional to

(1) $\frac{b}{a}$ (2) $\frac{b^2}{a^2}$

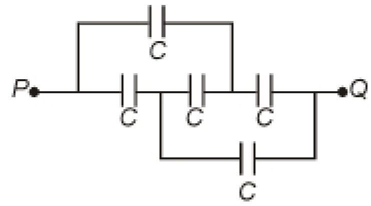
(3) $\sqrt{\frac{b}{a}}$ (4) $\log_e\left(\frac{b}{a}\right)$

14. 27 identical drops of water are equally and similarly charged to a potential V. They are then united to form a bigger drop. The potential of the bigger drop is

(1) $9V$ (2) $27V$

(3) $6V$ (4) $3V$

15. In the circuit shown the equivalent capacitance between the points P and Q is



(1) $C/5$ (2) $C/3$

(3) $C/2$ (4) C

16. A parallel plate capacitor is charged from a battery and then disconnected from it. The separation between the plates is now doubled. Which of the following is false?

(1) The potential difference between the plates of the capacitor doubles

(2) The electric field between the plates of the capacitor will not change

(3) The energy of the capacitor doubles

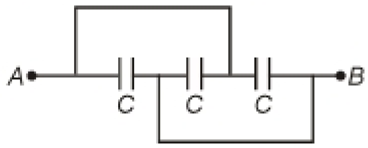
(4) The energy of the capacitor doesn't change

17. A parallel plate capacitor is made by stacking n equally spaced plates connected alternately. If the capacitance between any two plates is x, then the total capacitance is

(1) $(n-1)x$ (2) nx

(3) $\frac{x}{n-1}$ (4) $\frac{x}{n}$

18. Three equal capacitors each with capacitance C are connected as shown. Then the equivalent capacitance between A and B is



(1) C (2) $3C$

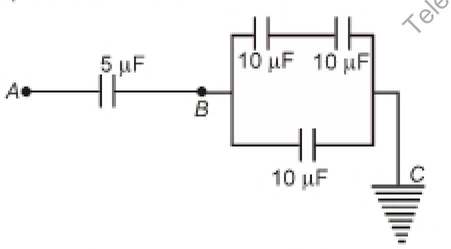
(3) $C/3$ (4) $3C/2$

19. Two capacitors of capacitances C_1 and C_2 are connected in series and potential difference V is applied across the combination. Then the potential difference across C_1 will be

(1) $\frac{VC_2}{C_1}$ (2) $V\left(\frac{C_1+C_2}{C_1}\right)$

(3) $\frac{VC_2}{C_1+C_2}$ (4) $V\frac{C_1}{C_1+C_2}$

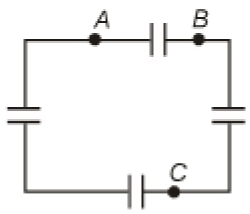
20. In the given circuit, if point C is earthed and a potential of +2000 V is given to the point A then the potential at B is



(1) 1500 V (2) 1000 V

(3) 500 V (4) 400 V

21. Four capacitor each of capacity 3 μF, are connected as shown in fig. The ratio of equivalent capacitance between A and B & between A and C will be



(1) 4 : 3 (2) 3 : 4

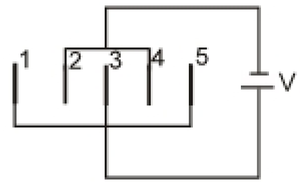
(3) 2 : 3 (4) 3 : 2

22. To form a composite capacitor of (16 μF, 1000V) from a supply of identical capacitors marked (8μF, 250V), the minimum number of capacitors required is

(1) 40 (2) 32

(3) 8 (4) 2

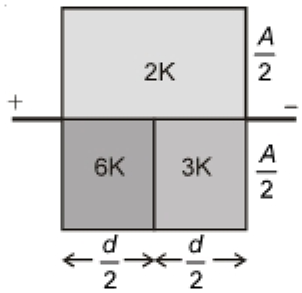
23. Five identical plates, each of area A are joined as shown. The distance between the plates is d. The plates are connected to a batery of V (volt). The charge on plates 1 and 4 will be



(1) $\frac{\varepsilon_0 AV}{d}, \frac{2\varepsilon_0 AV}{d}$ (2) $-\frac{\varepsilon_0 AV}{d}, \frac{2\varepsilon_0 AV}{d}$

(3) $\frac{\varepsilon_0 AV}{d}, \frac{-2\varepsilon_0 AV}{d}$ (4) $-\frac{\varepsilon_0 AV}{d}, \frac{-2\varepsilon_0 AV}{d}$

24. A parallel plate capacitor with air between the plates has capacitance 'C'. When it is filled with dielectric medium as shown, its capacitance becomes



(1) $3CK$ (2) $\frac{CK}{3}$

(3) $\frac{4}{3}CK$ (4) $\frac{3}{4}CK$

25. If the dielectric constant and dielectric strength be denoted by K and k respectively, then a material suitable for use as a dielectric in a capacitor must have

(1) Low K and low k

(2) Low K and high k

(3) High K and low k

(4) High K and high k

SECTION - B

Previous Years Questions

1. An electric dipole of moment p is placed in an electric field of intensity E. The dipole acquires a position such that the axis of the dipole makes an angle θ with the direction of the field. Assuming that the potential energy of the dipole to be zero when $\theta = 90°$, the torque and the potential energy of the dipole will respectively be **[AIPMT 2012]**

   (1) $pE \sin\theta$, $2pE \cos\theta$ (2) $pE \cos\theta$, $-pE \sin\theta$

   (3) $pE \sin\theta$, $-pE \cos\theta$ (4) $pE \sin\theta$, $-2pE \cos\theta$

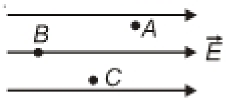
2. Four points charges $-Q$, $-q$, $2q$ and $2Q$ are placed, one at each corner of the square. The relation between Q and q for which the potential at the centre of the square is zero is

   [AIPMT 2012]

   (1) $Q = q$ (2) $Q = \frac{1}{q}$

   (3) $Q = -q$ (4) $Q = -\frac{1}{q}$

3. A, B and C are three points in a uniform electric field. The electric potential is **[NEET-2013]**



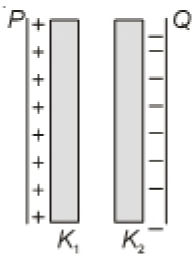
   (1) Maximum at B

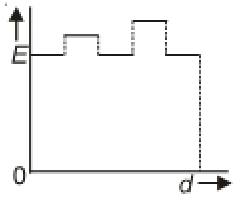
   (2) Maximum at C

   (3) Same at all the three points A, B and C

   (4) Maximum at A

4. Two thin dielectric slabs of dielectric constants K_1 and K_2 ($K_1 < K_2$) are inserted between plates of a parallel plate capacitor, as shown in the figure. The variation of electric field E between the plates with distance d as measured from plate P is correctly shown by **[AIPMT 2014]**



(1)


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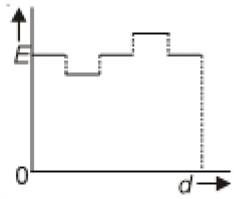

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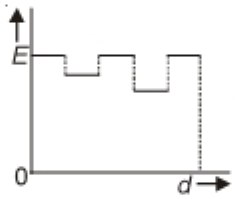

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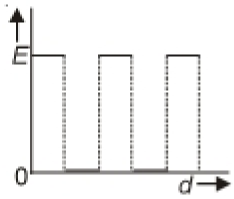


5. A conducting sphere of radius R is given a charge Q. The electric potential and the electric field at the centre of the sphere respectively are **[AIPMT 2014]**

   (1) Zero and $\frac{Q}{4\pi\varepsilon_0 R^2}$ (2) $\frac{Q}{4\pi\varepsilon_0 R}$ and zero

   (3) $\frac{Q}{4\pi\varepsilon_0 R}$ and $\frac{Q}{4\pi\varepsilon_0 R^2}$ (4) Both are zero

6. In a region, the potential is represented by $V(x, y, z) = 6x - 8xy - 8y + 6yz$, where V is in volts and x, y, z are in metres. The electric force experienced by a charge of 2 coulomb situated at point (1, 1, 1) is **[AIPMT 2014]**

   (1) $6\sqrt{5}$ N (2) 30 N

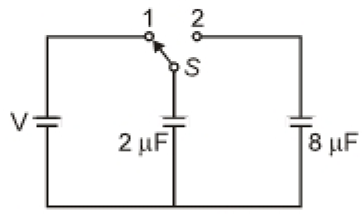
   (3) 24 N (4) $4\sqrt{35}$ N

7. A parallel plate air capacitor has capacity C, distance of separation between plates is d and potential difference V is applied between the plates. Force of attraction between the plates of the parallel plate air capacitor is **[Re-AIPMT-2015]**

   (1) $\frac{C^2V^2}{2d^2}$ (2) $\frac{C^2V^2}{2d}$

   (3) $\frac{CV^2}{2d}$ (4) $\frac{CV^2}{d}$

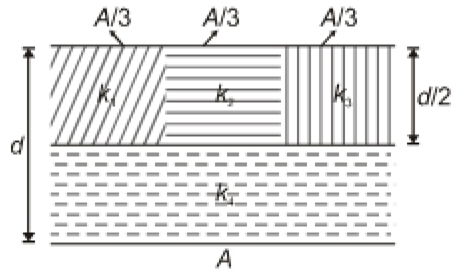
8. A capacitor of 2 μF is charged as shown in the diagram. When the switch S is turned to position 2, the percentage of its stored energy dissipated is **[NEET 2016]**



   (1) 80% (2) 0%

   (3) 20% (4) 75%

9. A parallel-plate capacitor of area A, plate separation d and capacitance C is filled with four dielectric materials having dielectric constants k_1, k_2, k_3 and k_4 as shown in the figure below. If a single dielectric material is to be used to have the same capacitance C in this capacitor, then its dielectric constant k is given by **[NEET (Phase-2) 2016]**



(1) $k = k_1 + k_2 + k_3 + 3k_4$

(2) $k = \frac{2}{3}(k_1 + k_2 + k_3) + 2k_4$

(3) $\frac{2}{k} = \frac{3}{k_1 + k_2 + k_3} + \frac{1}{k_4}$

(4) $\frac{1}{k} = \frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3} + \frac{3}{2k_4}$

10. A capacitor is charged by a battery. The battery is removed and another identical uncharged capacitor is connected in parallel. The total electrostatic energy of resulting system **[NEET-2017]**

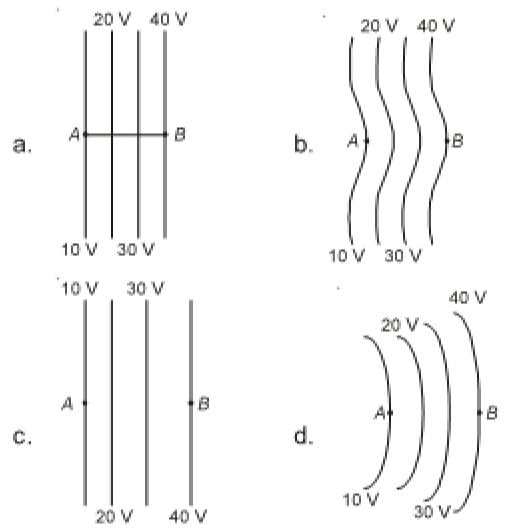
(1) Increases by a factor of 4

(2) Decreases by a factor of 2

(3) Remains the same

(4) Increases by a factor of 2

11. The diagrams below show regions of equipotentials.



A positive charge is moved from A to B in each diagram. **[NEET-2017]**

(1) Maximum work is required to move q in figure (c).

(2) In all the four cases the work done is the same.

(3) Minimum work is required to move q in figure (a).

(4) Maximum work is required to move q in figure (b).

12. The electrostatic force between the metal plates of an isolated parallel plate capacitor C having a charge Q and area A, is **[NEET-2018]**

(1) Independent of the distance between the plates

(2) Linearly proportional to the distance between the plates

(3) Inversely proportional to the distance between the plates

(4) Proportional to the square root of the distance between the plates

13. Two metal spheres, one of radius R and the other of radius $2R$ respectively have the same surface charge density σ. They are brought in contact and separated. What will be the new surface charge densities on them? **[NEET-2019 (Odisha)]**

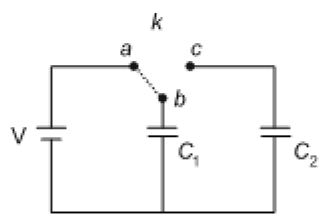
(1) $\sigma_1 = \frac{5}{3}\sigma, \sigma_2 = \frac{5}{6}\sigma$

(2) $\sigma_1 = \frac{5}{6}\sigma, \sigma_2 = \frac{5}{2}\sigma$

(3) $\sigma_1 = \frac{5}{2}\sigma, \sigma_2 = \frac{5}{6}\sigma$

(4) $\sigma_1 = \frac{5}{2}\sigma, \sigma_2 = \frac{5}{3}\sigma$

14. Two identical capacitors C_1 and C_2 of equal capacitance are connected as shown in the circuit. Terminals a and b of the key k are connected to charge capacitor C_1 using battery of emf V volt. Now disconnecting a and b the terminals b and c are connected. Due to this, what will be the percentage loss of energy? **[NEET-2019 (Odisha)]**



(1) 25%

(2) 75%

(3) 0%

(4) 50%

❑ ❑ ❑

Chapter 3

Current Electricity

Sub-topics *Electric current, flow of electric charges in a metallic conductor, drift velocity and mobility, and their relation with electric current; Ohm's law, electrical resistance, V-I characteristics (linear and non-linear), electrical energy and power, electrical resistivity and conductivity. Carbon resistors, colour code for carbon resistors; series and parallel combinations of resistors; temperature dependence of resistance. Internal resistance of a cell, potential difference and emf of a cell, combination of cells in series and in parallel. Kirchhoff's laws and simple applications. Wheatstone bridge, metre bridge. Potentiometer-principle and applications to measure potential difference, and for comparing emf of two cells; measurement of internal resistance of a cell.*

Electric Current : Time rate of flow of charge, through a cross-section is called electric current.

$I = \frac{dQ}{dt}$ (1 ampere = 1 C/s)

Steady Current : Current is constant. ($Q \propto t$)

Variable Current : Current varies with time.

Note : *For an electron revolving with speed v, frequency ν, angular velocity ω in a circle of radius 'r',*

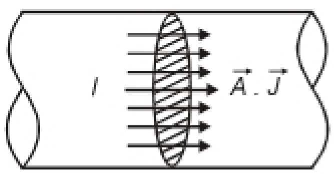
$I_{eq} = e\nu = \frac{e\omega}{2\pi} = \frac{ev}{2\pi r}$

Flow of electric charges in a metallic conductor

Emf : Electromotive force $E = \frac{W}{Q}$.

W = Work done in moving a charge Q once through a complete circuit.

Current Density : $J = \frac{I}{A}$, it is a vector quantity such that $I = \vec{J} \cdot \vec{A}$ $\left(I = \int \vec{J}.d\vec{s}\right)$



Drift Velocity : Average velocity with which electrons drift from negative end to positive end of the conductor.

$I = neAv_d$ or $v_d = \frac{I}{neA}$, $v_d \propto I/A$

$$v_d = \frac{V}{ne\rho\ell} \Rightarrow v_d \propto \frac{V}{\ell}$$

n = Number density of free electrons, e = Charge of electron

A = Area of cross-section, v_d = Drift velocity

ρ = Resistivity of material V = Potential difference

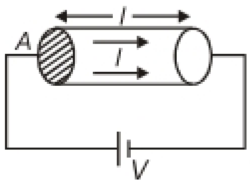
Mobility : $\mu = \frac{v_d}{E} = \frac{e\tau}{m}$

Ohm's Law : $\vec{J} = \sigma\vec{E}$ or $\vec{J} \propto \vec{E}$ (Physical conditions remaining same)

Here σ is conductivity

$$\frac{I}{A} = \frac{1}{\rho}\times E$$

$$nev_d = \frac{1}{\rho}E$$



or $v_d \propto E \Rightarrow v_d = \mu E$ where $\mu = \frac{1}{\rho ne}$ = mobility of electrons

As, $E = \frac{V}{\ell} \Rightarrow \frac{I}{A} = \frac{1}{\rho}\frac{V}{\ell} \Rightarrow V = \frac{\rho\ell}{A}I$ i.e., $V = IR$

$\Rightarrow R$ = constant

Resistance : It is opposition offered to flow of current.

$R = \frac{V}{I}$ (volt/A = ohm)

For a conductor of length l and area of cross-section A,

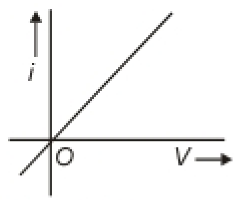
$R = \frac{\rho l}{A}$ ρ = resistivity (characteristic of a material)

$\sigma = \frac{1}{\rho}$ = conductivity (unit-siemen/meter)

ρ depends on material and temperature.

***V-I* characteristics (Linear and Non-linear)**

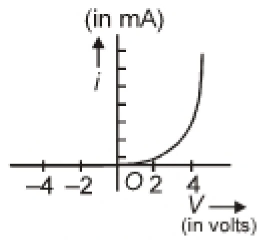
Modern microelectronics civilization depends almost totally on devices that do not obey Ohm's law. Following graphs show the variation of i with V for some circuit devices. Figure (a) is a plot for a resistor obeying Ohm's law.



(a) For resistor

The slope $\frac{i}{V}$ of the straight line is same for all values of V. This means that the resistance $R = \frac{V}{i}$ of the resistor is independent of the magnitude and polarity of the applied potential difference V.

Figure (b) is a plot when the device is a semiconductor *pn* junction diode. Current flows through the device only when the polarity of V is positive and applied potential difference is more than 1.5 V approximately. And when current does flow, the relation between i and V is not linear, it depends on the value of the applied potential difference V. Hence, Ohm's law is not obeyed.



(b) For a *pn*-junction diode

Applications :

(1) $R = \frac{\rho \ell}{A} \Rightarrow R \propto \ell, \quad R \propto \frac{1}{A}$

(2) If a wire is cut into n parts of equal length, $R' = \frac{R}{n}$ for each part.

(3) For a given mass of material

$$R = \frac{\rho \ell}{A} = \frac{\rho \ell^2}{V} \qquad [V = A \times \ell \text{ i.e., volume}]$$

i.e., $R \propto \ell^2$ or $R \propto \frac{1}{A^2}$ *i.e.*, $R \propto \frac{1}{r^4}$

(4) If a wire is **stretched**, then $R \propto \ell^2$

(a) If length is doubled $R' = 4R$

(b) If length is halved by twisting $R' = \frac{R}{4}$

(5) If a wire is **twisted** $R \propto \frac{1}{A^2}$ or $\frac{1}{r^4}$

(a) Area is doubled $R' = \frac{R}{4}$

(b) Thickness is doubled $R' = \frac{R}{16}$

(6) For small % change in length

$$\frac{\Delta R}{R} \times 100 = \frac{2\Delta \ell}{\ell} \times 100$$

(7) For small % change in radius

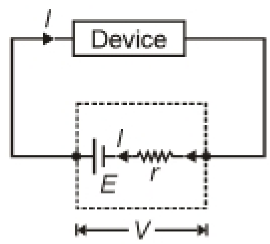
$$\frac{\Delta R}{R} \times 100 = 4\frac{\Delta r}{r} \times 100$$

(8) A resistance wire has a resistance R. Half of this wire is stretched to double its length and half is twisted to double its thickness, then $R' = \left(\frac{R}{2}\right) \times 4 + \frac{R}{2} \times \frac{1}{16} = 2R + \frac{R}{32} = \frac{65R}{32}$

(9) If ratio of lengths is $l_1 : l_2 : l_3$ and ratio of masses is $m_1 : m_2 : m_3$.

Ratio of their resistances is $\frac{l_1^2}{m_1} : \frac{l_2^2}{m_2} : \frac{l_3^2}{m_3}$

Electrical Energy and Power



V = Potential difference across the device

I = Current through the device

(1) Source of power is chemical energy stored in the cell.

(2) Total power supplied by the cell = EI (equals to rate of consumption of chemical energy)

(3) Rate of heat loss inside the cell = I^2r

(4) Net power out put = $EI - I^2r = (E - Ir)I = VI$

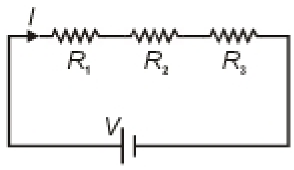
(5) Power delivered to device = I^2R

Applications :

(1) When the device is purely resistive like a bulb, then

$V = IR, \quad \therefore \quad P = VI = I^2R = \frac{V^2}{R}$

(2) $P_1 = I^2R_1,\ P_2 = I^2R_2,\ P_3 = I^2R_3$



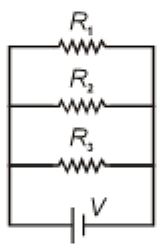
$\therefore \quad P_1 : P_2 : P_3 :: R_1 : R_2 : R_3$

$P_{Total} = P_1 + P_2 + P_3 = I^2 [R_1 + R_2 + R_3]$

$= \frac{V^2}{R_1 + R_2 + R_3}$

***Note :** Here P_1 is the electrical power consumed in resistor R_1 and so on.*

(3) $P_1 = \frac{V^2}{R_1},\ P_2 = \frac{V^2}{R_2},\ P_3 = \frac{V^2}{R_3}$

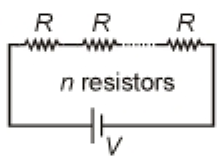


$P_1 : P_2 : P_3 :: \frac{1}{R_1} : \frac{1}{R_2} : \frac{1}{R_3}$

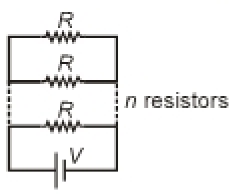
$P_{Total} = \frac{V^2}{R_1} + \frac{V^2}{R_2} + \frac{V^2}{R_3}$

$= V^2\left[\frac{1}{R}\right]$ where $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

(4) $P_S = \frac{V^2}{nR}$



(5) $P_P = \frac{V^2}{R/n} = \frac{nV^2}{R}$



$\frac{P_S}{P_P} = \frac{1}{n^2}$

(6) A 60W, 220V and a 100W, 220V bulb are given

(a) $R_{60} = \frac{(220)^2}{60},\ R_{100} = \frac{(220)^2}{100} \quad \therefore \quad R_{60} > R_{100}$

(b) When both are connected in series $P_{60} : P_{100} :: R_{60} : R_{100}$

$\therefore \quad P_{60} > P_{100}$

(c) When both are in parallel, $P_{60} : P_{100} :: \frac{1}{R_{60}} : \frac{1}{R_{100}}$

$\therefore \quad P_{60} < P_{100}$

(d) Both are connected to 440V in series, 60W will fuse. As the voltage appearing across 60W bulb is more then its rated voltage *i.e.*, 220V.

(e) Total power of bulbs in series = $\frac{P_{60}P_{100}}{P_{60}+P_{100}}$ (When connected across 220 V)

(7) A heater coil has a resistance R. It can boil certain amount of water in time t. Its power is P.

(a) When the coil is cut in two halves, power of each half = $2P$.

(b) When the coil is stretched to double its length, power = $P/4$.

(c) When the coil is twisted to double its area, power = $4P$.

(d) When the coil is twisted to double its thickness, power = $16P$.

(e) Time taken to boil $t \propto \frac{1}{P} \Rightarrow \boxed{\frac{t_1}{t_2} = \frac{P_2}{P_1}}$.

(8) Two coils boil separately a certain amount of water in time t_1 and t_2.

(a) When they are used together in series, time $t_s = t_1 + t_2$.

(b) When they are used together in parallel, time $t_p = \frac{t_1 t_2}{t_1 + t_2}$.

Fuse Wire

1. Made of lead, tin alloy.
2. Has low melting point.
3. Current capacity (current at which it blows)

$$I^2 \propto \frac{r^3}{\rho}$$

(a) $I \propto r^{3/2}$, (b) $I \propto \frac{1}{\sqrt{\rho}}$, (c) I is independent of length

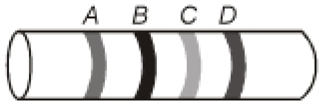
4. Time taken to melt $t \propto A^2$ or $t \propto r^4$. 't' is also independent of length.
5. A fuse wire is connected in series with live or phase wire of main supply.

Carbon Resistors : Colour Code

A resistor is a current device made of specific value of resistance. The value of resistances used in electrical and electronic circuits vary over a very wide range. A colour code is used to indicate the value of resistances.

A resistor has usually four concentric rings or bands A, B, C and D of different colours. The colours of first two bands A and B indicate the first two significant figures of the resistance in ohm, while the colour of third band C indicates the decimal multiplier. The colour of fourth ring or D (which is either silver or gold) tells the tolerance. Sometimes, only three colour bands A, B and C are marked.

The colours of first two bands A and B correspond to figures 0, 1, 2, 3, 4, 5, 6, 7, 8, 9 and the colour of the third band C corresponds to multipliers 10^0, 10^1, 10^2, 10^3, 10^4, 10^5, 10^6, 10^7, 10^8 and 10^9, respectively. If the colour of the fourth band is gold, the tolerance is 5% and in case the colour is silver, the tolerance is 10%. In case, there is no fourth band, then its tolerance is 20%.



$R = AB \times 10^{C} \pm D\%$

The following table gives the colour code for carbon resistance :

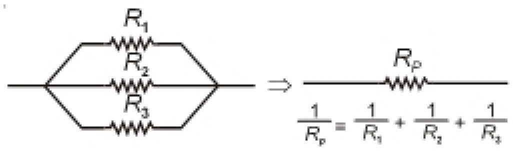
Letters as an aid to Memory	Colour	Figure	Multiplier	Colour	Figure
B	Black	0	10^0	Gold	5%
B	Brown	1	10^1	Silver	10%
R	Red	2	10^2	No colour	20%
O	Orange	3	10^3		
Y	Yellow	4	10^4		
G	Green	5	10^5		
B	Blue	6	10^6		
V	Violet	7	10^7		
G	Grey	8	10^8		
W	White	9	10^9		
	Gold		10^{-1}		
	Silver		10^{-2}		

To remember the colours in correct sequence, one may remember ***B.B. ROY in Great Britain has Very Good Wife****. The capital letters correspond to colours in the correct sequence.*

Combination of Resistors

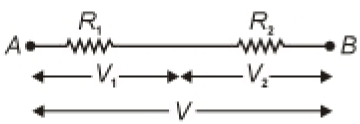
1. **Series Grouping :** 

$R_s = R_1 + R_2 + R_3$

2. **Parallel Grouping :** 

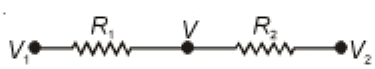
$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

Applications :

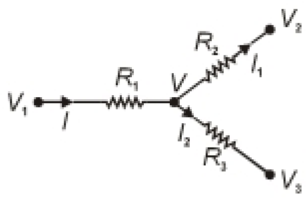
(i) 

(a) $V_1 = \frac{R_1 V}{R_1 + R_2}$

(b) $V_2 = \frac{R_2 V}{R_1 + R_2}$

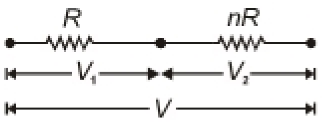
(ii) 

$V = \frac{\frac{V_1}{R_1} + \frac{V_2}{R_2}}{\frac{1}{R_1} + \frac{1}{R_2}} = \frac{V_1 R_2 + V_2 R_1}{R_1 + R_2}$

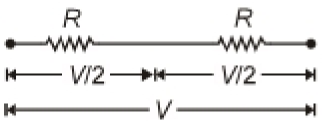
(iii) 

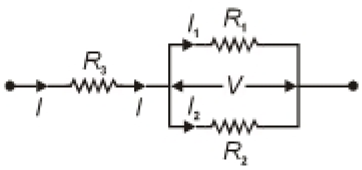
(a) $V = \dfrac{\dfrac{V_1}{R_1}+\dfrac{V_2}{R_2}+\dfrac{V_3}{R_3}}{\dfrac{1}{R_1}+\dfrac{1}{R_2}+\dfrac{1}{R_3}}$ (b) $I_1 = \dfrac{V_1 - V}{R_1}$

(c) $I_2 = \dfrac{V - V_2}{R_2}$ (d) $I_3 = \dfrac{V - V_3}{R_3}$

(iv) 

$V_1 = \dfrac{V}{n+1}, V_2 = \dfrac{nV}{n+1}$

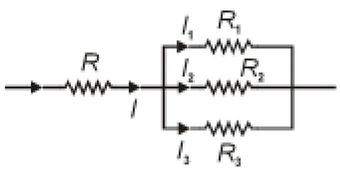
(v) 

(vi) 

$V = I_1R_1 = I_2R_2$ $I_1 = \dfrac{R_2}{R_1+R_2}I$

$I_1 + I_2 = I$ $I_2 = \dfrac{R_1}{R_1+R_2}I$

(vii) $I_1 : I_2 : I_3 :: \dfrac{1}{R_1} : \dfrac{1}{R_2} : \dfrac{1}{R_3}$

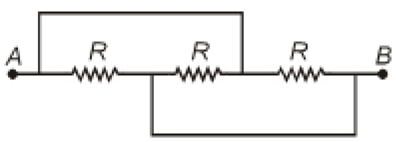


$I_1 + I_2 + I_3 = I \quad \Rightarrow \quad I_1 = \dfrac{R_2R_3}{R_1R_2 + R_2R_3 + R_1R_3}I$

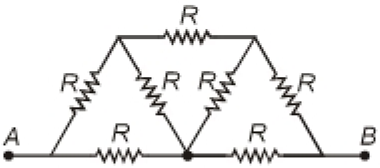
$I_2 = \dfrac{R_1R_3}{R_1R_2 + R_2R_3 + R_3R_1}I$

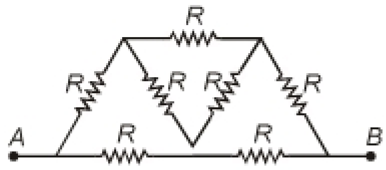
$I_3 = \dfrac{R_1R_2}{R_1R_2 + R_2R_3 + R_3R_1}I$

Various Combinations

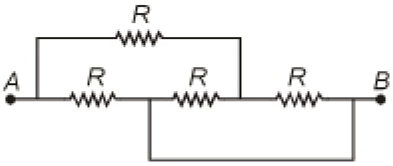
(1) 

$\Rightarrow$ $R_{AB} = R/3$ [Parallel combination]

(2) 

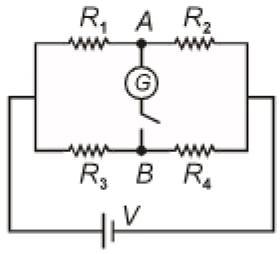
$\Rightarrow$ 

$\Rightarrow R_{eq} = \dfrac{8R}{7}$

(3) 

$R_{AB} = \dfrac{3R}{5}$

(4) $V_A - V_B = \left[\dfrac{R_2R_3 - R_1R_4}{(R_1+R_2)(R_3+R_4)}\right]V$

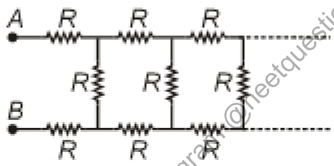


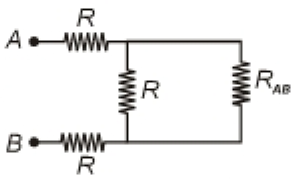
(a) If $R_2R_3 > R_1R_4$, current through the galvanometer on closing key will flow from *A* to *B*.

(b) $R_2R_3 < R_1R_4$, current flows from *B* to *A*.

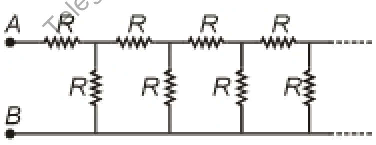
(c) $R_2R_3 = R_1R_4$, no current flows through '*G*'. [Balanced Wheatstone bridge]

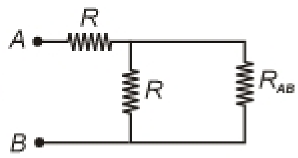
(5) $R_{AB} = R(1+\sqrt{3})$



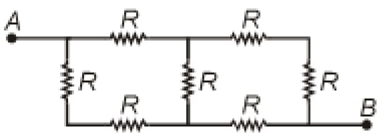
$\Rightarrow R_{AB} =$ 

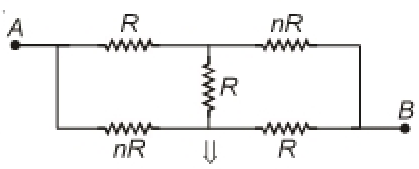
(6) $R_{AB} = \dfrac{R(1+\sqrt{5})}{2}$



$\Rightarrow R_{AB} =$ 

(7) $R_{AB} = \dfrac{7R}{5}$





$\Downarrow$

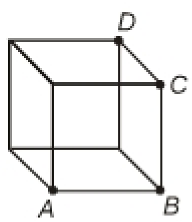
$R_{AB} = \dfrac{(3n+1)}{(n+3)}R$

(8) **Skeleton Cube :** Each wire has a resistance '*r*'.

(a) $R_{AB} = \dfrac{7r}{12}$, Equivalent resistance between adjacent corner

(b) $R_{AC} = \dfrac{3r}{4}$, Equivalent resistance between face diagonal

(c) $R_{AD} = \dfrac{5r}{6}$, Equivalent resistance between body diagonal



Temperature dependence of resistance

Conductors : Low resistivity at room temperature. It increases with increase in temperature according to the formula,

$\rho_t = \rho_0 (1 + \alpha t)$

ρ_t = Resistivity at temperature t°C

ρ_0 = Resistivity at temperature 0°C

α = Temperature coefficient of resistivity

As $\rho_t = \rho_0 (1 + \alpha t)$

$\therefore \quad R_t = R_0 (1 + \alpha t) \qquad [\because R \propto \rho]$

At temperature t_1, $R_1 = R_0 (1 + \alpha t_1)$

At temperature t_2, $R_2 = R_0 (1 + \alpha t_2)$

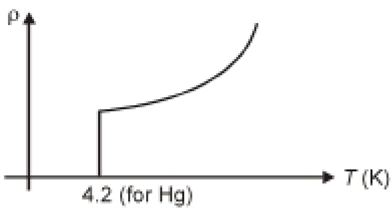
(a) $\alpha = \dfrac{R_2 - R_1}{R_1 t_2 - R_2 t_1}$

(b) $R_0 = \dfrac{R_1 t_2 - R_2 t_1}{t_2 - t_1}$

Insulators : Very high resistivity at all temperatures. Variation in resistivity is very small with temperature.

Semiconductors : Resistivity lies between conductors and insulators at room temperature. At 0 K, ρ is infinite, or conductivity is zero. The conductivity of semiconductors increases with increase in temperature. Thus when a piece of germanium and a piece of copper are cooled, then resistivity of germanium increases and that of copper decreases.

Superconductors : At very low temperatures, a conductor starts behaving like a superconductor.

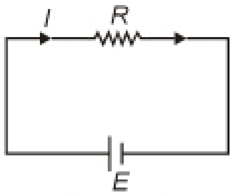


(a) At critical temperature, resistivity of metals suddenly become zero.

(b) Superconductors act like perfect diamagnetic substances (Meissner's effect)

Internal resistance, potential difference and EMF of a cell

(1) Ideal cell : $E = IR$, internal resistance = zero



(2) Real cell

(a) $I = \frac{E}{R+r}$

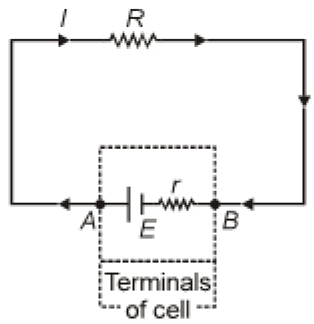
(b) $V_{AB} = IR = \frac{ER}{R+r}$ = Terminal potential difference

$E = IR + Ir$

$IR = E - Ir$

$V = E - Ir$(During discharging of cell)

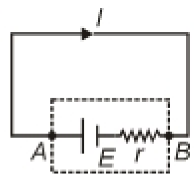
(c) $r = \frac{E-V}{I} = \left(\frac{E-V}{V}\right)R$



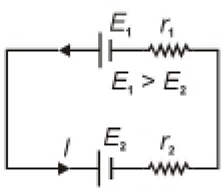
Note : *When a cell is being discharged V < E as V = E – Ir and during changing V > E, V = E + Ir*

(3) A cell is short circuited

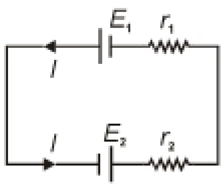
$I = \frac{E}{r}$, $V_{AB} = 0$, [current is maximum]



Combination of cells

(i)


$I = \frac{E_1 - E_2}{r_1 + r_2}$, $V = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}$

(ii)


$I = \frac{E_1 + E_2}{r_1 + r_2}$

Potential difference across each cell

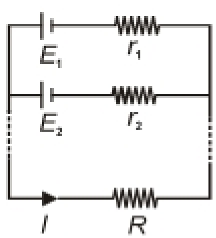
$V = E_1 - Ir_1$

$V = E_1 - \frac{(E_1 + E_2)}{r_1 + r_2} r_1$

$V = \frac{E_1 r_2 - E_2 r_1}{r_1 + r_2}$

if $V = 0$, $\frac{E_1}{r_1} = \frac{E_2}{r_2}$

(iii) $I = \frac{E}{R+r}$

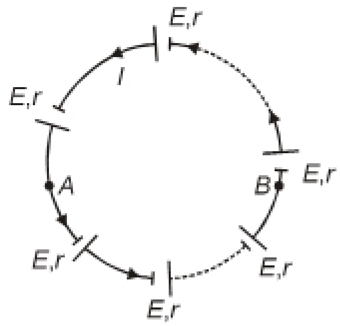


Where $E = \frac{\frac{E_1}{r_1} + \frac{E_2}{r_2} + ...}{\frac{1}{r_1} + \frac{1}{r_2} + ...}$

and $\frac{1}{r} = \frac{1}{r_1} + \frac{1}{r_2} + ...$

(iv) Any number of cells are connected symmetrically,

$I = \frac{E}{r}$, $V_A - V_B = 0$



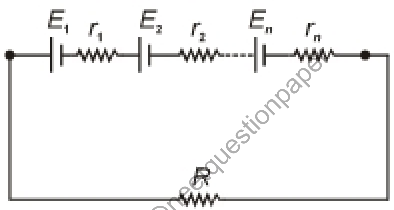
Note : *A and B are any two arbitrary points. If some external resistance is connected across them, no current flows through it.*

Cells in series

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

$E = \Sigma E_i$

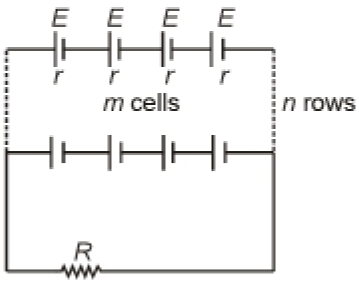
$r = \Sigma r_i$



Cells in mixed grouping

Total number of cells = *mn*

$I = \frac{mnE}{nR + mr}$



I is maximum when $nR = mr$

Note : *Arrangement of N identical cells each of emf E and internal resistance r to obtain maximum current in external resistance of R*

$\Rightarrow$ *no. of cells in each rows* $m = \sqrt{\frac{NR}{r}}$

$\Rightarrow$ *no. of rows* $n = \sqrt{\frac{Nr}{R}}$

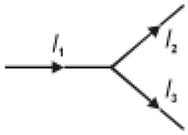
$i_{max} = \frac{E}{2}\sqrt{\frac{N}{rR}}$

Kirchhoff's Law

(1) **Junction Rule :** It is based on conservation of charge.

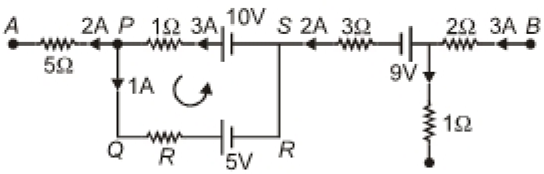
At any junction

$$\sum i_{in} = \sum i_{out}$$



$I_1 = I_2 + I_3$

(2) **Loop Rule :** It is based on conservation of energy.



For closed loop *PQRSP*, total rise in potential + total fall in potential = 0.

$\Rightarrow \quad -1 \times R - 5 + 10 - 3 = 0$

$\Rightarrow \quad R = -5 - 3 + 10 = 2\Omega$

For open part *APSB*, V_A is potential of *A* and V_B is potential of *B* then

$V_A + (5 \times 2) + (3 \times 1) - 10 + (2 \times 3) + 9 + (2 \times 3) = V_B$

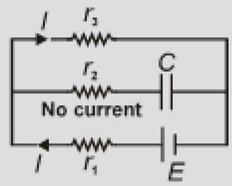
$V_A + 10 + 3 - 10 + 6 + 9 + 6 = V_B$

$V_A - V_B = -24\text{V}$

Note : *RC circuit (steady state)*

(a) In steady state capacitor gets fully charged and hence no current flows across it.

$$I = \frac{E}{r_1 + r_3},$$

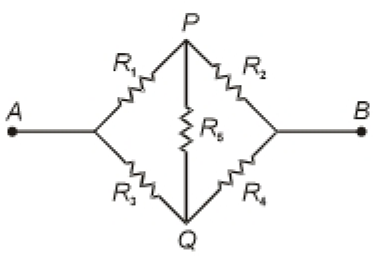


(b) Potential drop across capacitor $V = Ir_3$

$$V = \frac{E}{r_1 + r_3} r_3.$$ *This is also the reading of ideal voltmeter connected in place of capacitor.*

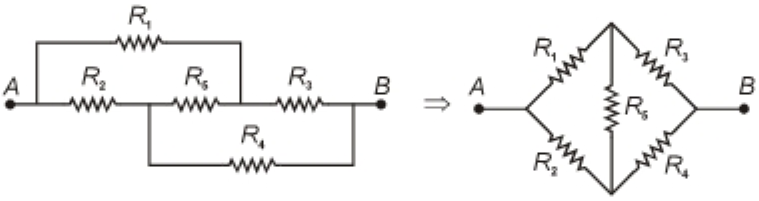
(1) WHEATSTONE BRIDGE (BALANCED)

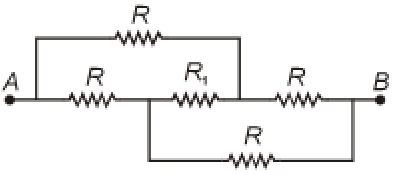
When $\dfrac{R_1}{R_2} = \dfrac{R_3}{R_4}$, then $V_P = V_Q \Rightarrow R_5$ can be removed



$$R_{AB} = \frac{(R_1 + R_2)(R_3 + R_4)}{R_1 + R_2 + R_3 + R_4}$$

$$= \frac{R_1 R_3}{R_1 + R_3} + \frac{R_2 R_4}{R_2 + R_4}$$

(2) 

(3) 

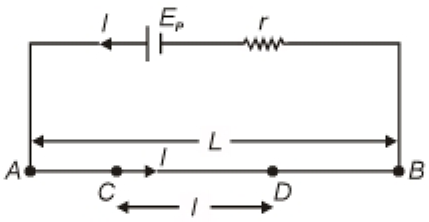
$\Rightarrow \quad R_{AB} = R$ [Example of Wheatstone bridge]

Potentiometer : It can measure potential difference without drawing a current from the circuit. Thus it gives accurate reading. It can

(a) Measure internal resistance of a cell.

(b) Measure emf of a cell.

(c) Compare emf's of two cells.



AB is the potentiometer wire of resistance R and length L.

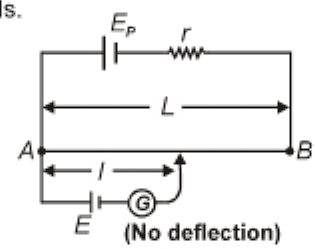
Any two point C and D on the wire are separated by length 'l'.

$$V_{CD} = IR_{CD} = \left(\frac{E_P}{r+R}\right).\frac{R}{L}\times l \quad ...(1)$$

$\therefore \quad V_{CD} \propto l$ (all other factors are constant) This is principle of potentiometer

Applications :

(1) To measure potential difference and for comparing emf of two cells.

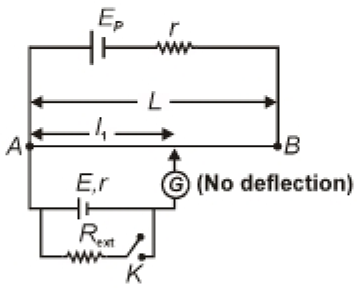


A cell of emf E is balanced against length 'l' of wire then

$$E = V_{CD} = \left(\frac{E_P}{r+R}\right)\frac{R}{L}.l$$

i.e., $E \propto l$ or $\frac{E_1}{E_2} = \frac{l_1}{l_2}$

(2) Measurement of internal resistance of a Cell



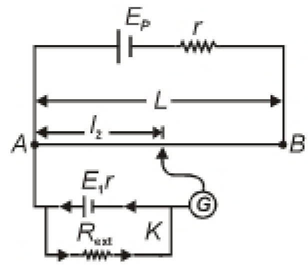
Step I

Key K is kept open, balance point is at length l_1.

$\Rightarrow E \propto l_1$

Step II

Key K is closed, balance point is at length l_2. (V is terminal potential difference)



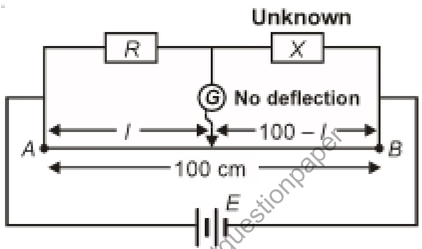
$$\Rightarrow V \propto l_2 \qquad \text{or} \qquad \frac{E}{V} = \frac{l_1}{l_2}$$

$$r = \left(\frac{E - V}{V}\right) R_{ext} = \left(\frac{l_1 - l_2}{l_2}\right) R_{ext}$$

Sensitivity of a potentiometer : Smaller is the potential drop per unit length more is the sensitivity. Therefore, $\frac{V}{l}$ should be small.

This can be achieved by increasing the length of potentiometer wire or decreasing the current through it.

Meter Bridge : It is based on Wheatstone bridge principle. It is used to find unknown resistance.



When there is no deflection, $\frac{R}{l} = \frac{X}{100 - l} \Rightarrow X = R\left(\frac{100 - l}{l}\right)$

***Note :** Location of null point is independent of resistivity or area of cross-section of wire AB.*

❑ ❑ ❑

Try Yourself

SECTION - A

Objective Type Questions

1. The resistance of a conductor is 5 ohm at 50ºC and 6 ohm at 100ºC. Its resistance at 0ºC is

   (1) 3 Ω (2) 4 Ω
   (3) 1 Ω (4) 2 Ω

2. A wire of resistance R is cut into n equal parts perpendicular to its length. These parts are then connected in parallel. The equivalent resistance of the combination is

   (1) nR (2) $\frac{R}{n}$
   (3) $\frac{R}{n^2}$ (4) n^2R

3. A copper wire is stretched to make it 0.1% longer. The % increase in resistance will be

   (1) 0.2 (2) 2
   (3) 1 (4) 0.1

4. A piece of copper and a piece of germanium are cooled from the room temperature down to 80 K

   (1) The resistance of each of them decreases
   (2) The resistance of each of them increases
   (3) The resistance of copper increases and that of germanium decreases
   (4) The resistance of copper decreases and that of germanium increases

5. The masses of three wires of copper are in the ratio of 1 : 3 : 5 and their lengths are in the ratio of 5 : 3 : 1. The ratio of their electrical resistances is

   (1) 125 : 15 : 1 (2) 5 : 3 : 1
   (3) 1 : 3 : 5 (4) 1 : 15 : 125

6. For which of the following dependence of drift velocity V_d on electric field, Ohm's law is obeyed?

   (1) $V_d \propto E^2$ (2) $V_d \propto \sqrt{E}$
   (3) $V_d \propto E$ (4) $V_d \propto E^0$

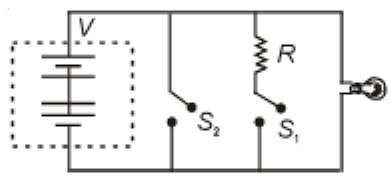
7. An electric cell does 5 joule of work in carrying 10 coulomb of charge around a closed electric circuit. The electromotive force of cell is

   (1) 2 V
   (2) 2.5 V
   (3) 3 V
   (4) 0.5 V

8. When both the length and area of cross-section of a wire are doubled, then its resistance will be

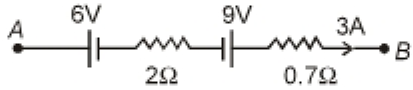
   (1) Halved (2) Doubled
   (3) Same (4) Quadrupled

9. Which of the two switches S_1 and S_2 will produce short circuiting?



   (1) S_1 (2) S_2
   (3) Both S_1 and S_2 (4) Neither S_1 nor S_2

10. The potential difference between A and B in the figure is



   (1) 3 V (2) 15 V
   (3) 5.1 V (4) 23.1 V

11. A wire of resistance R is connected to a potential difference V. Keeping potential same, resistance wire is stretched to double its length, the drift velocity of electrons

(1) Remain same

(2) Become double

(3) Become half

(4) Become four times

12. A non conducting ring of radius r has charge q distributed uniformly over it. If it rotates with an angular velocity ω. The equivalent current is

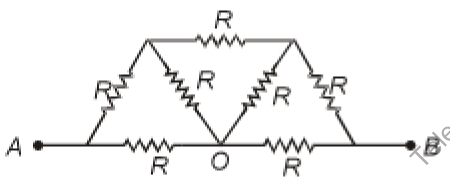
(1) $\frac{q\omega}{2\pi}$

(2) $\frac{2\pi}{q\omega}$

(3) $\frac{q\omega}{2\pi r}$

(4) $qr\omega$

13. The effective resistance between A and B is ($R = 1\ \Omega$)



(1) $\frac{4}{3}\Omega$ (2) $\frac{3}{2}\Omega$

(3) $7\ \Omega$ (4) $\frac{8}{7}\Omega$

14. A cell of e.m.f. 4 V, when short circuited gives a current of 8 A. The internal resistance of the cell is

(1) $0.5\ \Omega$ (2) $1\ \Omega$

(3) $2\ \Omega$ (4) $4\ \Omega$

15. An electron in the potentiometer wire experiences a force of 3.2×10^{-19} N. The length of the potentiometer is 4 m. The e.m.f. of the battery across the wire is

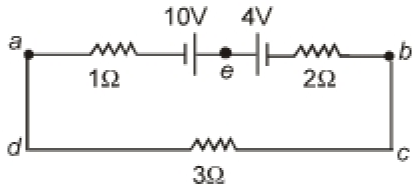
(1) 1.6 V

(2) 3.2 V

(3) 4.8 V

(4) 8 V

16. In the circuit shown, the magnitude and direction of the flow of current respectively would be



(1) $\frac{7}{3}$A from a to b via e

(2) $\frac{7}{3}$A from b to a via e

(3) 1 A from b to a via e

(4) 1 A from a to b via e

17. Upon a six fold increase in the external resistance of a circuit, the voltage across the terminals of a battery increases from 5V to 10V. The e.m.f. of the battery is

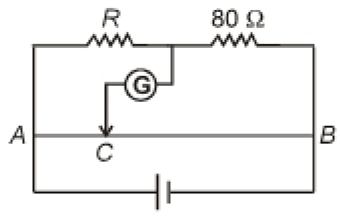
(1) 15 V

(2) 18 V

(3) 12.5 V

(4) 11 V

18. AB is a wire of uniform cross-section. The galvanometer G shows no current when the length AC = 20 cm and CB = 80 cm. The resistance R is equal to



(1) $2\ \Omega$ (2) $8\ \Omega$

(3) $20\ \Omega$ (4) $40\ \Omega$

19. The current flowing through a coil of resistance $800\ \Omega$ is to be reduced by 80%. What value of shunt should be connected across the coil?

(1) $200\ \Omega$

(2) $80\ \Omega$

(3) $8\ \Omega$

(4) $10\ \Omega$

20. A cell of e.m.f. E and internal resistance r is connected across an external resistance nr. The ratio of terminal potential difference to e.m.f is

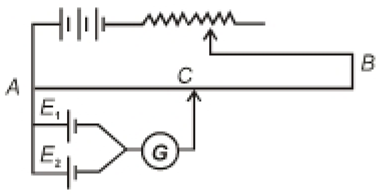
(1) $\frac{1}{n}$

(2) $\frac{1}{n+1}$

(3) $\frac{n}{n+1}$

(4) $\frac{n+1}{n}$

21. The circuit shown here is used to compare the e.m.f's of two cells E_1 and E_2 ($E_1 > E_2$) by a potentiometer. The null point is at C when the galvanometer is connected to E_1. When the galvanometer is connected to E_2, the null point will be



(1) To the left of C (2) To the right of C

(3) At C itself (4) Nowhere on AB

22. The emf of driving cell in a potentiometer circuit is 100 V. Its internal resistance is 10 Ω. Length of potentiometer wire is 200 cm. A cell of emf 5 V and internal resistance 0.1 Ω is balanced against 20 cm length of the wire. The length against with a cell of emf 6 V and internal resistance 0.2 Ω can be balanced is

(1) 24 cm (2) 20 cm

(3) 22.5 cm (4) 40 cm

23. To get maximum current in a resistance of 3 Ω, one can use n rows of m cells (connected in series) connected in parallel. If the total number of cells is 24 and the internal resistance of a cell is 0.5 Ω, then

(1) $m = 12$, $n = 2$

(2) $m = 8$, $n = 3$

(3) $m = 2$, $n = 12$

(4) $m = 6$, $n = 4$

24. The specific resistance of manganese is 50×10^{-8} Ω m. The resistance of a cube of length 50 cm between its two opposite face will be

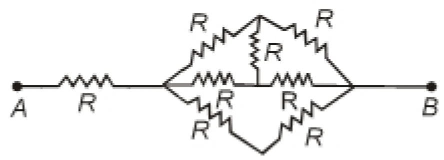
(1) 10^{-6} Ω

(2) 2.5×10^{-6} Ω

(3) 10^{-8} Ω

(4) 5×10^{-4} Ω

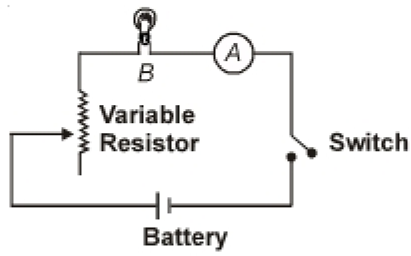
25. In the network of resistance shown in figure the effective resistance between AB is



(1) $\frac{5}{3}R$ (2) $\frac{8}{3}R$

(3) 5 R (4) 8 R

26. In the circuit below, bulb B does not light although ammeter A indicates that the current is flowing. Why does the bulb not light ?



(1) The bulb is fused

(2) There is a break in the circuit between bulb and ammeter

(3) The variable resistance has a too large resistance

(4) There is a break in the circuit between bulb and variable resistor

27. The capacity of a storage cell is 5 A hour. The maximum amount of current it can supply for ten hour is

(1) 5 A (2) 0.5 A

(3) 50 A (4) 0.25 A

28. If the current in the bulb decreases by 0.5% due to fluctuation in supply then the power in the bulb decreases by approximately

(1) 1% (2) 2%

(3) 0.5% (4) 0.25%

29. A fuse wire is made up of

(1) Lead tin alloy (2) Tungsten

(3) Copper (4) Nichrome

30. Two cells each of emf E and internal resistance r, are connected in parallel across a resistor R. The power delivered to the resistor is maximum if R is equal to

(1) $\frac{r}{2}$ (2) r

(3) $2r$ (4) Zero

31. A house is served by 220 V supply line. In a circuit protected by a fuse marked "9 ampere" the maximum number of (60 W, 220 V) bulbs that can safely connected in parallel is

(1) 11 (2) 22

(3) 33 (4) 44

32. If 2.2 kW power is transmitted through a 10 Ω line at 22,000 V, the power loss in the form of heat will be

(1) 0.1 W (2) 1 W

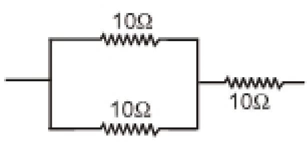
(3) 10 W (4) 100 W

33. Two bulbs of wattage (25 W, 220 V) and (100 W, 220 V) are connected in series with the supply of 440 volt, which bulb will fuse?

(1) 100 W (2) 25 W

(3) Both (1) & (2) (4) None will fuse

34. Three equal resistance each of 10 Ω are connected as shown. The maximum power which can be consumed by each is 20 W. What is the maximum power that can be consumed by the combination?



(1) 5 W (2) 15 W

(3) 30 W (4) 60 W

35. According to Joule's law if potential difference across a conductor having a material of specific resistance ρ remains constant then heat produced in the conductor is directly proportional to

(1) ρ (2) ρ^2

(3) $\frac{1}{\sqrt{\rho}}$ (4) $\frac{1}{\rho}$

36. An electrical source with internal resistance r is used to opera te a lamp of resistance R. What fraction of the total power is delivered to the lamp?

(1) $\frac{R+r}{R}$ (2) $\frac{R-r}{R}$

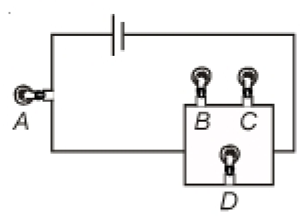
(3) $\frac{R}{R+r}$ (4) $\frac{R}{r}$

37. A heater boils 1 kg of water in time t_1 and another heater boils the same water in time t_2 across the same source. If both are connected in series across that source, the combination will boil the same water in time

(1) $\frac{t_1t_2}{t_1+t_2}$ (2) $t_1 + t_2$

(3) $\frac{t_1t_2}{t_1-t_2}$ (4) $\sqrt{t_1t_2}$

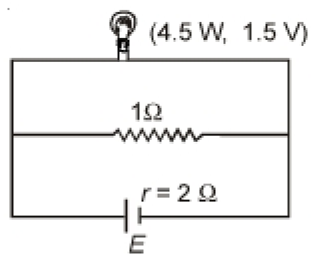
38. All bulbs in the fig. are identical. Which bulb lights more brightly?



(1) A (2) B

(3) C (4) D

39. A torch bulb rated at (4.5W, 1.5V) is connected to a cell as shown. The emf of the cell needed to make the bulb glow at full intensity is



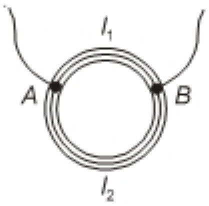
(1) 4.5 V (2) 1.5 V

(3) 7.5 V (4) 10.5 V

SECTION - B

Previous Years Questions

1. A ring is made of a wire having a resistance R_0 = 12 Ω. Find the points *A* and *B*, as shown in the figure, at which a current carrying conductor should be connected so that the resistance *R* of the sub circuit between these points is equal to $\frac{8}{3}\Omega$. **[AIPMT 2012]**



(1) $\frac{l_1}{l_2}=\frac{3}{8}$ (2) $\frac{l_1}{l_2}=\frac{1}{2}$

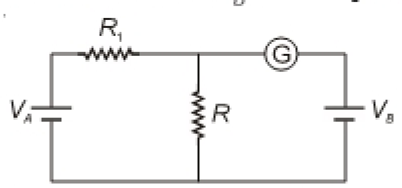
(3) $\frac{l_1}{l_2}=\frac{5}{8}$ (4) $\frac{l_1}{l_2}=\frac{1}{3}$

2. If voltage across a bulb rated 220 volt - 100 watt drops by 2.5% of its rated value, the percentage of the rated value by which the power would decrease is **[AIPMT 2012]**

(1) 5% (2) 10%

(3) 20% (4) 2.5%

3. In the circuit shown the cells *A* and *B* have negligible resistances. For V_A = 12 V, R_1 = 500 Ω and *R* = 100 Ω the galvanometer (G) shows no deflection. The value of V_B is **[AIPMT 2012]**



(1) 12 V (2) 6 V

(3) 4 V (4) 2 V

4. A wire of resistance 4 Ω is stretched to twice its original length. The resistance of stretched wire would be **[NEET-2013]**

(1) 4 Ω (2) 8 Ω

(3) 16 Ω (4) 2 Ω

5. The internal resistance of a 2.1 V cell which gives a current of 0.2 A through a resistance of 10 Ω is **[NEET-2013]**

(1) 0.5 Ω (2) 0.8 Ω

(3) 1.0 Ω (4) 0.2 Ω

6. The resistances of the four arms *P*, *Q*, *R* and *S* in a Wheatstone's bridge are 10 ohm, 30 ohm, 30 ohm and 90 ohm, respectively. The e.m.f. and internal resistance of the cell are 7 volt and 5 ohm respectively. If the galvanometer resistance is 50 ohm, the current drawn from the cell will be **[NEET-2013]**

(1) 0.2 A (2) 0.1 A

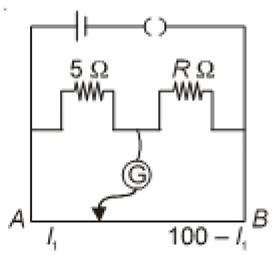
(3) 2.0 A (4) 1.0 A

7. Two cities are 150 km apart. Electric power is sent from one city to another city through copper wires. The fall of potential per km is 8 volt and the average resistance per km is 0.5 Ω. The power loss in the wire is **[AIPMT 2014]**

(1) 19.2 W (2) 19.2 kW

(3) 19.2 J (4) 12.2 kW

8. The resistances in the two arms of the meter bridge are 5 Ω and *R* Ω, respectively. When the resistance *R* is shunted with an equal resistance, the new balance point is at 1.6 l_1. The resistance *R*, is : **[AIPMT 2014]**



(1) 10 Ω (2) 15 Ω

(3) 20 Ω (4) 25 Ω

9. A potentiometer circuit has been set up for finding the internal resistance of a given cell. The main battery, used across the potentiometer wire, has an emf of 2.0 V and a negligible internal resistance. The potentiometer wire itself is 4 m long. When the resistance, *R*, connected across the given cell, has values of (i) Infinity, (ii) 9.5 Ω, the 'balancing lengths', on the potentiometer wire are found to be 3 m and 2.85 m, respectively. The value of internal resistance of the cell is **[AIPMT 2014]**

(1) 0.25 Ω (2) 0.95 Ω

(3) 0.5 Ω (4) 0.75 Ω

10. A potentiometer wire of length *L* and a resistance *r* are connected in series with a battery of e.m.f. E_0 and a resistance r_1. An unknown e.m.f. *E* is balanced at a length *l* of the potentiometer wire. The e.m.f. *E* will be given by **[Re-AIPMT-2015]**

(1) $\frac{LE_0r}{(r+r_1)l}$ (2) $\frac{LE_0r}{lr_1}$

(3) $\frac{E_0r}{(r+r_1)}\cdot\frac{l}{L}$ (4) $\frac{E_0l}{L}$

11. Two metal wires of indentical dimensions are connected in series. If σ_1 and σ_2 are the conductivities of the metal wires respectively, the effective conductivity of the combination is **[Re-AIPMT-2015]**

(1) $\dfrac{\sigma_1 \sigma_2}{\sigma_1 + \sigma_2}$ (2) $\dfrac{2\sigma_1 \sigma_2}{\sigma_1 + \sigma_2}$

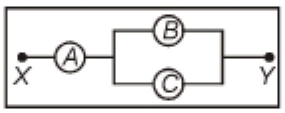
(3) $\dfrac{\sigma_1 + \sigma_2}{2\,\sigma_1 \sigma_2}$ (4) $\dfrac{\sigma_1 + \sigma_2}{\sigma_1 \sigma_2}$

12. A circuit contains an ammeter, a battery of 30 V and a resistance 40.8 ohm all connected in series. If the ammeter has a coil of resistance 480 ohm and a shunt of 20 ohm, the reading in the ammeter will be **[Re-AIPMT-2015]**

(1) 1 A (2) 0.5 A

(3) 0.25 A (4) 2 A

13. *A*, *B* and *C* are voltmeters of resistance *R*, 1.5*R* and 3*R* respectively as shown in the figure. When some potential difference is applied between *X* and *Y*, the voltmeter readings are V_A, V_B and V_C respectively, then **[AIPMT-2015]**



(1) $V_A \neq V_B \neq V_C$ (2) $V_A = V_B = V_C$

(3) $V_A \neq V_B = V_C$ (4) $V_A = V_B \neq V_C$

14. A potentiometer wire has length 4 m and resistance 8 Ω. The resistance that must be connected in series with the wire and an accumulator of e.m.f. 2 V, so as to get a potential gradient 1 mV per cm on the wire is **[AIPMT-2015]**

(1) 48 Ω (2) 32 Ω

(3) 40 Ω (4) 44 Ω

15. A potentiometer wire is 100 cm long and a onstant potential difference is maintained across it. Two cells are connected in series first to support one another and then in opposite direction. The balance points are obtained at 50 cm and 10 cm from the positive end of the wire in the two cases. The ratio of emf's is **[NEET-2016]**

(1) 3 : 2 (2) 5 : 1

(3) 5 : 4 (4) 3 : 4

16. The charge flowing through a resistance *R* varies with time *t* as $Q = at - bt^2$, where *a* and *b* are positive constants. The total heat produced in *R* is **[NEET-2016]**

(1) $\dfrac{a^3R}{b}$ (2) $\dfrac{a^3R}{6b}$

(3) $\dfrac{a^3R}{3b}$ (4) $\dfrac{a^3R}{2b}$

17. The potential difference $(V_A - V_B)$ between the points *A* and *B* in the given figure is **[NEET (Phase-2) 2016]**

(1) –3 V (2) +3 V

(3) +6 V (4) +9 V

18. A filament bulb (500 W, 100 V) is to be used in a 230 V main supply. When a resistance *R* is connected in series, it works perfectly and the bulb consumes 500 W. The value of *R* is

[NEET (Phase-2) 2016]

(1) 230 Ω (2) 46 Ω

(3) 26 Ω (4) 13 Ω

19. The resistance of a wire is '*R*' ohm. If it is melted and stretched to '*n*' times its original length, its new resistance will be **[NEET-2017]**

(1) nR (2) $\dfrac{R}{n}$

(3) n^2R (4) $\dfrac{R}{n^2}$

20. A potentiometer is an accurate and versatile device to make electrical measurements of E.M.F, because the method involves : **[NEET-2017]**

(1) Cells

(2) Potential gradients

(3) A condition of no current flow through the galvanometer

(4) A combination of cells, galvanometer and resistances

21. Current sensitivity of a moving coil galvanometer is 5 div/mA and its voltage sensitivity (angular deflection per unit voltage applied) is 20 div/V. The resistance of the galvanometer is

[NEET-2018]

(1) 40 Ω (2) 25 Ω

(3) 500 Ω (4) 250 Ω

22. A carbon resistor of (47 4.7) kΩ is to be marked with rings of different colours for its identification. The colour code sequence will be **[NEET-2018]**

(1) Violet – Yellow – Orange – Silver

(2) Yellow – Violet – Orange – Silver

(3) Green – Orange – Violet – Gold

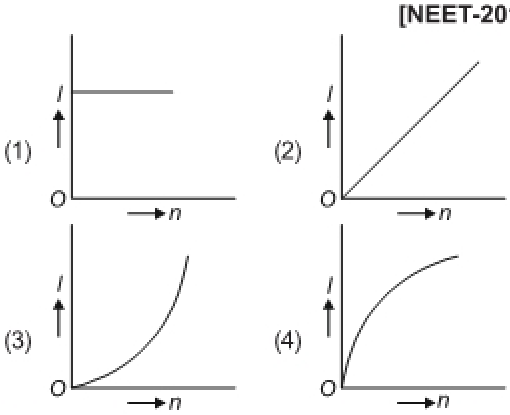
(4) Yellow – Green – Violet – Gold

23. A set of 'n' equal resistors, of value 'R' each, are connected in series to a battery of emf 'E' and internal resistance 'R'. The current drawn is I. Now, the 'n' resistors are connected in parallel to the same battery. Then the current drawn from battery becomes 10 I. The value of 'n' is **[NEET-2018]**

(1) 10 (2) 11

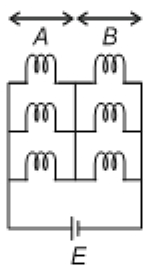
(3) 9 (4) 20

24. A battery consists of a variable number 'n' of identical cells (having internal resistance 'r' each) which are connected in series. The terminals of the battery are short-circuited and the current I is measured. Which of the graphs shows the correct relationship between I and n? **[NEET-2018]**



25. Six similar bulbs are connected as shown in the figure with a DC source of emf E and zero internal resistance.

The ratio of power consumption by the bulbs when (i) all are glowing and (ii) in the situation when two from section A and one from section B are glowing, will be : **[NEET-2019]**



(1) 4 : 9 (2) 9 : 4

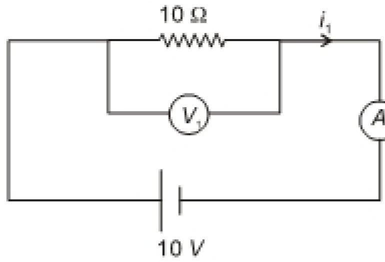
(3) 1 : 2 (4) 2 : 1

26. Which of the following acts as a circuit protection device? **[NEET-2019]**

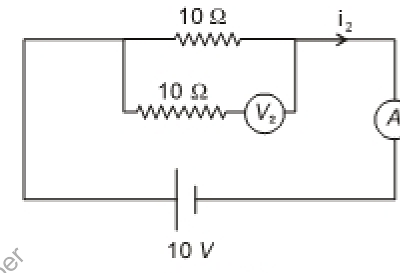
(1) Conductor (2) Inductor

(3) Switch (4) Fuse

27. In the circuits shown below, the readings of voltmeters and the ammeters will be **[NEET-2019]**



Circuit 1



Circuit 2

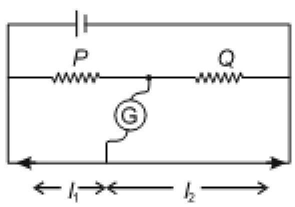
(1) $V_2 > V_1$ and $i_1 = i_2$

(2) $V_1 = V_2$ and $i_1 > i_2$

(3) $V_1 = V_2$ and $i_1 = i_2$

(4) $V_2 > V_1$ and $i_1 > i_2$

28. The metre bridge shown is in balance position with $\frac{P}{Q} = \frac{l_1}{l_2}$. If we now interchange the positions of galvanometer and cell, will the bridge work? If yes, what will be balance condition? **[NEET-2019 (Odisha)]**



(1) Yes, $\frac{P}{Q} = \frac{l_1}{l_2}$ (2) Yes, $\frac{P}{Q} = \frac{l_2 - l_1}{l_2 + l_1}$

(3) No, no null point (4) Yes, $\frac{P}{Q} = \frac{l_2}{l_1}$

❑ ❑ ❑

Chapter 4

Moving Charges and Magnetism

Sub-topics *Concept of magnetic field, Oersted's experiment. Biot-Savart law and its application to current carrying circular loop. Ampere's law and its applications to infinitely long straight wire, straight and toroidal solenoids. Force on a moving charge in uniform magnetic and electric fields. Cyclotron. Force on a current-carrying conductor in a uniform magnetic field. Force between two parallel current-carrying conductors-definition of ampere. Torque experienced by a current loop in a magnetic field; moving coil galvanometer-its current sensitivity and conversion to ammeter and voltmeter. Current loop as a magnetic dipole and its magnetic dipole moment. Magnetic dipole moment of a revolving electron.*

Concept of Magnetic Field

A stationary charge produces an electric field around it and a moving charge produces both electric as well as magnetic field around it.

An electric field exerts a force on both stationary charge as well as moving charge, while a magnetic field exerts force only on a moving charge.

$\vec{F} = q(\vec{v} \times \vec{B})$ $\quad (\vec{F} \perp \vec{v}, \vec{F} \perp \vec{B}) \Rightarrow \vec{F}.\vec{v} = \vec{a}.\vec{v} = \vec{F}.\vec{B} = \vec{a}.\vec{B} = 0$

$F = qvB \sin\theta$

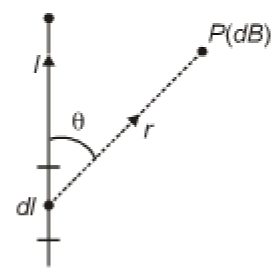
$B = \dfrac{F}{qv\sin\theta}$ $\rightarrow$ Magnetic field strength. [Unit-tesla (T)]

Oersted's Experiment

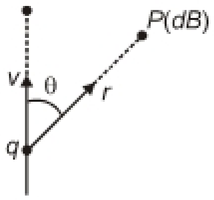
In the summer of 1820, the Danish physicist Hans Christian Oersted, while preparing for a lecture noticed that a current in a straight wire caused a noticeable deflection in a nearby magnetic compass needle. Oersted concluded that moving charges or currents produced a magnetic field in the surrounding space.

Biot-Savart Law

(a) $d\vec{B} = \dfrac{\mu_0}{4\pi}\dfrac{I\vec{dl} \times \hat{r}}{r^2}$ or $dB = \dfrac{\mu_0}{4\pi}\dfrac{Idl\sin\theta}{r^2}$

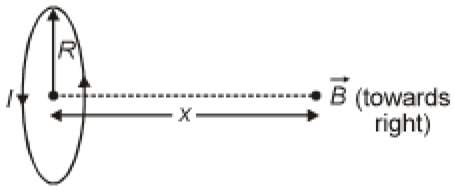


(b) $dB = \frac{\mu_0}{4\pi}\frac{qv\sin\theta}{r^2}$



Applications to current carrying circular loops

1.



$$B = \frac{\mu_0}{4\pi}\frac{2\times I\times \pi R^2 N}{(R^2+x^2)^{3/2}} = \frac{\mu_0}{4\pi}\frac{2M}{(R^2+x^2)^{3/2}}$$

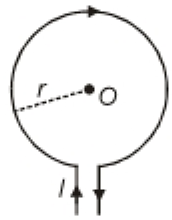
when $M = NI \times \pi R^2$ is called magnetic moment

$\vec{M} = NI \times \vec{A}$ units (Am^2)

→ directed outwards for anticlockwise current

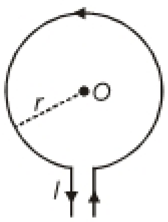
→ directed inwards for clockwise current

2.



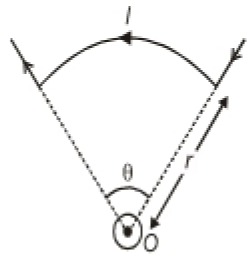
At 'O', magnetic field is into the plane of paper given by $B_0 = \frac{\mu_0 I}{2r}$

3.



$B_0 = \frac{\mu_0 I}{2r}$ (outward from the plane)

4.

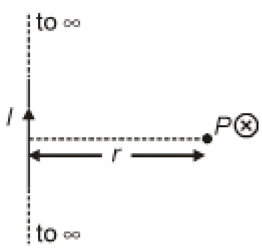


$B_0 = \frac{\mu_0 I}{2r}\times\frac{\theta}{2\pi}$ (outward from the plane)

Ampere's Law : $\oint \vec{B}.d\vec{l} = \mu_0 I_{enclosed}$

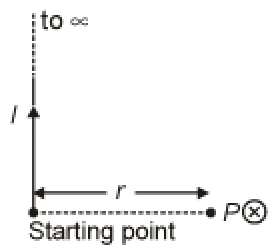
Applications to infinitely long straight wires

1.



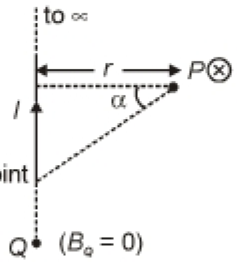
$B = \frac{\mu_0 I}{2\pi r}$

2.



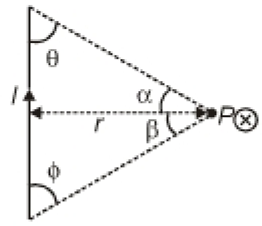
$B_P = \frac{\mu_0 I}{4\pi r}$

3. Starting point



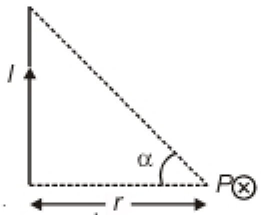
$$B_P = \frac{\mu_0 I}{4\pi r}[\sin\alpha + 1]$$

4.



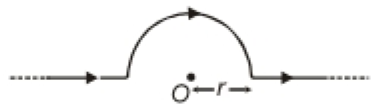
$$B_P = \frac{\mu_0 I}{4\pi r}[\sin\alpha + \sin\beta] = \frac{\mu_0 I}{4\pi r}[\cos\theta + \cos\varphi]$$

5.



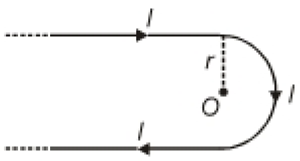
$$B_P = \frac{\mu_0 I}{4\pi r}[\sin\alpha]$$

6.



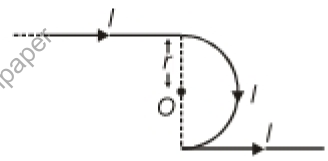
$B_O = \frac{\mu_0 I}{4r}$ (into the plane)

7.



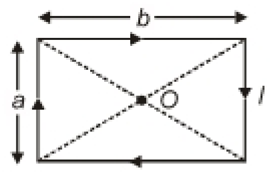
$B_0 = \frac{\mu_0 I}{2\pi r} + \frac{\mu_0 I}{4r}$ (into the plane)

8.



$B_0 = \frac{\mu_0 I}{4r}$ (into the plane)

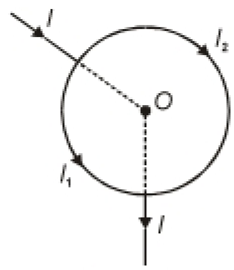
9.



$B_0 = \frac{8\mu_0 I}{4\pi}\frac{\sqrt{a^2+b^2}}{ab}$ (into the plane)

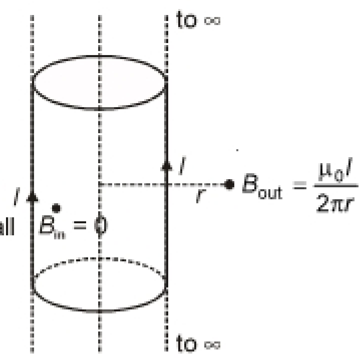
when $a = b$ $B_0 = \frac{8\sqrt{2}\mu_0 I}{4\pi a}$

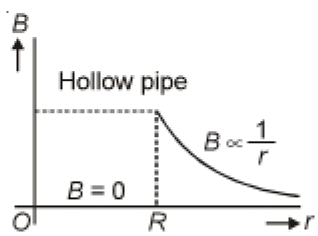
10.



B_0 = 0 always

11. Hollow pipe of metal carrying current in its wall



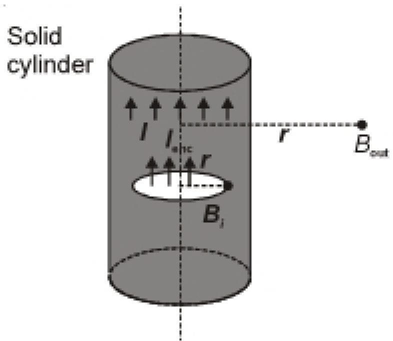


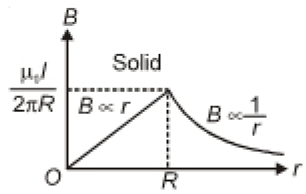
12. **Solid Cylinder :**

$$B_{in} = \frac{\mu_0 I_{enc}}{2\pi r}$$

or, $$B_{in} = \frac{\mu_0 I r}{2\pi R^2} \quad (r \le R)$$

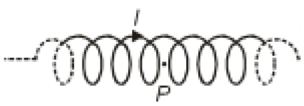
$$B_{out} = \frac{B_0 I}{2\pi r} \quad (r > R)$$

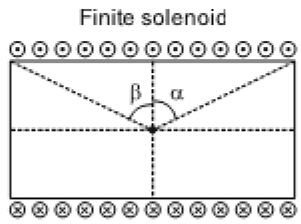




Straight solenoids

Long solenoid carrying current I and number of turns/length 'n'.





$B_P = \mu_0 n I$ (in between)

$$B = \frac{\mu_0 n I}{2}[\sin\beta + \sin\alpha]$$

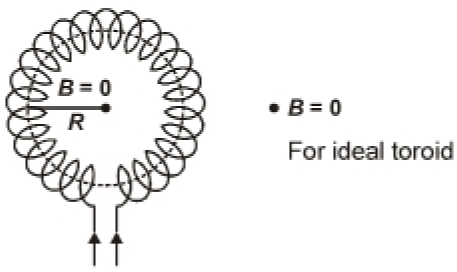
$B_{end} = \frac{\mu_0 n I}{2}$ (near one end) [for semi-infinite solenoid]

Toroidal solenoid

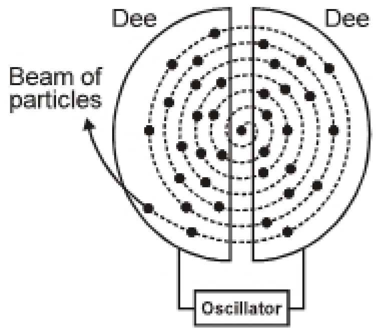
$B = \mu_0 n I$ (in the core)

$$n = \frac{N}{2\pi R}$$

N = Total number of turns



Cyclotron



A uniform magnetic field out of plane of paper exists in the region.

Circulating charge spirals outward with the dees, gaining energy every time it crosses the gap.

Frequency of rotation = frequency of oscillator = $\frac{qB}{2\pi m}$

V is potential difference between Dees

If the charge circulates n times, kinetic energy acquired $KE = 2nqV$.

$$KE_{max} = \frac{1}{2} m v_{max}^2 = \frac{1}{2} m \times \left(\frac{qBR}{m}\right)^2$$, R is radius of dee

$$KE_{max} = \frac{B^2 q^2 R^2}{2m}$$

Force on a moving charge in uniform magnetic and electric fields (Lorentz Force)

$$\vec{F} = q\vec{E} + q(\vec{v} \times \vec{B})$$

if $\vec{F} = 0 \Rightarrow q\vec{E} = -q(\vec{v} \times \vec{B})$ *i.e.,* $\vec{E} = -(\vec{v} \times \vec{B})$

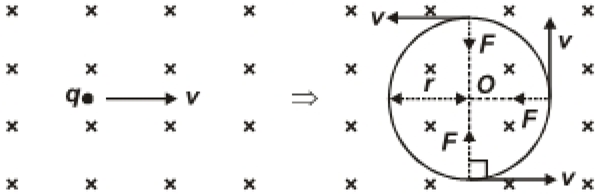
or $E = vB$ (when $\vec{v} \perp \vec{B}$)

If force on a charge particle is zero then the various possibilities are given here.

1. The charge is not acted by any field or
2. The charge is at rest or moving parallel to magnetic field in a region containing only magnetic field. or
3. The charge is moving with speed $v = E/B$ in perpendicular electric and magnetic fields such that electrostatic and magnetic forces are equal in magnitude and opposite in direction.

Motion of charged particle in magnetic field $\vec{B}$

(1) Velocity is perpendicular to magnetic field.



'q' at rest is suddenly imparted a velocity v. It will move in a circular orbit as shown and plane of circular path is perpendicular to the field applied

$$F = qvB = \frac{mv^2}{r}$$

$$\Rightarrow r = \frac{mv}{qB} = \frac{\sqrt{2mE}}{qB}$$ (E is kinetic energy) $= \sqrt{\frac{2mV}{qB^2}}$ (V is accelerating voltage)

(a) $\vec{F} \perp \vec{v}$ ∴ Uniform circular motion.

(b) Speed is constant.

(c) Kinetic energy is constant.

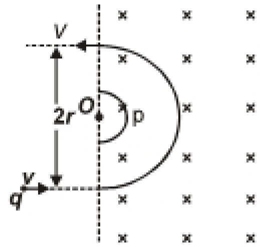
(d) Work done and power is zero.

(e) Velocity and momentum change continuously

(f) $T = \dfrac{2\pi r}{v} = \dfrac{2\pi m}{qB}$ (Independent of speed)

(g) $f = \dfrac{qB}{2\pi m}$, $\omega = \dfrac{qB}{m}$

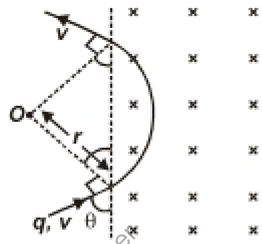
Applications



(a) $r = \dfrac{mv}{qB}$

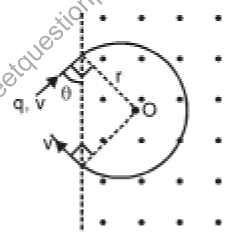
Time spent in magnetic field

$t = \dfrac{\pi m}{qB}$



(b) $r = \dfrac{mv}{qB}$

$t = \dfrac{2\theta m}{qB}$

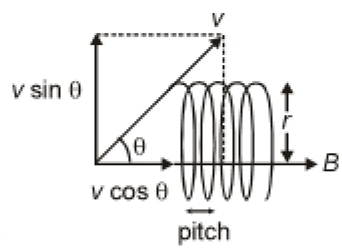


(c) $r = \dfrac{mv}{qB}, t = \dfrac{(2\pi - 2\theta)\, m}{qB}$

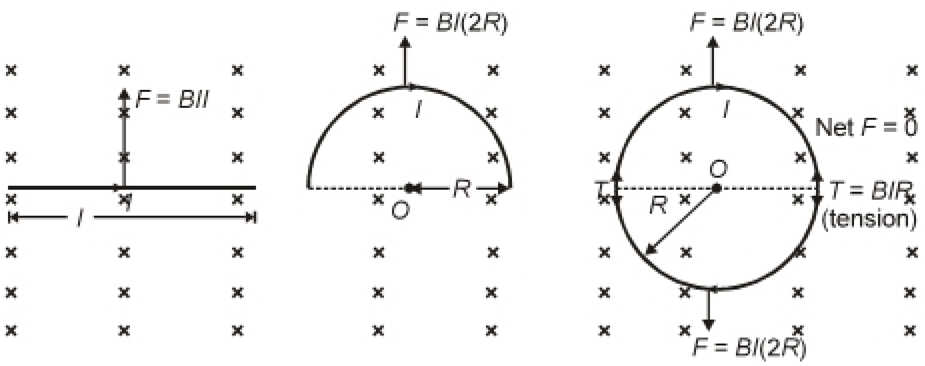
(2) $\vec{v}$ not ⊥ to $\vec{B}$. 'θ' is angle between $\vec{v}$ and $\vec{B}$.

Particle moves in a helical path.

$r = \dfrac{mv\sin\theta}{qB}, T = \dfrac{2\pi m}{qB}$, pitch = $v\cos\theta \times T$



Force on a Current carrying Conductor in a Uniform Magnetic Field



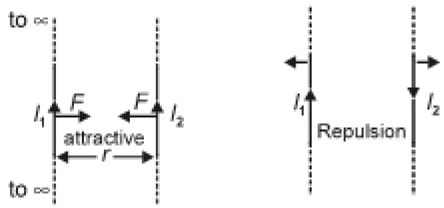
Magnetic Force between Two Parallel Current carrying Conductors: Definition of Ampere

F = Force/unit length

$$F = \frac{\mu_0 I_1 I_2}{2\pi r}$$

Attractive force on a segment of length 'l' is

$$= \frac{\mu_0 I_1 I_2}{2\pi r} \times l$$



If two infinitely long parallel wires separated by 1 m, apply a force of 2 × 10^{-7} N/m, then we say that each wire carries a current of one ampere.

Current Loop as a Magnetic dipole and its magnetic dipole moment

A current-carrying coil behaves like a bar magnet. It will attract iron objects such as iron pins. If suspended freely, it will orient itself in the north-south direction just as a bar magnet does. A bar magnet has two opposite poles at its ends; it is called a magnetic dipole. To see this connection, consider a circular current loop. The magnitude of the magnetic field at a distance r from the centre of the loop and along the axis passing through it (in a direction perpendicular to the plane of the loop) is given by

$$B = \frac{\mu_0}{2} \cdot \frac{Ia^2}{(r^2 + a^2)^{3/2}}$$

where a is the radius of the circular loop. At distance $r >> a$, this expression reduces to

$$B = \frac{\mu_0}{2} \frac{Ia^2}{r^3} = \frac{\mu_0}{4\pi} \cdot \frac{2I(\pi a^2)}{r^3}$$

or $$\boxed{B = \left(\frac{\mu_0}{4\pi}\right) \cdot \frac{2IA}{r^3}} \quad \text{...(i)}$$

where $A = \pi a^2$ is the area of the circular loop. Let us compare it with the electric field due to an electric dipole at a point far away from it and at a point on the dipole axis. This field has been calculated in earlier chapter and has a magnitude given by

$$\vec{E} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2\vec{p}}{r^3} \quad \text{...(ii)}$$

where $\vec{p}$ is the electric dipole moment. Notice that B due to a current loop and E due to an electric dipole have the same ($1/r^3$) dependence on distance. Equation (i) may be written as

$$\vec{B} = \left(\frac{\mu_0}{4\pi}\right) \cdot \frac{2\vec{M}}{r^3} \quad \text{...(iii)}$$

where $\vec{M} = I\vec{A}$. By analogy with electric dipole moment $\vec{p}$ in Eq. (ii), quantity $\vec{M}$ is called the magnetic dipole moment, it is a vector quantity :

and for 'n' number of turns, $\vec{M} = nI\vec{A}$ ....(iv)

where $\vec{A}$ is the area vector.

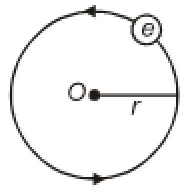
Thus the current loop behaves as a small magnetic dipole with its axis along the axis of the loop. One face of a current loop is the north pole and the other face the south pole. The face with clockwise current behaves as south pole and the face with anticlockwise current behaves as north pole.

Magnetic Dipole moment of Revolving electron

An electron is revolving in an orbit such that

v = speed

f = frequency



(a) Equivalent current $I = \frac{e}{T} = ef = \frac{ev}{2\pi R}$

(b) $B_0 = \frac{\mu_0 I}{2r}$

(c) $\vec{M} = I\vec{A} \Rightarrow M = \frac{ev}{2\pi R} \times \pi R^2$

(d) $\vec{M} = -\frac{e\vec{L}}{2m}$

where 'L' is angular momentum ($L = mvr$), $\vec{M}$ and $\vec{L}$ are in opposite direction.

(e) For any uniform charge distribution rotating with angular speed 'ω', $\vec{M} = \frac{q}{2m}\vec{L}$,

where M is magnetic moment, L = angular momentum = $I\omega$

M = mass, q = charge

Torque experienced by a current loop in a magnetic field.

θ is angle between $\vec{B}$ and $\vec{A}$

Case-I : $\theta = 90°$

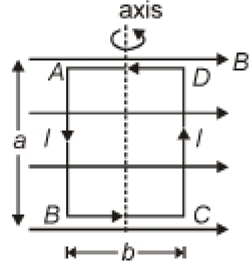
(1) $\vec{M} = NI\vec{A}$ ($\perp$ to plane of loop)

$\vec{\tau} = \vec{M} \times \vec{B}$

$\tau = MB = NIAB$ (Maximum)

where A = area = Nab ; N = number of turns

Potential energy $U = -\vec{M}.\vec{B} = 0$



(a)

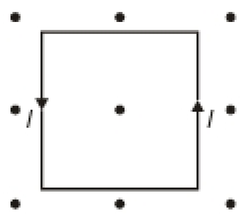
Case-II : $\theta = 0°$

(2) $\vec{B}$ (out)

$\vec{M} = I\vec{A}$ (out)

$\tau = 0$ as $\vec{M}$ parallel $\vec{B}$

$U = -\vec{M}.\vec{B} = -MB$



(b)

Work done in rotating coil from position θ_1 to θ_2 against the magnetic field.

$W = MB(\cos\theta_1 - \cos\theta_2)$

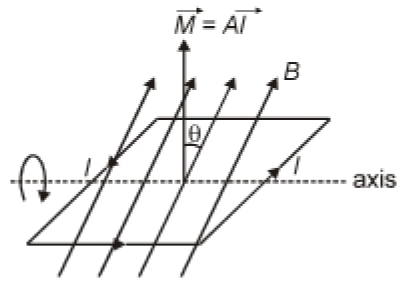
(1) $\theta_1 = 0°, \theta_2 = 180°$ $W = 2MB$

(2) $\theta_1 = 0°, \theta_2 = 90°$ $W = MB$

(3) $\theta_1 = 90°, \theta_2 = 180°$ $W = +MB$

(4) $\theta_1 = 0°, \theta_2 = \theta$ $W = MB(1 - \cos\theta)$

(5) $\theta_1 = 90°, \theta_2 = \theta$ $W = -MB\cos\theta$



$\tau = MB\sin\theta$, $U_{min} = -MB\ (\theta = 0)$

$U = -MB\cos\theta$, $U_{max} = MB\ (\theta = 180°)$

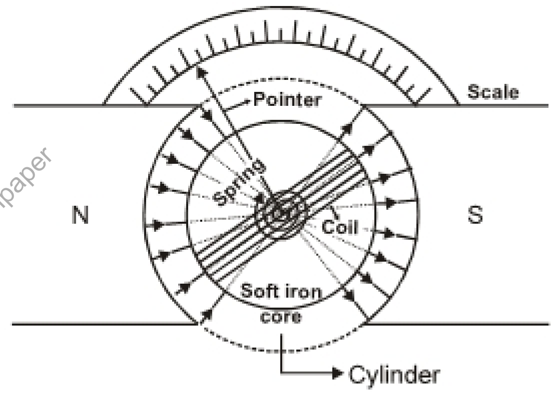
Moving coil galvanometer

N is number of turns, *I* is the current flowing through coil of area *A* kept in radial magnetic field *B*. *C* is the torque required to produce a unit angular twist in suspension strip.

$\tau = NIAB$ [θ = 90° due to radial field]

$= C\theta$ (restoring torque)

Where θ is angle formed by the pointer and *C* is restoring torque/twist in the suspension wire.



$I = \frac{C\theta}{NBA}, \frac{\theta}{I} = \frac{NBA}{C}$ current sensitivity

Current sensitivity $\frac{\theta}{I} = \frac{NBA}{C}$

Voltage sensitivity $\frac{\theta}{V} = \frac{\theta}{IR} = \frac{NBA}{CR}$

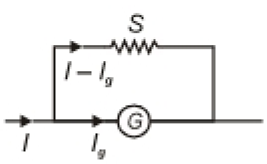
Instruments

Ideal ammeter has zero resistance, so that current drawn from cell remain unchanged

Ammeter : It is a low resistance device connected in series to measure current.

A galvanometer of resistance *G* and full scale deflection current I_g is converted into an ammeter of range $0 - I$ by shunting it with resistance *S* such that

$S = \frac{I_g G}{I - I_g}$



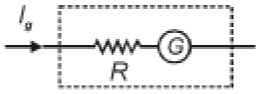
Total resistance of ammeter $G' = \frac{SG}{S+G}$, $G' < S < G$

Voltmeter : A high resistance device connected in parallel to measure potential difference between two points.

Ideal volmeter has infinite resistance.

A galvanometer of resistance *G* and full scale deflection current I_g is converted into a voltmeter of range $0 - V$ volt by connecting a high resistance *R* given by

$$R = \frac{V}{I_g} - G$$



Total resistance of voltmeter $G' = R + G$, $G < R < G'$

Important points about the measuring instruments

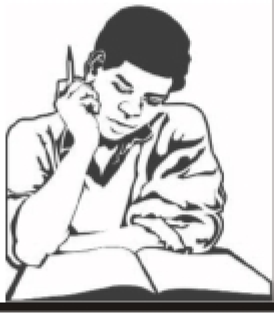
(1) When an ammeter is connected in a circuit, it alters the current flowing in the circuit. It will read less than actual value.

(2) When a voltmeter is connected in the circuit, it alters the current flowing in the circuit. It will read less than actual value.

(3) An ideal ammeter should have zero resistance so that it may give accurate reading.

(4) An ideal voltmeter should have infinite resistance so that it may give accurate reading.

❑ ❑ ❑



Try Yourself

SECTION - A

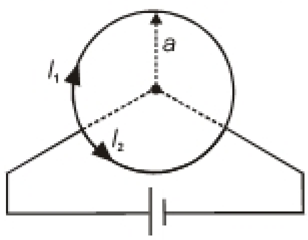
Objective Type Questions

1. A positively charged particle falls vertically downward. The horizontal component of earth's magnetic field will deflect it towards
   (1) North (2) South
   (3) East (4) West

2. An electron and a proton enter a perpendicular uniform magnetic field. Both have same K.E. Which of the following is true?
   (1) Trajectory of electron is less curved
   (2) Trajectory of proton is less curved
   (3) Both the trajectories are equally curved
   (4) Both move on straight line path

3. A charge moves in a circle perpendicular to a magnetic field. The time period of revolution is independent of
   (1) Magnetic field
   (2) Charge
   (3) Mass of the particle
   (4) Velocity of the particle

4. A cell is connected between two points of a uniformly thick circular conductor of radius *a*. The magnetic field at the centre of loop will be



   (1) Zero (2) $\frac{\mu_0}{2a}(i_1+i_2)$
   (3) $\frac{\mu_0}{2a}(i_1-i_2)$ (4) $\frac{\mu_0}{a}(i_1+i_2)$

5. A wire of length *L* carrying a current *I* is bent in the form of a circle. The magnetic moment is
   (1) IL^2 (2) $\frac{IL}{4\pi}$
   (3) $\frac{IL^2}{4\pi}$ (4) $\frac{IL^2}{2\pi}$

6. An electron is moving along positive *x*-axis. To get it moving on an anticlockwise (as seen from above) circular path in *x-y* plane, a magnetic field is applied
   (1) Along + *y*-axis (2) Along + *z*-axis
   (3) Along – *y*-axis (4) Along – *x*-axis

7. An experiment investigates the variation of the force F between two long parallel current carrying conductors a distance *d* apart. A straight line graph should be obtained on plotting
   (1) F against *d* (2) F against $\frac{1}{d}$
   (3) F against $\frac{1}{d^2}$ (4) F against d^2

8. In a current carrying long solenoid, the field produced does not depend on
   (1) Number of turns per unit length
   (2) Current that flows
   (3) Radius of solenoid
   (4) All of these

9. A charged particle of energy 15 eV moves through a perpendicular magnetic field. The energy of the particle on emerging out of the magnetic field is
   (1) 15 eV
   (2) > 15 eV
   (3) < 15 eV
   (4) May be greater or lesser depending on the sense of applied field

10. A rectangular coil of area A and of N turns has a current I flowing in clockwise direction when looked at from above. The magnetic moment associated with it

(1) Points upwards

(2) Points vertically downward

(3) Is zero

(4) Is directly proportional to A^2

11. The magnetic induction associated with current flowing in a hollow copper tube will be

(1) Only inside

(2) Only outside

(3) Both inside and outside

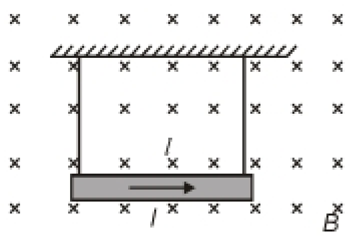
(4) Neither inside nor outside

12. An electron is revolving in a circular orbit of radius r in a hydrogen atom. The angular momentum of electron is L. The magnetic moment associated with it due to its revolution is

(1) $\left(\frac{e}{m}\right)L$ (2) $\left(\frac{e}{2m}\right)L$

(3) $\left(\frac{m}{e}\right)L$ (4) $\left(\frac{2m}{e}\right)L$

13. A bar of mass m and length l is suspended by two wires in uniform magnetic field as shown. The current through the bar is I. At equilibrium, the tension in each wire is



(1) $\frac{mg}{2}$ (2) $2BIl$

(3) $mg - BIl$ (4) $\frac{mg - BIl}{2}$

14. Which of the following particle will have minimum frequency of revolution when projected with the same velocity perpendicular to a magnetic field?

(1) Electron (2) Proton

(3) He^+ (4) Li^+

15. A particle of mass m carrying charge q is accelerated by a potential difference of V. It enters perpendicularly in a region of uniform magnetic field B and execute circular arc of radius R, then $\frac{q}{m}$ is equal to

(1) $\frac{V}{2BR}$ (2) $\frac{2V}{BR}$

(3) $\frac{2V}{B^2R^2}$ (4) $\frac{mV}{BR}$

16. A charged particle moves in a uniform magnetic field. The velocity of the particle at some instant makes an acute angle with the magnetic field. The path of the particle will be

(1) Straight line

(2) A circle

(3) A helix with uniform pitch

(4) A helix with non-uniform pitch

17. The coil of a galvanometer consists of 100 turns and effective area of 1 cm^2. The restoring couple is 10^{-8} Nm rad^{-1}. The magnetic field between the pole pieces is 5 T. The current sensitivity of this galvanometer will be

(1) $5\times10^4 \frac{rad}{\mu A}$

(2) 5×10^{-6} rad per A

(3) 2×10^{-7} rad per A

(4) 5 rad/μA

18. A charged particle is projected in a plane perpendicular to a uniform magnetic field. The area bounded by the path described by the particle is directly proportional to its

(1) Velocity (2) Momentum

(3) Kinetic energy (4) Both (1) & (2)

19. Two concentric circular coils of 10 turns each are situated in the same plane. Their radii are 20 cm and 40 cm and they carry respectively 0.2 A and 0.3 A current in opposite direction. The magnetic field in Wbm^{-2} at the centre is

(1) $\frac{\mu_0}{80}$ (2) $\frac{5}{4}\mu_0$

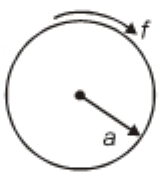
(3) $\frac{7}{4}\mu_0$ (4) $\frac{35}{4}\mu_0$

20. An arbitrary shaped closed coil of a wire of length L and a current I amp. is flowing in it. If the plane of the coil is perpendicular to magnetic field, the force on the coil is

(1) Zero (2) IBL

(3) $2IBL$ (4) $\frac{1}{2}BIL$

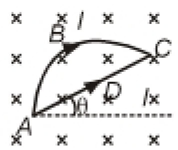
21. A ring of radius a and charge q rotates with frequency f about its own axis. The magnetic induction at centre is (Assume that whole charge is situated at its outer surface)



(1) $\frac{qf}{a}$ (2) $\frac{\mu_0 qf}{a}$

(3) $\frac{\mu_0 qf}{2a}$ (4) $\frac{\mu_0 qf}{4a}$

22. A semi circular wire ABC and a straight conductor ADC each carrying current I are kept in the magnetic field then



(1) Magnitude of force on ABC > magnitude of force on ADC

(2) Magnitude of forces on ABC < magnitude of force on ADC

(3) Magnitude of force on ABC = magnitude of force on ADC

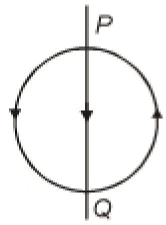
(4) Force on ADC is opposite to force on ABC

23. A straight section PQ of a circuit is placed along the x-axis from $x = -a/2$ to $x = +a/2$ and carries a steady current I. The magnetic field due to the section PQ at a point $x = +a$ will be

(1) Proportional to a (2) Proportional to a^2

(3) Proportional to $\frac{1}{a}$ (4) Zero

24. A circular coil of wire carries a current. PQ is a part of a very long wire carrying a current and passing close to the circular coil. If the directions of the currents are those as shown in fig. What is the direction of force acting on PQ?



(1) Parallel to PQ, towards P

(2) Parallel to PQ, towards Q

(3) At right angle to PQ, to the right

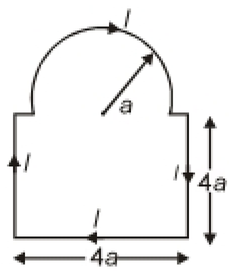
(4) At right angle to PQ, to the left

25. If an electron describes half a revolution in a circle of radius r in a magnetic field B, the energy acquired by it is

(1) Zero (2) ∞

(3) $\frac{1}{2}mv^2$ (4) $\pi r \times Bev$

26. The magnetic dipole moment of the given arrangement is



(1) $16a^2I$ (2) $\frac{\pi a^2}{2}I$

(3) $\left(16 + \frac{\pi}{2}\right)a^2I$ (4) Zero

27. If one moves on the axis of a current carrying circular coil starting from the centre of coil, then magnetic field induction

(1) Decreases

(2) Increases

(3) First decreases then increases

(4) First increases then decreases

28. A circular loop of area 1 cm^2, carrying a current of 10A, is placed in a magnetic field of 0.1 T perpendicular to the plane of the loop. The torque on the loop due to the magnetic field is

(1) Zero (2) 10^{-4} Nm

(3) 10^{-2} Nm (4) 1 Nm

29. An electric charge in motion (uniform) produces
    (1) An electric field only
    (2) A magnetic field only
    (3) Both electric and magnetic field
    (4) No such field at all

30. One metre length of a wire carries a constant current. The wire is bent to form a circular loop. The magnetic field at the centre of this loop is B. The same wire is now bent to form a circular loop of smaller radius to have 4 turns in the loop. The magnetic field at the centre of this new loop is
    (1) $4B$ (2) $16B$
    (3) $B/2$ (4) $B/4$

31. A magnetic field of 0.004 $\hat{k}$ tesla exerts a force of $(4\hat{i}+3\hat{j})\times10^{-10}$N on a particle having charge of 10^{-9} C and moving in x-y plane. The velocity of the particle is
    (1) $(75\hat{i}+100\hat{j})$m/s (2) $(75\hat{i}-100\hat{j})$m/s
    (3) $(-75\hat{i}+100\hat{j})$m/s (4) $(-75\hat{i}-100\hat{j})$m/s

32. A proton and a deutron both having same K.E. enter perpendicularly into a uniform magnetic field B. For motion of proton and deutron on circular path of radius R_p and R_d respectively, the correct statement is
    (1) $R_d=\sqrt{2}R_p$ (2) $R_d=\frac{R_p}{\sqrt{2}}$
    (3) $R_d = R_p$ (4) $R_d = 2R_p$

SECTION - B

Previous Years Questions

1. A milli voltmeter of 25 milli volt range is to be converted into an ammeter of 25 ampere range. The value (in ohm) of necessary shunt will be **[AIPMT 2012]**
    (1) 1 (2) 0.05
    (3) 0.001 (4) 0.01

2. Two similar coils of radius R are lying concentrically with their planes at right angles to each other. The currents flowing in them are I and $2I$, respectively. The resultant magnetic field induction at the centre will be **[AIPMT 2012]**
    (1) $\frac{\mu_0 I}{2R}$ (2) $\frac{\mu_0 I}{R}$
    (3) $\frac{\sqrt{5}\,\mu_0 I}{2R}$ (4) $\frac{3\,\mu_0 I}{2R}$

3. An alternating electric field, of frequency ν, is applied across the dees (radius = R) of a cyclotron that is being used to accelerate protons (mass = m). The operating magnetic field (B) used in the cyclotron and the kinetic energy (K) of the proton beam, produced by it, are given by **[AIPMT 2012]**
    (1) $B=\frac{2\pi m\nu}{e}$ and $K = 2m\pi^2\nu^2R^2$
    (2) $B=\frac{m\nu}{e}$ and $K = m^2\pi\nu R^2$
    (3) $B=\frac{m\nu}{e}$ and $K = 2m\pi^2\nu^2R^2$
    (4) $B=\frac{2\pi m\nu}{e}$ and $K = m^2\pi\nu R^2$

4. A current loop in a magnetic field **[NEET-2013]**
    (1) Can be in equilibrium in one orientation
    (2) Can be in equilibrium in two orientations, both the equilibrium states are unstable
    (3) Can be in equilibrium in two orientations, one stable while the other is unstable
    (4) Experiences a torque whether the field is uniform or non uniform in all orientations

5. When a proton is released from rest in a room, it starts with an initial acceleration a_0 towards west. When it is projected towards north with a speed v_0 it moves with an initial acceleration $3a_0$ toward west. The electric and magnetic fields in the room are **[NEET-2013]**
    (1) $\frac{ma_0}{e}$ west, $\frac{2ma_0}{ev_0}$ down
    (2) $\frac{ma_0}{e}$ east, $\frac{3ma_0}{ev_0}$ up
    (3) $\frac{ma_0}{e}$ east, $\frac{3ma_0}{ev_0}$ down
    (4) $\frac{ma_0}{e}$ west, $\frac{2ma_0}{ev_0}$ up

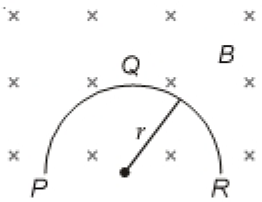
6. In an ammeter 0.2% of main current passes through the galvanometer. If resistance of galvanometer is G, the resistance of ammeter will be **[AIPMT 2014]**
    (1) $\frac{1}{499}G$ (2) $\frac{499}{500}G$
    (3) $\frac{1}{500}G$ (4) $\frac{500}{499}G$

7. Two identical long conducting wires *AOB* and *COD* are placed at right angle to each other, with one above other such that *O* is their common point for the two. The wires carry I_1 and I_2 currents, respectively. Point *P* is lying at distance *d* from *O* along a direction perpendicular to the plane containing the wires. The magnetic field at the point *P* will be **[AIPMT 2014]**

(1) $\frac{\mu_0}{2\pi d}\left(\frac{I_1}{I_2}\right)$ (2) $\frac{\mu_0}{2\pi d}(I_1+I_2)$

(3) $\frac{\mu_0}{2\pi d}(I_1^2-I_2^2)$ (4) $\frac{\mu_0}{2\pi d}\left(I_1^2+I_2^2\right)^{1/2}$

8. A thin semicircular conducting ring (*PQR*) of radius *r* is falling with its plane vertical in a horizontal magnetic field *B*, as shown in figure. The potential difference developed across the ring when its speed is *v*, is **[AIPMT 2014]**



(1) Zero

(2) $Bv\pi r^2/2$ and *P* is at higher potential

(3) πrBv and *R* is at higher potential

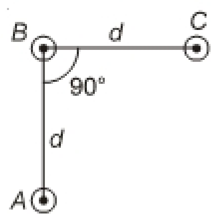
(4) $2rBv$ and *R* is at higher potential

9. A long solenoid of diameter 0.1 m has 2×10^4 turns per meter. At the centre of the solenoid, a coil of 100 turns and radius 0.01 m is placed with its axis coinciding with the solenoid axis. The current in the solenoid reduces at a constant rate to 0 A from 4 A in 0.05 s. If the resistance of the coil is $10\pi^2\ \Omega$, the total charge flowing through the coil during this time is **[NEET-2017]**

(1) $32\pi\ \mu C$ (2) $16\ \mu C$

(3) $32\ \mu C$ (4) $16\pi\ \mu C$

10. An arrangement of three parallel straight wires placed perpendicular to plane of paper carrying same current '*I*' along the same direction is shown in Fig. Magnitude of force per unit length on the middle wire '*B*' is given by **[NEET-2017]**



(1) $\frac{\mu_0 I^2}{2\pi d}$ (2) $\frac{2\mu_0 I^2}{\pi d}$

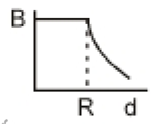
(3) $\frac{\sqrt{2}\mu_0 I^2}{\pi d}$ (4) $\frac{\mu_0 I^2}{\sqrt{2}\pi d}$

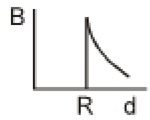
11. Ionized hydrogen atoms and α-particles with same momenta enters perpendicular to a constant magnetic field, B. The ratio of their radii of their paths $r_H : r_\alpha$ will be **[NEET-2019]**

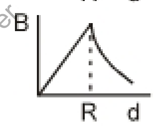
(1) 2 : 1 (2) 1 : 2

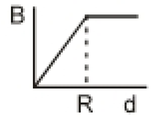
(3) 4 : 1 (4) 1 : 4

12. A cylindrical conductor of radius R is carrying a constant current. The plot of the magnitude of the magnetic field B with the distance d from the centre of the conductor, is correctly represented by the figure : **[NEET-2019]**

(1) 

(2) 

(3) 

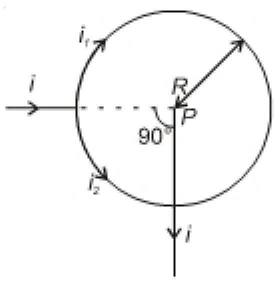
(4) 

13. Two toroids 1 and 2 have total no. of turns 200 and 100 respectively with average radii 40 cm and 20 cm respectively. If they carry same current *i*, the ratio of the magnetic fields along the two loops is, **[NEET-2019 (Odisha)]**

(1) 1 : 2 (2) 1 : 1

(3) 4 : 1 (4) 2 : 1

14. A straight conductor carrying current i splits into two parts as shown in the figure. The radius of the circular loop is *R*. The total magnetic field at the centre *P* of the loop is, **[NEET-2019 (Odisha)]**



(1) $\frac{\mu_0 i}{2R}$, inward (2) Zero

(3) $3\mu_0 i/32R$, outward (4) $3\mu_0 i/32R$, inward

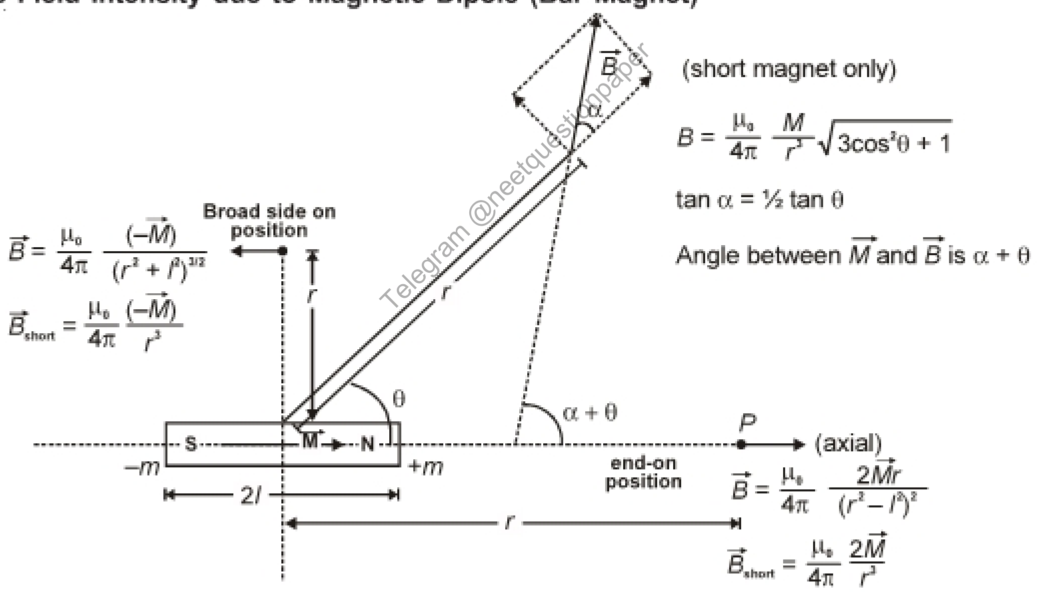
❑ ❑ ❑

Chapter 5

Magnetism and Matter

Sub-topics *Magnetic field intensity due to a magnetic dipole (bar magnet) along its axis and perpendicular to its axis. Torque on a magnetic dipole (bar magnet) in a uniform magnetic field; bar magnet as an equivalent solenoid, magnetic field lines; Earth's magnetic field and magnetic elements. Para-, dia-and ferro-magnetic substances, with examples. Electromagnetic and factors affecting their strengths. Permanent magnets.*

Magnetic Field Intensity due to Magnetic Dipole (Bar Magnet)



(1) Geometric length = $2l$.

(2) Magnetic length = **0.8** geometric length

(3) $\vec{B}_{axial}$ parallel $\vec{M}$. (Direction of $\vec{M}$ *i.e.*, magnetic dipole moment is from south pole to north pole)

(4) $\vec{B}_{equatorial}$ is antiparallel to $\vec{M}$.

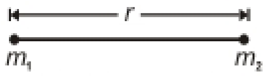
(5) $\vec{B} \perp \vec{M}$ when $\theta + \alpha = 90°$ *i.e.*, $\theta = 90° - \alpha$

As $\tan\alpha = \frac{1}{2}\tan\theta \Rightarrow \cot\theta = \frac{1}{2}\tan\theta$ or $\tan\theta = \sqrt{2}$. In this case $B = \frac{\mu_0}{4\pi}\frac{\sqrt{2}M}{r^3}$.

(6) $\vec{M} = m \times \vec{2l}$ where 'm' is pole strength. [Direction along magnetic axis from $-m$ to $+m$ or from S to N]

Coulomb's law in magnetism

$$F = \frac{\mu_0}{4\pi}\frac{m_1 m_2}{r^2}$$



(isolated imaginary poles)

Torque on a Magnetic Dipole (Bar Magnet) in a Uniform Magnetic Field

1. $\vec{\tau} = \vec{M} \times \vec{B}$ $\quad \tau_{max} = MB\ [\theta = 90°]$

   Net force is zero. $\tau_{min} = 0 \begin{bmatrix} \theta = 0° \rightarrow \text{stable equilibrium} \\ \theta = 180° \rightarrow \text{unstable equilibrium} \end{bmatrix}$

2. $U = -\vec{M}.\vec{B}$ $\quad U_{min} = -MB$ at $\theta = 0°$

   $U_{max} = MB$ at $\theta = 180°$

3. Work done in rotating bar magnet from angular position θ_1 to θ_2 is $W = MB\,[\cos\theta_1 - \cos\theta_2]$

Note : *A bar magnet kept in a non-uniform magnetic field may experience a net force and also a torque (if not parallel to field).*

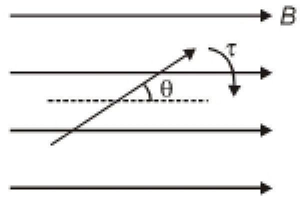
Oscillations of a bar magnet in magnetic field

$\tau = MB \sin\theta$ $\quad$ [$\sin\theta \approx \theta$, for very small value of θ]

$\tau = -MB\,\theta$ $\quad$ [restoring torque]

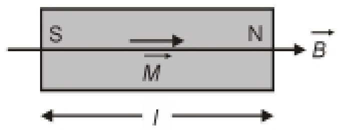
$\Rightarrow \alpha = \frac{-MB\theta}{I}$ $\quad$ I = moment of inertia of the magnet

$\therefore \omega = \sqrt{\frac{MB}{I}} \Rightarrow T = 2\pi\sqrt{\frac{I}{MB}}$

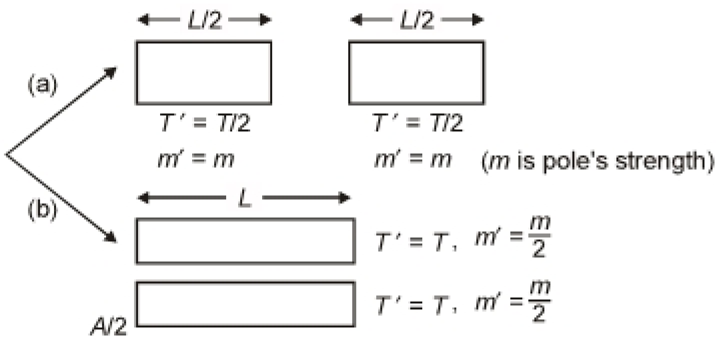


Applications :

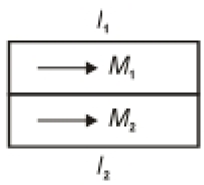
(1) $T = 2\pi\sqrt{\frac{I}{MB}}$



(2) A bar magent is cut into two halves



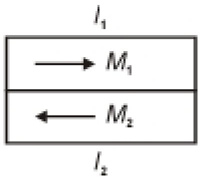
(3) $T_1 = 2\pi\sqrt{\frac{I_1 + I_2}{(M_1 + M_2)B}}$



[Sum position]

(4) $T_2 = 2\pi\sqrt{\frac{I_1 + I_2}{(M_1 - M_2)B}}$

$\frac{T_2^2 + T_1^2}{T_2^2 - T_1^2} = \frac{M_1}{M_2}$

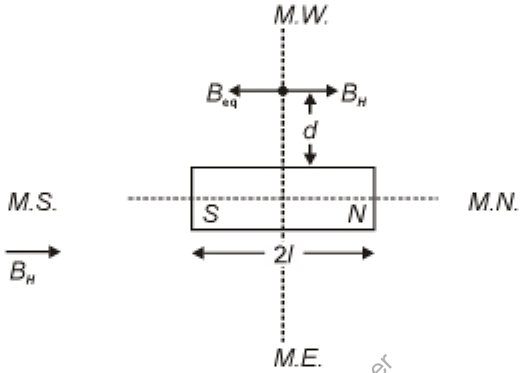


[Difference position]

Neutral Points

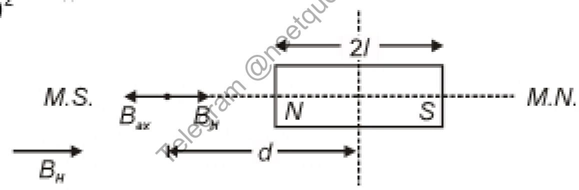
Case I : (N-N position)

$$B_H = B_{eq.} \Rightarrow \frac{\mu_0}{4\pi}\frac{M}{(d^2 + l^2)^{3/2}} = B_H$$



Case II : (N-S position)

$$B_H = B_{ax} \Rightarrow \frac{\mu_0}{4\pi}\frac{2Md}{(d^2 - l^2)^2} = B_H$$



Bar Magnet as an Equivalent Solenoid

For a bar magnet the dipole moment is

$\mu = ml$

where m = Pole strength and

l = Length of the bar magnet

For a solenoid of length l and number of turns per unit length n and area of each loop as A

We have dipole moment as

μ = (Current) × (Area) = $InlA$

So, $ml = InlA$

or $m = InA$

Magnetic Field Lines

The space surrounding a magnet in which its effects are perceptible is called the magnetic field of that magnet.

Michael Faraday visualised the magnetic field graphically, which were called lines of force by him. This nomenclature will not be adopted here because the curve representing the field does not give the direction of the force on a moving charge. So, we will call these curves as magnetic field lines. We may define these lines as follows.

"The magnetic field lines are imaginary curves, the tangent to which at a point gives the direction of the field at that point."

Properties of Magnetic Field Lines

(1) These are continuous closed curves. Note that electrostatic field lines are not closed.

(2) The direction of field lines is from north pole to south pole outside the magnet and from south pole to north pole inside the magnet without any starting or ending points. Note that electric field lines start from positive charge and end at negative charge.

(3) Magnetic field lines emerge from or enter the surface of a magnet at any angle (not necessarily normally to the surface of a conductor as in the case of electric field lines.)

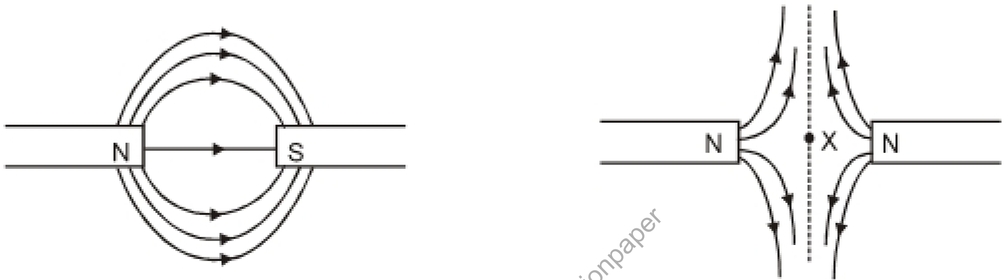
(4) Two lines of magnetic field never intersect each other because if this is so, there will be more than one direction of the magnetic field at the point of intersection (which is impossible).

(5) The field is strong at places where field lines are crowded; while it is weak at places, these are farther apart.

(6) The number of field lines at the poles is proportional to pole-strength.

(7) In the region of uniform field, the field lines are parallel straight lines equally spaced.

(8) Magnetic field lines have tendency to contract longitudinally like a stretched elastic string. [as in figure (a)] and repel each other laterally [as in figure (b)].



(a) (b)

Earth's Magnetic Field and Magnetic Elements

Elements of earth's magnetic field.

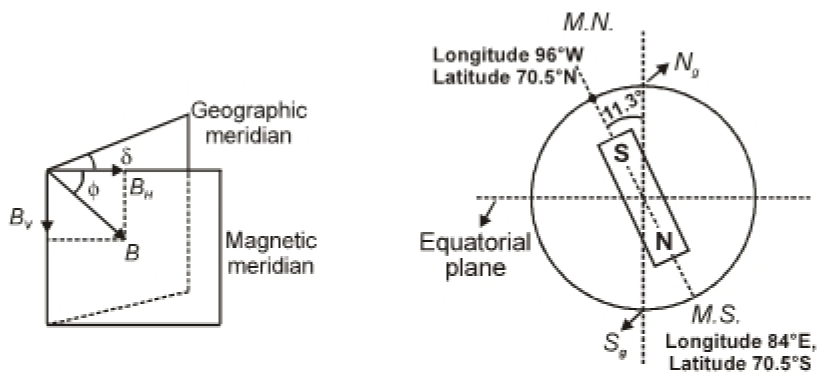
(1) Magnetic declination

(2) Magnetic inclination (Angle of dip)

(3) Horizontal component of earth's magnetic field

δ = angle of declination

ϕ = angle of dip



$B_H = B \cos \phi$

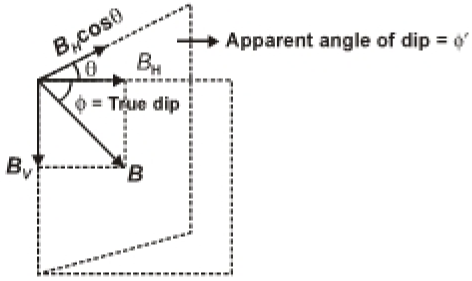
$B_V = B \sin \phi$

$B_H^2 + B_V^2 = B^2$

The needle of a vertical compass in magnetic meridian points toward B.

Applications :

(1) $\tan\phi = \frac{B_V}{B_H}$

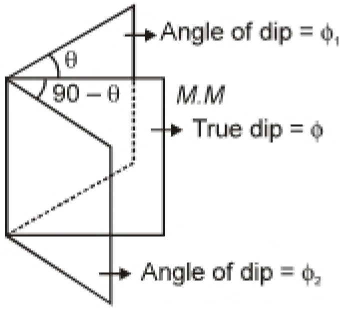


$\tan\phi' = \frac{B_V}{B_H\cos\theta}$ (apparent dip)

i.e., $\boxed{\tan\phi' = \frac{\tan\phi}{\cos\theta}}$

If θ = 90° then φ′ = 90°, Angle of dip on meridian perpendicular to magnetic meridian is always 90°

(2) $\tan\phi_1 = \frac{\tan\phi}{\cos\theta}$



$\tan\phi_2 = \frac{\tan\phi}{\cos(90-\theta)}$

$\Rightarrow \quad \cot^2\phi = \cot^2\phi_1 + \cot^2\phi_2$

$\Rightarrow \quad \tan\theta = \frac{\tan\phi_1}{\tan\phi_2}$

Note:

When north pole of a dip needle points downward, then angle of dip is positive and when north pole points upwards then angle of dip is negative.

So, in northern magnetic hemisphere, where a dip needle shows angle of dip, say, 30° N, can be also written as +30°. In southern magnetic hemisphere, where dip needle shows, say, 30° S, can be also written as –30°.

At magnetic north pole and magnetic south pole angle of dip are +90° and –90° respectively.

Para-, Dia and Ferromagnetic Substances

1. **Magnetic Intensity (Magnetising Force) :** $\vec{H} = \frac{\vec{B}_0}{\mu_0}$, $\vec{B}_0$ is magnetic field in vacuum.

   SI units = A/m

   CGS units = oersted. 1 oersted = 80 A/m.

2. **Intensity of magnetisation :** Magnetic moment developed/volume

   $\vec{I} = \frac{\vec{M}}{V}$ (Units A/m or oersted)

   $I = \frac{\text{Pole strength}}{\text{area}}$ $\quad \begin{bmatrix} \because M = m \times l \\ \because V = A \times l \end{bmatrix}$

3. **Magnetic Induction or Magnetic Flux Density** $(\vec{B})$ **:** It represents the number of magnetic field lines crossing per unit area normally through a magnetic substance.

   $\vec{B} = \vec{B}_0 + \mu_0\vec{I}$

   $\vec{B} = \mu_0\vec{H} + \mu_0\vec{I}$ $\quad \begin{bmatrix} \vec{B}_0 = \text{applied magnetic field} \\ \mu_0\vec{I} = \text{magnetic field due to magnetisation} \end{bmatrix}$

   $\vec{B} = \mu_0(\vec{H} + \vec{I})$

4. **Magnetic Susceptibility :** $\chi_m = \frac{I}{H}$ (no units)

5. **Magnetic Permeability :** $\mu = \frac{B}{H} \Rightarrow \vec{B} = \mu\vec{H}$

From above $B = \mu_0(H + I)$

$\Rightarrow \quad \mu H = \mu_0 (H + I)$

$\Rightarrow \quad \frac{\mu}{\mu_0} = 1 + \frac{I}{H}$

$\boxed{\mu_r = 1 + \chi_m}$ where μ_r = relative permeability.

Diamagnetic Substance

The properties of diamagnetic substances are as under :

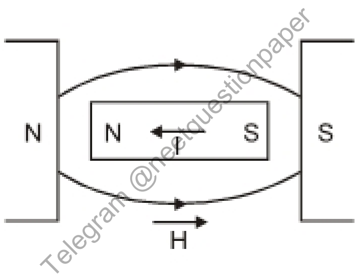
(1) χ_m is small and negative

(2) $\mu_r < 1$.

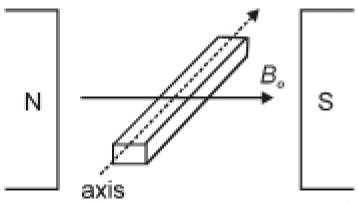
(3) As $\chi_m = \frac{I}{H} \Rightarrow I$ is small and opposite to H.

$\therefore$ They are magnetised weakly and opposite to applied magnetic field.

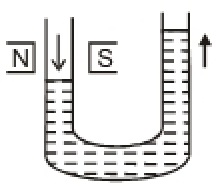
(4) Magnetic field lines do not cross through perfect diamagnetic materials e.g. superconductors



(5) When freely suspended, they align perpendicular to $\vec{B}_o$.



(6) They are repelled by magnetic field, so they move from stronger to weaker regions of magnetic field.



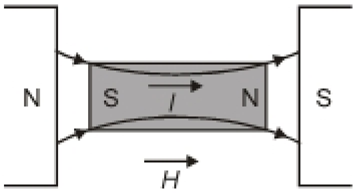
(7) The examples of diamagnetic substances are Cu, Zn, Bi, Ag, Au, Glass, NaCl, Diamond (C), Water (H_2O), Hydrogen (H_2).

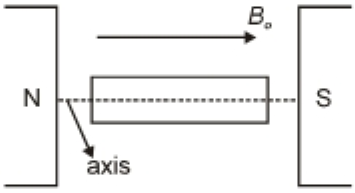
Paramagnetic and Ferromagnetic Substances

(1) For paramagnetic, χ_m is small and positive, $\mu_r > 1$.

(2) For ferromagnetic, χ_m is large and positive, $\mu_r >> 1$.

(3) Both get magnetised in the direction of applied field.

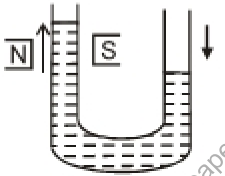




(4) Magnetic field lines cross through them.

(5) When freely suspended, they align along the applied field.

(6) They are attracted by magnetic field, so they move towards stronger region of magnetic field.



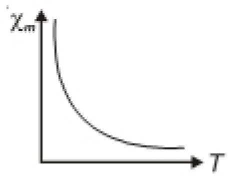
(7) Paramagnetic - Al, Na, Sb, Pt, Mn, $CuCl_2$, O_2 etc.

(8) Ferromagnetic - Fe, Ni, Co, Magnetite (Fe_3O_4) etc.

Curie Law

Magnetic susceptibility of paramagnetic material is inversely proportional to its absolute temperature.

$$\chi_m \propto \frac{1}{T} \quad \text{or} \quad \chi_m = \frac{C}{T}$$



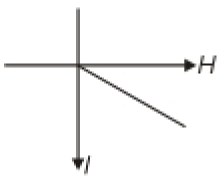
(1) Diamagnetic materials do not obey Curie law.

(2) Magnetic susceptibility of a ferromagnetic substance also decreases with increase in temperature. At a particular temperature T_C called 'CURIE POINT', a ferromagnetic substance is converted into paramagnetic.

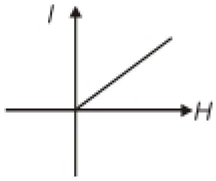
Curie - Weiss Law : $\chi_m \propto \dfrac{1}{T - T_C}$ for a ferromagnetic material.

Variation of *I* with *H*

1. Diamagnetic



2. Paramagnetic

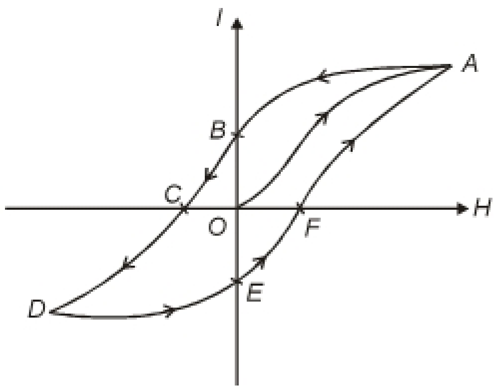


3. Ferromagnetic

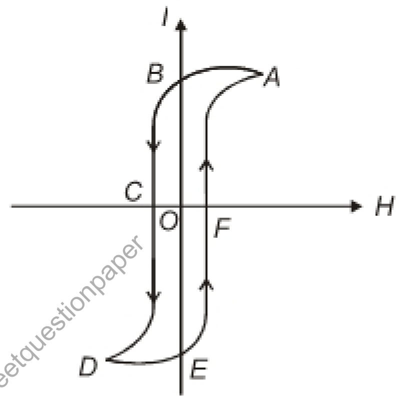
OB = Retentivity (residual magnetism even after magnetising field is reduced to zero)

OC = Coercivity (reverse magnetic field required to reduce residual magnetism to zero)

Area *ABCDEFA* = Energy loss/cycle per unit volume during magnetisation and demagnetisation.



Steel
(High coercivity, high retentivity)



Soft iron
(Low coercivity, low retentivity)

Area of *BH* loop is greater than the area of *IH* loop.

Electromagnets and Factors affecting their strengths. Permanent magnets.

(a) Steel is used making permanent magnets.

(b) Soft iron is used in electromagnets.

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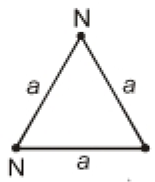
Try Yourself

SECTION - A

Objective Type Questions

1. Two imaginary magnetic north poles each of m (amp. meter) are placed at the two vertices of an equilateral triangle of side a. The resultant magnetic induction at the third vertex is



(1) $\frac{\mu_0}{4\pi}\cdot\frac{m}{a^2}$ (2) $\frac{\mu_0}{4\pi}\cdot\frac{\sqrt{3}\,m}{a^2}$

(3) $\frac{\mu_0}{4\pi}\cdot\frac{\sqrt{2}\,m}{a^2}$ (4) $\frac{\mu_0}{4\pi}\cdot\frac{4\,m}{a^2}$

2. A magnetised wire of magnetic moment M and length l is bent in the form of a semicircle of radius r. Now the new magnetic moment is

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

(3) $\frac{M}{\pi}$ (4) $\frac{\pi}{M}$

3. In two separate experiments at a place, the neutral points due to two small magnets are at a distance of r and $2r$ in broad side on position. The ratio of their magnetic moments will be

(1) 4 : 1 (2) 1 : 2

(3) 2 : 1 (4) 1 : 8

4. The work done in turning a magnet of magnetic moment M by an angle 90° from the stable equilibrium position is n times the corresponding work done to turn it through an angle of 60°. The value of n is

(1) 2 (2) 1

(3) $\frac{1}{2}$ (4) $\frac{1}{4}$

5. A magnetic needle lying parallel to magnetic field requires W units of work to turn it through 60°. The torque needed to maintain the needle in this position will be

(1) $\sqrt{3}W$ (2) W

(3) $\frac{\sqrt{3}}{2}W$ (4) $2\,W$

6. At a certain place, the angle of dip is 30° and the horizontal component of earth's magnetic field is 0.50 oersted. The earth's total magnetic field (in oersted) is

(1) $\sqrt{3}$ (2) 1

(3) $\frac{1}{\sqrt{3}}$ (4) $\frac{1}{2}$

7. Time period of a magnet is T. If it is divided in four equal parts such that each part has half of original length and half of cross-sectional area, then time period for each part will be

(1) $4\,T$ (2) $\frac{T}{4}$

(3) $\frac{T}{2}$ (4) T

8. The correct value of dip angle at a place is 45°. If the dip circle is rotated by 45° out of meridian then the tangent of the angle of apparent dip is

(1) 1 (2) $\frac{1}{\sqrt{2}}$

(3) $\sqrt{2}$ (4) $\frac{1}{2}$

9. The area of hysteresis loop is a measure of

(1) Retentivity (2) Susceptibility

(3) Permeability (4) Energy loss per cycle

10. At null point, the period of vibration of a bar magnet is

(1) Zero (2) 1 second

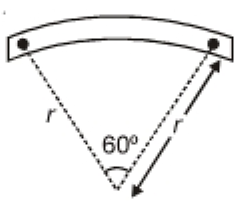
(3) Infinite (4) 2 second

11. A magnet can be completely demagnetised by
    (1) Heating it slightly
    (2) Dropping it into ice cold water
    (3) Applying reverse field of appropriate strength
    (4) Breaking the magnet into small piece
12. Meisner effect is associated with
    (1) Diamagnetism (2) Paramagnetism
    (3) Ferromagnetism (4) Conductors
13. The susceptibility of a paramagnetic material is K at 27°C. At what temperature will its susceptibility be 0.5 K?
    (1) 54°C (2) 327°C
    (3) 600°C (4) 237°C
14. Line joining the places having same angle of dip is known as
    (1) Isogonic line (2) Agonic line
    (3) Isoclinic line (4) Isodynamic line
15. Lines due to earth's horizontal magnetic field at a place are
    (1) Parallel and straight (2) Elliptical
    (3) Concentric circles (4) Curved lines
16. Two north poles of pole strength 0.4 unit and 6.4 unit are separated by 10 cm. The distance of the neutral point from pole of strength 0.4 unit is
    (1) 2 cm (2) 4 cm
    (3) 8 cm (4) 10 cm

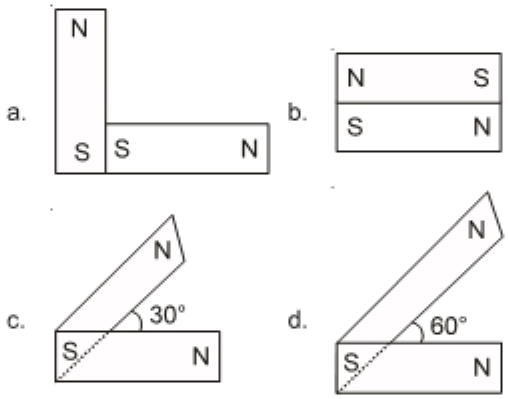
SECTION - B

Previous Years Questions

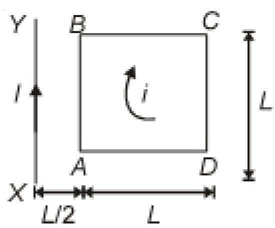
1. A compass needle which is allowed to move in a horizontal plane is taken to a geomagnetic pole. It **[AIPMT 2012]**
    (1) Will stay in north-south direction only
    (2) Will stay in east-west direction only
    (3) Will become rigid showing no movement
    (4) Will stay in any position
2. A bar magnet of length l and magnetic dipole moment M is bent in the form of an arc as shown in figure. The new magnetic dipole moment will be **[NEET-2013]**



    (1) $\frac{3}{\pi}M$ (2) $\frac{2}{\pi}M$
    (3) $\frac{M}{2}$ (4) M
3. Following figures show the arrangement of bar magnets in different configurations. Each magnet has magnetic dipole moment $\vec{m}$. Which configuration has highest net magnetic dipole moment? **[AIPMT 2014]**



    (1) a (2) b
    (3) c (4) d
4. A long straight wire of radius a carries a steady current I. The current is uniformly distributed over its cross-section. The ratio of the magnetic fields B and B' at radial distances $\frac{a}{2}$ and $2a$ respectively, from the axis of the wire is **[NEET-2016]**
    (1) 4 (2) $\frac{1}{4}$
    (3) $\frac{1}{2}$ (4) 1
5. A square loop $ABCD$ carrying a current i, is placed near and coplanar with a long straight conductor XY carrying a current I, the net foce on the loop will be **[NEET-2016]**



    (1) $\frac{\mu_0 IiL}{2\pi}$ (2) $\frac{2\mu_0 Ii}{3\pi}$
    (3) $\frac{\mu_0 Ii}{2\pi}$ (4) $\frac{2\mu_0 IiL}{3\pi}$

6. The magnetic susceptibility is negative for **[NEET-2016]**

(1) Paramagnetic and ferromagnetic materials

(2) Diamagnetic material only

(3) Paramagnetic material only

(4) Ferromagnetic material only

7. A bar magnet is hung by a thin cotton thread in a uniform horizontal magnetic field and is in equilibrium state. The energy required to rotate it by 60° is *W*. Now the torque required to keep the magnet in this new position is **[NEET (Phase-2) 2016]**

(1) $\frac{W}{\sqrt{3}}$ (2) $\sqrt{3}W$

(3) $\frac{\sqrt{3}W}{2}$ (4) $\frac{2W}{\sqrt{3}}$

8. An electron is moving in a circular path under the influence of a transverse magnetic field of 3.57×10^{-2} T. If the value of e/m is 1.76×10^{11} C/kg, the frequency of revolution of the electron is **[NEET (Phase-2) 2016]**

(1) 1 GHz (2) 100 MHz

(3) 62.8 MHz (4) 6.28 MHz

9. A 250-Turn rectangular coil of length 2.1 cm and width 1.25 cm carries a current of 85 μA and subjected to a magnetic field of strength 0.85 T. Work done for rotating the coil by 180° against the torque is **[NEET-2017]**

(1) 9.1 μJ (2) 4.55 μJ

(3) 2.3 μJ (4) 1.15 μJ

10. If θ_1 and θ_2 be the apparent angles of dip observed in two vertical planes at right angles to each other, then the true angle of dip θ is given by **[NEET-2017]**

(1) $\cot^2\theta = \cot^2\theta_1 + \cot^2\theta_2$

(2) $\tan^2\theta = \tan^2\theta_1 + \tan^2\theta_2$

(3) $\cot^2\theta = \cot^2\theta_1 - \cot^2\theta_2$

(4) $\tan^2\theta = \tan^2\theta_1 - \tan^2\theta_2$

11. A metallic rod of mass per unit length 0.5 kg m^{-1} is lying horizontally on a smooth inclined plane which makes an angle of 30° with the horizontal. The rod is not allowed to slide down by flowing a current through it when a magnetic field of induction 0.25 T is acting on it in the vertical direction. The current flowing in the rod to keep it stationary is **[NEET-2018]**

(1) 7.14 A (2) 5.98 A

(3) 11.32 A (4) 14.76 A

12. At a point *A* on the earth's surface the angle of dip, $\delta = +25°$. At a point *B* on the earth's surface the angle of dip, $\delta = -25°$. We can interpret that: **[NEET-2019]**

(1) *A* and *B* are both located in the northern hemisphere.

(2) *A* is located in the southern hemisphere and *B* is located in the northern hemisphere.

(3) *A* is located in the northern hemisphere and *B* is located in the southern hemisphere.

(4) *A* and *B* are both located in the southern hemisphere.

13. The relations amongst the three elements of earth's magnetic field, namely horizontal component *H*, vertical component *V* and dip δ are, (B_E = total magnetic field) **[NEET-2019 Odisha]**

(1) $V = B_E$, $H = B_E \tan\delta$

(2) $V = B_E \tan\delta$, $H = B_E$

(3) $V = B_E \sin\delta$, $H = B_E \cos\delta$

(4) $V = B_E \cos\delta$, $H = B_E \sin\delta$

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Chapter 6

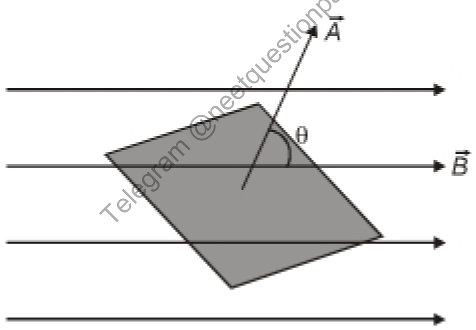
Electromagnetic Induction

Sub-topics *Electromagnetic induction; Faraday's law, induced emf and current; Lenz's Law, Eddy currents. Self and mutual inductance.*

Electromagnetic Induction

Magnetic Flux

$\phi = \vec{B}.\vec{A} = BA\cos\theta$



Units : Wb (SI), maxwell (C.G.S.), 1 maxwell = 10^{-8} Wb

Faraday's Laws, Induced emf and Current

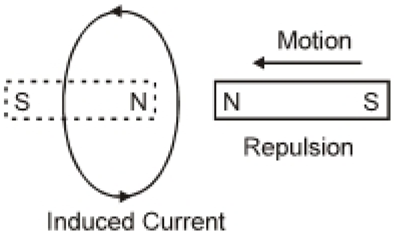
1. An emf is induced in a loop when the number of magnetic field lines passing through the loop is changing.
2. Magnitude of the emf '*e*' induced in a conducting loop is equal to the rate at which the magnetic flux ϕ_B through that loop changes with time.

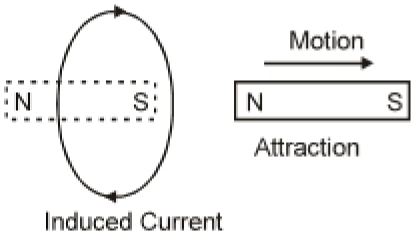
$$e = -\frac{d\phi_B}{dt}$$

Note : *Negative sign indicates opposition to induced emf* (*explained by Lenz's law*).

Lenz's Law

The induced current has a direction such that the magnetic field due to the current opposes the change in the magnetic field that induces the current.

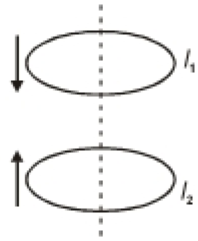
(1) 

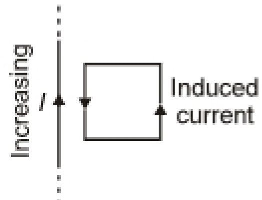
(2) 

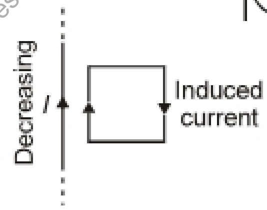
(3) Two current loops with their planes parallel to each other approach towards each other then

(a) When they carry current in same sense,
Current in each loop decreases

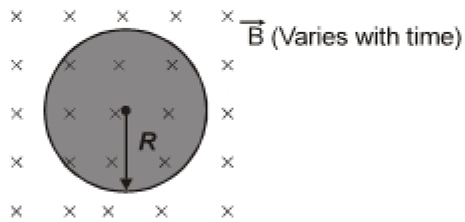
(b) When they carry current in opposite sense,
Current in each loop increases



(4) 

(5) 

Methods of Inducing EMF



By Changing $\vec{B}$

$\phi = BA = B \times \pi R^2$

$$\frac{d\phi}{dt} = \pi R^2 \frac{dB}{dt} \quad \Rightarrow \quad e = -\pi R^2 \frac{dB}{dt}$$

(1) If $\vec{B}$ increases, current is anticlockwise direction producing outward magnetic field.

(2) If $\vec{B}$ decreases, current is in clockwise direction.

By Changing Area

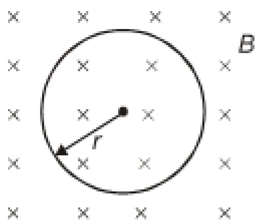
1. Let area changes from A_1 to A_2 in time t.

$\phi_1 = BA_1$

$\phi_2 = BA_2$

Average emf $e = -\dfrac{(\phi_2 - \phi_1)}{t}$

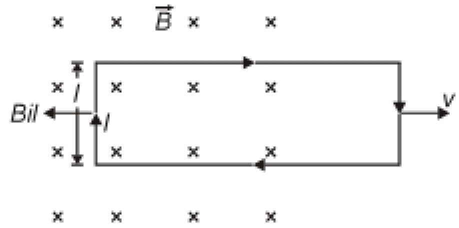
$$e = \frac{B(A_1 - A_2)}{t}$$



2. Radius of the loop starts increasing at rate $\frac{dr}{dt}$

   Instantaneous emf $e = -\frac{d}{dt}(B \times \pi r^2) = -B \times 2\pi r \frac{dr}{dt}$

3. A loop is moved out of a uniform field.



   $e = Bvl$

   R = resistance of loop

   $I = \frac{e}{R}$ (clockwise)

   Force required to pull the loop with constant velocity

   $F = BIl = \frac{Bl \times e}{R} = \frac{B^2 l^2 v}{R}$

   Power of external force = $Fv = \frac{B^2 l^2 v^2}{R}$

   Rate of heat loss = $I^2 R = \frac{B^2 l^2 v^2}{R}$

   $\therefore$ External power = thermal power dissipated

   If the loop is pushed inside, current will be anticlockwise.

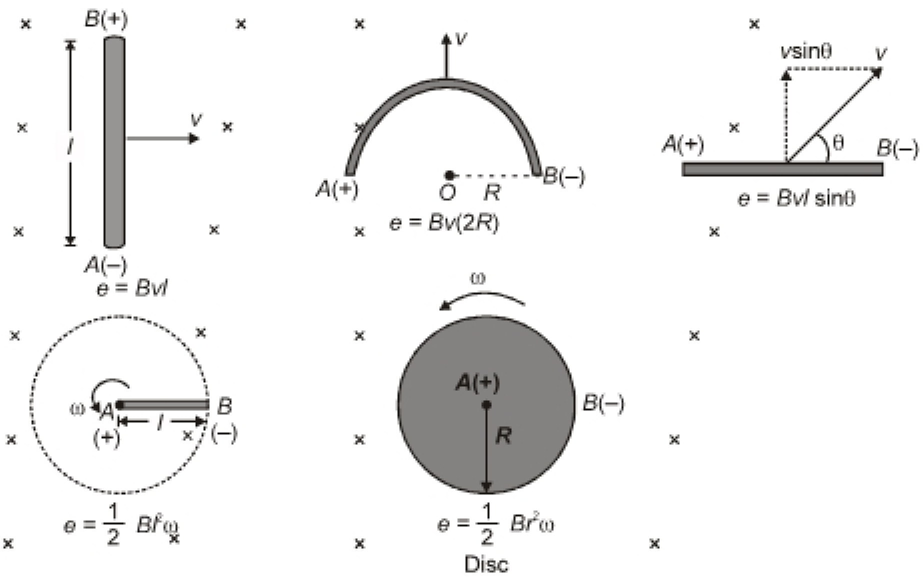
Charge Flowed through a Circuit

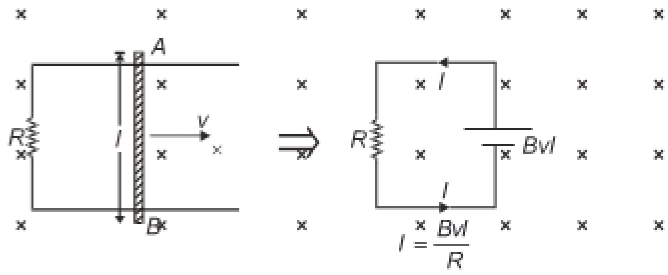
$|e| = \frac{d\phi}{dt}$ in a loop of resistance R.

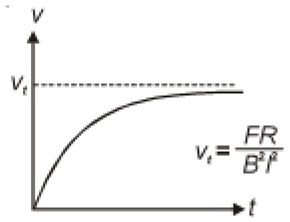
Then $I = \frac{e}{R} = \frac{d\phi}{Rdt}$

$$I = \frac{dq}{dt} = \frac{d\phi}{Rdt} \quad \Rightarrow \quad q = \frac{\Delta\phi}{R}$$

Motional EMF







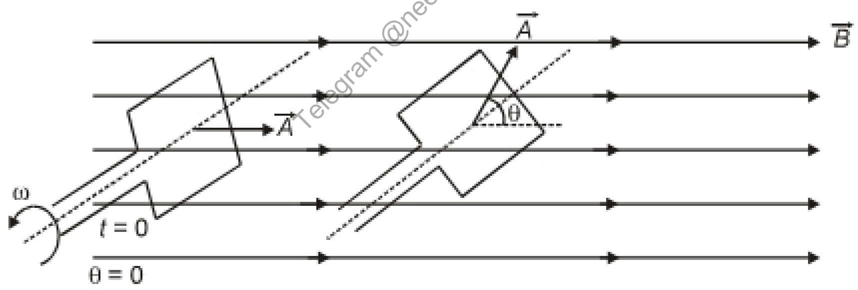
at t = 0, rod is at rest

When $Bil = F$

or $\frac{B^2l^2v}{R} = F$, Net force = 0

⇒ Rod will move with terminal velocity.

Inducing emf by changing 'θ'

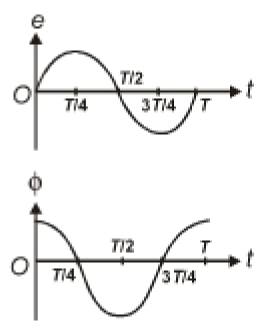


At any instant,

$\theta = \omega t$

$\phi = NBA\cos\theta$ where N = Number of turns.

$= NBA\cos\omega t$



$e = \frac{-d\phi}{dt} = + NBA\omega \sin\omega t$

$e = e_0 \sin\omega t$

Alternating emf is produced in the coil

$\boxed{e_0 = NBA\omega}$ Maximum emf

This is the working principle of a generator.

Eddy Currents

In general, the current resulting from the induced EMF, flows in a conductor or a coil only if the circuit is complete and the current flows in a definite path. In many cases, however, the induced currents circulate in a metal when the metal is moving in a varying magnetic field or the metal is placed in changing magnetic field. Such currents induced in the metal are known as Eddy or Focault currents.

Due to the production of eddy currents, heat is produced in the mass of the metal. In electrical machinery, *e.g.*, induction coils, dynamos and transformers, the iron core which forms the magnetic circuit carries an alternating magnetic field. If the iron core is one solid piece, the heat produced due to eddy currents is large.

Eddy currents cannot be completely eliminated but are much reduced by using laminated iron cores. Due to this reason, the iron core in the induction coil consists of thin wires insulated from each other and in a transformer it consists of a large number of laminations insulated from each other.

Applications

Eddy currents are usefully employed in the following cases

(i) Induction furnace.

(ii) Dead beat galvanometer.

(iii) Speedometers.

(iv) Damping.

(v) Induction motor.

(vi) Electric brakes.

Mutual Induction

Mutual Induction : Property of two coils by virtue of which each opposes any change in the magnitude of current flowing through the other by inducing an emf in itself provided magnetic flux of one coil is linked with other.

Let I_1 is current through one coil.

ϕ_2 is flux linked with other coil.

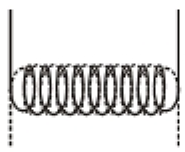
$\phi_2 \propto I_1$

$\Rightarrow$ $\phi_2 = MI_1$, where M is mutual induction

$$\Rightarrow \quad e = \frac{-d\phi_2}{dt} = -M\frac{dI_1}{dt}$$

(1) Mutual inductance of two solenoids :

$$M = \frac{\mu_0 N_1 N_2 A}{l}$$



N_1 = Number of turns in one coil

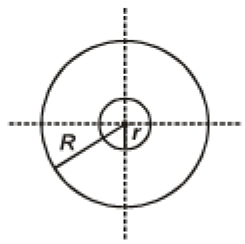
N_2 = Number of turns in other coil

A = Area of cross-section

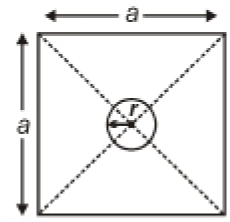
l = Length of coil

(2) Two loops :

(a) $M = \frac{\mu_0 \pi r^2}{2R}$ (for $R >> r$)



(b) $M = \dfrac{2\sqrt{2}\mu_0 r^2}{a}$ (for $a >> r$)



Self Induction : Property of a coil by which it opposes any change in the magnitude of current flowing through it by inducing an emf in itself.

Here $\phi = LI$, $e = \dfrac{-LdI}{dt}$, L = Coefficient of self-induction

***Note :** Both M and L have unit henry*

$$1 \text{ henry} = \frac{1 \text{ volt second}}{\text{Ampere}} = 1 \text{ JA}^{-2}$$

Ideal Inductor : It is a part of long solenoid having zero resistance

$L = \mu_0 n^2 Al$ (air cored solenoid)

$= \dfrac{\mu_0 N^2 A}{l}$

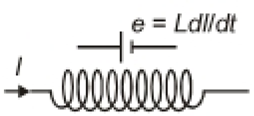
l = length, A = area of cross-section

n = number of turns/length, N = total number of turns

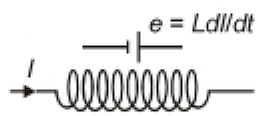
$L = \mu_0 \mu_r n^2 Al$ (for medium cored solenoid)

Direction of Induced emf

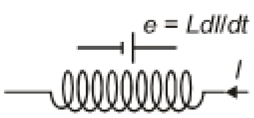
(a) I is increasing



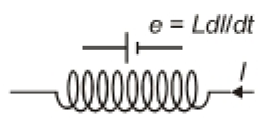
(b) I is decreasing



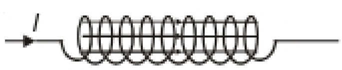
(c) I increasing



(d) I is decreasing

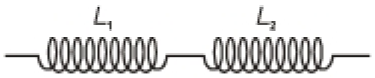


(1) An inductor is a device to store energy in the form of magnetic field.



Energy $U_B = \dfrac{1}{2}LI^2$, Energy Density = $\dfrac{1}{2}\dfrac{B^2}{\mu_0}$

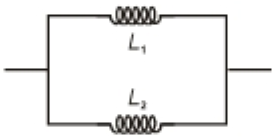
(2) Inductor in series



(a) $L = L_1 + L_2$

(b) $L = L_1 + L_2 \quad 2M$ (If mutual inductance is also considered)

(3) Inductor in parallel



$$\frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2}$$ (Neglecting mutual induction)

(4) $M = K\sqrt{L_1 L_2}$

M = Mutual inductance of two inductors L_1 and L_2

K = Coefficient of coupling

For a tight coupling $K = 1$, otherwise $K < 1$.

❑ ❑ ❑

Try Yourself

SECTION - A

Objective Type Questions

1. When a wire loop is rotated in a magnetic field the direction of induced e.m.f changes in

(1) 1 revolution (2) $\frac{1}{2}$ revolution

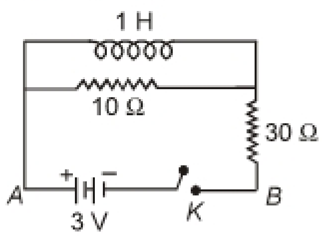
(3) $\frac{1}{4}$ revolution (4) 2 revolutions

2. R/L has the same dimensional formula as that of

(1) Time (2) Mass

(3) Length (4) Frequency

3. The value of steady state current in 30 Ω resistor when key K is inserted is



(1) 0.1 A (2) 0.2 A

(3) 0.3 A (4) Zero

4. The particle accelerator that uses the phenomenon of electromagnetic induction is the

(1) Cyclotron

(2) Betatron

(3) Van de Graaff generator

(4) Positron

5. Two inductors when connected in series show an effective inductance of 10 H and when connected in parallel have an effective inductance 2.4 H. Then the individual inductances are

(1) 5 H each (2) 7 H and 3 H

(3) 6 H and 4 H (4) 8 H and 2 H

6. The amplitude of induced e.m.f of a generator when the strength of poles is doubled and angular speed is doubled is

(1) Halved (2) Remains same

(3) Doubled (4) Quadrupled

7. If a wheel of radius L rotates in a uniform magnetic field B, about an axis passing through its axle and parallel to field lines, with uniform angular velocity ω, then emf induced in the spoke between its axle and rim is

(1) $\frac{1}{2}B\omega^2L$ (2) $\frac{1}{2}BL^2\omega$

(3) $\frac{1}{2}B^2L\omega$ (4) $\frac{1}{2}BL^2\omega^2$

8. Two coils of self inductance L_1 and L_2 are placed so close together that the effective flux in one coil is completely linked with the other. If M is the mutual inductance between them, then

(1) $M = L_1 + L_2$ (2) $M = \frac{L_1}{L_2}$

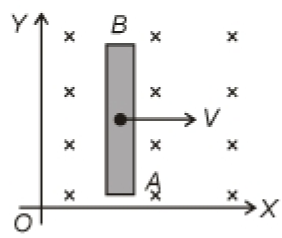
(3) $M = \frac{L_1L_2}{L_1 + L_2}$ (4) $M = \sqrt{L_1L_2}$

9. A solenoid of resistance 20 Ω and inductance 2 H carries a current of 1 A. The magnetic energy stored in it is

(1) 2 J (2) 1 J

(3) 20 J (4) 10 J

10. A conducting rod AB moves parallel to X-axis in a uniform magnetic field pointing in the negative Z direction. The ends A and B are charged as



(1) Negative (2) Positive

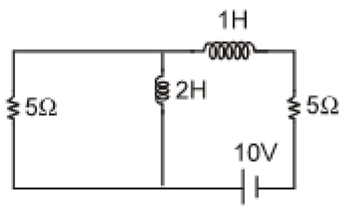
(3) B is +, A is – (4) B is –, A is +

11. A 100 mH coil carries a current of 1 A Energy stored in its magnetic field is

(1) 0.5 J (2) 1 J

(3) 0.05 J (4) 0.1 J

12. The value of current supplied by the battery at steady state is



(1) 2 A (2) 1 A

(3) 4 A (4) 10 A

13. weber/m^2 is equal to

(1) volt (2) maxwell

(3) tesla (4) All of these

14. A solenoid contains 6000 turns and its self inductance is 108 mH. The self inductance of identical solenoid containing 5000 turns will be

(1) 75 mH (2) 80 mH

(3) 100 mH (4) 150 mH

15. The unit of inductance is equivalent to

(1) $\frac{\text{volt} \times \text{ampere}}{\text{second}}$

(2) $\frac{\text{ampere}}{\text{volt} \times \text{second}}$

(3) $\frac{\text{volt}}{\text{ampere} \times \text{second}}$

(4) $\frac{\text{volt} \times \text{second}}{\text{ampere}}$

16. The magnetic flux (in webers) through a coil varies with time as $\phi = 10 - 4t + t^2$ (where t is in seconds). The induced emf at $t = 4$ s is

(1) –4 V (2) –2 V

(3) Zero (4) –20 V

17. A magnet is moved towards a coil (i) Quickly (ii) Slowly, then the work done is

(1) Larger in (ii)

(2) Larger in (i)

(3) Equal in both cases

(4) Larger or smaller depending upon the material of coil

18. A horizontal ring of radius r spins about its axis with an angular velocity ω in a uniform vertical magnetic field of magnitude B. The e.m.f. induced in the ring is

(1) Zero (2) $\pi r^2 \omega B$

(3) $\frac{Br^2\omega}{2}$ (4) $Br^2\omega$

19. A coil of wire is kept stationary in a non uniform magnetic field. Select the correct alternative

(1) e.m.f. is induced in the coil

(2) No e.m.f. is induced in the coil

(3) No e.m.f. but a current is induced in the coil

(4) No current but e.m.f. is induced in the coil

20. A coil of area 5 cm^2 and having 20 turns is placed in a uniform magnetic field of 10^3 gauss. The normal to the plane of the coil makes an angle of 60° with the magnetic field. The flux in maxwell through the coil is

(1) 10^5

(2) 5×10^4

(3) 2×10^4

(4) 5×10^3

21. A coil having an area A_0 is placed in a magnetic field which changes from B_0 to $4B_0$ in time interval t. The e.m.f induced in the coil will be

(1) $\frac{3A_0B_0}{t}$

(2) $\frac{4A_0B_0}{t}$

(3) $\frac{3B_0}{A_0t}$

(4) $\frac{4B_0}{A_0t}$

22. The magnetic flux through a circuit of resistance R changes by an amount $\Delta\phi$ in time Δt. Then the total quantity of electric charge q which passes during this time through any point of the circuit is given by

(1) $q = \frac{\Delta\phi}{\Delta t}$ (2) $q = \frac{\Delta\phi}{\Delta t}.R$

(3) $q = -\frac{\Delta\phi}{\Delta t} + R$ (4) $q = \frac{\Delta\phi}{R}$

23. A 0.1 m long conductor carrying current of 50 A is perpendicular to a magnetic field of 1.25 T. The mechanical power required to move the conductor with a speed of 1 m/s in a direction opposite to the direction of magnetic force acting upon it is

(1) 6.25 W (2) 62.5 W

(3) 0.625 W (4) 1 W

24. A horizontal copper rod moves parallel to the horizontal. Induced e.m.f developed across its ends due to earth's magnetic field will be maximum at

(1) Equator

(2) Latitude 30°

(3) Latitude 60°

(4) Poles

SECTION - B

Previous Years Questions

1. A coil of resistance 400 Ω is placed in a magnetic field. If the magnetic flux ϕ (wb) linked with the coil varies with time t (sec) as

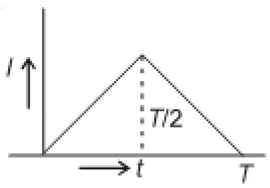
$\phi = 50t^2 + 4$

The current in the coil at t = 2 sec is **[AIPMT 2012]**

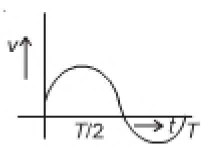
(1) 2 A (2) 1 A

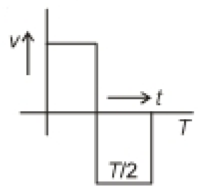
(3) 0.5 A (4) 0.1 A

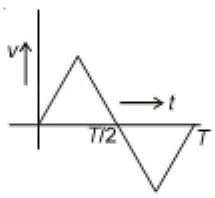
2. The current (I) in the inductance is varying with time according to the plot shown in figure.

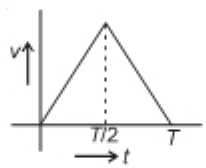


Which one of the following is the correct variation of voltage with time in the coil? **[AIPMT 2012]**

(1)


(2)


(3)


(4)


3. A wire loop is rotated in a magnetic field. The frequency of change of direction of the induced e.m.f. is **[NEET-2013]**

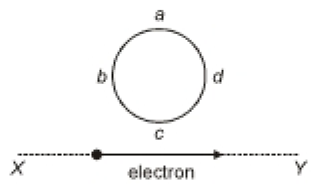
(1) Twice per revolution

(2) Four times per revolution

(3) Six times per revolution

(4) Once per revolution

4. An electron moves on a straight line path XY as shown. The abcd is a coil adjacent to the path of electron. What will be the direction of current, if any, induced in the coil?



[Re-AIPMT-2015]

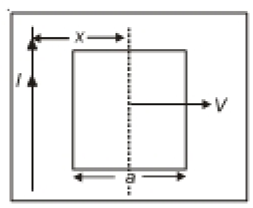
(1) No current induced

(2) *abcd*

(3) *adcb*

(4) The current will reverse its direction as the electron goes past the coil

5. A conducting square frame of side a and a long straight wire carrying current I are located in the same plane as shown in the figure. The frame moves to the right with a constant velocity V. The emf induced in the frame will be proportional to



[AIPMT-2015]

(1) $\dfrac{1}{(2x-a)(2x+a)}$

(2) $\dfrac{1}{x^2}$

(3) $\dfrac{1}{(2x-a)^2}$

(4) $\dfrac{1}{(2x+a)^2}$

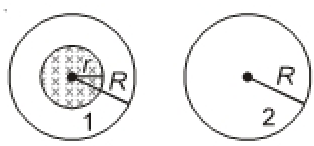
6. A long solenoid has 1000 turns. When a current of 4 A flows through it, the magnetic flux linked with each turn of the solenoid is 4×10^{-3} Wb. The self-inductance of the solenoid is **[NEET-2016]**

(1) 1 H (2) 4 H

(3) 3 H (4) 2 H

7. A uniform magnetic field is restricted within a region of radius *r*. The magnetic field changes with time at a rate $\frac{d\vec{B}}{dt}$. Loop 1 of radius $R > r$ encloses the region *r* and loop 2 of radius *R* is outside the region of magnetic field as shown in the figure below. Then the e.m.f. generated is

[NEET (Phase-2) 2016]



(1) Zero in loop 1 and zero in loop 2

(2) $-\frac{d\vec{B}}{dt}\pi r^2$ in loop 1 and $-\frac{d\vec{B}}{dt}\pi r^2$ in loop 2

(3) $-\frac{d\vec{B}}{dt}\pi R^2$ in loop 1 and zero in loop 2

(4) $-\frac{d\vec{B}}{dt}\pi r^2$ in loop 1 and zero in loop 2

8. A thin diamagnetic rod is placed vertically between the poles of an electromagnet. When the current in the electromagnet is switched on, then the diamagnetic rod is pushed up, out of the horizontal magnetic field. Hence the rod gains gravitational potential energy. The work required to do this comes from **[NEET-2018]**

(1) The current source

(2) The magnetic field

(3) The induced electric field due to the changing magnetic field

(4) The lattice structure of the material of the rod

9. In which of the following devices, the eddy current effect is not used? **[NEET-2019]**

(1) Induction furnace

(2) Magnetic braking in train

(3) Electromagnet

(4) Electric heater

10. A 800 turn coil of effective area 0.05 m^2 is kept perpendicular to a magnetic field 5×10^{-5} T. When the plane of the coil is rotated by 90° around any of its coplanar axis in 0.1 s, the emf induced in the coil will be **[NEET-2019]**

(1) 2 V

(2) 0.2 V

(3) 2×10^{-3} V

(4) 0.02 V

11. A cycle wheel of radius 0.5 m is rotated with constant angular velocity of 10 rad/s in a region of magnetic field of 0.1 T which is perpendicular to the plane of the wheel. The EMF generated between its centre and the rim is,

[NEET-2019-Odisha]

(1) Zero

(2) 0.25 V

(3) 0.125 V

(4) 0.5 V

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Chapter 7

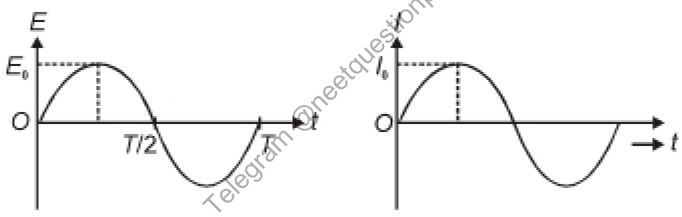
Alternating Current

Sub-topics *Alternating currents, peak and rms value of alternating current/ voltage; reactance and impedance; LC oscillations (qualitative treatment only), LCR series circuit, resonance; power in AC circuits, wattless current. AC generator and transformer.*

Alternating Currents

$I = I_0 \sin \omega t$

$E = E_0 \sin \omega t$



T = time period

$\frac{1}{T} = \nu$ = frequency

Peak and rms value of Alternating current/voltage

Mean value for time '*t*'

$$E_{\text{mean}} = \frac{1}{t}\int_0^t E\,dt,\ \ I_{\text{mean}} = \frac{1}{t}\int_0^t I\,dt$$

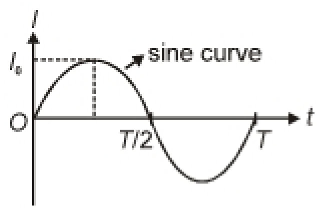
Root Mean Square Value

$$E_{\text{rms}}^2 = \frac{1}{t}\int_0^t E^2 dt,\ \ I_{\text{rms}}^2 = \frac{1}{t}\int_0^t I^2 dt$$

Applications :

(1) $I_{\text{mean}} = 0$ for $t = 0$ to T

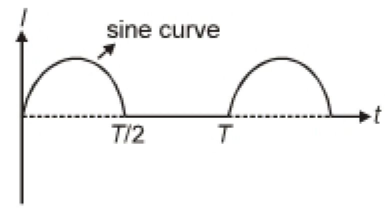
$I_{\text{mean}} = \frac{2I_0}{\pi}$ for $t = 0$ to $T/2$



$I_{rms} = \dfrac{I_0}{\sqrt{2}}$ for $t = 0$ to T

$I_{rms} = \dfrac{I_0}{\sqrt{2}}$ for $t = 0$ to $T/2$

(2) $I_{mean} = \dfrac{I_0}{\pi}$ for $t = 0$ to T

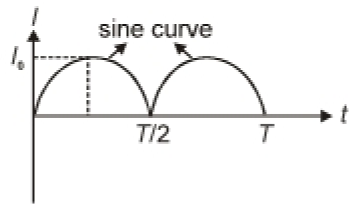


$I_{mean} = \dfrac{2I_0}{\pi}$ for $t = 0$ to $T/2$

$I_{rms} = \dfrac{I_0}{2}$ for $t = 0$ to T

$I_{rms} = \dfrac{I_0}{\sqrt{2}}$ for $t = 0$ to $T/2$

(3) $I_{mean} = \dfrac{2I_0}{\pi}$ for $t = 0$ to $T/2$



$I_{mean} = \dfrac{2I_0}{\pi}$ for $t = 0$ to T

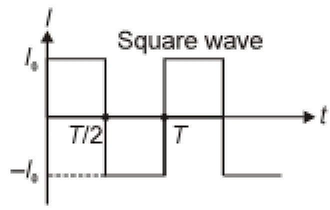
$I_{rms} = \dfrac{I_0}{\sqrt{2}}$ for $t = 0$ to T

$I_{rms} = \dfrac{I_0}{\sqrt{2}}$ for $t = 0$ to $T/2$

(4) $I_{mean} = 0$ for $t = 0$ to T

$I_{mean} = I_0$ for $t = 0$ to $T/2$

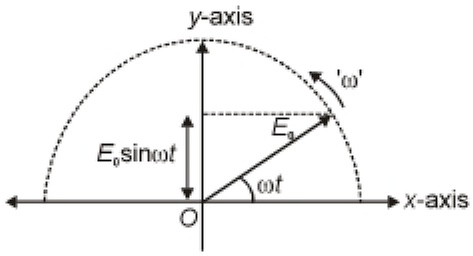
$I_{rms} = I_0$ for $t = 0$ to T



Reactance and Impedance

Phasor

(1) It is a vector rotating in anticlockwise direction with angular velocity 'ω'.



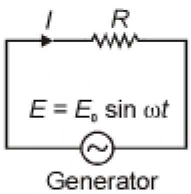
(2) Its length is equal to amplitude of alternating quantity.

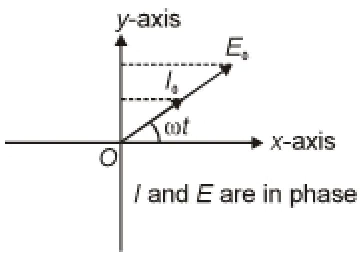
(3) Projection of vector on y-axis gives the instantaneous value of alternating quantity.

Resistive Circuit

$I = I_0 \sin \omega t$

$I_0 = \dfrac{E_0}{R}$





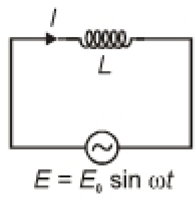
Inductive Circuit

$I = I_0 \sin (\omega t - \pi/2)$

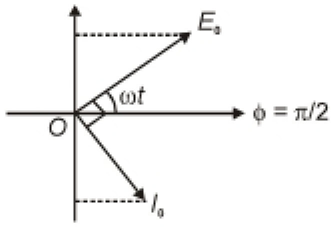
$I_0 = \dfrac{E_0}{X_L}$

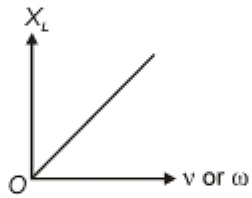
$X_L = \omega L = 2\pi\nu L$

$X_L \propto \nu$



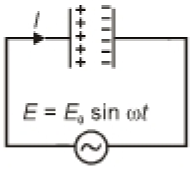
$X_L \propto L$ Current lags behind the applied emf by an angle $\dfrac{\pi}{2}$

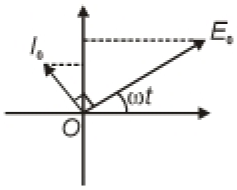




Capacitive Circuit

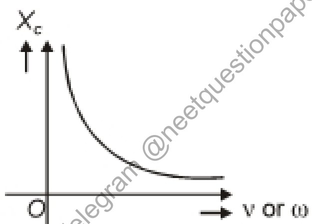
$I = I_0 \sin (\omega t + \pi/2)$





$I_0 = \dfrac{E_0}{X_C}$

$X_C = \dfrac{1}{\omega C} = \dfrac{1}{2\pi\nu C}$



$X_C \propto \dfrac{1}{\nu}$

$X_C \propto \dfrac{1}{C}$ Current leads the applied emf by an angle $\dfrac{\pi}{2}$.

(a) For high frequency *AC*, low inductance is required.

∴ Air-cored inductors are used.

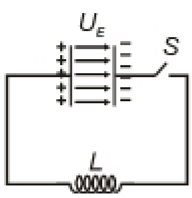
(b) For low frequency *AC*, high inductance is required.

∴ Iron-cored inductors are used.

L-C Oscillations (Qualitative treatment only)

A charged capacitor is connected to an inductor and switch is closed at $t = 0$.

At any instant i = current through inductor, q is charge on capacitor.



Total energy = $\dfrac{1}{2}Li^2 + \dfrac{q^2}{2C}$

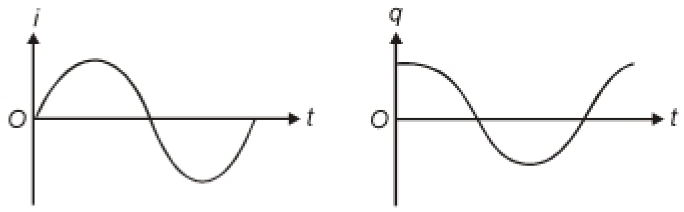
If there is no resistance ∴ total energy = constant $\Rightarrow \dfrac{q_0^2}{2C} = \dfrac{1}{2}Li^2 + \dfrac{q^2}{2C}$

$\dfrac{q_0^2}{2C}$ = initial energy stored in the capacitor.

The charge and current vary sinusoidally.

(a) $q = q_0 \cos \omega t$ [∵ at $t = 0$, $q = q_0$]

(b) $i = i_0 \sin \omega t$ [$\because$ at $t = 0$, $i = 0$]



$i_0 = \frac{q_0}{\sqrt{LC}}, \omega = \frac{1}{\sqrt{LC}}, \nu = \frac{1}{2\pi\sqrt{LC}}$ is frequency of LC oscillations

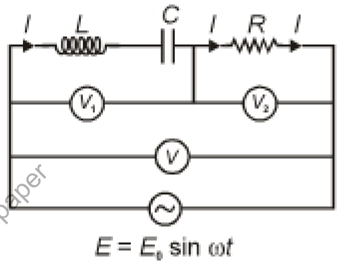
If there is some resistance, there is a continuous loss of energy.

$\therefore$ Amplitude of charge or current decays with time.

(c) During oscillations, voltage across capacitor at any instant = emf induced in the inductor.

(d) Energy stores in capacitor or inductor oscillates with frequency 2ν.

LCR Series Circuit



$V = \frac{E_0}{\sqrt{2}}$ = rms value of applied voltage

V_1 = rms voltage across L-C = $V_L - V_C$

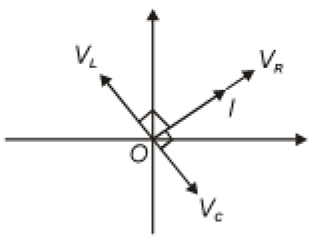
V_2 = rms voltage across R = V_R

Phase Relationship

I and V_R are in same phase.

V_L leads I by 90°.

V_C lags behind I by 90°.



Case I :

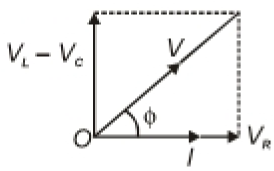
$V_L > V_C$

$\Rightarrow$ V leads I by ϕ

where $\tan\phi = \frac{V_L - V_C}{V_R}$

$\tan\phi = \frac{X_L - X_C}{R}$

Here $X_L > X_C$ *i.e.*, $\omega > \frac{1}{\sqrt{LC}}$

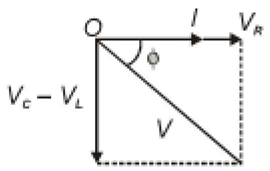


Case II :

$V_L < V_C$

i.e., V lags behind I by ϕ.

$\tan\phi = \frac{V_C - V_L}{V_R} = \frac{X_C - X_L}{R}$



Here $X_C > X_L$ *i.e.,* $\omega < \frac{1}{\sqrt{LC}}$

In both cases $V = \sqrt{V_R^2 + (V_L - V_C)^2} = I\sqrt{R^2 + (X_L - X_C)^2}$

$Z = \sqrt{R^2 + (X_L - X_C)^2}$ = Impedance

Power factor $\cos\phi = \frac{R}{Z} = \frac{R}{\sqrt{R^2 + (X_L - X_C)^2}}$

Resonance:

$V_L = V_C$ *i.e.,* $X_L = X_C$ *i.e.,* $\omega = \frac{1}{\sqrt{LC}}$ [Resonance]

In this case

(1) $V_2 = V = \frac{E_0}{\sqrt{2}}$

(2) $V_1 = V_L - V_C = 0$

(3) $\tan\phi = 0$, or $\phi = 0$

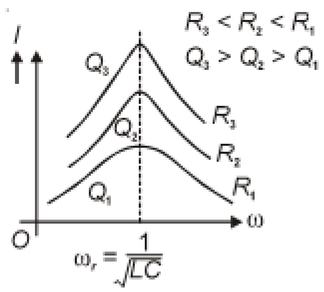
(4) Power factor = $\cos\phi = 1$

(5) $Z = R$ (minimum) or current is maximum

(6) Power consumed is maximum.

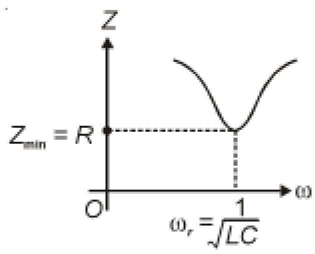
Applications :

(1)



Series *LCR* circuit (Acceptor Circuit)

(2)



Series *LCR* circuit

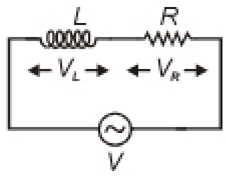
(3) In a series *LCR* circuit, when voltage leads current, then to bring resonance state, either *L* or *C* should be decreased.

(4) If voltage lags behind current, then to bring resonance state either *L* or *C* should be increased.

(5) Quality factor *Q* represents the sharpness of tuning at resonance.

$Q = \frac{1}{R}\sqrt{\frac{L}{C}}$ *i.e.,* $Q \propto \frac{1}{R}$

(6) Series *LR* Circuit

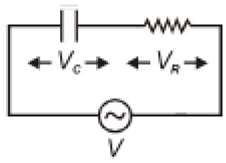


$$Z = \sqrt{R^2 + X_L^2}$$

$$V = \sqrt{V_R^2 + V_L^2}$$

$I = \dfrac{V}{Z}$ $\cos\phi = \dfrac{R}{\sqrt{R^2 + X_L^2}}$, $\tan\phi = \dfrac{X_L}{R}$. Voltage leads current.

(7) Series *CR* Circuit

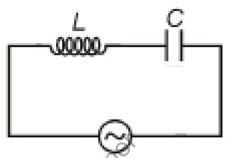


$$V = \sqrt{V_R^2 + V_C^2}$$

$$Z = \sqrt{R^2 + X_C^2}$$

$\cos\phi = \dfrac{R}{Z} = \dfrac{R}{\sqrt{R^2 + X_C^2}}$, $\tan\phi = \dfrac{X_C}{R}$. Voltage lags behind current.

(8) Series *LC* Circuit



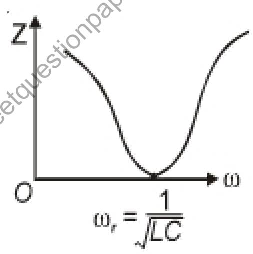
$V = V_L - V_C$

$Z = X_L - X_C$

$I = \dfrac{V}{Z}$, $\phi = \dfrac{\pi}{2}$

when $X_L = X_C$, $Z = 0$

i.e., $\omega = \dfrac{1}{\sqrt{LC}}$

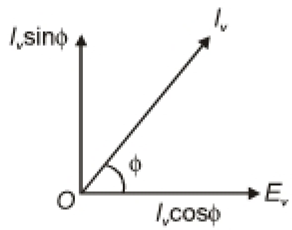


Power in A.C. circuits

$E = E_0 \sin \omega t$ $P_{av} = \dfrac{1}{T}\int_0^T EIdt$

$I = I_0 \sin(\omega t + \phi)$

$P_{av} = \dfrac{E_0 I_0}{2}\cos\phi = \dfrac{E_0}{\sqrt{2}}.\dfrac{I_0}{\sqrt{2}}\cos\phi = E_v I_v \cos\phi$



(1) For pure resistor $\phi = 0$, $P_{av} = \dfrac{E_0 I_0}{2}$

(2) For pure inductor or capacitor, $P_{av} = 0$ as $\phi = 90°$

(3) Power consumed is independent of $I_v \sin\phi$. This is called watt less component.

(4) $\cos\phi$ = Power factor.

In a series *LCR* circuit

$$P_{av} = E_v I_v \cos\phi = \frac{E_v^2}{Z}\cos\phi = I_v^2 Z\cos\phi = I_v^2 R$$

(1) At resonance *i.e.*, at $\omega_r = \dfrac{1}{\sqrt{LC}}$, $Z = R$ power is maximum

(2) At frequencies other than $\omega_r \left(= \frac{1}{\sqrt{LC}}\right)$. Power consumed is less.

(3) At $\omega = \omega_1$ or ω_2, power = half the maximum power

$P_{max} = I^2{}_{max}R$

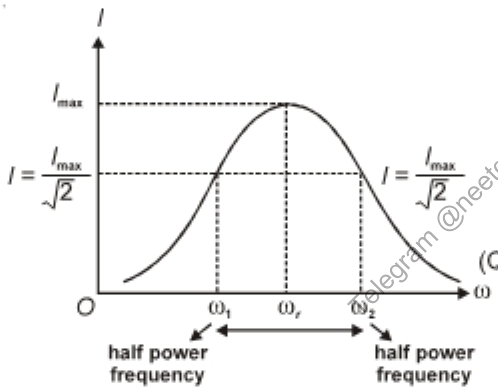
$$P_{1/2} = \frac{I_{max}^2 R}{2} = \left(\frac{I_{max}}{\sqrt{2}}\right)^2 R$$

i.e., when $I = \frac{I_{max}}{\sqrt{2}}$, power is half

$$I_{max} = \frac{E_v}{R}, I_v = \frac{E_v}{Z}$$

$$I = \frac{I_{max}}{\sqrt{2}} \Rightarrow \boxed{Z = R\sqrt{2}}$$

or, $\sqrt{(X_L - X_C)^2 + R^2} = R\sqrt{2} \Rightarrow \boxed{X_L - X_C = R}$



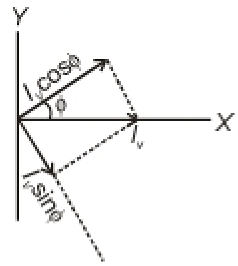
(Quality factor) $Q = \frac{\omega_r}{\omega_2 - \omega_1} = \frac{1}{R}\sqrt{\frac{L}{C}}$

$\left(\omega_2 - \omega_1 = \frac{R}{L}\right)$ is band width

Wattless Current

The current which consumes no power for its maintenance in the circuit is called wattless current or idle current. Average power over a complete cycle in an inductive circuit is the product of virtual emf (E_v), virtual current (I_v) and cosine of the phase angle (ϕ) between the EMF and current i.e. $P = E_v I_v \cos\phi$.

In a particular circuit suppose E_V leads I_V by phase angle ϕ, as shown in figure.



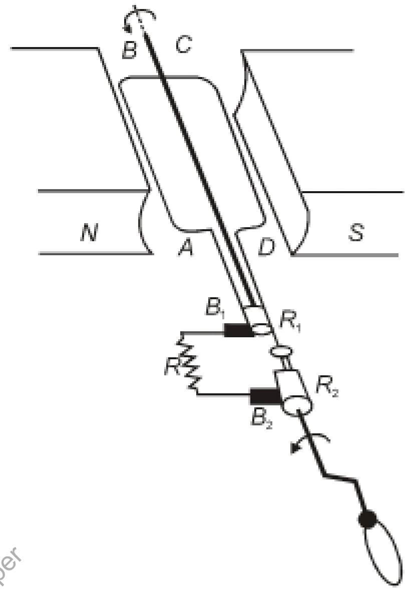
I_V can be resolved into two rectangular components : $I_V\cos\phi$ along E_V and $I_V\sin\phi$ perpendicular to E_V. Thus I_V is the vector sum of two perpendicular components $I_V\cos\phi$ and $I_V\sin\phi$. As phase angle between E_V and $I_V \cos\phi$ is zero, therefore, average power consumed per cycle in the circuit due to component $I_V\cos\phi$ is

$P_{av} = E_V(I_V \cos\phi) \cos 0° = E_V I_V \cos\phi$.

Again, as phase angle between E_V and $I_V \sin\phi$ is $\pi/2$, therefore, average power consumed per cycle in the circuit due to component $I_V \sin\phi$ is zero.

As the component $I_V \sin\phi$ makes no contribution to the consumption of power in the AC circuit, therefore this component $I_V \sin\phi$ is called the wattless component of AC.

AC Generator

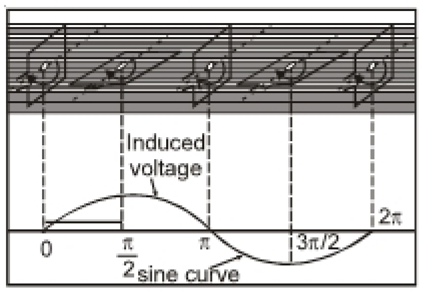


AC generator or dynamo is a device used to convert mechanical energy into electrical energy. It is based on the principle of electromagnetic induction. The electric current is generated by induction in the machines which contain coils moving in a magnetic field. The simple form of a generator consists of two parts :

(1) **Field Magnet:** In a dynamo the field magnet is a permanent magnet whereas in large generators it is an electromagnet.

(2) **Armature:** A copper wire is wound on an iron core that rotates in the magnetic field. The ends of the coil are connected to flat brass rings R_1 and R_2 known as the slip rings. The carbon brushes B_1 and B_2 make contact with the rings R_1 and R_2. The brushes B_1 and B_2 are connected to a load R in the circuit. The axis of rotation is in the plane of the coil but perpendicular to the magnetic field.

When the armature rotates, the magnetic flux linked with it changes and electric current is induced in the coil which flows through the load. Consider the armature to be in the vertical position and let it rotates in the anti-clockwise direction. The wire *AB* moves downward and *CD* moves upward. According to Fleming's right hand rule the induced current flows from *B* to *A* and from *D* to *C*. Therefore, during the first half rotation of the armature, the current flows in the coil in the direction *DCBA*. During the second half rotation, the current flows in the direction *ABCD*. In this way, alternating current is produced by the generator.



EMF in a generator: The EMF in the rotating coil of a dynamo can be calculated . Suppose the number of turns of the coil = *N*, area of the armature = *A* and magnetic field = *B*.

If the armature makes an angle θ with the vertical, then the component of the field *B* normal to the armature = $B\cos\theta$.

Magnetic flux $\phi = NAB\cos\theta$.

If the coil rotates with an angular velocity ω, then the induced EMF,

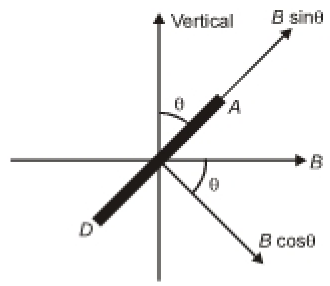
$$\varepsilon = \frac{-d\phi}{dt} = \frac{-d}{dt}(NAB\cos\theta)$$

$\varepsilon = +NAB\,\omega\sin\omega t$, or $\varepsilon = \varepsilon_0 \sin\omega t$ where $\theta = \omega t$ $\qquad \varepsilon_0 = NAB\omega$

The EMF, ε sends an alternating current of a similar sine equation through a load connected across the coil.

(i) When the armature is vertical,

$\omega t = 0, \quad \varepsilon = 0.$



(ii) When the armature is horizontal,

$\omega t = \frac{\pi}{2}$

$\sin\frac{\pi}{2} = 1, \ \varepsilon = \varepsilon_0 = NAB\omega$

(iii) When the armature is again vertical, $\omega t = \pi, \ \varepsilon = 0$

(iv) When the armature is again horizontal, $\omega t = \frac{3\pi}{2}, \ \varepsilon = -\varepsilon_0 = -NAB\omega$

(v) Finally when the armature returns to its original position.

$\omega t = 2\pi, \quad \text{and} \quad \varepsilon = 0.$

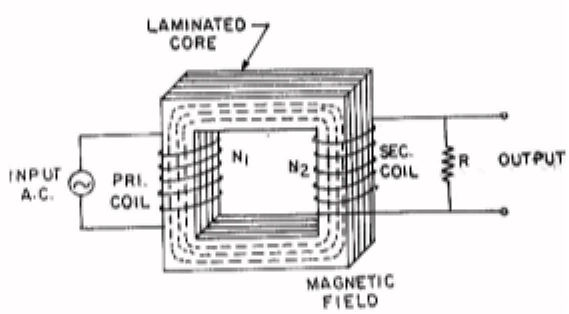
Thus, the EMF induced in the coil of the generator varies sinusoidally *i.e.*, just like a sine curve.

In India, the frequency of AC supply is 50 cycles/second *i.e.*, the number of cycles which the current goes through in one second is 50.

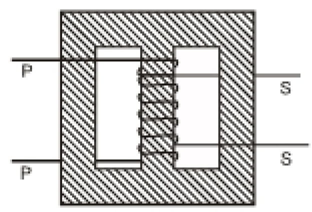
Transformer

A transformer is a device used to convert alternating electric power at high voltage into electric power at low voltage and vice versa. One of the most useful features of the AC is the ease and efficiency with which potentials and currents may be changed from one value to the other with the help of a transformer. Moreover, there is no moving part in a transformer and hence the efficiency is very high. The possibility of using the transformer in this way has helped in adoption of AC system throughout the world.

A transformer consists essentially of two coils, electrically insulated from each other and wound on the same silicon-iron core.



(a)



(b)

The coil to which energy is supplied is called the primary, and that from which energy is delivered to the outer circuit is called the secondary. An alternating current in the primary coil sets up an alternating magnetic flux in the core. This change in flux linked with the secondary coil induces an alternating EMF in the secondary coil. In this way power is transferred from one coil to the other coil via the changing magnetic flux in the core.

There are two types of transformers;

(1) Core Type : In the core type, the iron core is largely surrounded by the coils. In order to reduce eddy currents, the iron core is built up of laminations. Figure (a)

(2) Shell Type : In the shell type, the coils are very largely surrounded by the iron core. This provides two magnetic circuits in parallel.

Theory

Transformer on no-load and voltage ratio : The primary coil has large inductance but negligible resistance. It is assumed that there are no losses and that there is no leakage of flux. The current in the primary lags behind the voltage in the primary by 90º (since it works as an inductance only).

The EMF induced across each turn of the secondary is equal to the induced EMF across each turn of the primary because the same flux links with both the primary and the secondary coils. Therefore, the total induced EMF across the secondary depends upon its number of turns.

Suppose, EMF induced across the secondary = E_2

EMF induced across the primary = E_1

Number of turns of the secondary = N_2

Number of turns of the primary = N_1

$$\frac{E_2}{E_1} = \frac{N_2}{N_1} \quad \text{...(i)}$$

At no-load condition, the induced EMF, E, across the primary is numerically equal to the terminal potential difference V_1 across the primary and induced EMF, E_2, across the secondary is equal to the terminal potential difference V_2.

$$\frac{V_2}{V_1} = \frac{N_2}{N_1} \quad \text{...(ii)}$$

In case of a step–up transformer, $V_2 > V_1$. Therefore $N_2 > N_1$.

In a step-down transformer $V_2 < V_1$. Therefore $N_2 < N_1$.

$\frac{N_2}{N_1}$ is known as the transformation ratio.

If there are no losses, the power input is equal to the power output. Suppose, the current in the primary and the secondary are I_1 and I_2 respectively.

Power input = $E_1 \times I_1$

Power output = $E_2 \times I_2$

$\therefore E_1I_1 = E_2I_2$

$$\text{or } \frac{E_2}{E_1} = \frac{I_1}{I_2} \quad \text{...(iii)}$$

This shows that whatever is the gain in voltage, same is the corresponding loss in current. In a step up transformer $E_2 > E_1$ but $I_2 < I_1$. In a step down transformer $E_2 < E_1$ but $I_2 > I_1$.

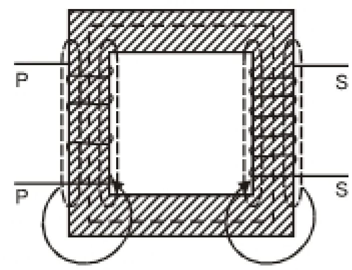
Power Losses in a Transformer

The losses in a transformer are much less compared to that in rotating machinery. However, there are five main losses :

(1) Copper losses : Heat is produced in the primary and the secondary windings due to Joule heating effect. The power loss = $I^2 R$, where I is the current flowing and R is the resistance of the copper winding.

(2) Iron losses (eddy current) : This is due to the eddy current produced in the core of the transformer. This is minimized by using a laminated iron core.

(3) Flux leakage : In an actual transformer the magnetic flux is not confined entirely to the iron core but some of the flux lines return through air. The leakage of magnetic flux takes place both in the primary and the secondary windings. The flux leakage is minimised by making the corners rounded.



(4) Hysteresis loss : There is loss of power in magnetizing an iron core and taking it through a complete cycle of magnetisation. This loss in power is known as hysteresis loss. It can be minimised by using silicon-iron core having a narrow hysteresis loop or low hysteresis loss.

(5) Magnetostriction loss : Losses in the form of vibration and humming sound.

Efficiency and Cooling

The efficiency of a transformer is more than 90%. If the insulations are perfect and the losses are minimised, the efficiency can be increased up to 99%. Thus, the electrical power output is always less than the electrical power input.

$$\text{Efficiency} = \frac{\text{Output electrical power}}{\text{Input electrical power}}$$

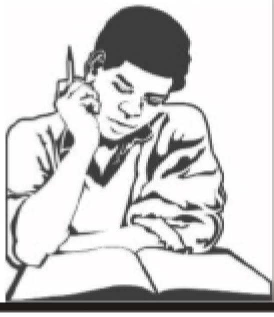
$$= \frac{\text{Input power} - \text{Losses}}{\text{Input power}}$$

$$\eta = 1 - \frac{\text{Losses}}{\text{Input power}}$$

$$= 1 - \frac{\text{Losses}}{\text{Output power} + \text{Losses}}$$

The natural cooling properties are poor in a transformer because only convection currents can produce air circulation. Therefore, transformers are usually immersed in a tank containing oil. In case of very large transformers used in power houses and generating stations, oil is circulated by a pump through the external cooling arrangement.

❑ ❑ ❑



Try Yourself

SECTION - A

Objective Type Questions

1. The instantaneous current in a circuit is given by $I = 2\cos(\omega t + \phi)$ ampere. The r.m.s value of the current is
   (1) Zero (2) $\sqrt{2}$ A
   (3) 2 A (4) $2\sqrt{2}$ A

2. When the frequency of A.C. is doubled, the impedance of an R–L circuit
   (1) Is halved (2) Is doubled
   (3) Increases (4) Decreases

3. Power factor of series RLC circuit at resonance is
   (1) Infinity (2) 1
   (3) $\frac{1}{LC}$ (4) 0

4. In an a.c. circuit
   $V = 100\sin(100t)$ volt, and
   $I = 100\sin(100t)$ mA.
   Find average power dissipated.
   (1) 10^4 W (2) 10 W
   (3) 2.5 W (4) 5 W

5. Power factor is one for
   (1) Pure inductor
   (2) Pure capacitor
   (3) Pure resistor
   (4) An inductor and a capacitor

6. For long distance transmission, the voltage is stepped up because at high voltage, the transmission is
   (1) Faster
   (2) More efficient
   (3) Undamped
   (4) Less dangerous

7. In a circuit containing an inductance of zero resistance, the current lags the applied a.c. voltage by a phase angle of
   (1) 90º (2) –90º
   (3) 0º (4) 180º

8. Transformers are used in
   (1) D.C. circuits only
   (2) A.C. circuits only
   (3) Both D.C. and A.C. circuits
   (4) Integrated circuits

9. In a choke coil, the reactance X_L and resistance R are such that
   (1) $X_L = R$ (2) $X_L >> R$
   (3) $X_L << R$ (4) $X_L = \infty$

10. At resonance in a series LCR circuit, which relation does not hold true?
   (1) $\omega = \frac{1}{LC}$ (2) $\omega = \frac{1}{\sqrt{LC}}$
   (3) $L\omega = \frac{1}{\omega C}$ (4) $\sqrt{C\omega} = \frac{1}{\sqrt{L\omega}}$

11. Which quantity is increased in step-down transformer?
   (1) Current
   (2) Voltage
   (3) Power
   (4) Frequency

12. Hot wire instruments (ammeter) can be used for measuring
   (1) D.C. only
   (2) A.C. only
   (3) Both A.C and D.C
   (4) Neither A.C. nor D.C

13. Resonance frequency of a series LCR circuit is f. If the capacitance is made 4 times the initial value, then the resonance frequency will become

(1) $\frac{f}{2}$

(2) $2f$

(3) f

(4) $\frac{f}{4}$

14. In a series LCR circuit, current leads voltage, then

(1) $\omega > \frac{1}{\sqrt{LC}}$

(2) $\omega < \frac{1}{\sqrt{LC}}$

(3) $\omega = \frac{1}{\sqrt{LC}}$

(4) $\omega = 0$

15. Coil having inductance $\frac{0.03}{\pi}$ henry and 4 Ω resistance is connected across alternating emf $E = 100 \sin \omega t$, 50 Hz, supply. Rms value of current in it is

(1) 20 A (2) 10 A

(3) $20\sqrt{2}$ A (4) $10\sqrt{2}$ A

16. 100 V ac is applied to a capacitor and resistance of 10 Ω in series. If rms voltage drop across capacitor is 60 V, rms value of current in the circuit is

(1) 4 A (2) 6 A

(3) 8 A (4) 2 A

17. The frequency of applied voltage at which current becomes $\frac{1}{\sqrt{2}}$ times the current at resonance frequency in an LCR circuit is called

(1) Half power frequency

(2) Quality factor

(3) Half current frequency

(4) Band width

18. Power factor of L-R circuit is always

(1) = 1 (2) > 1

(3) < 1 (4) ≤ 1

SECTION - B

Previous Years Questions

1. In an electrical circuit R, L, C and an $a.c.$ voltage source are all connected in series. When L is removed from the circuit, the phase difference between the voltage and the current in the circuit is $\frac{\pi}{3}$. If instead, C is removed from the circuit, the phase difference is again $\frac{\pi}{3}$. The power factor of the circuit is: **[AIPMT 2012]**

(1) 1

(2) $\frac{\sqrt{3}}{2}$

(3) $\frac{1}{2}$

(4) $\frac{1}{\sqrt{2}}$

2. A coil of self-inductance L is connected in series with a bulb B and an AC source. Brightness of the bulb decreases when **[NEET-2013]**

(1) Number of turns in the coil is reduced

(2) A capacitance of reactance $X_C = X_L$ is included in the same circuit

(3) An iron rod is inserted in the coil

(4) Frequency of the AC source is decreased

3. A transformer having efficiency of 90% is working on 200 V and 3 kW power supply. If the current in the secondary coil is 6A, the voltage across the secondary coil and the current in the primary coil respectively are **[AIPMT 2014]**

(1) 300 V, 15 A (2) 450 V, 15 A

(3) 450 V, 13.5 A (4) 600 V, 15 A

4. A series R-C circuit is connected to an alternating voltage source. Consider two situations

(a) When capacitor is air filled.

(b) When capacitor is mica filled.

Current through resistor is i and voltage across capacitor is V then **[Re-AIPMT-2015]**

(1) $V_a = V_b$ (2) $V_a < V_b$

(3) $V_a > V_b$ (4) $i_a = i_b$

5. Across a metallic conductor of non-uniform cross-section a constant potential difference is applied. The quantity which remains constant along the conductor is **[AIPMT-2015]**

(1) Electric field (2) Current density

(3) Current (4) Drift velocity

6. A resistance R draws power P when connected to an AC source. If an inductance is now placed in series with the resistance, such that the impedance of the circuit becomes Z, the power drawn will be **[AIPMT-2015]**

(1) P (2) $P\left(\frac{R}{Z}\right)^2$

(3) $P\sqrt{\frac{R}{Z}}$ (4) $P\left(\frac{R}{Z}\right)$

7. An inductor 20 mH, a capacitor 50 μF and a resistor 40 Ω are connected in series across a source of emf V = 10sin340t. The power loss in A.C. circuit is **[NEET-2016]**

(1) 0.89 W (2) 0.51 W

(3) 0.67 W (4) 0.76 W

8. A small signal voltage $V(t) = V_0 \sin\omega t$ is applied across an ideal capacitor C **[NEET-2016]**

(1) Current $I(t)$ leads voltage $V(t)$ by 180°

(2) Current $I(t)$ lags voltage $V(t)$ by 90°

(3) Over a full cycle the capacitor C does not consume any energy from the voltage source

(4) Current $I(t)$ is in phase with voltage $V(t)$

9. Which of the following combinations should be selected for better tuning of an L-C-R circuit used for communication? **[NEET (Phase-2) 2016]**

(1) R = 20 Ω, L = 1.5 H, C = 35 μF

(2) R = 25 Ω, L = 2.5 H, C = 45 μF

(3) R = 15 Ω, L = 3.5 H, C = 30 μF

(4) R = 25 Ω, L = 1.5 H, C = 45 μF

10. The potential differences across the resistance, capacitance and inductance are 80 V, 40 V and 100 V respectively in an L-C-R circuit. The power factor of this circuit is **[NEET (Phase-2) 2016]**

(1) 0.4 (2) 0.5

(3) 0.8 (4) 1.0

11. The magnetic potential energy stored in a certain inductor is 25 mJ, when the current in the inductor is 60 mA. This inductor is of inductance **[NEET-2018]**

(1) 0.138 H (2) 138.88 H

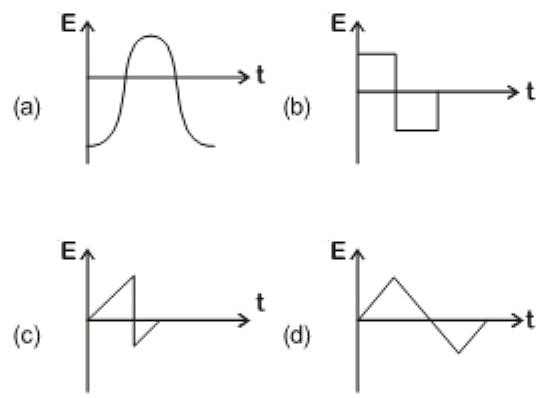
(3) 13.89 H (4) 1.389 H

12. An inductor 20 mH, a capacitor 100 μF and a resistor 50 Ω are connected in series across a source of emf, V = 10 sin 314 t. The power loss in the circuit is **[NEET-2018]**

(1) 0.79 W (2) 0.43 W

(3) 1.13 W (4) 2.74 W

13. The variation of EMF with time for four types of generators are shown in the figures. Which amongst them can be called AC? **[NEET-2019 (Odisha)]**



(1) Only (a) (2) (a) and (d)

(3) (a), (b), (c), (d) (4) (a) and (b)

14. A circuit when connected to an AC source of 12 V gives a current of 0.2 A. The same circuit when connected to a DC source of 12 V, gives a current of 0.4 A. The circuit is **[NEET-2019 (Odisha)]**

(1) Series LCR (2) Series LR

(3) Series RC (4) Series LC

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Chapter 8

Electromagnetic Waves

Sub-topics *Need for displacement current. Electromagnetic waves and their characteristics (qualitative ideas only). Transverse nature of electromagnetic waves. Electromagnetic spectrum (radio waves, microwaves, infrared, visible, ultraviolet, x-rays, gamma rays) including elementary facts about their uses.*

Need for Displacement Current

Maxwell developed Ampere's Circuital Law, $\oint \vec{B} \cdot d\vec{l} = \mu_0 I$. Later in the process of charging a capacitor Maxwell found this equation incomplete. To make Ampere's law complete, Maxwell gave the concept of displacement current and modified Ampere's circuital Law. Now putting Gauss's law, Faraday's law of electromagnetic induction and modified Ampere's law together Maxwell observed symmetry between electric and magnetic fields. These laws together are called Maxwell's four equations. Solution of these four equations predicted the presence of Electromagnetic waves.

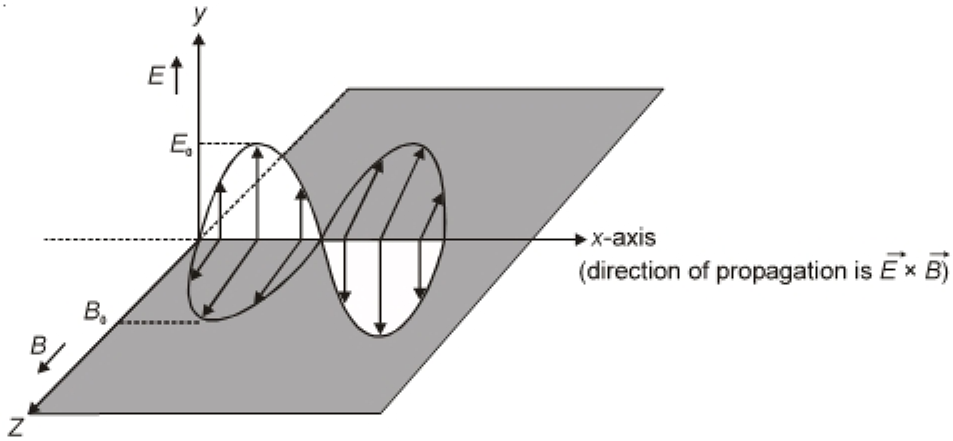
Displacement current exists where electric field changes with time. During charging of a capacitor, conduction current in the wire and displacement current in the gap are exactly equal.

Displacement current, $I_d = \varepsilon_0 \dfrac{d(\phi_E)}{dt} = \varepsilon_0 \dfrac{d\oint \vec{E}.d\vec{s}}{dt} = \dfrac{CdV}{dt}$

Electromagnetic waves and their characteristics

Transverse nature of electromagnetic waves

(1) Transverse waves



(2) Both electric and magnetic field vary in phase with each other.

(3) $E_y = E_0 \sin(\omega t - kx)$, $B_Z = B_0 \sin(\omega t - kx)$, speed $v = \frac{\omega}{k}$

(4) In vacuum, $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$. In a medium $v = \frac{1}{\sqrt{\mu\varepsilon}}$.

(5) $\frac{E}{B} = \frac{E_0}{B_0} = \frac{E_{rms}}{B_{rms}} = c$ (speed)

(6) Average energy density $U_{av} = \frac{1}{2}\varepsilon_0 E_0^2 = \frac{1}{2}\frac{B_0^2}{\mu_0} = \frac{1}{4}\varepsilon_0 E_0^2 + \frac{1}{4}\frac{B_0^2}{\mu_0}$

(7) **Radiation pressure (P):**

(i) $P = \frac{I}{c}$ (where I = intensity of radiation, c : speed of light) (When radiations totally absorbed).

(ii) $P = \frac{2I}{c}$ (where I = intensity of radiation, c : speed of light) (When radiations totally reflected).

Electromagnetic Spectrum

In the spectrum of sun light, we see all colours from red to violet in the order "VIBGYOR". This spectrum is called the 'visible spectrum'. The red region has the longest wavelength (nearly 7.8×10^{-7} metre) and the violet region has the smallest wavelength (4.0×10^{-7} metre). Thus the visible spectrum extends from 7.8×10^{-7} metre to 4.0×10^{-7} metre. Later on, it was discovered that the sun's spectrum is not limited from red to violet colours, but it extends above the red colour and below the violet colour. These parts of the spectrum are not observed to our eye. Hence, they are called 'invisible spectrum'. The region of longer wavelengths above the red colour is called the 'infrared spectrum' and that of smaller wavelengths below the violet colour is called the 'ultraviolet spectrum'.

Besides ultraviolet, infrared and visible region, X–rays, γ–rays and radio waves also form the part of electromagnetic spectrum. The range of the wavelengths of these waves is very large and on this basis these can be arranged in an order. This order is called the 'electromagnetic spectrum'. Wavelength ranges from the very small value for gamma rays to the very long value for radio waves. The visible spectrum is only a very small part of the electromagnetic spectrum. The wavelength ranges, the method of production and the properties of the whole electromagnetic spectrum are summarised below.

Table : Complete Electromagnetic Spectrum

	Name of rays	Wavelength & Frequency (Hz)	Method of production/source	Properties and Uses
1.	γ-rays	10^{-14} m to 10^{-10} m 3×10^{22} to 3×10^{18}	Emitted on the disintegration of nuclei of atoms.	Phosphorescence, fluorescence, polarisation, diffraction, neutral, highly penetrating, affect photographic plates, used for cancer therapy and other treatment.
2.	X-rays	10^{-13} m to 10^{-8} m 3×10^{21} to 3×10^{16}	Produced by striking high speed electrons on heavy target.	Chemical reaction on photographic plates, fluorescence, phosphoresence, ionisation, etc, but less penetrating than gamma rays, used in radiography for medical diagnosis and in cancer therapy.
3.	Ultra-violet radiaton	6×10^{-10} m to 4×10^{-7} m 5×10^{17} to 7×10^{14}	Sun, hot vaccum, spark arc, spark and ionised gases.	All properties of gamma rays, but less penetrating, produce photoelectric effect, harmful to us if absorbed in large amount.
4.	Visible radiation	4×10^{-7} m to 7.0×10^{-7} m 4×10^{14} to 7×10^{14}	Radiated from ionised gases and incandescent bodies.	Reflection, refraction, interference, diffraction, polarisation, photoelectric effect, photographic action and sensation of sight.

	Name of rays	Wavelength & Frequency (Hz)	Method of production/source	Properties and Uses
5.	Infrared radiation	7.0×10^{-7} m to 10^{-3} m 4×10^{14} to 3×10^{11}	From hot bodies	Heating effect on thermopiles and bolometer, reflection, refraction, diffraction, photographic action, used in physio therapy. Also, called heat wave.
6.	Microwaves	10^{-4} m to 1m 3×10^{12} to 3×10^{8}	Produced by spark discharge	They are reflected, refracted and produce spark in the gaps of receiving circuits. Wave of wavelengths from 10^{-3}m to 3×10^{-2}m are also called 'microwaves' used in radar and satellite communication, cooking.
7.	Long radio or wireless waves	10^{-2} m to 10^{4}m 3×10^{10} to 3×10^{4}	From spark gap discharges and oscillating electric circuits.	They are reflected, refracted and diffracted, used in radio and TV communication.

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Try Yourself

SECTION - A

Objective Type Questions

1. Which of the following is not a Maxwell's equation?

   (1) $\oint \vec{E}.\vec{dl} = -\frac{d\phi_B}{dt}$ (2) $\oint \vec{E}.\vec{ds} = \frac{q_{in}}{\varepsilon_0}$

   (3) $\oint \vec{B}.\vec{ds} = 0$ (4) $\oint \vec{B}.\vec{dl} = -\frac{d\phi_E}{dt}$

2. Electromagnetic waves do not transport

   (1) Energy (2) Charge

   (3) Momentum (4) Information

3. Amplitudes of electric and magnetic fields in an electromagnetic wave are related to each other as

   (1) $E_0 = B_0$ (2) $E_0 = cB_0$

   (3) $E_0 = \frac{B_0}{c}$ (4) $E_0 = \frac{c}{B_0}$

4. An electromagnetic wave, going through vacuum is $E = E_0 \sin(Kx - \omega t)$. Which one of the following is independent of wavelength?

   (1) K (2) ω

   (3) $\frac{K}{\omega}$ (4) $K\omega$

5. Speed of electromagnetic waves in a medium is independent of

   (1) Permeability (2) Permittivity

   (3) Elasticity (4) Both (1) & (2)

6. Infrared waves are called heat waves as they can

   (1) Vibrate molecules of a substance

   (2) Excite electrons

   (3) Produce sensation of visibility at human eyes

   (4) Be absorbed by the atmosphere

7. The amplitude of magnetic field part of a harmonic electromagnetic wave in vacuum is B_0 = 510 nT. The possible expression for electric field is

   (1) $E = 510 \sin\frac{2\pi}{\lambda}(ct - x)$

   (2) $E = 153 \sin\frac{2\pi}{\lambda}(ct - x)$

   (3) $E = 153 \sin \omega t \cos kx$

   (4) $E = 510 \sin \omega t \cos kx$

8. Which of the following is not an electromagnetic wave?

   (1) Radio wave (2) γ rays

   (3) β rays (4) Microwaves

9. The rate at which potential difference between the plates of a parallel plate capacitor with a 2.0 μF capacitance be changed to produce a displacement current of 1.5 A is

   (1) 0.75 MV/s (2) 7.5 MV/s

   (3) 75 MV/s (4) 3 MV/s

10. Angle between electric field and magnetic field in EM wave

    (1) 90° (2) 180°

    (3) 45° (4) All of these

11. If μ and ε are permeability and permittivity of a medium, then speed of electromagnetic wave in the medium is

    (1) $\sqrt{\frac{\mu}{\varepsilon}}$ (2) $\sqrt{\frac{\varepsilon}{\mu}}$

    (3) $\sqrt{\mu\varepsilon}$ (4) $\frac{1}{\sqrt{\mu\varepsilon}}$

12. Phase difference between electric field and magnetic field in an EM wave is

    (1) π (2) $\frac{\pi}{2}$

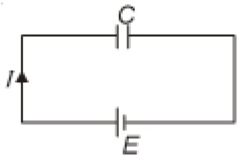
    (3) Zero (4) $\frac{3\pi}{2}$

13. If u_E and u_B are electric energy density and magnetic energy density in an EM wave then

    (1) $u_E > u_B$ (2) $u_E < u_B$

    (3) $u_E = u_B$ (4) All of these

14. If current through the battery in the circuit is I, then displacement current in the capacitor is



(1) $\frac{I}{2}$ (2) I

(3) $2I$ (4) $\frac{I}{4}$

SECTION - B

Previous Years Questions

1. The electric field associated with an e.m. wave in vacuum is given by $\vec{E} = \hat{i}\,40\cos(kz - 6\times10^8 t)$, where E, z and t are in volt/m, metre and seconds respectively. The value of wave vector k is **[AIPMT 2012]**

(1) 6 m^{-1} (2) 3 m^{-1}

(3) 2 m^{-1} (4) 0.5 m^{-1}

2. The condition under which a microwave oven heats up a food item containing water molecules most efficiently is **[NEET-2013]**

(1) The frequency of the microwaves has no relation with natural frequency of water molecules

(2) Microwaves are heat waves, so always produce heating

(3) Infra-red waves produce heating in a microwave oven

(4) The frequency of the microwaves must match the resonant frequency of the water molecules

3. Light with an energy flux of 25 × 10^4 Wm^{-2} falls on a perfectly reflecting surface at normal incidence. If the surface area is 15 cm^2, the average force exerted on the surface is **[AIPMT 2014]**

(1) 1.25 × 10^{-6} N (2) 2.50 × 10^{-6} N

(3) 1.20 × 10^{-6} N (4) 3.0 × 10^{-6} N

4. The energy of the em waves is of the order of 15 keV. To which part of the spectrum does it belong? **[Re-AIPMT-2015]**

(1) γ-rays (2) X-rays

(3) Infra-red rays (4) Ultraviolet rays

5. A radiation of energy E falls normally on a perfectly reflecting surface. The momentum transferred to the surface is (C = velocity of light) **[AIPMT-2015]**

(1) $\frac{E}{C^2}$ (2) $\frac{E}{C}$

(3) $\frac{2E}{C}$ (4) $\frac{2E}{C^2}$

6. Out of the following options which one can be used to produce a propagating electromagnetic wave?

(1) An accelerating charge **[NEET-2016]**

(2) A charge moving at constant velocity

(3) A stationary charge

(4) A chargeless particle

7. A 100 Ω resistance and a capacitor of 100 Ω reactance are connected in series across a 220 V source. When the capacitor is 50% charged, the peak value of the displacement current is **[NEET (Phase-2) 2016]**

(1) 2.2 A (2) 11 A

(3) 4.4 A (4) $11\sqrt{2}$ A

8. In an electromagnetic wave in free space the root mean square value of the electric field is E_{rms} = 6 V/m. The peak value of the magnetic field is **[NEET-2017]**

(1) 1.41 × 10^{-8} T (2) 2.83 × 10^{-8} T

(3) 0.70 × 10^{-8} T (4) 4.23 × 10^{-8} T

9. An em wave is propagating in a medium with a velocity $\vec{V} = V\hat{i}$. The instantaneous oscillating electric field of this em wave is along +y axis. Then the direction of oscillating magnetic field of the em wave will be along **[NEET-2018]**

(1) –z direction (2) +z direction

(3) –x direction (4) –y direction

10. Which colour of the light has the longest wavelength? **[NEET-2019]**

(1) Red (2) Blue

(3) Green (4) Violet

11. A parallel plate capacitor of capacitance 20 μF is being charged by a voltage source whose potential is changing at the rate of 3 V/s. The conduction current through the connecting wires, and the displacement current through the plates of the capacitor, would be, respectively. **[NEET-2019]**

(1) Zero, 60 μA (2) 60 μA, 60 μA

(3) 60 μA, zero (4) Zero, zero

12. For a transparent medium, relative permeability and permittivity, μ_r and ϵ_r are 1.0 and 1.44 respectively. The velocity of light in this medium would be **[NEET-2019 (Odisha)]**

(1) 4.32 × 10^8 m/s (2) 2.5 × 10^8 m/s

(3) 3 × 10^8 m/s (4) 2.08 × 10^8 m/s

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Chapter 9

Ray Optics and Optical Instruments

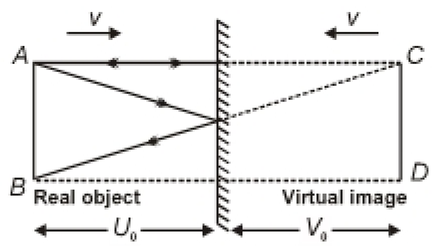
Sub-topics *Reflection of light, spherical mirrors, mirror formula. Refraction of light, total internal reflection and its applications optical fibres, refraction at spherical surfaces, lenses, thin lens formula, lens-maker's formula. Magnification, power of a lens, combination of thin lenses in contact combination of a lens and a mirror. Refraction and dispersion of light through a prism. Scattering of light- blue colour of the sky and reddish appearance of the sun at sunrise and sunset.* ***Optical instruments:*** *Human eye, image formation and accommodation, correction of eye defects (myopia and hypermetropia) using lenses. Microscopes and astronomical telescopes (reflecting and refracting) and their magnifying powers.*

OPTICS

Reflection of Light

Angle of incidence = Angle of reflection

Plane Mirror



(1) $AB = CD$

(2) $|U_0| = |V_0|$

(3) Focal length = ∞

(4) Power = 0

(5) Speed of object relative to mirror is v.

(6) Speed of image relative to mirror is v.

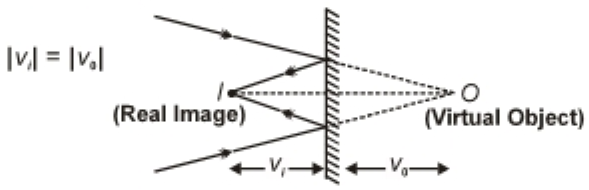
(7) Speed of image relative to object is $2v$.

(8) Keeping incident ray fixed, if a plane mirror rotates by θ w.r.t. incident ray reflected ray rotates by 2θ.

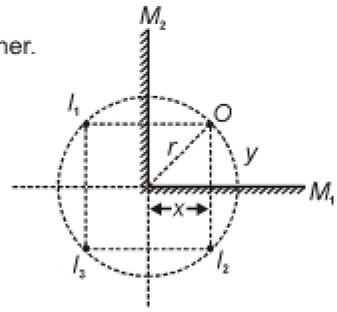
(9) A thick plane mirror forms a number of images of an object in front of it, out of these images, 2nd image will be brightest.

(10) If a clock shows x hrs, y min, z second when seen in a plane mirror, true time is $11 - x$ hrs, $59 - y$ min, $60 - z$ second.

(11) A plane mirror can form a real image, if object is virtual.



Combination of mirrors :



(1) 3 images are formed. When plane mirrors are perpendicular to each other.

O, I_1, I_2, I_3 lie on circle $x^2 + y^2 = r^2$

(2) Three mutually perpendicular mirrors are placed adjacent to each other. For a person standing in front of them.

(a) No. of images formed = 7

(b) Maximum no. of images seen at a time = 6

(3) For two mirrors inclined at an angle 'θ', number of images formed by the mirrors for an object are

(a) $\frac{360}{\theta}-1$, if $\frac{360}{\theta}$ = even number

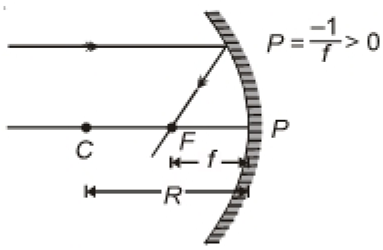
(b) $\frac{360}{\theta}-1$, when $\frac{360}{\theta}$ = odd and object is placed symmetrically.

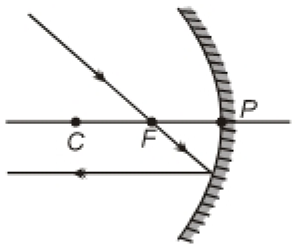
(c) $\frac{360}{\theta}$, when $\frac{360}{\theta}$ = odd and object is placed unsymmetrically.

(4) Power of mirror = $-\frac{1}{f_{mirror}}$, for plane mirror; power = 0

Spherical Mirrors

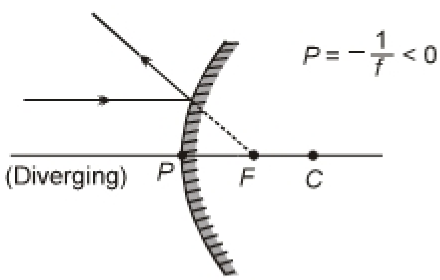
Concave Mirror

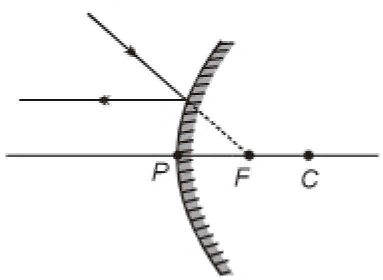




$f \approx \frac{R}{2}$ Converging behaviour

Convex Mirror



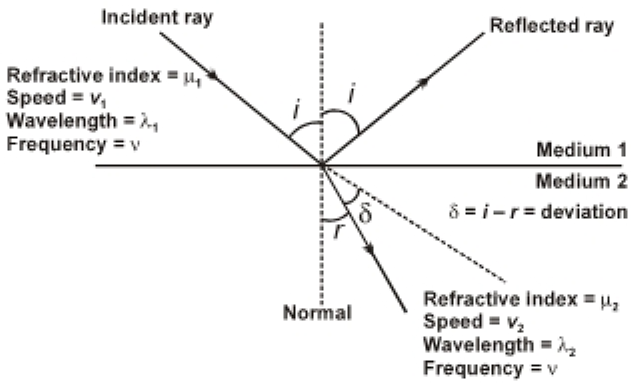


Mirror formula, $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$ $\quad m=\frac{h_i}{h_o}=-\frac{v}{u}=\frac{f}{f-u}=\frac{f-v}{f}$

Refraction of Light

(1) $\mu_1 \sin i = \mu_2 \sin r$ (Snell's law)

or, $\frac{\mu_2}{\mu_1} = \frac{\sin i}{\sin r} = {}^1\mu_2$ [refractive index of medium 2 w.r.t. medium 1]



(2) If $\mu_2 > \mu_1 \Rightarrow \quad r < i$

(3) If $\mu_2 < \mu_1 \Rightarrow \quad r > i$

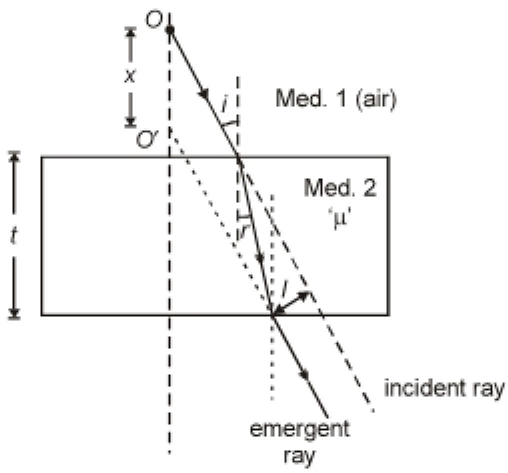
(4) Incident and emergent ray are parallel for glass slab.

(5) l (lateral displacement) = $\frac{t \sin(i-r)}{\cos r}$ for glass slab.

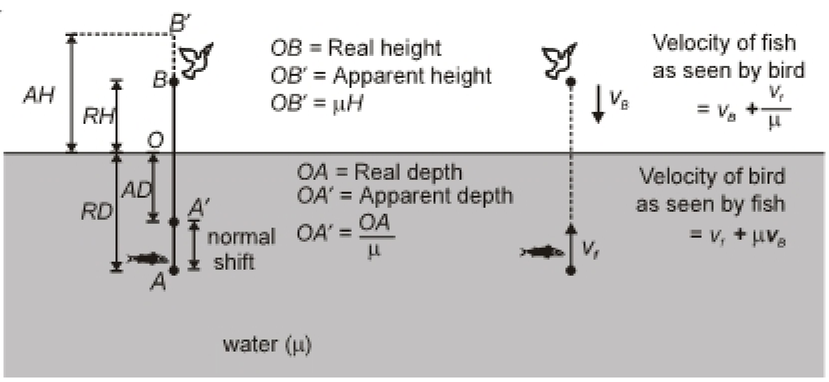
(6) $l_{max} = t$, when $i \to 90°$ as $\sin(i - r) \to 1$ and $\cos r \to 1$

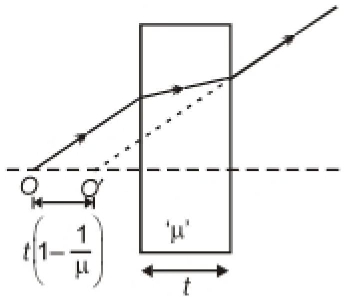
(7) x (normal shift) = $t\left(1 - \frac{1}{\mu}\right)$

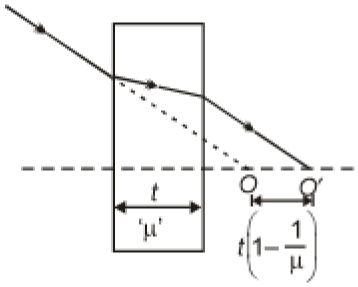
(for very small angle of incidence)



(8) **Real and apparent depth**

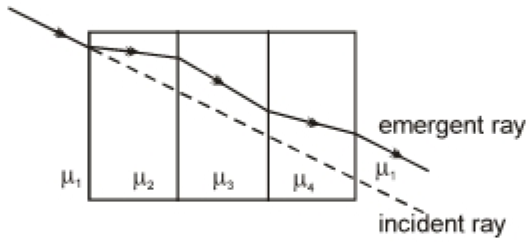


(9) 

(10) 

(For diverging ray shifting fowards the slab) (For converging ray shift is away from the slab)

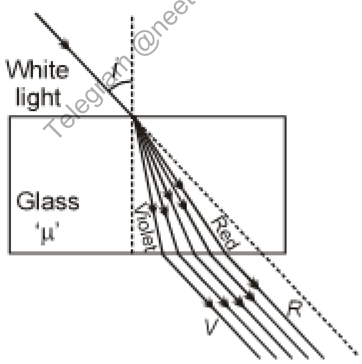
(11) For refraction at plane and parallel faces, when incident and emergent rays are in same medium, they are always parallel.



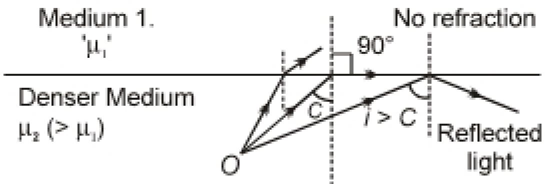
(12) μ depends on wavelength as

$$\mu = a + \frac{b}{\lambda^2} + \frac{c}{\lambda^4} \text{ (Cauchy's equation)}$$

$\Rightarrow$ Greater wavelength means smaller refractive index.



Total Internal Reflection



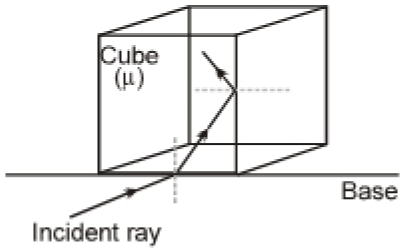
C = critical angle of incidence

$$\mu_2 \sin C = \mu_1 \sin 90°$$

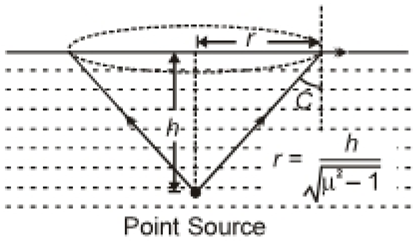
$$\sin C = \frac{\mu_1}{\mu_2} \text{ or } \sin C = \frac{1}{\mu} \qquad \left[\frac{1}{\mu} = \frac{\mu_1}{\mu_2} = \frac{\mu_{rarer}}{\mu_{denser}}\right]$$

Applications :

(1) If any ray entering from the base suffers total internal reflection at side walls then $\mu > \sqrt{2}$. *i.e.*, objects below base can not be seen through side faces.



(2)



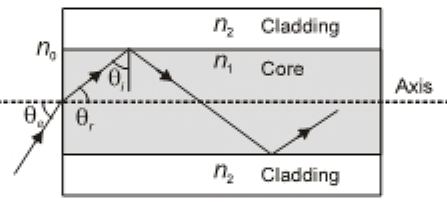
$$\sin C = \frac{1}{\mu} \therefore \tan C = \frac{1}{\sqrt{\mu^2 - 1}} = \frac{r}{h}$$

r = radius of base of cone of light from the source which is able to come out.

Optical Fibres

An optical fibre consists of a transparent core fibre of refractive index n_1 surrounded by a transparent glass sheath or cladding of slightly lower index n_2 with both enclosed in an opaque protective envelope.

Figure shows a cross-section through the axis of an optical fibre. A ray entering the core from an external medium of index n_0 at an angle θ_e will make an angle θ_r with respect to axis inside the core. The ray continuing in the core will be incident on the core cladding boundary at an angle θ_i. If $\theta_i > \theta_c$ where θ_c is the critical angle, the ray will be totally internally reflected and continue to propagate inside the core.



Using laws of refraction it can be proved that, $\sin\theta_e = \frac{\sqrt{n_1^2 - n_2^2}}{n_0}$

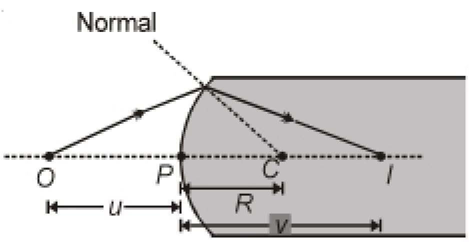
where, θ_e = Entrance angle on the axis of the core

n_1 = Refractive index of core

n_2 = Refractive index of cladding

n_0 = Refractive index of external medium

Refraction at Spherical Surfaces

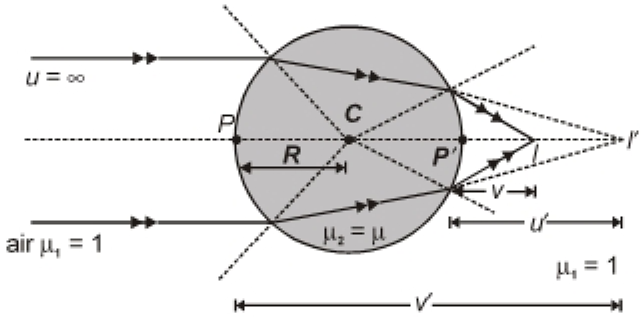


$PC = +R$
$PO = -u$
$PI = +v$

$$\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$$

Glass sphere in Air

(1) Parallel Beam



For refraction at P,

$u = -\infty$, $PI' = v'$, $PC = +R$

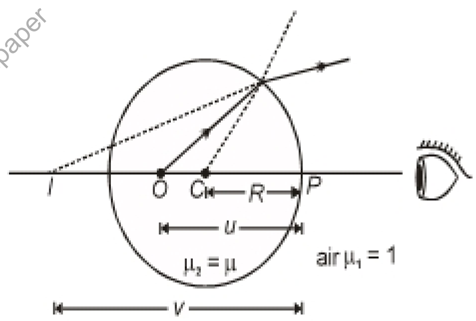
$$\frac{\mu}{v'} - \frac{1}{-\infty} = \frac{\mu - 1}{R}$$

For refraction at P'

$P'I' = +u'$, $P'C = -R$, $P'I = +v$

$$\frac{1}{v} - \frac{\mu}{v'} = \frac{1-\mu}{-R}$$

(2) A point object inside glass sphere



$$\frac{\mu_1}{v} - \frac{\mu_2}{u} = \frac{\mu_1 - \mu_2}{R}$$

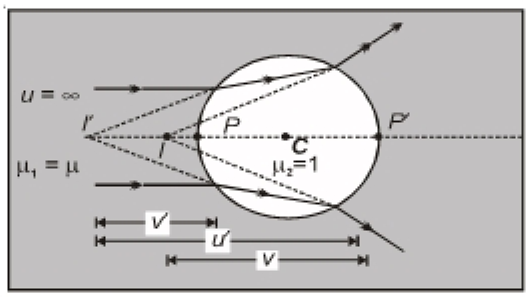
u is negative.

R is negative.

$$\frac{1}{v} - \frac{\mu}{(-u)} = \frac{1-\mu}{(-R)}$$

From this v will come out with a negative sign.

(3) Air Bubble Inside Water



For refraction at P $u = +\infty$

$PI' = V'$, $R > 0$

$$\frac{1}{v'} - \frac{\mu}{(-u)} = \frac{1-\mu}{R} \quad (V' \text{ will come out –ve})$$

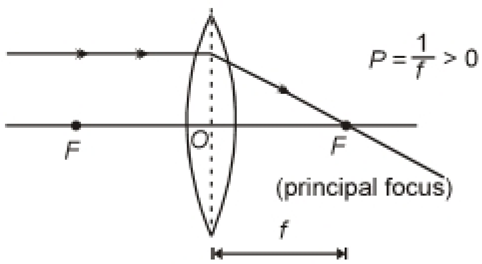
For refraction at P'

$P'I' = u'$ (–ve). $PI = v$(–ve)

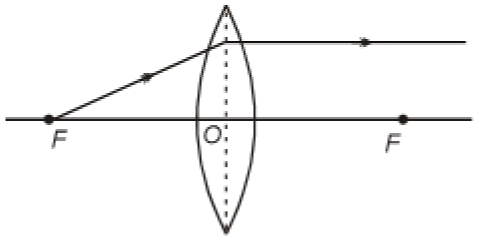
$$\frac{\mu}{v} - \frac{1}{(-u')} = \frac{\mu - 1}{(-R)}$$

Lenses

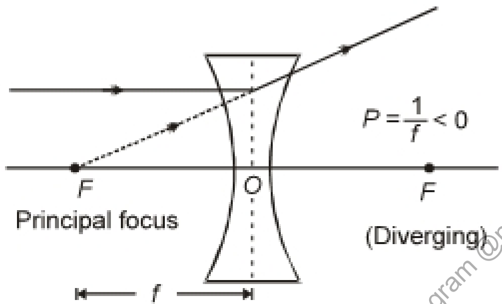
Convex Lens

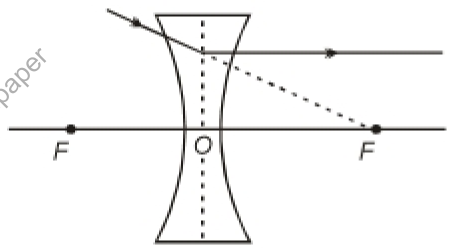


Converging lens



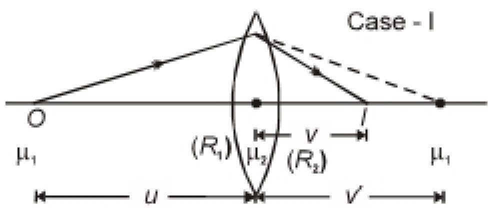
Concave Lens





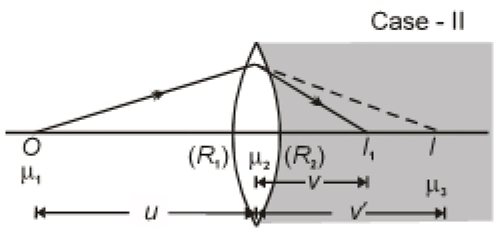
Thin lens formula $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

Lens Maker's formula : (For thin lenses)



Case I : $P = \frac{1}{f} = \frac{1}{v} - \frac{1}{u} = \left(\frac{\mu_2}{\mu_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

Case II : $\frac{\mu_3}{v} - \frac{\mu_1}{u} = \frac{\mu_3 - \mu_2}{R_2} + \frac{\mu_2 - \mu_1}{R_1}$



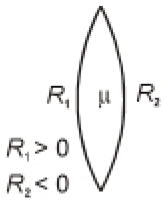
For an equiconvex lens

$R_2 = -R, \quad R_1 = +R$

$\Rightarrow \frac{\mu_3}{v} - \frac{\mu_1}{u} = \frac{2\mu_2 - \mu_1 - \mu_3}{R}$

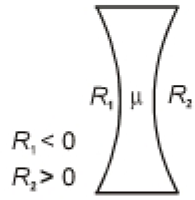
Application of Lens Maker's Formula

(1) Double convex lens



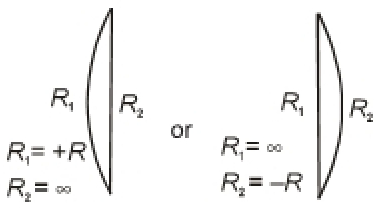
$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) > 0$$

(2) Double concave lens



$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) < 0$$

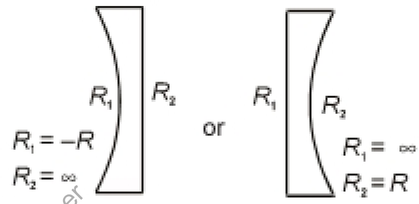
(3) Planoconvex lens



$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R}\right) > 0$$

If $\mu = 1.5$, $f = 2R$

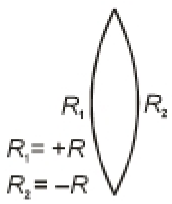
(4) Planoconcave lens



$$\frac{1}{f} = (\mu - 1)\left(-\frac{1}{R}\right) < 0$$

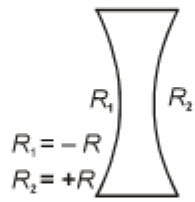
If $\mu = 1.5$, $f = -2R$

(5) Equiconvex lens



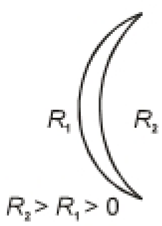
$$\frac{1}{f} = (\mu - 1)\left(\frac{2}{R}\right)$$ (If $\mu = 1.5$, $f = R$)

(6) Equiconcave lens



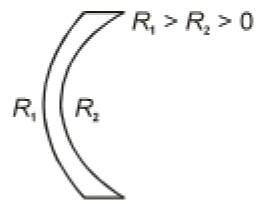
$$\frac{1}{f} = (\mu - 1)\left(-\frac{2}{R}\right)$$ (If $\mu = 1.5$, $f = -R$)

(7) Convex meniscus lens



$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) > 0$$

(8) Concave meniscus lens



$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) < 0$$

Magnification $m = \frac{I}{O}$ $\left[\begin{array}{l} m < \text{zero for inverted image and if } |m| > 1 \text{ image is magnified} \\ m > \text{zero for erect image and if } |m| < 1 \text{ image is diminished} \end{array}\right]$

(a) In mirrors, $m = -\frac{v}{u} = \frac{f}{f-u} = \frac{f-v}{f}$

(b) In lenses, $m = \frac{v}{u} = \frac{f}{f+u} = \frac{f-v}{f}$

Power of a lens, $P = \frac{1}{f}$

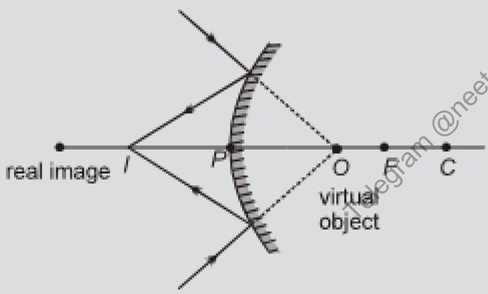
Note : (1) *A concave mirror and a convex lens can form either real or virtual, magnified or diminished image of an object.*

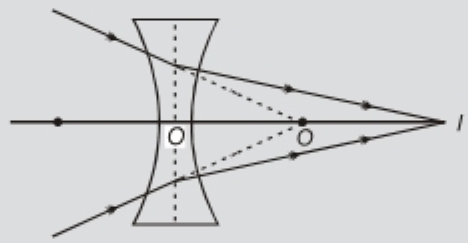
(2) *For a real object, image formed by a convex mirror is always virtual, diminished and lies between P and F.*

(3) *For a real object, image formed by a concave lens is always virtual, diminished and lies between O and F.*

(4) *Virtual image formed by a convex lens/concave mirror is always magnified.*

(5) *A convex mirror or a concave lens can form a real image if object is virtual as shown.*



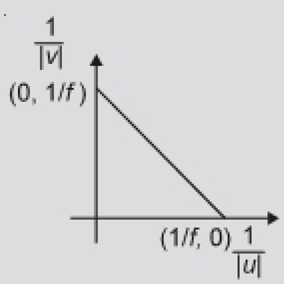


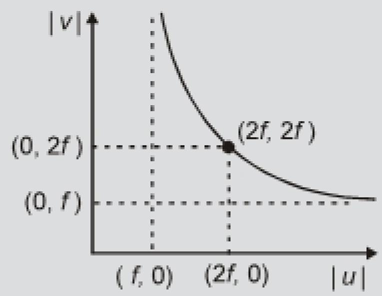
(6) *A real image is actually formed at its position. It can be taken on a screen.*

(7) *A virtual image is not actually formed at its position. It appears to be there. If we place a screen at the position, no image will be formed on the screen.*

(8) *A virtual image can be photographed as camera lens forms a real image of this virtual image on the photographic film.*

(9) *An object moves along the axis of a concave mirror/convex lens from infinity towards its focus with a constant speed.*





(a) *When the object moves from ∞ to 2F, image moves very slowly from F to 2F.*

(b) *When the object moves from 2F to F, image moves very fast from 2F to ∞.*

At any instant $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$ *for a mirror*

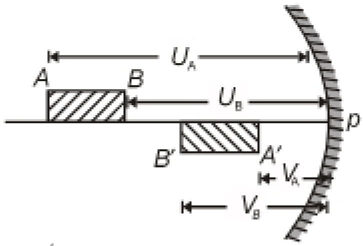
$$-\frac{1}{v^2}\frac{dv}{dt}+\frac{(-1)}{u^2}\frac{du}{dt}=0$$

$$\Rightarrow \quad \frac{dv}{dt}=-\frac{v^2}{u^2}\frac{du}{dt} \quad i.e., \quad V_i=-\frac{v^2}{u^2}V_0$$

For a lens $V_i=\frac{v^2}{u^2}V_0=m^2V_0$

Longitudinal Magnification

$$m_L=\frac{A'B'}{AB}=\frac{V_B-V_A}{U_A-V_B}$$



For short object,

$$m_L=\frac{dv}{du}$$

For a concave mirror, $m_L=-\frac{v^2}{u^2}$

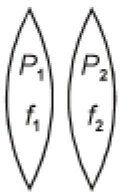
For a convex lens, $m_L=\frac{v^2}{u^2}$

Combination of thin Lenses in contact

1. In contact :

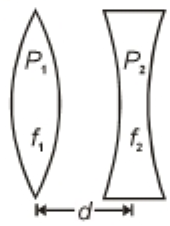
$P=P_1+P_2$, P is taken with sign

$$\frac{1}{f}=\frac{1}{f_1}+\frac{1}{f_2}$$

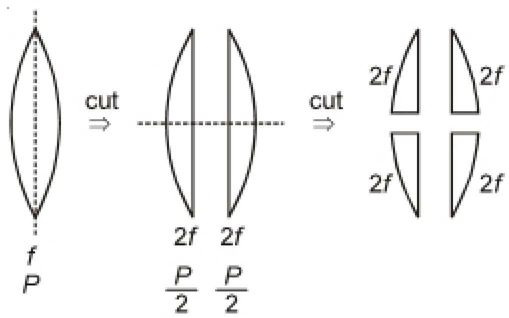


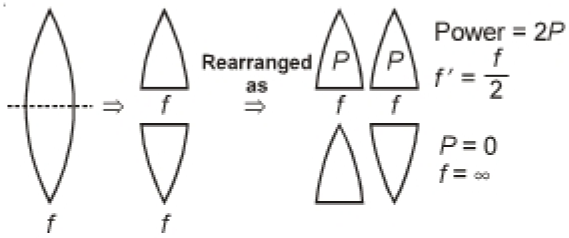
2. $P=P_1+P_2-dP_1P_2$

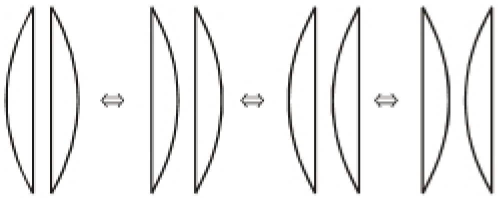
$$\frac{1}{f}=\frac{1}{f_1}+\frac{1}{f_2}-\frac{d}{f_1f_2}$$ (applicable only for parallel rays)



3.



4. 

5. 

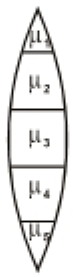
Each of the above arrangement will have same power and focal length

6. A convex lens made of more than one material may have more than one focal length.

(a) Number of focal lengths

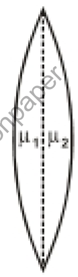
= Number of different medium

= Number of images formed = 5

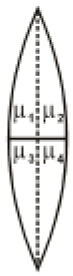


(b) This has a single focal length

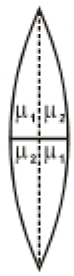
∴ Only one image.



(c) Two images

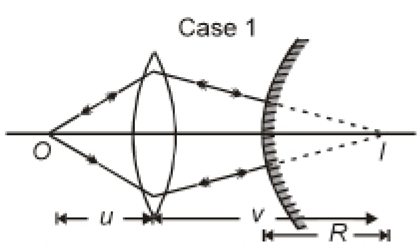


(d) One image

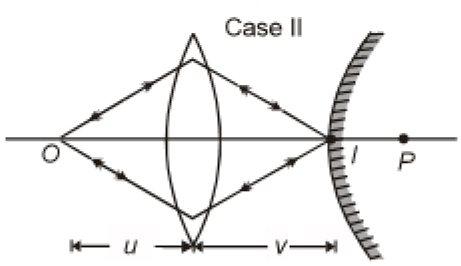


Combination of a Lens and a Mirror

A point object is placed in front of a convex lens. A convex mirror is placed behind the lens, so that final image coincides with the object itself.



Final image is real and erect and coincides with O



Final image is real and inverted and coincides with O

Note : ***Achromatic Combination***

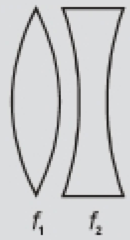
Lenses in contact

Power $P = \frac{1}{f_1} + \frac{1}{f_2} = P_1 + P_2$

Condition for achromatism

$\frac{\omega_1}{f_1} + \frac{\omega_2}{f_2} = 0$ *or* $\omega_1 P_1 + \omega_2 P_2 = 0$

$\Rightarrow$ *P_1 and P_2 or f_1 and f_2 should be of opposite sign. Also $\omega_1 \neq \omega_2$ as P will become zero.*

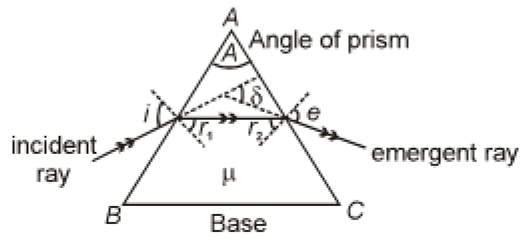


Refraction and Dispersion of Light Through a Prism

$\delta = i + e - A$

$A = r_1 + r_2$

$\mu = \frac{\sin i}{\sin r_1} = \frac{\sin e}{\sin r_2}$



Thin prisms : A, i, e, r_1, r_2 are small angles

$\delta = (\mu - 1)A$

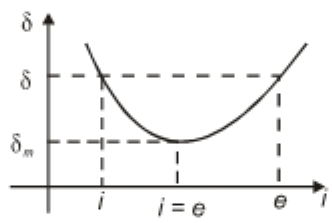
At a particular angle of incidence δ is minimum

when $\delta = \delta_m$, $i = e$ $\therefore$ $r_1 = r_2$

$\Rightarrow$ $A = r_1 + r_2 = 2r$ OR $r = \frac{A}{2}$

$\delta_m = i + e - A = 2i - A$ OR $i = \frac{A + \delta_m}{2}$

$$\mu = \frac{\sin i}{\sin r} = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin \frac{A}{2}}$$



Results

(1) Under minimum deviation, ray passes symmetrically through the prism.

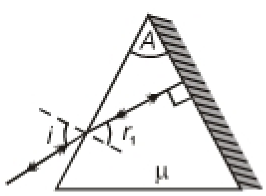
(2) If prism is isosceles or equilateral, refracted ray is parallel to base of prism under minimum deviation.

(3) If $A > 2C$ or $\mu > \text{cosec}\left(\frac{A}{2}\right)$, there will be no emergent light whatever may be the angle of incidence.

(4) $A = 2C$ is called limiting value of angle of prism.

(5) If $A < C$, total internal reflection at second face can never take place.

(6)



For incident ray to retrace its path after reflection from 2nd face.

$r_2 = 0$ $r_1 = A$

$\mu = \frac{\sin i}{\sin A}$

(7) Angle of deviation is maximum when angle of incidence = 90º.

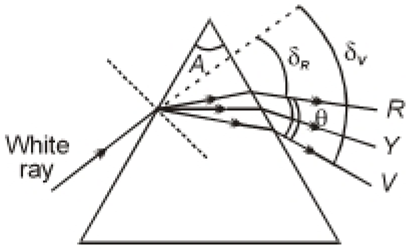
Dispersion

$\delta = (\mu - 1)A$

as $\lambda_V < \lambda_R$

$\Rightarrow \mu_V > \mu_R$

$\Rightarrow \delta_V < \delta_R$



θ = angular dispersion

$\theta = \delta_V - \delta_R$

$\theta = (\mu_V - \mu_R)A$

Dispersive power $\omega = \frac{\theta}{\delta} = \frac{(\mu_V - \mu_R)A}{(\mu - 1)A} = \frac{\mu_V - \mu_R}{\mu - 1} = \frac{d\mu}{\mu - 1}$

$d\mu$ = difference in refractive index

μ = mean refractive index = $\frac{\mu_V + \mu_R}{2} = \mu_Y$

Combination of thin prisms

(a) Dispersion without deviation:

$$\frac{A'}{A} = \frac{-(\mu - 1)}{(\mu' - 1)}$$

Net dispersion $\theta = (\mu - 1)A\,(\omega - \omega')$

(b) Deviation without dispersion (Achromatism)

$$\frac{A'}{A} = \frac{-(\mu_V - \mu_R)}{(\mu'_V - \mu'_R)}$$

Net deviation = $\delta\left(1 - \frac{\omega}{\omega'}\right)$

Scattering of Light

In 1817, Lord Rayleigh showed that the intensity of light scattered from fine particles (scatterer particle dimension 'a' comparable to wavelength λ of light) varies inversely as the fourth power of wavelength of light *i.e.*, $I \propto \frac{I}{\lambda^4}$. So blue colour of light scatters more compared to red light and that explains blue colour of sky in general and red colour at sunrises and sunsets. Large particles like dust and water droplets present in the atmosphere behave differently. For $a << \lambda$ one has $I \propto \frac{I}{\lambda^4}$. But for $a >> \lambda$ *i.e.*, large scattering objects (*e.g.*, raindrops, large dust or ice particles) this is not true; in fact all wavelengths are scattered nearly equally. Thus, clouds which have droplets of water with $a >> \lambda$ are generally white.

Optical Instruments

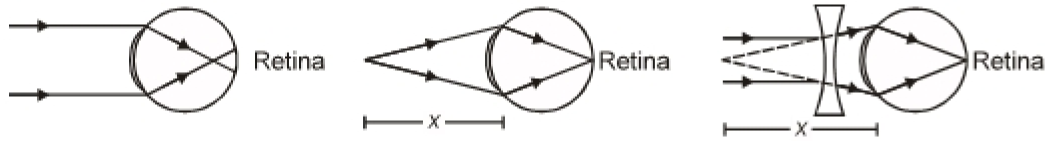
Human Eye

Human eye consists of a natural convex lens which forms real, inverted and diminished image on the retina. Ciliary muscles can change the focal length of the human eye. For a grown-up person the separation between the retina and the lens is about 2.5 cm, which is the image distance.

A normal eye can see upto maximum distance of infinity and the minimum distance of clear vision is about 25 cm. For seeing maximum distance of infinity, eye muscles are fully relaxed having maximum focal length and for seeing at minimum distance, muscles are strained having minimum focal length.

Some Common Defects

(A) Nearsightedness or Myopia : A person suffering from this defect cannot see a distant object but near objects are clearly seen. In this f_{max} is less than the distance from the lens to the retina and hence the image of a distant object is formed short of retina (see figure a). For remedy, a divergent lens is given to a myopic person (see figure c). This lens forms the image of a distant object at a distance x, which is maximum distance of clear vision.

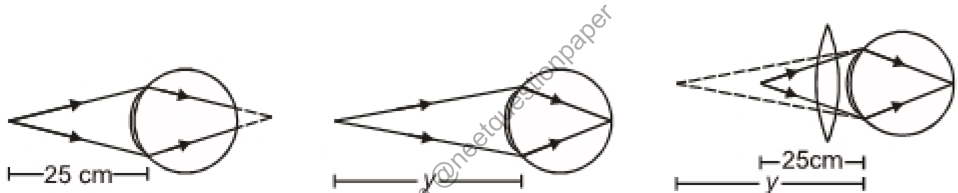


(a) (b) (c)

For a myopic eye far point is not infinity. Let it be a distance x. Then power of concave lens required is $P = \frac{1}{x}$ (–ve).

(B) Farsightedness or Hypermetropia : A person suffering from this defect cannot see a near object. (see figure (a)). For remedy, a convergent lens is used (see figure (c))

If y is the minimum distance upto which eye can clearly see, the converging lens should form the image of an object at distance y = 25 cm.



(a) (b) (c)

For hypermetropic eye near point is not 25 cm (D). It is at a larger distance say D′ (metre), then power of the convex lens is $P = \frac{1}{f} = -\frac{1}{D'} + \frac{1}{D} = 4 - \frac{1}{D'}$

(C) Presbyopia is a special type of hypermetropia where eye muscles are not able to focus image of a nearby object on the retina due to age factor (eye muscles have lost their elasticity). So, this defect is corrected by using a convex lens. When a person suffers from myopia as well as hypermetropia, bifocal lenses are used.

(D) Astigmatism : Person is not able to focus at horizontal and vertical lines simultaneously as focal length of eye lens is different in different directions. This defect occurs due to irregular shape of cornea or the imperfect spherical nature of the eye lens. This is corrected by using cylindrical lenses.

(1) Simple microscope / Magnifying glass : It uses a single convex lens of focal length f.

$m = \frac{-D}{u}$, where u is distance of object

(a) For relaxed eye, $u = -f$, image is formed at $\infty \Rightarrow m = \frac{D}{f} > 0$

(b) For strained eye, image is formed at $D \Rightarrow m = 1 + \frac{D}{f} > 0$

(2) Compound microscope : It uses two convex lens objective (f_o) and eyepiece (f_e)

u_0 = object distance from objective (u_0 is close to f_o)

v_0 = image distance from objective (close to length of tube)

$$m_0 = \frac{v_0}{u_0} \text{ (–ve)}$$

$$m_e = \frac{-D}{u_e}$$

Magnification for microscope,

$$m = m_0 \times m_e = -\frac{v_0}{u_0}\times\frac{D}{u_e}$$

(a) Relaxed eye : $m = \frac{v_0}{u_0}\times\frac{D}{f_e} = \frac{-L}{f_o}\left(\frac{D}{f_e}\right)$ ($\because$ $v_0 = L,\ u_0 = -f_o$) (Normal adjustment)

(b) Strained eye : $m = \frac{v_0}{u_0}\left(1+\frac{D}{f_e}\right) \approx -\frac{L}{f_o}\left(1+\frac{D}{f_e}\right)$ (Distinct adjustment)

(3) Astronomical Telescope : f_o is focal length of objective and f_e is focal length of eye-piece.

$m = m_0 \times m_e$ here $m_0 < 0$, $m_e > 0$., $m < 0$

(a) For relaxed eye *i.e.*, normal adjustment. $m = -\frac{f_o}{f_e}$

Length of tube $L = f_o + f_e$

(b) For strained eye : $m = \frac{-f_o}{f_e}\left(1+\frac{f_e}{D}\right)$; length of tube $L < f_o + f_e$

(4) Newtonian (reflective type) telescope : It uses a concave mirror as objective and convex lens as eye piece.

$$m = \frac{-f_o}{f_e} \text{ (negative)}$$

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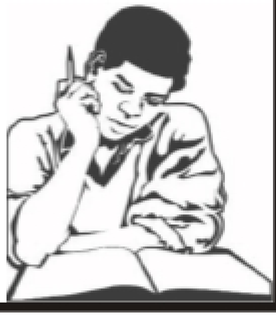


Try Yourself

SECTION - A

Objective Type Questions

1. A clock having marks instead of numbers on its dial appears to indicate 4 : 35 when viewed through a plane mirror facing it. The correct time is

(1) 8.25 (2) 7.25

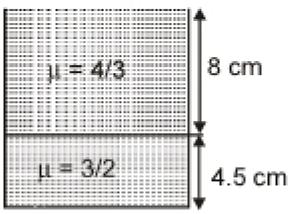
(3) 7.20 (4) 5.40

2. The minimum distance between a real object and its real image for a convex lens is [*f*-focal length]

(1) 4*f* (2) 2*f*

(3) *f* (4) Zero

3. A coin is placed at the bottom of a tank which is filled by two liquid layers as shown. The apparent depth of coin from top surface for normal viewing is



(1) 9 cm (2) 10 cm

(3) 8 cm (4) 6 cm

4. For a given light ray, critical angle is more in case of which of the following medium pair?

(1) Glass-water (2) Water-air

(3) Glass-air (4) Same for all

5. A thin prism P_1 with angle 4° and made from glass of refractive index 1.54 is combined with another prism P_2 made from glass of refractive index 1.72 to produce dispersion without deviation. The angle of prism of P_2 is

(1) 3° (2) 4°

(3) 2° (4) 5°

6. A plano-convex lens behaves as a concave mirror of focal length 30 cm when its plane surface is silvered and as a concave mirror of focal length 10 cm when its curved surface is silvered. The refractive index of the material of lens is

(1) 1.5 (2) $\sqrt{2}$

(3) $\sqrt{3}$ (4) 2

7. A lens of refractive index $\frac{3}{2}$ has a power of 5 D in air. Then its power when completely submerged in water of refractive index $\frac{4}{3}$ is

(1) 1.25 D (2) 2.5 D

(3) 10 D (4) 20 D

8. An object and a screen are fixed at a distance 50 cm apart. When a converging lens is placed at two positions *A* and *B* between the object and screen, the image of object is found on screen. If the distance between *A* and *B* is 10 cm, then focal length of lens is

(1) 12 cm (2) 10 cm

(3) 8 cm (4) 6 cm

9. An achromatic convergent doublet of two lenses in contact has a power +2 D. The convex lens has a power +5 D. The ratio of dispersive powers of the convergent and divergent lens is

(1) 2 : 5 (2) 3 : 5

(3) 5 : 2 (4) 5 : 3

10. A person can see objects clearly when they are at a distance lesser than 2 m from him. The power of lens he must use to see a star clearly is

(1) +0.5 D (2) –0.5 D

(3) +2 D (4) –2 D

11. A compound microscope has magnifying power –30. The focal length of its eye piece is 5 cm. Assuming the final image to be at 25 cm from eye piece, the magnification produced by objective is

(1) –6 (2) +6

(3) +5 (4) –5

12. A terrestial telescope in normal adjustment has an objective of focal length 180 cm and has an eye piece of focal length 6 cm. The erecting lens has a focal length 3.5 cm. The length of telescope is

(1) 193 cm (2) 186 cm

(3) 189.5 cm (4) 200 cm

13. Analyse the following two statements (a) and (b)

(a) Angular dispersion is produced by a prism and it is not so in case of a glass slab while both of them are made of same material of glass

(b) A prism produces angular deviation while a glass slab doesn't produce angular deviation

(1) Both (a) & (b) are true

(2) Only (a) is true

(3) Only (b) is true

(4) Both (a) & (b) are false

14. A man approaches a plane mirror with a velocity v in a direction making an angle α with the normal to the mirror. The relative velocity of image of man with respect to him is

(1) $2v$ (2) $2v\cos\alpha$

(3) $2v\sin\alpha$ (4) $\sqrt{2}v$

15. The image of a real object in a convex mirror is 4 cm from the mirror. If the mirror has a radius of curvature of 24 cm, the magnification is

(1) 1 (2) $\frac{1}{3}$

(3) $\frac{3}{4}$ (4) $\frac{2}{3}$

16. A concave mirror can never form the image of a real object as

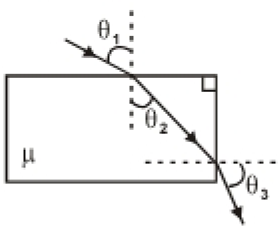
(1) Real and diminished

(2) Real and enlarged

(3) Virtual and enlarged

(4) Virtual and diminished

17. In the figure shown below



(1) $\frac{\sin\theta_1}{\sin\theta_3} = \tan\theta_2$ (2) $\sin\theta_3 = \sin\theta_1\tan\theta_2$

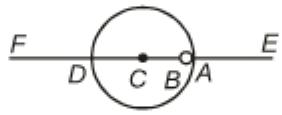
(3) $\tan\theta_2 = \sin\theta_1\sin\theta_3$ (4) $\theta_3 = \theta_1$

18. A prism with angle $A = 60°$ produces a minimum deviation 30°. The refractive index of prism material is

(1) $\sqrt{2}$ (2) $\sqrt{3}$

(3) 1 : 2 (4) 2

19. In a spherical glass paper - weight of radius 2 cm and $\mu = 1.5$, there is an air bubble (B) at a distance 1 cm from the centre as shown. Where will the bubble appear as seen from F?



(1) At C (2) At D

(3) At A (4) Between A & C

20. An object and screen is fixed at a distance D apart. A thin converging lens of focal length f is placed in two positions between them to get the image on screen. If the gap between two positions is x and the magnification for two positions is m_1 and m_2, then

(1) $f = \frac{x}{m_1 - m_2}$ (2) $f = \frac{x}{m_1 + m_2}$

(3) $f = \frac{x(m_1 + m_2)}{m_1 m_2}$ (4) $f = \frac{x(m_1 - m_2)}{m_1 m_2}$

21. A far-sighted person can not focus distinctly objects closer than 150 cm. The lens that will permit him to read from a distance 25 cm will have a focal length

(1) – 60 cm (2) + 60 cm

(3) – 30 cm (4) + 30 cm

22. The focal lengths of the objective and eyepiece of a compound microscope are 2 cm and 3 cm respectively. The distance between the objective and eyepiece is 15 cm. The final image formed by eyepiece is at infinity. The distance of image produced by objective, from the objective lens is

(1) 3 cm (2) 2.4 cm

(3) 8.6 cm (4) 12 cm

23. If the objective and eyepiece of an astronomical telescope are interchanged, then the initial magnifying power (M) under normal adjustment, will now become

(1) Remain same (2) Doubled

(3) Halfed (4) Inversed

24. "From the surface of moon, one can see the stars even when the sun is shining brightly while one can not do so from the surface of earth". This phenomenon is related with

(1) Scattering of light (2) Dispersion of light
(3) Polarisation of light (4) Diffraction of light

SECTION - B

Previous Years Questions

1. The magnifying power of a telescope is 9. When it is adjusted for parallel rays the distance between the objective and eyepiece is 20 cm. The focal length of lenses are **[AIPMT 2012]**

(1) 18 cm, 2 cm (2) 11 cm, 9 cm
(3) 10 cm, 10 cm (4) 15 cm, 5 cm

2. A ray of light is incident at an angle of incidence, *i*, on one face of a prism of angle *A* (assumed to be small) and emerges normally from the opposite face. If the refractive index of the prism is μ, the angle of incidence *i*, is nearly equal to **[AIPMT 2012]**

(1) $\frac{A}{\mu}$ (2) $\frac{A}{2\mu}$
(3) μA (4) $\frac{\mu A}{2}$

3. A concave mirror of focal length 'f_1' is placed at a distance of '*d*' from a convex lens of focal length 'f_2'. A beam of light coming from infinity and falling on this convex lens - concave mirror combination returns to infinity. The distance *d* must equal **[AIPMT 2012]**

(1) $2f_1 + f_2$ (2) $-2f_1 + f_2$
(3) $f_1 + f_2$ (4) $-f_1 + f_2$

4. When a biconvex lens of glass having refractive index 1.47 is dipped in a liquid, it acts as a plane sheet of glass. This implies that the liquid must have refractive index. **[AIPMT 2012]**

(1) Greater than that of glass
(2) Less than that of glass
(3) Equal to that of glass
(4) Less than one

5. A plano-convex lens fits exactly into a plano concave lens. Their plane surfaces are parallel to each other. If lenses are made of different materials of refractive indices μ_1 and μ_2 and *R* is the radius of curvature of the curved surface of the lenses, then the focal length of the combination is **[NEET-2013]**

(1) $\frac{R}{(2\mu_1 - \mu_2)}$ (2) $\frac{R}{(\mu_1 - \mu_2)}$
(3) $\frac{2R}{(\mu_2 - \mu_1)}$ (4) $\frac{R}{2(\mu_1 + \mu_2)}$

6. For a normal eye, the cornea of eye provides a converging power of 40 D and the least converging power of the eye lens behind the cornea is 20 D. Using this information, the distance between the retina and the cornea - eye lens can be estimated to be **[NEET-2013]**

(1) 2.5 cm
(2) 1.67 cm
(3) 1.5 cm
(4) 5 cm

7. If the focal length of objective lens is increased then magnifying power of **[AIPMT 2014]**

(1) Microscope will increase but that of telescope decrease
(2) Microscope and telescope both will increase
(3) Microscope and telescope both will decrease
(4) Microscope will decrease but that of telescope will increase

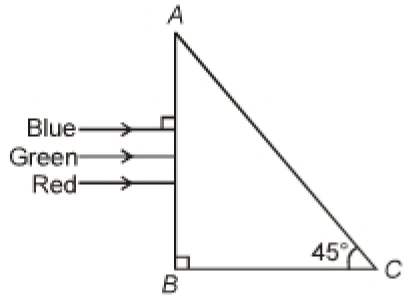
8. The angle of a prism is *A*. One of its refracting surfaces is silvered. Light rays falling at an angle of incidence 2*A* on the first surface returns back through the same path after suffering reflection at the silvered surface. The refractive index μ, of the prism is **[AIPMT 2014]**

(1) 2sin *A* (2) 2 cos *A*
(3) $\frac{1}{2}\cos A$ (4) tan *A*

9. In an astronomical telescope in normal adjustment a straight black line of length *L* is drawn on inside part of objective lens. The eyepiece forms a real image of this line. The length of this image is *I*. The magnification of the telescope is **[Re-AIPMT-2015]**

(1) $\frac{L}{I}$ (2) $\frac{L}{I}+1$
(3) $\frac{L}{I}-1$ (4) $\frac{L+I}{L-I}$

10. A beam of light consisting of red, green and blue colours is incident on a right angled prism. The refractive index of the material of the prism for the above red, green and blue wavelengths are 1.39, 1.44 and 1.47, respectively



The prism will **[Re-AIPMT-2015]**

(1) Separate the red colour part from the green and blue colours

(2) Separate the blue colour part from the red and green colours

(3) Separate all the three colours from one another

(4) Not separate the three colours at all

11. The refracting angle of a prism is *A*, and refractive index of the material of the prism is cot(*A*/2). The angle of minimum deviation is **[AIPMT-2015]**

(1) 180° + 2*A* (2) 180° – 3*A*

(3) 180° – 2*A* (4) 90° – *A*

12. Two identical thin plano-convex glass lenses (refractive index 1.5) each having radius of curvature of 20 cm are placed with their convex surfaces in contact at the centre. The intervening space is filled with oil of refractive index 1.7. The focal length of the combination is **[AIPMT-2015]**

(1) 50 cm (2) – 20 cm

(3) – 25 cm (4) – 50 cm

13. Match the corresponding entries of column-1 with column-2. [Where *m* is the magnification produced by the mirror]

Column-1	**Column-2**
(A) $m = -2$	(a) Convex mirror
(B) $m = -\frac{1}{2}$	(b) Concave mirror
(C) $m = +2$	(c) Real image
(D) $m = +\frac{1}{2}$	(d) Virtual image

[NEET-2016]

(1) A → c and d; B → b and d; C → b and c ; D → a and d

(2) A → b and c; B → b and c; C → b and d; D → a and d

(3) A → a and c; B → a and d; C → a and b; D → c and d

(4) A → a and d; B → b and c; C → b and d; D → b and c

14. A astronomical telescope has objective and eyepiece of focal length 40 cm and 4 cm respectively. To view an object 200 cm away from the objective, the lenses must be separated by a distance **[NEET-2016]**

(1) 54.0 cm (2) 37.3 cm

(3) 46.0 cm (4) 50.0 cm

15. The angle of incidence for a ray of light at a refracting surface of a prism is 45°. The angle of prism is 60°. If the ray suffers minimum deviation through the prism, the angle of minimum deviation and refractive index of the material of the prism respectively, are **[NEET-2016]**

(1) $30°; \frac{1}{\sqrt{2}}$ (2) $45°; \frac{1}{\sqrt{2}}$

(3) $30°; \sqrt{2}$ (4) $45°; \sqrt{2}$

16. Two identical glass (μ_g = 3/2) equiconvex lenses of focal length *f* each are kept in contact. The space between the two lenses is filled with water (μ_w = 4/3). The focal length of the combination is

[NEET (Phase-2) 2016]

(1) $f/3$ (2) f

(3) $4f/3$ (4) $3f/4$

17. An air bubble in a glass slab with refractive index 1.5 (near normal incidence) is 5 cm deep when viewed from one surface and 3 cm deep when viewed from the opposite face. The thickness (in cm) of the slab is **[NEET (Phase-2) 2016]**

(1) 8 (2) 10

(3) 12 (4) 16

18. A person can see clearly objects only when they lie between 50 cm and 400 cm from his eyes. In order to increase the maximum distance of distinct vision to infinity, the type and power of the correcting lens, the person has to use, will be

[NEET (Phase-2) 2016]

(1) Convex, +2.25 diopter

(2) Concave, –0.25 diopter

(3) Concave, –0.2 diopter

(4) Convex, +0.15 diopter

19. A beam of light from a source L is incident normally on a plane mirror fixed at a certain distance x from the source. The beam is reflected back as a spot on a scale placed just above the source L. When the mirror is rotated through a small angle θ, the spot of the light is found to move through a distance y on the scale. The angle θ is given by **[NEET - 2017]**

(1) $\frac{y}{2x}$ (2) $\frac{y}{x}$

(3) $\frac{x}{2y}$ (4) $\frac{x}{y}$

20. A thin prism having refracting angle 10° is made of glass of refractive index 1.42. This prism is combined with another thin prism of glass of refractive index 1.7. This combination produces dispersion without deviation. The refracting angle of second prism should be **[NEET - 2017]**

(1) 4° (2) 6°

(3) 8° (4) 10°

21. An object is placed at a distance of 40 cm from a concave mirror of focal length 15 cm. If the object is displaced through a distance of 20 cm towards the mirror, the displacement of the image will be **[NEET - 2018]**

(1) 30 cm away from the mirror

(2) 36 cm away from the mirror

(3) 36 cm towards the mirror

(4) 30 cm towards the mirror

22. An astronomical refracting telescope will have large angular magnification and high angular resolution, when it has an objective lens of **[NEET - 2018]**

(1) Small focal length and large diameter

(2) Large focal length and small diameter

(3) Small focal length and small diameter

(4) Large focal length and large diameter

23. The refractive index of the material of a prism is $\sqrt{2}$ and the angle of the prism is 30°. One of the two refracting surfaces of the prism is made a mirror inwards, by silver coating. A beam of monochromatic light entering the prism from the other face will retrace its path (after reflection from the silvered surface) if its angle of incidence on the prism is **[NEET - 2018]**

(1) 60° (2) 45°

(3) Zero (4) 30°

24. Two similar thin equi-convex lenses, of focal length f each, are kept coaxially in contact with each other such that the focal length of the combination is F_1. When the space between the two lenses is filled with glycerine (which has the same refractive index (μ = 1.5) as that of glass then the equivalent focal length is F_2. The ratio $F_1 : F_2$ will be **[NEET - 2019]**

(1) 2 : 1 (2) 1 : 2

(3) 2 : 3 (4) 3 : 4

25. Pick the wrong answer in the context with rainbow. **[NEET - 2019]**

(1) When the light rays undergo two internal reflections in a water drop, a secondary rainbow is formed

(2) The order of colours is reversed in the secondary rainbow

(3) An observer can see a rainbow when his front is towards the sun

(4) Rainbow is a combined effect of dispersion, refraction and reflection of sunlight

26. In total internal reflection when the angle of incidence is equal to the critical angle for the pair of media in contact, what will be angle of refraction? **[NEET - 2019]**

(1) 180°

(2) 0°

(3) Equal to angle of incidence

(4) 90°

27. An equiconvex lens has power P. It is cut into two symmetrical halves by a plane containing the principal axis. The power of one part will be **[NEET-2019 (Odisha)]**

(1) P (2) 0

(3) $\frac{P}{2}$ (4) $\frac{P}{4}$

28. A double convex lens has focal length 25 cm. The radius of curvature of one of the surfaces is double of the other. Find the radii if the refractive index of the material of the lens is 1.5. **[NEET-2019 (Odisha)]**

(1) 50 cm, 100 cm (2) 100 cm, 50 cm

(3) 25 cm, 50 cm (4) 18.75 cm, 37.5 cm

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Chapter 10

Wave Optics

Sub-topics *Wavefront and Huygens' principle, reflection and refraction of plane wave at a plane surface using wavefronts. Proof of laws of reflection and refraction using Huygens' principle. Interference, Young's double hole experiment and expression for fringe width, coherent sources and sustained interference of light. Diffraction due to a single slit, width of central maximum. Resolving power of microscopes and astronomical telescopes. Polarisation, plane polarized light; Brewster's law, uses of plane polarized light and Polaroids.*

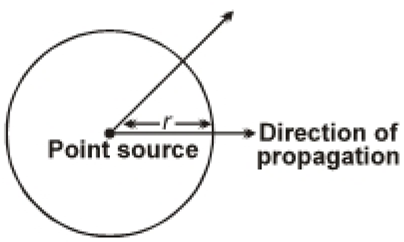
Wave Front

It is a continuous locus of all those points which are vibrating in same phase.

1. **Spherical wave front**

   Amplitude $\propto \frac{1}{r}$

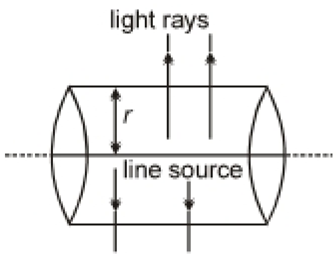
   Intensity $\propto \frac{1}{r^2}$



2. **Cylindrical wave front**

   Amplitude $\propto \frac{1}{\sqrt{r}}$

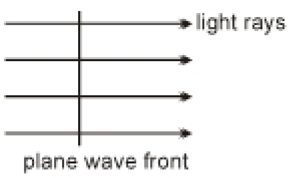
   Intensity $\propto \frac{1}{r}$



3. **Plane wave front**

   Amplitude = constant

   Intensity = constant



Source at infinity

Huygens' Principle

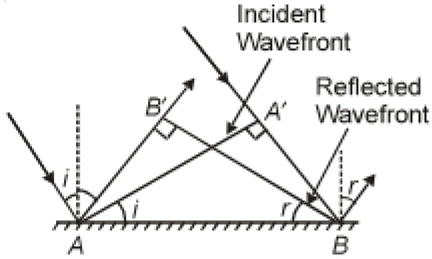
(1) Rays are straight lines normal to the wavefronts only in a homogeneous isotropic material (a material with the same properties in all regions and in all directions).

(2) At a boundary surface between two materials, the wave speed and the direction of a ray may change but the ray segments in a particular homogeneous isotropic medium will be always straight lines.

(3) The spacing between two wavefronts in an isotropic homogeneous medium is constant, and hence the time for light to travel from one wavefront to another is same along any ray.

Reflection and Refraction

Reflection : Figure shows a plane incident wavefront AA' with the angle of incidence i. After time t, the new wavefront is BB'. Clearly, the angle of reflection is $\angle ABB' = r$ (say). $A'B = AB' = vt$, where v is the wave speed.



From, the geometry of the figure, the triangles ABB' and BAA' are congruent. Hence, $\angle ABB' = \angle BAA'$

or, $i = r$ ...(law of reflection)

Refraction : Figure shows a plane incident wave AA' falling on the boundary surface SS' between two transparent materials of refractive indices μ_1 and μ_2 respectively. The wave speeds in the two materials are v_1 and v_2 respectively. After a time t, the refracted wavefront is BB'.

The angle of incidence is $\angle A'AB = i$ and the angle of refraction is $\angle ABB' = r$.

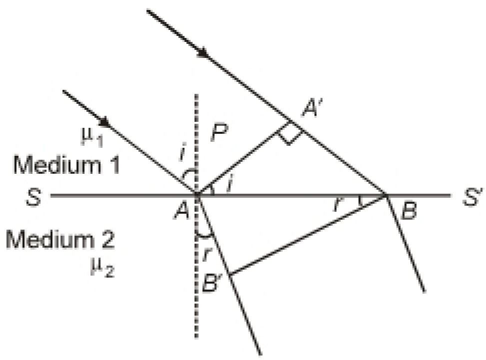
In the triangle $A'AB$,

$$\sin i = \frac{v_1 t}{AB}$$

In the ABB'

$$\sin r = \frac{v_2 t}{AB}$$

$$\therefore \quad \frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \frac{\mu_2}{\mu_1} \quad \text{...[Snell's law]}$$



Interference

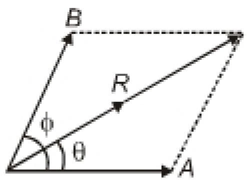
Superposition of Waves

$y_1 = A \sin \omega t$

$y_2 = B \sin (\omega t + \phi)$

$y = y_1 + y_2 = R \sin (\omega t + \theta)$

Where $R = \sqrt{A^2 + B^2 + 2AB\cos\phi}$



Intensity ∝ (Amp)^2 ∴ $I_1 \propto A^2$, $I_2 \propto B^2$, $I \propto R^2$

as $R^2 = A^2 + B^2 + 2AB\cos\phi \Rightarrow I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$

(1) When cos φ = 0 or φ = 2nπ or Δx = nλ (path difference)

$R_{max} = A + B$,

$$I_{max} = \left(\sqrt{I_1} + \sqrt{I_2}\right)^2 = (A+B)^2$$

(2) When cos φ = – 1

or $\phi = (2n - 1)\pi$

or $\Delta x = (2n-1)\dfrac{\lambda}{2}$

$$R_{min} = A - B,\ I_{min} = (\sqrt{I_1} - \sqrt{I_2})^2 = (A-B)^2 \Rightarrow \frac{R_{max}}{R_{min}} = \frac{A+B}{A-B}$$

$$\frac{I_{max}}{I_{min}} = \left(\frac{\sqrt{I_1}+\sqrt{I_2}}{\sqrt{I_1}-\sqrt{I_2}}\right)^2 = \left(\frac{\sqrt{\beta}+1}{\sqrt{\beta}-1}\right)^2$$

When $\beta = \dfrac{I_1}{I_2}$

(3) Fringe visibility = $\dfrac{I_{max} - I_{min}}{I_{max} + I_{min}}$

(4) When $I_1 = I_2 = I_0 \Rightarrow I_{max} = 4I_0$, $I_{min} = 0$

Fringe visibility = 1

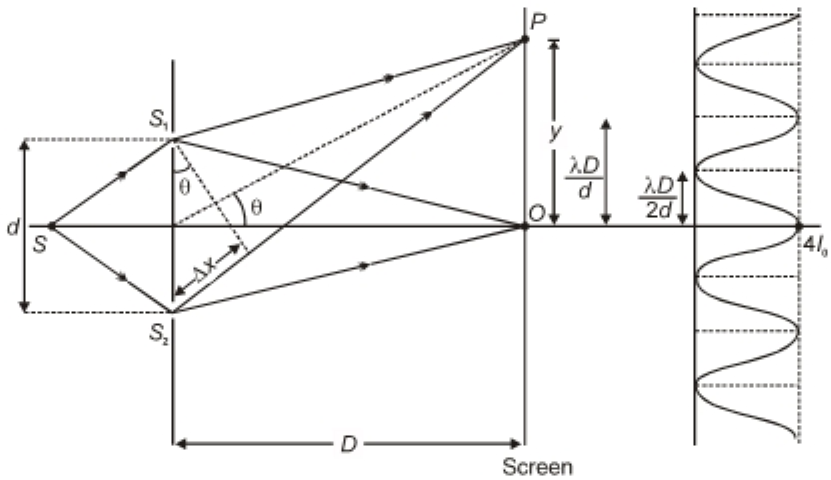
Also, in general $I = 4I_0\cos^2\dfrac{\phi}{2} = I_{max}\cos^2\dfrac{\phi}{2}$

(5) For superposition of incoherent waves, resultant intensity is

$I = I_1 + I_2$ or $I = 2I_0$

Interference : Phenomenon of redistribution of energy on account of superposition of waves.

Young's Double Slit Experiment



For maxima $\Delta x = n\lambda \Rightarrow y = n\dfrac{\lambda D}{d}$ (n = 0, 1, 2, . . .)

For minima $\Delta x = (2n-1)\frac{\lambda}{2} \Rightarrow y = \frac{(2n-1)\lambda D}{2d}$ $(n = 1, 2, ...)$

At 'O' $n = 0$, central maxima. $I_{max} = 4I_0$ where I_0 is intensity due to single slit.

At point P, $I = 4\, I_0 \cos^2\frac{\phi}{2}$, where $\varphi = \frac{2\pi}{\lambda}\cdot\Delta x$, $\Delta x = \frac{2\pi d}{\lambda D}y$.

Expression for Fringe Width

$\beta = \frac{\lambda D}{d}$ is the distance between consecutive maximas = distance between consecutive minimas = fringe width.

Note : *(1) Distance between n^{th} maxima and m^{th} minima*

(a) When they lie on same side of O is $n\frac{\lambda D}{d} - (2m-1)\frac{\lambda D}{2d}$

(b) When they lie on opposite side of O is $\frac{n\lambda D}{d} + \frac{(2m-1)\lambda D}{2d}$

(2) When YDSE arrangement is kept in a medium of refractive index 'μ', $\beta' = \frac{\beta}{\mu}$ *i.e.,* $\beta' < \beta$*. Intensity remains same. On changing medium fringes will shift towards or away from the centre.*

(3) When slits do not emit light of same intensity (say one of the slit is covered slightly), then

(a) Dark fringes will not be exactly dark, they become slightly brighter

(b) Bright fringes become less bright.

(4) When white light is used in place of monochromatic light,

(a) Central fringe will be white, as all the wavelengths are present

(b) All other fringes will be colored

(c) First maxima formed after central maxima will be of violet color but red colour is seen after central maximum.

(d) Two wavelengths may have maxima at the same position given by $n_1\lambda_1 = n_2\lambda_2$*, where* n_1^{th} *maxima of* λ_1 *coincides with* n_2^{th} *maxima of* λ_2*.*

(5) If one of the slits (say S_1) is covered with a small film of thickness 't' and refractive index 'μ' then

(a) The rays from S_1 and S_2 will have an initial path difference $(\mu - 1)t$.

(b) At 'O', path difference is not zero. It is $(\mu - 1)t$.

(c) A maxima may be formed at 'O' if $(\mu - 1)t = n\lambda$ *(no change will be observed on the fringe pattern)*

(d) A minima may be formed at 'O' if $(\mu-1)t = (2n-1)\frac{\lambda}{2}$

(e) The point where path difference is zero will shift upwards (toward S_1). This will be called central maxima.

(f) The distance moved by central maxima and the whole fringe pattern = $\frac{(\mu-1)tD}{d} = (\mu-1)t\frac{\beta}{\lambda}$

(g) Number of fringes shifted up $= \frac{(\mu-1)t}{\lambda}$

(h) Fringe width will remain same.

(6) If the source 'S' displaced upwards from centre, central maxima shifts downward.

Coherent sources and sustained interference of light

Sources are coherent, when the phase difference between light from S_1 and S_2 is constant.

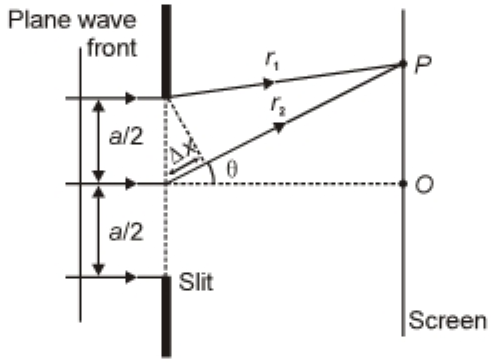
(a) Direct sunlight is partially coherent, if the slits are very close.

(b) Two independent monochromatic light sources cannot be coherent.

Diffraction

Flaring of light as it emerges from a narrow slit.

Diffraction due to a single slit



(1) $\Delta x = \frac{a}{2}\sin\theta$

(2) For '*O*' waves from all points in the slit travel about the same distance and are in phase

(3) At *P*, rays r_1 and r_2 have a phase difference $\Delta x = \frac{a}{2}\sin\theta$

(4) When $\frac{a}{2}\sin\theta = \frac{\lambda}{2}$, there will be destructive interference.

$\therefore$ when $a\sin\theta = \lambda$, first minima will be formed at *P*.

(5) In general $a\sin\theta = n\lambda$ is position of n^{th} minima.

(6) Angular position of first minima $\theta = \sin^{-1}\left(\frac{\lambda}{a}\right)$

(7) Angular spread of central maxima is 2θ.

(8) When $\lambda > a \Rightarrow \sin\theta > 1$ which is not possible

$\therefore$ Diffraction can not be observed.

(9) $\lambda << a$, then $\sin\theta \approx \theta = \frac{\lambda}{a}$ (in radians)

Width of Central Maxima

Width of central maxima = $\frac{2\lambda D}{a}$

Width of other fringes = $\frac{\lambda D}{a}$

If I_0 is the intensity of central maxima, then intensity of n^{th} maxima is $I_n = \frac{4I_0}{(2n+1)^2\pi^2}$

$I_0 : I_1 : I_2 = 1 : \frac{1}{22.5} : \frac{1}{62.5}$

$I_0 : I_1 : I_2 = 1 : 0.045 : 0: 016.$

Resolving Power

Diffraction by a circular aperture or a lens with diameter '*d*' produces a central maximum and concentric maxima and minima, with the first minimum at angle θ given by $\sin\theta = 1.22\frac{\lambda}{d}$

Two objects can be resolved by an optical instrument when the central maximum of diffraction pattern of one source is centered on the first minimum of the diffraction pattern of the other.

Resolving power of a telescope : $R.P. = \frac{d}{1.22\lambda} = \frac{1}{\theta}$

d = diameter of objective *i.e.*, aperture

λ = wavelength of light

θ = minimum angular separation between the objects (limit of resolution)

Resolving power of microscope : $R.P. = \frac{2\mu\sin\theta}{1.22\lambda}$, ('$\mu\sin\theta$' is the numerical aperture)

μ = Refractive index of medium between object and objective

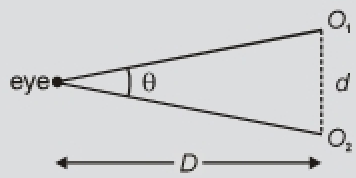
θ = semi-vertex angle of cone of light from the object.

Note : *Limit of resolution of a normal human eye.* $R.P. = 1' = \left(\frac{1}{60}\right)^\circ$

$R.P = \frac{1}{60} \times \frac{\pi}{180}$ rad

$\theta = \frac{d}{D} \geq$ *limit of resolution for the objects to be resolved*

$\Rightarrow \frac{d}{D} > \frac{1}{60} \times \frac{\pi}{180}$, *i.e.,* $\frac{d}{D} > 3 \times 10^{-4}$



Polarisation

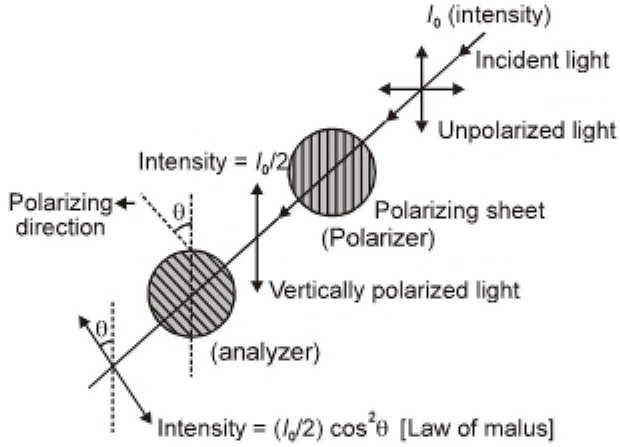
(1) Unpolarized light consists of waves with randomly directed electric fields.

(2) The plane containing the Electric field vector is called the plane of oscillation

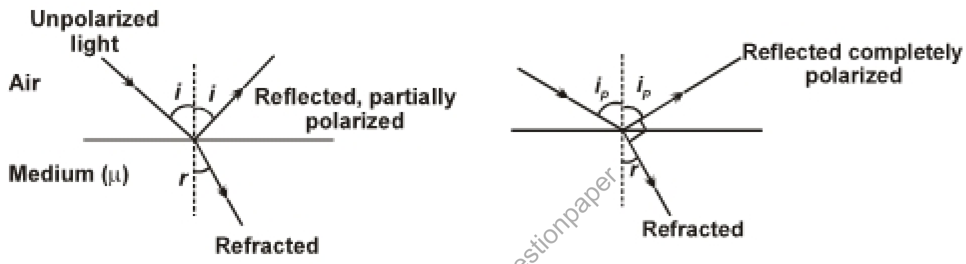
Plane polarised light

A plane polarized electromagnetic wave has electric field vector only in one plane.

Circularly polarized light is a superposition of two plane electromagnetic waves of same amplitude, having their plane of oscillations perpendicular to each other and differing in phase by $\frac{\pi}{2}$.



Brewster's Law



(1) Reflected light is partially polarised.

(2) When $i = i_p$ (polarizing angle), reflected light's completely polarised, i_p is also called Brewster's angle.

(3) When reflected light is completely polarized, reflected and refracted light are perpendicular to each other.

(4) This was found experimentally by **Sir David Brewster**.

At this situation $i_p + r = 90°$

$\mu = \tan i_p$. This is called Brewster's law.

Uses of Plane Polarised Light and Polaroids

- Dermatologic surgeons estimate the size (area) of skin cancers with the help of polarization of light.
- In liquid crystals "LCD" (as in mobile phones, calculator etc.) letters are formed through polarization.
- VHF (very high frequency) television antennas in England are oriented vertically, but those in North America are horizontal. (This is just a matter of convention or the ego problems of the two countries). That means in England the transmitted VHF waves are vertically polarized and that in North America it is horizontally polarized.
- Bees use the polarization of sky light in navigating to and from their hives.
- The Vikings, used polarization of sunlight to navigate across the North sea when the daytime sun was below the horizon (because of the high latitude of the North sea). These early seafarers had discovered certain crystals (now called **cordierite**) that changed color when rotated in polarized light. By looking at the sky through such a crystal while rotating it about their line of sight, they could locate the hidden sun and thus determine which way was south.

- When an object is seen through calcite, quartz, or tourmaline crystals, we usually see two images of an object and if the crystal is rotated, one image rotates around the other.
- In CD or DVD player, polarized laser beam acts as a needle for producing sound.

Polaroid Sunglasses

Polarization by reflection is a common phenomenon. Sunlight reflected from water, glass, or snow is partially polarized. If the surface is horizontal, the electric field vector of the reflected light has a strong horizontal component. Sunglasses made of polarizing material reduce the glare, which is the reflected light. The transmission axes of the lenses are oriented vertically to absorb the strong horizontal component of the reflected light. Because the reflected light is mostly polarized, most of the glare can be eliminated without removing most of the normal light.

❑ ❑ ❑

Try Yourself

SECTION - A

Objective Type Questions

1. One of the slits of Young's double slit experiment is covered with a semitransparent paper. Then in interference pattern

   (1) Fringe width remains unchanged

   (2) Fringe width increases

   (3) Fringe width decreases

   (4) Fringes disappear

2. Two coherent sources of intensity *I* and 4*I* as used in an interference experiment. If path difference between them at a point on the screen is $\frac{\lambda}{4}$ (λ – wavelength of light), then intensity at that point is

   (1) 5*I* (2) 9*I*

   (3) *I* (4) Zero

3. In Young's double slit experiment, fringes of 0.1 mm width are obtained on a screen using light of λ = 4000Å. On replacing the source by λ = 6000Å and moving the screen to twice the distance earlier from slits, the fringe width becomes

   (1) 0.3 mm (2) 0.05 mm

   (3) 0.2 mm (4) 0.025 mm

4. On introducing a thin sheet of mica (thickness 8×10^{-5} cm) in the path of one of beams in a Young's double slit experiment, the central fringe is shifted to a distance equal to the spacing between susessive bright fringes. If wave length of light is 6×10^{-5} cm, the refractive index of mica is

   (1) 1.75 (2) 2

   (3) 2.5 (4) 1.5

5. The ratio of intensities of 1st and 2nd subsidiary maxima in a diffraction pattern obtained by single slit is

   (1) $\frac{5}{3}$ (2) $\frac{10}{3}$

   (3) $\frac{25}{9}$ (4) $\frac{7}{5}$

6. Unpolarised light of intensity 32 unit passes through three polaroids such that transmission axis of last polaroid is crossed with the first. If the intensity of emerging light is 3 unit, the angle between the transmission axis of first two polaroids is

   (1) 45° (2) 90°

   (3) 30° (4) 0°

7. If Young's double slit experiment is observed in air first and then it is repeated in water, then in interference pattern

   (1) Fringe width is more in air than in water

   (2) Fringe width is more in water than in air

   (3) Fringe width is same for air and water

   (4) In water, fringe pattern disappears

8. In a Young's double slit experiment with monochromatic light, fringes are obtained on a screen placed at a certain distance from the plane of slits. If the screen is moved by 5×10^{-2} m towards the slits, the change in fringe width is 3×10^{-5} m. If the distance between slits is 10^{-3} m, the wavelength of light used is

   (1) 6000 Å

   (2) 8000 Å

   (3) 10000 Å

   (4) 5000 Å

9. In a diffraction pattern obtained by single slit diffraction experiment, the ratio of width of principal maxima to any secondary maxima is

(1) 1 : 1

(2) 1.5 : 1

(3) 2 : 1

(4) 4 : 1

10. A bichromatic light consisting of wavelength 5000Å and 6000Å is used to obtain interference pattern in Young's double slit arrangement. If distance between slits is 1 mm and the distance between plane of slits and screen is 100 cm, then the least distance from the central maximum where bright fringes due to both the wavelength coincide is

(1) 0.3 cm

(2) 0.2 cm

(3) 0.1 cm

(4) 0.4 cm

11. The phenomenon of 'polarisation' is a sure proof of

(1) Wave nature of light

(2) Particle nature of light

(3) Transverse nature of light

(4) All of these

12. In Young's double slit experiment, the two slits give light of intensity I_0. The intensity on the screen at a distance $\beta/4$ from centre is (β is fringe width)

(1) I_0 (2) $4I_0$

(3) $2I_0$ (4) Zero

13. A double-slit arrangement produces interference fringes for sodium light (λ = 589 nm) that have an angular separation of 3.50×10^{-3} rad. The wavelength for which the angular separation be 10% longer is

(1) 648 nm

(2) 589 nm

(3) 59 nm

(4) 0.059 nm

14. In a single slit diffraction pattern, red light of λ = 650 nm is used and first minimum is found to lie at θ = 15°. The slit width '*a*' is

(1) 25 μm (2) 0.25 μm

(3) 0.25 mm (4) 2.5 μm

15. Resolving power of a microscope is maximum under

(1) White light (2) Red light

(3) Blue light (4) Violet light

16. An unpolarised light in incident on a polariser. The intensity in the transmitted light is *I*. If the polariser is rotated about the incident ray in a plane perpendicular to incident ray through 45°, then intensity in the transmitted light is

(1) I

(2) $\frac{I}{2}$

(3) $\frac{I}{4}$

(4) Zero

17. Resolving limit of human eye is

(1) $\frac{1}{2}'$ (2) 1′

(3) 2′ (4) $1\frac{1}{2}'$

18. Two sources are said to be coherent, if they have

(1) Same frequency

(2) Same wavelength

(3) Constant phase difference at a point

(4) All of these

19. Huygen's principle can explain

(1) Reflection and refraction only

(2) Interference only

(3) Diffraction only

(4) All of these

20. Law of Malus can be applicable to
    (1) Polariser only
    (2) Analyser only
    (3) Both (1) & (2)
    (4) Neither (1) nor (2)

SECTION - B

Previous Years Questions

1. In Young's double slit experiment, the slits are 2 mm apart and are illuminated by photons of two wavelengths λ_1 = 12000 Å and λ_2 = 10000 Å. At what minimum distance from the common central bright fringe on the screen 2 m from the slit will a bright fringe from one interference pattern coincide with a bright fringe from the other? **[NEET-2013]**
    (1) 6 mm (2) 4 mm
    (3) 3 mm (4) 8 mm

2. A parallel beam of fast moving electrons is incident normally on a narrow slit. A fluorescent screen is placed at a large distance from the slit. If the speed of the electrons is increased, which of the following statements is correct? **[NEET-2013]**
    (1) The angular width of the central maximum of the diffraction pattern will increase
    (2) The angular width of the central maximum will decrease
    (3) The angular width of the central maximum will be unaffected
    (4) Diffraction pattern is not observed on the screen in the case of electrons

3. A beam of light of λ = 600 nm from a distant source falls on a single slit 1 mm wide and the resulting diffraction pattern is observed on a screen 2 m away. The distance between first dark fringes on either side of the central bright fringe is **[AIPMT 2014]**
    (1) 1.2 cm (2) 1.2 mm
    (3) 2.4 cm (4) 2.4 mm

4. In the Young's double-slit experiement, the intensity of light at a point on the screen where the path difference is λ is K, (λ being the wavelength of light used). The intensity at a point where the path difference is $\frac{\lambda}{4}$, will be **[AIPMT 2014]**
    (1) K (2) $\frac{K}{4}$
    (3) $\frac{K}{2}$ (4) Zero

5. At the first minimum adjacent to the central maximum of a single-slit diffraction pattern, the phase difference between the Huygen's wavelet from the edge of the slit and the wavelet from the mid-point of the slit is **[Re-AIPMT-2015]**
    (1) $\frac{\pi}{8}$ radian (2) $\frac{\pi}{4}$ radian
    (3) $\frac{\pi}{2}$ radian (4) π radian

6. Two slits in Youngs experiment have widths in he ratio 1 : 25. The ratio of intensity at the maxima and minima in the interference pattern, $\frac{I_{max}}{I_{min}}$ is **[Re-AIPMT-2015]**
    (1) $\frac{4}{9}$ (2) $\frac{9}{4}$
    (3) $\frac{121}{49}$ (4) $\frac{49}{121}$

7. In a double slit experiment, the two slits are 1 mm apart and the screen is placed 1 m away. A monochromatic light of wavelength 500 nm is used. What will be the width of each slit for obtaining ten maxima of double slit within the central maxima of single slit pattern? **[AIPMT-2015]**
    (1) 0.02 mm (2) 0.2 mm
    (3) 0.1 mm (4) 0.5 mm

8. For a parallel beam of monochromatic light of wavelength λ, diffraction is produced by a single slit whose width a is of the order of the wavelength of the light. If D is the distance of the screen from the slit, the width of the central maxima will be **[AIPMT-2015]**
    (1) $\frac{2Da}{\lambda}$ (2) $\frac{2D\lambda}{a}$
    (3) $\frac{D\lambda}{a}$ (4) $\frac{Da}{\lambda}$

9. In a diffraction pattern due to a single slit of width *a*, the first minimum is observed at an angle 30° when light of wavelength 5000 Å is incident on the slit. The first secondary maximum is observed at an angle of **[NEET-2016]**

(1) $\sin^{-1}\left(\frac{3}{4}\right)$ (2) $\sin^{-1}\left(\frac{1}{4}\right)$

(3) $\sin^{-1}\left(\frac{2}{3}\right)$ (4) $\sin^{-1}\left(\frac{1}{2}\right)$

10. The intensity at the maximum in a Young's double slit experiment is I_0. Distance between two slits is $d = 5\lambda$, where λ is the wavelength of light used in the experiment. What will be the intensity in front of one of the slits on the screen placed at a distance $D = 10\ d$? **[NEET-2016]**

(1) $\frac{I_0}{2}$ (2) I_0

(3) $\frac{I_0}{4}$ (4) $\frac{3}{4}I_0$

11. The interference pattern is obtained with two coherent light sources of intensity ratio *n*. In the interference pattern, the ratio $\frac{I_{max} - I_{min}}{I_{max} + I_{min}}$ will be

[NEET (Phase-2) 2016]

(1) $\frac{\sqrt{n}}{n+1}$ (2) $\frac{2\sqrt{n}}{n+1}$

(3) $\frac{\sqrt{n}}{(n+1)^2}$ (4) $\frac{2\sqrt{n}}{(n+1)^2}$

12. A linear aperture whose width is 0.02 cm is placed immediately in front of a lens of focal length 60 cm. The aperture is illuminated normally by a parallel beam of wavelength 5×10^{-5} cm. The distance of the first dark band of the diffraction pattern from the centre of the screen is

[NEET (Phase-2) 2016]

(1) 0.10 cm (2) 0.25 cm

(3) 0.20 cm (4) 0.15 cm

13. The ratio of resolving powers of an optical microscope for two wavelengths λ_1 = 4000 Å and λ_2 = 6000 Å is **[NEET - 2017]**

(1) 8 : 27

(2) 9 : 4

(3) 3 : 2

(4) 16 : 81

14. Young's double slit experiment is first performed in air and then in a medium other than air. It is found that 8th bright fringe in the medium lies where 5th dark fringe lies in air. The refractive index of the medium is nearly **[NEET - 2017]**

(1) 1.25 (2) 1.59

(3) 1.69 (4) 1.78

15. Two Polaroids P_1 and P_2 are placed with their axis perpendicular to each other. Unpolarised light I_0 is incident on P_1. A third polaroid P_3 is kept in between P_1 and P_2 such that its axis makes an angle 45° with that of P_1. The intensity of transmitted light through P_2 is **[NEET - 2017]**

(1) $\frac{I_0}{2}$ (2) $\frac{I_0}{4}$

(3) $\frac{I_0}{8}$ (4) $\frac{I_0}{16}$

16. In Young's double slit experiment the separation d between the slits is 2 mm, the wavelength λ of the light used is 5896 Å and distance D between the screen and slits is 100 cm. It is found that the angular width of the fringes is 0.20°. To increase the fringe angular width to 0.21° (with same λ and D) the separation between the slits needs to be changed to **[NEET - 2018]**

(1) 1.8 mm

(2) 1.9 mm

(3) 1.7 mm

(4) 2.1 mm

17. Unpolarised light is incident from air on a plane surface of a material of refractive index 'μ'. At a particular angle of incidence 'i', it is found that the reflected and refracted rays are perpendicular to each other. Which of the following options is correct for this situation? **[NEET - 2018]**

(1) Reflected light is polarised with its electric vector parallel to the plane of incidence

(2) Reflected light is polarised with its electric vector perpendicular to the plane of incidence

(3) $i = \tan^{-1}\left(\frac{1}{\mu}\right)$

(4) $i = \sin^{-1}\left(\frac{1}{\mu}\right)$

18. In a double slit experiment, when light of wavelength 400 nm was used, the angular width of the first minima formed on a screen placed 1 m away, was found to be 0.2°. What will be the angular width of the first minima, if the entire experimental apparatus is immersed in water? (μ_{water} = 4/3) **[NEET - 2019]**

(1) 0.266° (2) 0.15°

(3) 0.05° (4) 0.1°

19. Angular width of the central maxima in the Fraunhofer diffraction for λ = 6000 Å is θ_0. When the same slit is illuminated by another monochromatic light, the angular width decreases by 30%. The wavelength of this light is **[NEET - 2019 (Odisha)]**

(1) 420 Å (2) 1800 Å

(3) 4200 Å (4) 6000 Å

20. In a Young's double slit experiment, if there is no initial phase difference between the light from the two slits, a point on the screen corresponding to the fifth minimum has path difference **[NEET - 2019 (Odisha)]**

(1) $11\frac{\lambda}{2}$

(2) $5\frac{\lambda}{2}$

(3) $10\frac{\lambda}{2}$

(4) $9\frac{\lambda}{2}$

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Chapter 11

Dual Nature of Matter and Radiation

Sub-topics *Photoelectric effect, Hertz and Lenard's observations; Einstein's photoelectric equation-particle nature of light. Matter waves-wave nature of particles, de Broglie relation. Davisson-Germer experiment (only conclusion should be explained).*

Photoelectric Effect

Particle Theory of Light : It was proposed by Einstein. The various points are given below.

(1) Light consists of packets of energy called photons.

(2) A photon moves with speed 299792458 m/s (3×10^8 m/s) in vacuum.

(3) A photon possess energy as well as momentum.

(4) Energy of a photon is $E = h\nu = \frac{hc}{\lambda}$.

(5) Momentum of a photon = $\frac{E}{c} = \frac{h}{\lambda}$.

(6) Mass of a photon cannot be defined in terms of Newtonian mechanics.

(7) Rest mass of a photon is zero. *i.e.*, photons do not exist at rest.

(8) Mass of a moving photon is $m = \frac{E}{c^2} = \frac{h}{\lambda c} = \frac{p}{c}$.

(9) A photon can collide with a material particle like electron.

(10) Total energy and momentum remain conserved during these collisions *i.e.*, the collisions are perfectly elastic.

(11) Intensity $I = nh\nu$, where n is number of photons crossing per second per unit area.

Hertz and Lenard's Observations

It was discovered by Hertz. The phenomenon of ejection of electrons from a metal surface, when light of suitable high frequency falls upon it, is known as photoelectric effect.

Work Function (ϕ) **:** It is the minimum energy of photon required to liberate most loosely bound electron from a metal surface. $\phi = h\nu_0$

Threshold Frequency (ν_0) : It is the frequency of incident radiation below which photoelectric effect does not take place. $\nu_0 = \frac{\phi}{h}$.

Stopping Potential (V_0) : The potential difference between cathode and anode to stop the fastest moving electrons emitted by the cathode. $eV_0 = KE_{max}$.

Laws of Photoelectric Emission

(1) The emission of photoelectrons takes place, when the frequency of the incident radiation is above threshold frequency.

(2) The emission of photoelectrons starts as soon as light falls on metal surface.

(3) The maximum kinetic energy (or stopping potential) is independent of intensity of light and depends only on its frequency.

(4) Photocurrent is independent of frequency, but depends only on intensity.

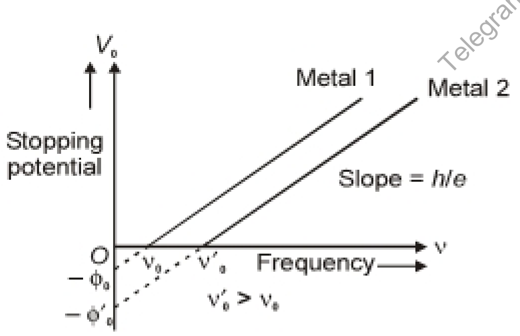
Einstein's Photoelectric Equation - Particle Nature of Light

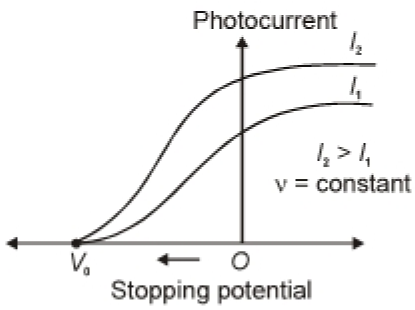
The kinetic energy of photoelectrons varies between zero to KE_{max}.

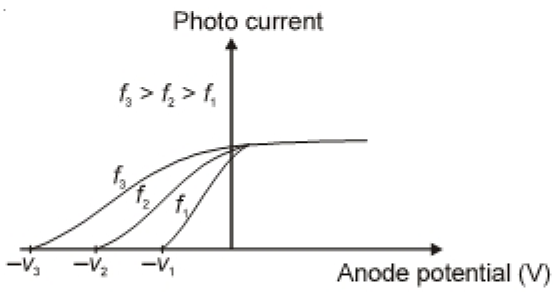
If ν is frequency of incident photons, $h\nu_0$ is work function then $h\nu - h\nu_0 = KE_{max}$. This is Einstein's photoelectric equation.

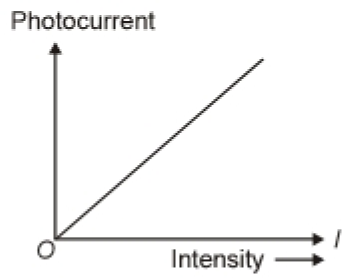
Efficiency of photoelectric emission is less than 1%.

Graphs for Photoelectric effect









Note : *These laws can be explained only by particle theory of light.*

Important Cases

1. When frequency of incident radiation is doubled, stopping potential or kinetic energy becomes more than double.

2. When light of wavelength λ falls on a metal surface having threshold wavelength λ_0, then photoelectric effect will take place if $\lambda < \lambda_0$.

3. A metal sphere having threshold wavelength λ_0 is radiated by light of wavelength $\lambda(<\lambda_0)$, photoelectric effect will start and stops after some time as the metal sphere acquires positive potential.

4. Number of electrons emitted after which photoelectric effect stops is given by $n = \frac{4\pi\varepsilon_0 r}{e^2} hc\left[\frac{1}{\lambda} - \frac{1}{\lambda_0}\right]$.

   Where r is radius of metal sphere.

Matter Waves and wave nature of particles: It was given by de-Broglie in 1924.

(1) A wave is associated with a moving particle.

(2) Wavelength of a particle $\lambda = \frac{h}{mv} = \frac{h}{p} = \frac{h}{\sqrt{2mE_k}}$. (de Broglie relation)

where $p = mv$ is momentum of particle

E_k = kinetic energy.

(3) For an electron accelerated through V volts.

$$E_k = eV \therefore \lambda = \frac{h}{\sqrt{2meV}} = \frac{12.27}{\sqrt{V}} \text{Å} \text{ or } \lambda = \sqrt{\frac{150}{V}} \text{Å}$$

For proton $\lambda = \frac{0.286}{\sqrt{V}}$Å, for deutron $\lambda = \frac{0.202}{\sqrt{V}}$Å, for α-particle $\lambda = \frac{0.101}{\sqrt{V}}$Å.

(4) An **electron Microscope** uses wave nature of electron. Limit of resolution of such microscope is proportional to de-broglie wavelength of the electron.

Davisson and Germer Experiment

On a Nickel crystal, a diffraction pattern is obtained using X-ray of wavelength λ. By using Bragg's X-ray diffraction equation

$2d \sin\theta = n\lambda$

the value of θ is obtained.

Now on the same θ, a different pattern of Ni crystal is obtained using electrons with speed v. Now when using the de Broglie equation $\lambda = \frac{h}{mv}$, wavelength λ is calculated then it matches the wavelength λ of the X-ray.

Conclusion: What a particle (electron) does, is done by waves (X-ray). So particle has wave behaviour as well.

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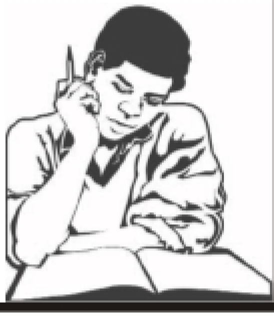


Try Yourself

SECTION - A

Objective Type Questions

1. In a photoelectric experiment, for an incident light of wavelength λ, stopping potential is found to be 3 V_0 and for a wavelength 2 λ, stopping potential is V_0. The threshold wavelength is

(1) 3 λ (2) 4 λ

(3) 6 λ (4) 7 λ

2. When light of frequency $2\nu_0$ and intensity *I* illuminates a metal in a photoelectric experiment, the stopping potential is 2 V and saturation current is 3 mA. Now If the frequency is reduced to one-fourth and intensity is doubled, the new stopping potential and saturation current are respectively [ν_0 is the threshold frequency]

(1) 0.5 V, 6 mA (2) 0.5 V, 3 mA

(3) 2 V, 6 mA (4) 0, 0

3. A proton and an α-particle are accelerated through same potential difference. Calculate the ratio of their respective de-Broglie wavelength

(1) 2 : 1 (2) $2\sqrt{2} : 1$

(3) $\sqrt{2} : 1$ (4) 4 : 1

4. A source of 30 W illuminates the cathode of a photocell with radiations of wavelength 6600 Å. The saturation current will be (efficiency of photoelectric emission is 1%)

(1) 0.16 A (2) 1.6 A

(3) 16 A (4) 160 A

5. In photoelectric experiments, the saturation current depends upon

(1) Frequency of illuminating light

(2) Wavelength of illuminating light

(3) Distance of source from cathode

(4) Color of light

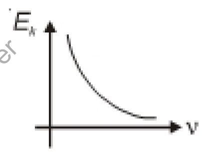
6. A potential difference of 30 V is applied across the cathode and anode in a photoelectric experiment. During the saturation state, the minimum kinetic energy with which photoelectrons emitted from the metal surface is

(1) 0 (2) 30 eV

(3) 15 eV (4) Can't be determined

7. The kinetic energy (E_k) of a photoelectron varies with frequency (ν) of the incident radiation as which graph?

(1)



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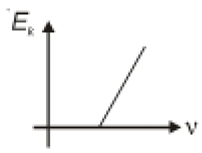

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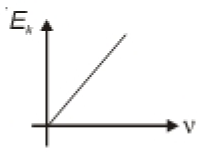

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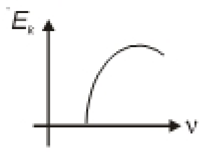


8. The work function of a metal is 3.4 eV. If the frequency of incident radiation is increased to twice, then the work function of the metal becomes

(1) 3.4 eV (2) 7.2 eV

(3) 6.8 eV (4) 1.7 eV

9. A photon of energy 4 eV is incident on a metal surface whose work function is 2 eV. The minimum reverse potential to be applied for stopping the emission of electrons is

(1) 2 V (2) 4 V

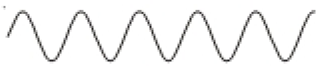
(3) 6 V (4) 8 V

10. An electron is accelerated through a potential difference of 100 V. The de Broglie wavelength of the electron is

(1) 1.227 Å (2) 12.27 Å

(3) 0.1227 Å (4) 0.01227 Å

11. de Broglie wave for a particle is shown in the diagram.



The probability of finding particle in the space is maximum

(1) At middle of the wave

(2) Probability of finding particle is same every where

(3) Cannot say

(4) Above wave cannot be de Broglie wave

12. Davisson and Germer experiment provides experimental proof for

(1) Huygens wave theory

(2) de Broglie wave hypothesis

(3) Compton shift

(4) All of these

SECTION - B

Previous Years Questions

1. An α-particle moves in a circular path of radius 0.83 cm in the presence of a magnetic field of 0.25 Wb/m^2. The de Broglie wavelength associated with the particle will be **[AIPMT 2012]**

(1) 10 Å (2) 0.01 Å

(3) 1 Å (4) 0.1 Å

2. Monochromatic radiation emitted when electron on hydrogen atom jumps from first excited to the ground state irradiates a photosensitive material. The stopping potential is measured to be 3.57 V. The threshold frequency of the material is **[AIPMT 2012]**

(1) 1.6×10^{15} Hz (2) 2.5×10^{15} Hz

(3) 4×10^{15} Hz (4) 5×10^{15} Hz

3. A 200 W sodium street lamp emits yellow light of wavelength 0.6 μm. Assuming it to be 25% efficient in converting electrical energy to light, the number of photons of yellow light it emits per second is **[AIPMT 2012]**

(1) 62×10^{20} (2) 3×10^{19}

(3) 1.5×10^{20} (4) 6×10^{18}

4. For photoelectric emission from certain metal the cut-off frequency is ν. If radiation of frequency 2ν impinges on the metal plate, the maximum possible velocity of the emitted electron will be (m is the electron mass) **[NEET-2013]**

(1) $\sqrt{\frac{h\nu}{m}}$

(2) $\sqrt{\frac{2h\nu}{m}}$

(3) $2\sqrt{\frac{h\nu}{m}}$

(4) $\sqrt{\frac{h\nu}{(2m)}}$

5. The wavelength λ_e of an electron and λ_p of a photon of same energy E are related by **[NEET-2013]**

(1) $\lambda_p \propto \lambda_e$ (2) $\lambda_p \propto \sqrt{\lambda_e}$

(3) $\lambda_p \propto \frac{1}{\sqrt{\lambda_e}}$ (4) $\lambda_p \propto \lambda_e^2$

6. When the energy of the incident radiation is increased by 20%, the kinetic energy of the photoelectrons emitted from a metal surface increased from 0.5 eV to 0.8 eV. The work function of the metal is **[AIPMT 2014]**

(1) 0.65 eV (2) 1.0 eV

(3) 1.3 eV (4) 1.5 eV

7. If the kinetic energy of the particle is increased to 16 times its previous value, the percentage change in the de-Broglie wavelength of the particle is **[AIPMT 2014]**

(1) 25 (2) 75

(3) 60 (4) 50

8. In the spectrum of hydrogen, the ratio of the longest wavelength in the Lyman series to the longest wavelength in the Balmer series is **[Re-AIPMT-2015]**

(1) $\frac{5}{27}$ (2) $\frac{4}{9}$

(3) $\frac{9}{4}$ (4) $\frac{27}{5}$

9. Light of wavelength 500 nm is incident on a metal with work function 2.28 eV. The de Broglie wavelength of the emitted electron is **[Re-AIPMT-2015]**

(1) $\leq 2.8\times10^{-12}$ m (2) $< 2.8\times10^{-10}$ m

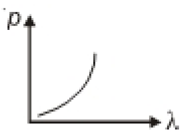
(3) $< 2.8\times10^{-9}$ m (4) $\geq 2.8\times10^{-9}$ m

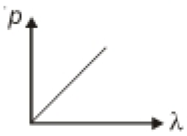
10. A photoelectric surface is illuminated successively by monochromatic light of wavelength λ and $\frac{\lambda}{2}$. If the maximum kinetic energy of the emitted photoelectrons in the second case is 3 times that in the first case, the work function of the surface of the material is (h = Planck's constant, c = speed of light) **[Re-AIPMT-2015]**

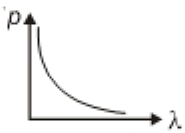
(1) $\frac{hc}{3\lambda}$ (2) $\frac{hc}{2\lambda}$

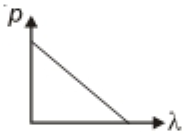
(3) $\frac{hc}{\lambda}$ (4) $\frac{2hc}{\lambda}$

11. Which of the following figures represent the variation of particle momentum and the associated de-Broglie wavelength? **[AIPMT-2015]**

(1) 

(2) 

(3) 

(4) 

12. A certain metallic surface is illuminated with monochromatic light of wavelength λ. The stopping potential for photo-electric current for this light is $3V_0$. If the same surface is illuminated with light of wavelength 2λ, the stopping potential is V_0. The threshold wavelength for this surface for photo-electric effect is **[AIPMT-2015]**

(1) $\frac{\lambda}{6}$ (2) 6λ

(3) 4λ (4) $\frac{\lambda}{4}$

13. When a metallic surface is illuminated with radiation of wavelength λ, the stopping potential is V. If the same surface is illuminated with radiation of wavelength 2λ, the stopping potential is $\frac{V}{4}$. The threshold wavelength for the metallic surface is

[NEET-2016]

(1) 3λ (2) 4λ

(3) 5λ (4) $\frac{5}{2}\lambda$

14. An electron of mass m and a photon have same energy E. The ratio of de-Broglie wavelengths associated with them is **[NEET-2016]**

(1) $\frac{1}{c}\left(\frac{2m}{E}\right)^{\frac{1}{2}}$ (2) $\frac{1}{c}\left(\frac{E}{2m}\right)^{\frac{1}{2}}$

(3) $\left(\frac{E}{2m}\right)^{\frac{1}{2}}$ (4) $c(2mE)^{\frac{1}{2}}$

(c being velocity of light)

15. Electrons of mass m with de-Broglie wavelength λ fall on the target in an X-ray tube. The cutoff wavelength (λ_0) of the emitted X-ray is

[NEET (Phase-2) 2016]

(1) $\lambda_0 = \frac{2mc\lambda^2}{h}$ (2) $\lambda_0 = \frac{2h}{mc}$

(3) $\lambda_0 = \frac{2m^2c^2\lambda^3}{h^2}$ (4) $\lambda_0 = \lambda$

16. Photons with energy 5 eV are incident on a cathode C in a photoelectric cell. The maximum energy of emitted photoelectrons is 2 eV. When photons of energy 6 eV are incident on C, no photoelectrons will reach the anode A, if the stopping potential of A relative to C is

[NEET (Phase-2) 2016]

(1) +3 V (2) +4 V

(3) –1 V (4) –3 V

17. The de-Broglie wavelength of a neutron in thermal equilibrium with heavy water at a temperature T (Kelvin) and mass m, is **[NEET - 2017]**

(1) $\frac{h}{\sqrt{mkT}}$ (2) $\frac{h}{\sqrt{3mkT}}$

(3) $\frac{2h}{\sqrt{3mkT}}$ (4) $\frac{2h}{\sqrt{mkT}}$

18. The photoelectric threshold wavelength of silver is 3250×10^{-10} m. The velocity of the electron ejected from a silver surface by ultraviolet light of wavelength 2536×10^{-10} m is (Given $h = 4.14 \times 10^{-15}$ eVs and $c = 3 \times 10^8$ ms^{-1}) **[NEET - 2017]**

(1) $\approx 6 \times 10^5$ ms^{-1}

(2) $\approx 0.6 \times 10^6$ ms^{-1}

(3) $\approx 61 \times 10^3$ ms^{-1}

(4) $\approx 0.3 \times 10^6$ ms^{-1}

19. An electron of mass m with an initial velocity $\vec{V} = V_0\hat{i}$ ($V_0 > 0$) enters an electric field $\vec{E} = -E_0\hat{i}$ (E_0 = constant > 0) at $t = 0$. If λ_0 is its de-Broglie wavelength initially, then its de-Broglie wavelength at time t is **[NEET - 2018]**

(1) $\dfrac{\lambda_0}{\left(1+\dfrac{eE_0}{mV_0}t\right)}$ (2) $\lambda_0\left(1+\dfrac{eE_0}{mV_0}t\right)$

(3) λ_0 (4) $\lambda_0 t$

20. When the light of frequency $2\nu_0$ (where ν_0 is threshold frequency), is incident on a metal plate, the maximum velocity of electrons emitted is v_1. When the frequency of the incident radiation is increased to $5\nu_0$, the maximum velocity of electrons emitted from the same plate is v_2. The ratio of v_1 to v_2 is **[NEET - 2018]**

(1) 1 : 2 (2) 1 : 4

(3) 2 : 1 (4) 4 : 1

21. An electron is accelerated through a potential difference of 10,000 V. Its de Broglie wavelength is, (nearly) : ($m_e = 9 \times 10^{-31}$ kg) **[NEET - 2019]**

(1) 12.2×10^{-13} m

(2) 12.2×10^{-12} m

(3) 12.2×10^{-14} m

(4) 12.2 nm

22. The work function of a photosensitive material is 4.0 eV. The longest wavelength of light that can cause photon emission from the substance is (approximately) **[NEET - 2019 (Odisha)]**

(1) 310 nm (2) 3100 nm

(3) 966 nm (4) 31 nm

23. A proton and an α–particle are accelerated from rest to the same energy. The de Broglie wavelengths λ_p and λ_α are in the ratio **[NEET - 2019 (Odisha)]**

(1) 4 : 1 (2) 2 : 1

(3) 1 : 1 (4) $\sqrt{2}:1$

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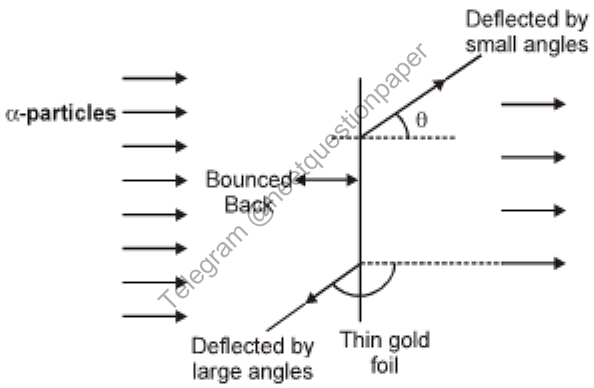
Chapter 12

Atoms

Sub-topics *Alpha-particle scattering experiments; Rutherford's model of atom; Bohr model, energy levels, hydrogen spectrum.*

Alpha particle scattering Experiment

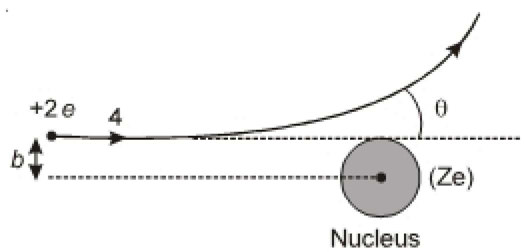


Rutherford's Model of Atom

1. Most of α-particles went approximately straight.
2. 1 in 8000 retraced their path or bounced back.
3. Atom has a lot of empty space in it.
4. The entire mass and positive charge is confined to extremely small central core. *i.e.*, Rutherford discovered nucleus.
5. Impact parameter (b) :

$$b = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2 \cot\theta/2}{\left(\frac{1}{2}mv^2\right)}$$

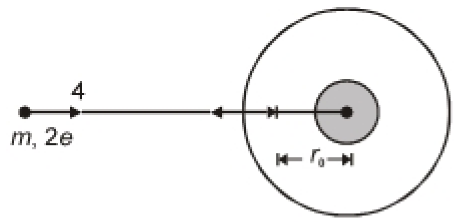
when $b = 0$, $\theta = 180°$



6. Distance of closest approach

$$\frac{1}{2}mv^2 = \frac{1}{4\pi\varepsilon_0}\frac{(Ze)(2e)}{r_0}$$

$$\Rightarrow \quad r_0 = \frac{1}{4\pi\varepsilon_0}\frac{2Ze^2}{\left(\frac{1}{2}mv^2\right)}$$



Note : *In Geiger - Marsden experiment,* $\frac{1}{2}mu^2$ *= 5.5 MeV, Z = 79*

$\Rightarrow \quad r_0 = 41.3$ fm.

Rutherford proposed that whole mass and positive charge is in a core *i.e.*, nucleus and electrons revolve around it in circular orbits so that electrostatic force of attraction provides centripetal force.

Drawbacks

By Maxwell's theory, accelerated charges radiate electromagnetic waves and lose energy. Therefore, when an electron revolves in circular orbit, it is subjected to centripetal acceleration and thus it should radiate energy and the radius should continuously decrease e^- should finally fall into nucleus. The e^- should follow spiral (helical) motion around the nucleus.

Bohr's Model

In 1913, Bohr explained hydrogen spectra using following assumptions.

1. Electrons can revolve round the nucleus in circular orbits.
2. It can do so in certain permitted orbits called stationary orbits.
3. Each stationary orbit is associated with a definite value of energy and angular momentum should be an integral multiple of $\frac{h}{2\pi}$.
4. Electron can jump from higher energy level E_2 to lower energy level E_1 emitting a photon of energy $h\nu = \frac{hc}{\lambda} = E_2 - E_1$ = energy of photon emitted.
5. In a stationary orbit $mvr = \frac{nh}{2\pi}$ ...(i) (angular momentum quantization)

   (n = principal quantum number)
6. $\frac{1}{4\pi\varepsilon_0}\frac{(Ze)(e)}{r^2} = \frac{mv^2}{r}$ ...(ii) (centripetal force is provided by electrostatic force between nucleus and electron)

   For H-like atom of atomic number Z
7. From (i) and (ii), $v_n = \frac{Ze^2}{2\varepsilon_0 nh} = \frac{Z}{n}(2.18\times10^6 \text{ m/s}) = \frac{Z}{n}\left(\frac{C}{137}\right)$ *i.e.* $v_n \propto \frac{Z}{n}$.
8. $r_n = \frac{\varepsilon_0 n^2h^2}{\pi mZe^2} = \frac{n^2}{Z}(0.53 \text{ Å})$ *i.e.*, $r_n \propto \frac{n^2}{Z}$.

Energy Levels

1. Total energy $E = \frac{-me^4}{8\varepsilon_0^2 h^2}\frac{Z^2}{n^2} = -13.6\frac{Z^2}{n^2}$ eV.

2. KE = |TE| = $\frac{13.6}{n^2}Z^2$ eV.

3. PE = 2TE = $-\frac{2\times 13.6}{n^2}Z^2$ eV.

4. For hydrogen atom $E_1 = -13.6$ eV, $E_2 = -3.4$ eV, E_3 =- – 1.51 eV, $E_4 = -0.84$ eV.

Note : *(a)* $f \propto \frac{Z^2}{n^3}$, $f = \frac{1}{T}$, $i \propto f$.

(b) $B \propto \frac{Z^3}{n^5}$. *(Magnetic field at center)*

Hydrogen Spectrum

At room temperature or below, hydrogen atoms is quite stable. When some extra energy is supplied, Radiation is emitted.

Note : *Always definite wavelengths are emitted by any element that's why spectral lines are called* ***finger prints of atoms****.*

Spectral Lines

$$\frac{1}{\lambda} = RZ^2\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right] \Rightarrow \lambda = \frac{1}{RZ^2\left(\frac{1}{n_1^2}-\frac{1}{n_2^2}\right)} = \frac{912\ \text{Å}}{Z^2\left(\frac{1}{n_1^2}-\frac{1}{n_2^2}\right)}$$

λ is wavelength of photon emitted when electron makes a transition from $n_2 \to n_1$.

R = Rydberg's Constant = $1.09677 \times 10^7\ \text{m}^{-1} = \frac{1}{912\ \text{Å}}$

Z = Atomic Number

For hydrogen $Z = 1$

Series	n_1	n_2	λ_{min}	λ_{max}	Region of Spectrum
LYMAN	1	2 to ∞	$n_2 = \infty$ 1/R	$n_2 = 2$ 4/3R	Ultraviolet only
BALMER	2	3 to ∞	$n_2 = \infty$ 4/R	$n_2 = 3$ 36/5R	λ_{min} in U.V. region rest in visible
PASCHEN	3	4 to ∞	$n_2 = \infty$ 9/R	$n_2 = 4$ 144/7R	Infra red
BRACKET	4	5 to ∞	$n_2 = \infty$ 16/R	$n_2 = 5$ 400/9R	Infra red
PFUND	5	6 to ∞	$n_2 = \infty$ 25/R	$n_2 = 6$ 900/11R	Infra red

Balmer first gave the formula for balmer series.

$$\lambda = \frac{912\,Å}{RZ^2\left(\frac{1}{n_1^2}-\frac{1}{n_2^2}\right)} \quad \begin{pmatrix} n_1 = 2 \\ n_2 = 3 \text{ to } \infty \end{pmatrix}$$

For $n_2 = 3$, the spectral line is called H_α (Red).

For $n_2 = \infty$ the spectral line is called H_∞. It lies in ultra violet region.

Binding Energy : It is the energy released, when constituents of a system are brought from infinity to form the system. $BE = -TE$.

Excitation Energy : Energy needed to take the atom from its ground state to an excited state is called excitation energy.

The hydrogen atom in ground state needs 10.2 eV to move to its first excited state.

Excitation Potential : The potential through which an electron should be accelerated to acquire excitation energy is called the excitation potential.

The excitation potential of hydrogen atom in first excited state is 10.2 V.

Some Points to Remember

1. Energy of He^+ ion in first excited state = 13.6 eV *i.e.*, same as energy of hydrogen atom in ground state.
2. When some energy is supplied to hydrogen sample, its atoms move to their excited state. When they come back to ground state, a number of spectral lines are emitted.
3. Let an electron jumps from $n = 1$ to $n = N$ (say). Then the number of different ways in which it can come back to ground state = Number of different spectral lines = $\frac{N(N-1)}{2}$.
4. Number of spectral lines possible when an electron makes a transition from $n = N$ to $n = M$ are $\frac{(N-M)(N-M+1)}{2}$.

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Try Yourself

SECTION - A

Objective Type Questions

1. Suppose the ground state radius and velocity of an electron in a Bohr's atom are r_0 and v_0 respectively. If hypothetically the mass of electron becomes 200 times of its present value, then the ground state radius and velocity will be respectively

   (1) r_0, 200 v_0 (2) $r_0, \dfrac{v_0}{200}$

   (3) 200 r_0, v_0 (4) $\dfrac{r_0}{200}, v_0$

2. The ratio of series limit frequencies of Balmer series to that of Bracket series for a H-like atom is

   (1) 16 : 1 (2) 1 : 16

   (3) 4 : 1 (4) 1 : 4

3. A hydrogen atom of mass m emits a photon corresponding to 1st line of Lyman series and recoils in the opposite direction. If R and h are respectively Rydberg's constant and Planck's constant, the recoiling velocity of H-atom is

   (1) $\dfrac{3Rh}{4m}$ (2) $\dfrac{4m}{3Rh}$

   (3) $\dfrac{4h}{3Rm}$ (4) $\dfrac{3Rm}{4h}$

4. Which series of hydrogen atom lies in infra-red region?

   (1) Lyman only

   (2) Balmer only

   (3) Bracket, Paschen and Pfund

   (4) Lyman and Balmer

5. The speed of an electron in the second orbit of hydrogen atom is

   (1) $\dfrac{c}{274}$ (2) $\dfrac{c}{137}$

   (3) $\dfrac{c}{2}$ (4) $\dfrac{c}{4}$

6. The potential energy of an electron in an excited state of H-atom is –1.7 eV. What is the total number of radiations possible when this electron moves to lower states?

   (1) 10 (2) 6

   (3) 3 (4) 1

7. The ratio of number of revolution per second made by an electron in 1st excited state of He^+ to another electron in 2nd excited state of Li^{++} is

   (1) 1 : 1 (2) 3 : 2

   (3) 2 : 1 (4) 4 : 3

8. Rydberg's constant for H atom is (symbols have their usual meaning)

   (1) $\dfrac{2\pi^2k^2me^4}{ch^3}$ (2) $\dfrac{2\pi^2mk^2e^4}{c^3h}$

   (3) $\dfrac{2\pi^2k^2me^2}{c^3h}$ (4) $\dfrac{2\pi^2k^2me^2}{ch^3}$

9. According to Bohr's theory, the moment of momentum of an electron revolving in the 3rd orbit of hydrogen atom will be

   (1) $3\pi h$ (2) $\dfrac{3h}{\pi}$

   (3) $\dfrac{3\pi}{h}$ (4) $\dfrac{3h}{2\pi}$

10. For hydrogen atom, the wavelength is minimum, among the following, for the transition from

    (1) n = 2 to n = 1 (2) n = 3 to n = 2

    (3) n = 4 to n = 3 (4) n = 5 to n = 4

11. When light of wavelength 800Å illuminates a metal, the most energetic photoelectron emitted can just ionise the hydrogen atom in ground state. What is the work function of the metal (approximately)?

    (1) 1.2 eV (2) 1.9 eV

    (3) 3.4 eV (4) 4.8 eV

12. The total energy of electron in the ground state of hydrogen atom is –13.6 eV. The kinetic energy of electron in the first excited state will be

    (1) 13.6 eV (2) 3.4 eV

    (3) 9.5 eV (4) 10.2 eV

SECTION - B

Previous Years Questions

1. Electron in hydrogen atom first jumps from third excited state to second excited state and then from second excited to the first excited state. The ratio of the wavelengths $\lambda_1 : \lambda_2$ emitted in the two cases is **[AIPMT 2012]**

(1) $\frac{27}{5}$ (2) $\frac{20}{7}$

(3) $\frac{7}{5}$ (4) $\frac{27}{20}$

2. An electron of a stationary hydrogen atom passes from the fifth energy level to the ground level. The velocity that the atom acquired as a result of photon emission will be **[AIPMT 2012]**

(1) $\frac{25\,m}{24\,hR}$ (2) $\frac{24\,m}{25\,hR}$

(3) $\frac{24\,hR}{25\,m}$ (4) $\frac{25\,hR}{24\,m}$

3. Ratio of longest wavelengths corresponding to Lyman and Balmer series in hydrogen spectrum is **[NEET-2013]**

(1) $\frac{3}{23}$ (2) $\frac{7}{29}$

(3) $\frac{9}{31}$ (4) $\frac{5}{27}$

4. Hydrogen atom in ground state is excited by a monochromatic radiation of λ = 975 Å. Number of spectral lines in the resulting spectrum emitted will be **[AIPMT 2014]**

(1) 3 (2) 2

(3) 6 (4) 10

5. Consider 3rd orbit of He^+ (Helium) using non-relativistic approach the speed of electron in this orbit will be (given $K = 9 \times 10^9$ constant $Z = 2$ and h (Planck's constant) = 6.6×10^{-34} Js). **[AIPMT-2015]**

(1) 3.0×10^8 m/s (2) 2.92×10^6 m/s

(3) 1.46×10^6 m/s (4) 0.73×10^6 m/s

6. When an α-particle of mass m moving with velocity v bombards on a heavy nucleus of charge 'Ze', its distance of closest approach from the nucleus depends on m as **[NEET-2016]**

(1) m (2) $\frac{1}{m}$

(3) $\frac{1}{\sqrt{m}}$ (4) $\frac{1}{m^2}$

7. Given the value of Rydberg constant is 10^7 m^{-1}, the wave number of the last line of the Balmer series in hydrogen spectrum will be **[NEET-2016]**

(1) 2.5×10^7 m^{-1} (2) 0.025×10^4 m^{-1}

(3) 0.5×10^7 m^{-1} (4) 0.25×10^7 m^{-1}

8. If an electron in a hydrogen atom jumps from the 3rd orbit to the 2nd orbit, it emits a photon of wavelength λ. When it jumps from the 4th orbit to the 3rd orbit, the corresponding wavelength of the photon will be **[NEET (Phase-2) 2016]**

(1) $\frac{16}{25}\lambda$ (2) $\frac{9}{16}\lambda$

(3) $\frac{20}{7}\lambda$ (4) $\frac{20}{13}\lambda$

9. The ratio of wavelengths of the last line of Balmer series and the last line of Lyman series is **[NEET - 2017]**

(1) 2 (2) 1

(3) 4 (4) 0.5

10. The total energy of an electron in an atom in an orbit is –3.4 eV. Its kinetic and potential energies are, respectively **[NEET-2019]**

(1) –3.4 eV, –3.4 eV

(2) –3.4 eV, –6.8 eV

(3) 3.4 eV, –6.8 eV

(4) 3.4 eV, 3.4 eV

11. The radius of the first permitted Bohr orbit, for the electron, in a hydrogen atom equals 0.51 Å and its ground state energy equals –13.6 eV. If the electron in the hydrogen atom is replaced by muon (μ^-) [charge same as electron and mass 207 m_e], the first Bohr radius and ground state energy will be **[NEET-2019 (Odisha)]**

(1) 2.56×10^{-13} m, –13.6 eV

(2) 0.53×10^{-13} m, –3.6 eV

(3) 25.6×10^{-13} m, –2.8 eV

(4) 2.56×10^{-13} m, –2.8 keV

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Chapter 13

Nuclei

Sub-topics *Composition and size of nucleus, atomic masses, isotopes, isobars; isotones. Radioactivity-alpha, beta and gamma particles/ rays and their properties decay law. Mass-energy relation, mass defect; binding energy per nucleon and its variation with mass number, nuclear fission and fusion.*

Composition and size of nucleus

(1) Nucleus was discovered by Rutherford. It is the core of an atom. It is made of protons and neutrons.

(2) $m_n = 1.6749286 \times 10^{-27}$ kg; $m_p = 1.6726231 \times 10^{-27}$ kg

(3) Mass is also written in form of energy $E = Mc^2$

1 a.m.u. = $1.6605402 \times 10^{-27}$ kg $= 931.478$ MeV/c^2

(4) Nucleus is represented by ${}^{A}_{Z}X$

$A \rightarrow$ mass number (Protons + Neutron) $Z \rightarrow$ atomic number (Protons)

(5) **Isotones :** Nuclei having same number of neutrons but different atomic numbers are called isotones and isotopes are nuclei having same atomic number but different mass numbers.

(6) **Isobars :** Nuclei having same mass number but different atomic numbers are called isobars.

(7) **Nuclear Radius :** The average radius of a nucleus is given by

$R = R_0A^{1/3}$ where $R_0 = 1.2 \times 10^{-15}$ m = 1.2 fm

A = atomic mass

(8) The radius of aluminium nuclei is (A = 27).

$R = R_0A^{1/3} = 3.6$ fm

(9) Nuclear Density

$$\rho = \frac{mA}{\text{Volume}} = \frac{mA}{\frac{4}{3}\pi R^3} = \frac{3m}{4\pi R_0^3} = \text{constant} = 2.27 \times 10^{17}\ \text{kg m}^{-3}$$ [where m = mass of a nucleon]

Nuclear density is independent of mass numbers (A)

Nuclear Forces

The nucleons in a nucleus are held together by strong nuclear force.

(1) These are short range forces. They become **negligible** for distance more than **10 fm**. This is called **Nuclear Range**.

(2) They are much stronger than electromagnetic forces (50 - 60 time stronger).

(3) They are independent of charge.

(4) The nuclear force is same between a Proton – Proton and Neutron – Neutron or Neutron – Proton.

(5) Nuclear force $F_{NN} = F_{NP} = N_{PP}$. Net force $F_{NN} = F_{NP} > F_{PP}$. (except gravitational force)

(6) This is not a **central force**.

(7) It depends on the **spin**. **Same spin means greater force.**

Radioactivity

Henry Becquerel (1896) observed that a photographic plate gets blackened, when placed near double sulphate of potassium and **uranium**. He further observed that **uranium** emitted special kind of rays. They were called **Becquerel rays.**

Pierre and **Marrie Curie** observed that the radiation from **pitchblende** was four times **stronger** than **uranium.** In 1898, they finally discovered two new substances Polonium ($_{84}Po^{210}$) and Radium ($_{88}Ra^{226}$). The radiation from radium was found to be more than million times that of uranium.

These newly discovered substances emitting radiations were called radioactive substances and this **property of emitting radiations spontaneously by these substances was named radioactivity.** Since then, many more radioactive substances have been discovered. Some occur naturally while others have been produced artificially.

Many more radioactive substances were discovered later on. **Schmidt** and **Curie** (1898) discovered **Thorium** and **Debierne** (1899) discovered **Actinium**.

Radioactivity is exhibited by elements of high atomic weight (Z > 82) where nuclei are unstable and break up on their own into simpler elements giving out radiations.

Properties of radioactive substances :

Radiations from radioactive substances have three outstanding properties :

(i) They affect a photographic plate like light or X-rays.

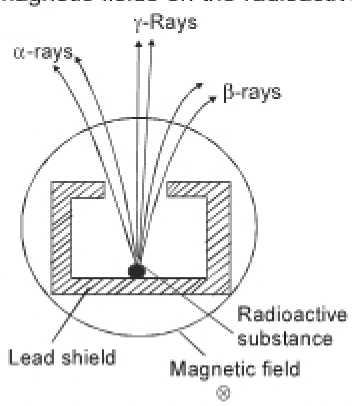
(ii) They penetrate through matter, the thickness depending upon the nature of radiations and source.

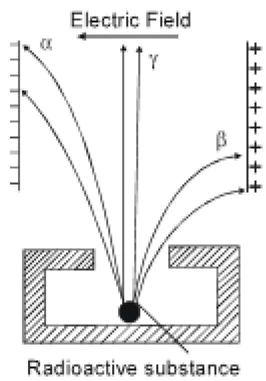
(iii) They ionise the gas through which they pass.

Nature of Radioactive Rays

Rutherford (1902) studied the effect of electric and magnetic fields on the radioactive rays emitted by different radioactive substances.

He kept a radioactive substance in a thick-walled lead box and applied an electrostatic field to the radioactive rays emerging from a narrow opening in the box. He also studied the behaviour of these radiations in magnetic field. He observed that radioactive rays or particles are of three types.





(i) **Alpha rays** (α-Rays)–Rays which are deflected towards the negative plate are called alpha rays.

(ii) **Beta rays** (β-rays)–Rays which are deflected towards the positive plate are called 'beta rays'.

(iii) **Gamma rays** (γ-rays)–Rays which go undeflected by the electric field are called 'gamma rays'.

(iv) The direction of deflection confirmed that α–particles are positively charged and β-particles are negatively charged.

No radioactive substance emits both α and β-particles simultaneously. γ–rays are emitted along with both α and β-particles.

Rutherford (1900) observed that Thorium gave off small amounts of radio active gas called **thorium emanation** or **thoron**.

Curie observed that radium gives off a radioactive gas, **radium emanation** or **radon**. While actinium produce **actinon**.

Comparison of the properties of α–particle, β–particle and γ–rays

Sr. No	Property	α-particle	β-particle	γ-Rays
1.	Nature	Helium nucleus	Fast moving electron	Highly energic photons or electromagnetic waves
2.	Penetrating power	Minimum	100 times that of α-particles	100 times that of β-particles
3.	Ionising power	100 times that of β-particles	100 times that of γ-rays	Minimum
4.	Charge	$+3.2 \times 10^{-19}$ C	-1.6×10^{-19} C	Zero
5.	Velocity	1.4×10^{7} to 2.2×10^{7} m/s	1% to 99% of the velocity of light	3×10^{8} m/s
6.	Rest mass	6.6×10^{-27} kg	9.1×10^{-31} kg	Zero

Radioactive Decay Law

It is the property by virtue of which a heavy element disintegrates itself without being forced by any external agent to do so.

It was discovered by **Henry Becquerel in 1896**.

Radioactivity is not affected by temperature, pressure or chemical combination.

There is absolutely no way to predict whether any given nucleus in the sample will be among the small number of nuclei that decay during the next second. All have an equal chance.

$-\frac{dN}{dt} \propto N$ N = number of nuclei present at the instant.

$-\frac{dN}{dt} = \lambda N$ (λ is decay constant)

$\Rightarrow N = N_0 e^{-\lambda t}$ N_0 = initial number of nuclei

Activity $A = -\frac{dN}{dt} = \lambda N_0 e^{-\lambda t} = \lambda N$

$A = A_0 e^{-\lambda t}$ A_0 = initial activity

Units 1 becquerel = 1 decay/second (Bq is SI unit of activity)

1 curie = 1Ci = 3.7×10^{10} Bq.

1 rutherford = 10^{6} disintegration/second

Half Life

When $N = \frac{N_0}{2}$ or $A = \frac{A_0}{2}$

$$\tau_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda}$$

Average Life

$$\tau_{av} = \frac{1}{\lambda} = \frac{\tau_{1/2}}{\ln 2} \text{ or } \tau_{av} = 1.44\,\tau_{1/2}$$

or

$$\tau_{1/2} = 0.693\,\tau_{av}$$

Applications :

(1) In one half life, concentration of the nuclei becomes half of initial value.

at $t = 0$ $N = N_0$

at $t = T_{1/2}$ $N = \frac{N_0}{2}$

at $t = 2T_{1/2}$ $N = \frac{N_0}{2 \times 2}$

at $t = nT_{1/2}$ $N = \frac{N_0}{2^n}$

$\frac{A}{A_0} = \frac{N}{N_0} = \left(\frac{1}{2}\right)^n$ (n is the number of half lives completed)

(2) The above results can be generalised as follows.

at $t = 0$ $N = N_0$

$t = T$ $N = \frac{N_0}{x}$ say

$\Rightarrow$ $t = 2T$ $N = \frac{N_0}{x^2}$

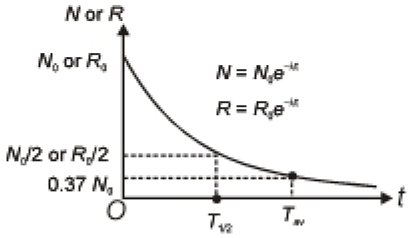
$t = nT$ $N = \frac{N_0}{x^n}$

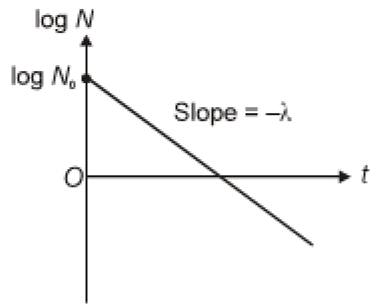
(3) In one mean/average life N = 37% of N_0 (0.37 N_0)

(4) In two mean/average life $N = 0.135\,N_0$.

(5) (a) $\log N = \log N_0 - \lambda t$

(b) $\log R = \log R_0 - \lambda t$





(6) As radiation penetrate into matter, the intensity goes on decreasing as $I = I_0e^{-\mu x}$ where x is thickness.

(7) α-decay ${}_{92}U^{238} \rightarrow {}^{234}Th_{90} + {}^{4}He_{2}$, Q = 4.25 MeV

(8) β-decay

(a) β^- decay ${}^{32}_{15}P \rightarrow {}^{32}_{16}S + e^- + \bar{\nu}$ ($n \rightarrow P + e^- + \bar{\nu}$)

(b) β^+ decay ${}^{64}_{29}Cu \rightarrow {}^{64}_{28}Ni + e^+ + \nu$ ($P \rightarrow n + e^+ + \nu$)

(c) Anti-neutrino $\bar{\nu}$ and neutrino v are massless particles having same spin.

(d) The above decay shows that neutrons and protons are not fundamental particles.

(e) Antinutrino and nutrino can not be detected easily. It's concept was introduced to conserve angular momentum and energy.

Binding Energy

The amount of energy needed to separate the constituent nucleons to large distances.

or

If the nucleons are initially well separated and are brought to form the nucleus, this much energy is released.

$$BE = (Zm_p + Nm_n - M)c^2$$ (where M = mass of nucleus)

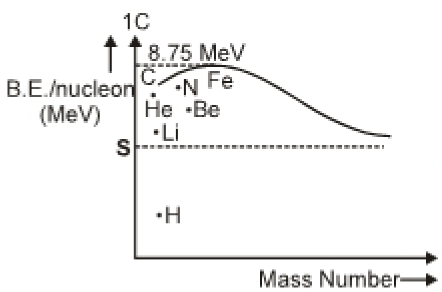
The binding energy of an α-particle from the following data is 28.3 MeV.

mass of ${}^{1}_{1}H$ = 1.007825 u   1u = 931 MeV

mass of neutron = 1.008625 u

mass of ${}^{4}_{2}He$ atom = 4.00260

Binding Energy Variation with Mass Number



BE/nucleon is maximum for A = 56

Nuclear Fission and Fusion

B.E./nucleon is very low for light nuclei. This means energy will be released if two nuclides combine to form a single middle mass nuclide.

Nuclear fusion occurs at high pressure (= 10^6 atm) and high temperature (10^7 to 10^8 K)

(a) Source of energy of stars and sun is nuclear fusion.

(b) Fusion reaction in sun (proton - proton cycle)

$$4\,{}_1H^1 \longrightarrow {}_2He^4 + 2\beta^+ + 2\gamma + 26.73 \text{ MeV}$$

(c) For the same mass of the fuel energy released in fusion is much more than in fission.

(d) Atom bomb → Based upon fission, hydrogen bomb → Based upon fusion.

Parallely, the low B.E. for heavy mass number indicates that if a single heavy mass nuclide breaks up into middle mass nuclide energy will be released. (Nuclear Fission).

Nuclear fission was discovered by **Ottohann** and **Strassman**

A stable nuclei maintains its constitution all the time.

An unstable nucleus emits some kind of particle and changes its constitution.

For light stable nuclei, the neutron number is equal to the proton number $\frac{N}{Z} = 1$.

In heavy nuclei, **radius is large** and many nucleons pairs may not interact with each other. But coulomb force is long range. Thus **repulsive force may be more**. To achieve stability, number of neutrons are more than protons. So $\frac{N}{Z}$ ratio increases with A.

But it is not necessary that more N/Z means more stability. A very large nucleus can not be stable for any value of N/Z. The heaviest stable nuclide is ${}^{209}_{83}Bi$.

(a) Fission of U^{235} occurs by slow neutrons (1 eV) or by thermal neutrons (of energy about 0.025 eV)

(b) Fission reaction of U^{235}

$${}_{92}U^{235} + {}_0n^1 \rightarrow \underset{\text{(Unstable)}}{{}_{92}U^{236}} \longrightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3\,{}_0n^1 + Q$$

(c) In fission of ${}_{92}U^{235}$, on an average 2.5 neutrons (energy-about – 2 MeV, named as fast neutrons) are liberated.

(d) Energy released in U^{235} fission is about 200 MeV.

(e) **Nuclear Reactor**

(i) Controlled chain reaction takes place

(ii) fuel used - enriched uranium, plutonium,

(iii) Moderator slows down neutron. *e.g.* D_2O, graphite.

(iv) Control rods absorb excess neutron *e.g.*, cadmium, boron.

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Try Yourself

SECTION - A

Objective Type Questions

1. Nuclear forces are not

   (1) Short range (2) Exchange forces

   (3) Spin independent (4) Charge independent

2. The value of Z and A in the following reaction are respectively

   $${}_{92}U^{238} \xrightarrow{\alpha} Th \xrightarrow{\beta} Pa \xrightarrow{\beta} U \xrightarrow{\alpha} Th \xrightarrow{\alpha} {}_{z}Ra^{A} \xrightarrow{\alpha} Rn \xrightarrow{\alpha} Po$$

   (1) 88, 230 (2) 88, 226

   (3) 90, 230 (4) 90, 226

3. Two radioactive nuclei having half life periods 20 years and 15 years respectively have initial activities in the ratio 1 : 2. After how many years, both posses equal activity?

   (1) 60 (2) 120

   (3) 180 (4) 30

4. The count rate of a radioactive source at t = 0 was 1600 counts/s and at t = 8 s, it was 100 counts/s. The count rate at t = 6 s was

   (1) 150 counts/s (2) 300 counts/s

   (3) 200 counts/s (4) 400 counts/s

5. In a sample of radio active material, what fraction of initial number of active nuclei will be disintegrated after half of a half life period?

   (1) $\frac{\sqrt{2}-1}{\sqrt{2}}$ (2) $\frac{1}{4}$

   (3) $\frac{1}{\sqrt{2}}$ (4) $\frac{\sqrt{2}-1}{2}$

6. In the following nuclear reaction, what is x ?

   $${}_{1}H^{2} + {}_{5}B^{10} \rightarrow {}_{6}C^{12} \rightarrow {}_{2}He^{4} + 2x$$

   (1) α-particle (2) Deutron

   (3) β-particle (4) Positron

7. A radioactive element X disintegrates to form Y. At any instant t, the ratio of number of atoms of X and Y are respectively 1 : 15. If initially there is no Y and half life period of X is 15 years, then t in years is

   (1) 70 (2) 50

   (3) 60 (4) 40

8. A radioactive nuclei, decay by two different processes. The half life for 1st and 2nd processes are 5 years and 2 years respectively. Then effective half life is

   (1) 7 years (2) $\frac{10}{7}$ years

   (3) $\frac{7}{10}$ years (4) 3 years

9. What is the relation between half life (t) and average life (T) of a radioactive nucleus?

   (1) $t = \frac{T}{0.693}$ (2) $t = \frac{0.693}{T}$

   (3) $T = \frac{0.639}{t}$ (4) $T = \frac{t}{0.693}$

SECTION - B

Previous Years Questions

1. If the nuclear radius of ^{27}Al is 3.6 fermi, the approximate nuclear radius of ^{64}Cu in fermi is **[AIPMT 2012]**

   (1) 4.8 (2) 3.6

   (3) 2.4 (4) 1.2

2. A mixture consists of two radioactive materials A_1 and A_2 with half lives of 20 s and 10 s respectively. Initially the mixture has 40 g of A_1 and 160 g of A_2. The amount of the two in the mixture will become equal after **[AIPMT 2012]**

   (1) 20 s (2) 40 s

   (3) 60 s (4) 80 s

3. A certain mass of Hydrogen is changed to Helium by the process of fusion. The mass defect in fusion reaction is 0.02866 u. The energy liberated per nucleon is (given 1 u = 931 MeV) **[NEET-2013]**

(1) 26.7 MeV (2) 6.675 MeV

(3) 13.35 MeV (4) 2.67 MeV

4. The half life of a radioactive isotope '*X*' is 20 years. It decays to another element '*Y*' which is stable. The two elements '*X*' and '*Y*' were found to be in the ratio 1 : 7 in a sample of a given rock. The age of the rock is estimated to be **[NEET-2013]**

(1) 60 years (2) 80 years

(3) 100 years (4) 40 years

5. The binding energy per nucleon of $^{7}_{3}Li$ and $^{4}_{2}He$ nuclei are 5.60 MeV and 7.06 MeV, respectively. In the nuclear reaction $^{7}_{3}Li + ^{1}_{1}H \rightarrow ^{4}_{2}He + ^{4}_{2}He + Q$, the value of energy Q released is **[AIPMT 2014]**

(1) 19.6 MeV (2) –2.4 MeV

(3) 8.4 MeV (4) 17.3 MeV

6. A radio isotope *X* with a half life 1.4×10^9 years decays of *Y* which is stable. A sample of the rock from a cave was found to contain *X* and *Y* in the ratio 1 : 7. The age of the rock is **[AIPMT 2014]**

(1) 1.96×10^9 years (2) 3.92×10^9 years

(3) 4.20×10^9 years (4) 8.40×10^9 years

7. A nucleus of uranium decays at rest into nuclei of thorium and helium. Then **[Re-AIPMT-2015]**

(1) The helium nucleus has less kinetic energy than the thorium nucleus

(2) The helium nucleus has more kinetic energy than the thorium nucleus

(3) The helium nucleus has less momentum than the thorium nucleus

(4) The helium nucleus has more momentum than the thorium nucleus

8. If radius of the $^{27}_{13}Al$ nucleus is taken to be R_{Al}, then the radius of $^{125}_{53}Te$ nucleus is nearly **[AIPMT-2015]**

(1) $\left(\frac{13}{53}\right)^{1/3} R_{Al}$ (2) $\left(\frac{53}{13}\right)^{1/3} R_{Al}$

(3) $\frac{5}{3}R_{Al}$ (4) $\frac{3}{5}R_{Al}$

9. The half-life of a radioactive substance is 30 minutes. The time (in minutes) taken between 40% decay and 85% decay of the same radioactive substance is **[NEET (Phase-2) 2016]**

(1) 15 (2) 30

(3) 45 (4) 60

10. Radioactive material 'A' has decay constant '8λ' and material 'B' has decay constant 'λ'. Initially they have same number of nuclei. After what time, the ratio of number of nuclei of material 'B' to that 'A' will be $\frac{1}{e}$? **[NEET - 2017]**

(1) $\frac{1}{\lambda}$ (2) $\frac{1}{7\lambda}$

(3) $\frac{1}{8\lambda}$ (4) $\frac{1}{9\lambda}$

11. The ratio of kinetic energy to the total energy of an electron in a Bohr orbit of the hydrogen atom, is **[NEET - 2018]**

(1) 1 : 1 (2) 1 : –1

(3) 1 : –2 (4) 2 : –1

12. For a radioactive material, half-life is 10 minutes. If initially there are 600 number of nuclei, the time taken (in minutes) for the disintegration of 450 nuclei is **[NEET - 2018]**

(1) 20 (2) 10

(3) 15 (4) 30

13. α-particle consists of **[NEET-2019]**

(1) 2 protons and 2 neutrons only

(2) 2 electrons, 2 protons and 2 neutrons

(3) 2 electrons and 4 protons only

(4) 2 protons only

14. The rate of radioactive disintegration at an instant for a radioactive sample of half life 2.2×10^9 s is 10^{10} s^{-1}. The number of radioactive atoms in that sample at that instant is **[NEET-2019 (Odisha)]**

(1) 3.17×10^{19} (2) 3.17×10^{20}

(3) 3.17×10^{17} (4) 3.17×10^{18}

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Chapter 14

Electronic Devices

Sub-topics

Energy bands in solids (qualitative ideas only), conductors, insulators and semiconductors; semiconductor diode-I-V characteristics in forward and reverse bias, diode as a rectifier; I-V characteristics of LED, photodiode, solar cell, and Zener diode; Zener diode as a voltage regulator. Junction transistor, transistor action, characteristics of a transistor; transistor as an amplifier (common emitter configuration) and oscillator. Logic gates (OR, AND, NOT, NAND and NOR). Transistor as a switch.

Energy Bands in Solids (Qualitative Ideas Only)

They can be classified as :

(1) Metals : They possess very low resistivity or high conductivity. (ρ is of the order of 10^{-2} to 10^{-8} Ω-m).

(2) Insulators : They have high resistivity ($\rho \sim 10^8$ Ω-m).

(3) Semiconductors : They have resistivity intermediate to metals and insulators. ($\rho \sim 10^5$ to 10^0 Ω-m).

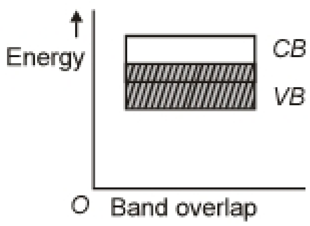
(a) Elemental semiconductor : Si and Ge

(b) Compound semiconductor : CdS, GaAs, anthracene, poly aniline etc.

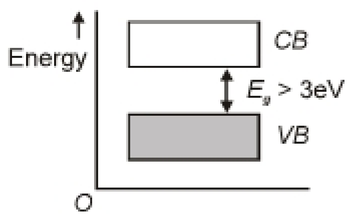
Energy Band : A group of closely spaced energy levels is called energy band. When a solid is formed by a collection of large number of atoms, the energy levels of single atom split into a group of closely spaced energy levels.

Due to merging and splitting of outer energy levels, two energy bands are formed. Lower energy band is called **valence band**. Higher energy band is called **conduction band**.

Conductors

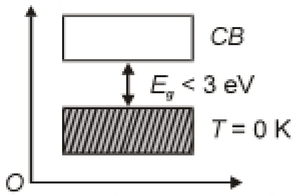


Insulator



Semiconductor

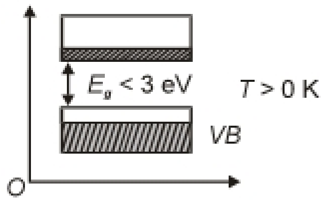
Instrinsic : A semiconductor in pure form.

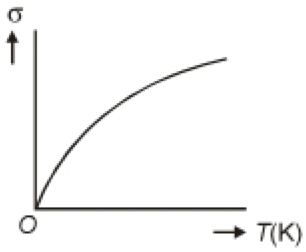


(1) In instrinsic semiconductor, at 0K, *VB* is completely filled and *CB* is completely empty.

(2) Instrinsic semiconductor is pure insulator at 0 K.

(3) At temperature above 0 K (say room temperature) *VB* is partially empty and *CB* is partially filled. Therefore it can conduct at room temperature.





(4) With increase in temperature, number of free electrons in conduction band vary as $n = n_0 e^{-E_g/2kT}$.

Therefore conductivity of semiconductor increases exponentially with increases in temperature.

(5) Jumping of an electron from *VB* to *CB* is equivalent to breaking up of a band and creation of electron- hole pair. The electron created moves to interstitial void.

(6) In an intrinsic semiconductor $n_e = n_h = n_i$

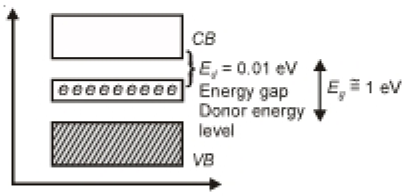
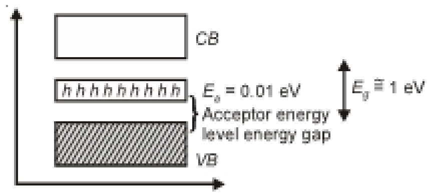
where n_i = number density of intrinsic charge carriers.

(7) n_i is a constant at a given temperature. By doping, n_e or n_h increases, but their product *i.e.*, $n_e n_h$ = constant.

$\Rightarrow$ $n_i^2 = n_e n_h$ = constant (at a given temperature).

Extrinsic Semiconductor

The conduction property of a semiconductor can be drastically changed by addition of impurities (DOPING). A semiconductor with impurity added is called extrinsic semiconductor.

N-type semiconductor	**P-type semiconductor**
1. Pentavalent impurity is added	1. Trivalent impurity is added
2. 	2. 
3. $n_e >> n_h$ but $n_i^2 = n_e n_h$	3. $n_h >> n_e$ but $n_i^2 = n_e n_h$
4. Electrically neutral	4. Electrically neutral
5. Majority charge carriers – electrons	5. Majority charge carriers – holes.

Conductivity : $\sigma = e[n_e\mu_e + n_h\mu_h]$.

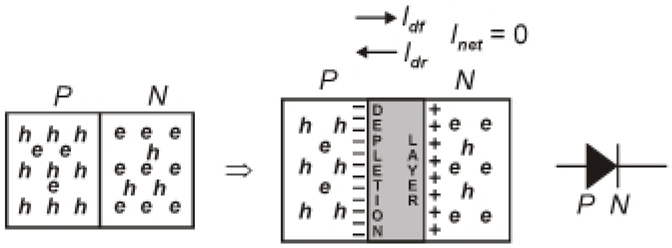
n_e = number density of conduction electrons

n_h = number density of holes

μ_e = mobility of electron = $\frac{v_e}{E}$ (v_e = drift velocity, E = electric field)

μ_h = mobility of holes = $\frac{v_h}{E}$

Semiconductor Diode



(1) Due to concentration difference, diffusion of holes from *P* to *N* and diffusion of electrons from *N* to *P* takes place.

(2) *P* side attains lower potential.

(3) *N* side attains higher potential.

(4) An electric field is created directed from *n*-side to *P*-side.

(5) Any hole near the junction is pushed into left half and electron is pushed into right half.

(6) No free charge carriers are left in a small region near the junction. This is called **Depletion layer**.

Diffusion Current : A current flows from *p*-side to *n*-side due to diffusion of electrons from *n*-side to *p*-side and diffusion of holes from *p*-side of *n*-side. This is due to majority charge carriers.

Drift Current : A current flows from *n*-side to *p*-side due to drifting of minority charge carriers.

Diffusion current increases with decrease in strength of electric field and vice versa.

Drift current is fairly independent of electric field unless it is very strong. In this situation, the electric field may cause breaking up of bonds and large amount of drift current flows in a circuit. This situation is called break down. Break down voltage depends on doping.

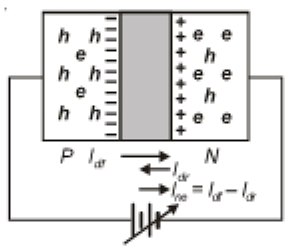
Zener breakdown : When doping is very high, zener breakdown takes place.

Avalanche Breakdown : When doping is not so high, avalanche break down takes place.

***Note :** For an unbiased P-N junction, $I_{df} = I_{dr}$ i.e., $I_{net} = 0$.*

I-V Characteristics

Forward Bias



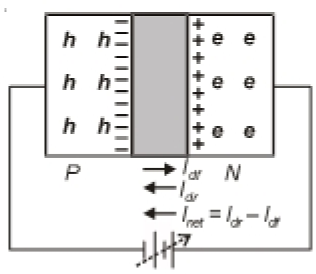
(1) Barrier electric field strength decreases.

(2) $I_{df} > I_{dr}$

(3) Thickness of depletion layer decreases.

(4) *P-N* junction offers low resistance.

Reverse Bias

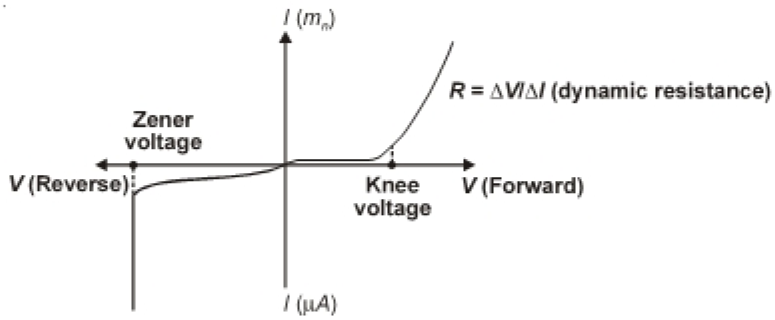


(1) Barrier electric field strength increases.

(2) $I_{dr} > I_{df}$

(3) Thickness of depletion layer increases.

(4) *P-N* junction offers high resistance.

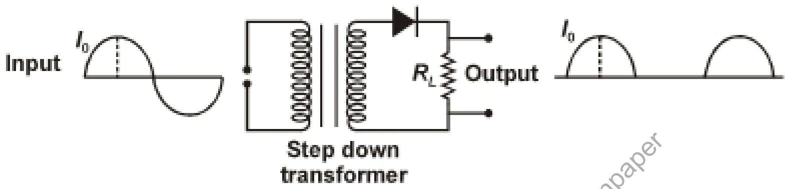


(5) In reverse bias resistance is high, but at breakdown, $R = 0 \Rightarrow \Delta V = 0$ or V = constant.

(6) As a *P-N* junction conduct only in one direction, it is called diode valve.

Diode as a rectifier

(a) Half wave rectifier



$I_{rms} = \frac{I_0}{2}$

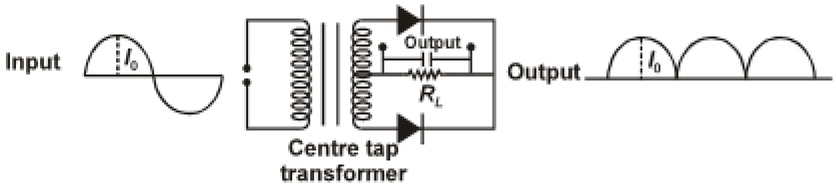
$I_{mean} = \frac{I_0}{\pi}$

(i) Input frequency = Output frequency of ripple

(ii) Maximum Efficiency = 40.6%

(iii) Ripple factor $r = \frac{\text{ac component}}{\text{dc component}} = \sqrt{\frac{I_{rms}^2}{I_{mean}^2} - 1} = 1.21$

(b) Full Wave Rectifier



$I_{rms} = \frac{I_0}{\sqrt{2}}$

$I_{mean} = \frac{2I_0}{\pi}$

(i) Output ripple frequency = 2 × input frequency

(ii) Maximum Efficiency = 81.2%.

(iii) Ripple factor $r = 0.48$

I-V characteristics of LED

When a junction diode is forward biased, energy is released at the junction due to recombination of electrons and holes. In case of silicon and germanium diodes, the energy released is in infrared region. In the junction diode made of gallium arsenide or indium phosphide, the energy is released in visible region. Forbidden energy gap for GaAs is 1.4 eV which gives infrared radiation when recombination of electrons and holes takes place but when this is doped with *Al*, the width of depletion region increases, so it gives visible light in forward bias.

Light emitting diode is a heavily doped *p-n* junction encapsulated with a transparent cover so that emitted light can come out. When the forward current of the diode is small the intensity of light emitted is small. As the forward current increases, intensity of light increases and reaches a maximum. Further increase in the forward current results in decrease of light intensity. LEDs are biased such that the light emitting efficiency is maximum.

The V-I characteristics of a LED is similar to that of a silicon junction diode but the threshold voltages are much higher and slightly different of each colour. The reverse breakdown voltages of LEDs are very low, approximately around 5 V. So high reverse voltages should not appear across them.

LEDs are used in remote controls, burglar alarm systems, optical communication system etc. Advantages of LEDs over low power conventional incandescent lamps is that they have less operational voltages, less power consumption, fast action with no warm up time, are nearly monochromatic, have long life and ruggedness and have quick switching on-off capability.

Photo diode

In semiconductors, current carriers are produced when energy is supplied to release electrons from valence band. In photo diodes this energy is supplied in the form of light energy. A junction diode made from photo sensitive semiconductor is called a photo diode. It is represented by the symbol as shown in figure. In photodiode one region is made so thin that incident light may reach the depletion region.

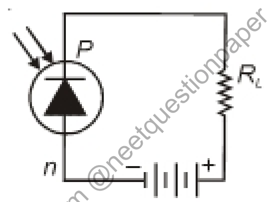


Photo diode is operated under reverse bias. When the photo diode is illuminated with energy greater than the energy gap (E_g) of the semiconductor, then electron-hole pairs are generated. The construction of photo diode is such that electron-hole pairs are generated in or near the depletion region of the diode. Inside the diode, electric field is such that electrons are collected on N-side and holes are collected on P-side giving rise to an emf. Hence, when an external resistance is connected then current flows through it. The photo- current is proportional to incident light intensity.

If a photo diode is forward biased then photo current will be more, still a photo-diode is connected in reverse bias because fractional change in reverse biased current is easier to observe when light intensity falling on it changes. Thus photodiodes can be used as photodetector to detect optical signals. The typical characteristics of photodiode is shown below.

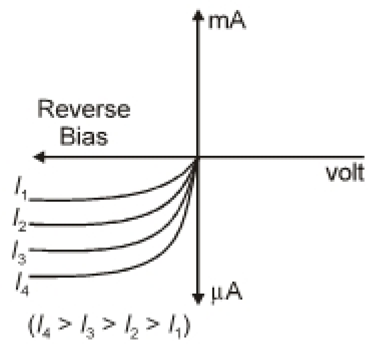
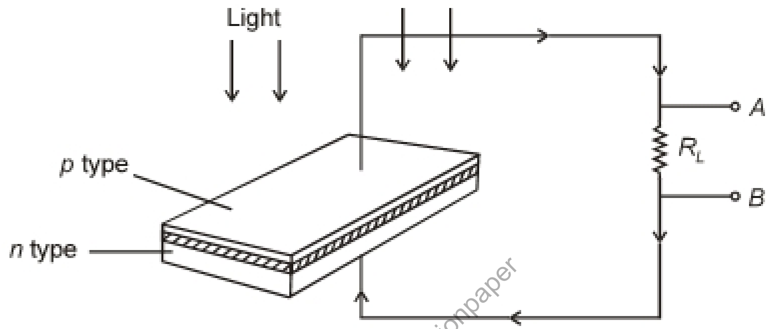


Fig. : Characteristics of photo diode for different illumination intensity $I_4 > I_3 > I_2 > I_1$

Solar cell

A junction diode, in which one of the *p* or *n*-regions is made very thin (so that the light energy falling on the diode is not greatly absorbed before reaching the junction), can be used to convert light energy into electrical energy.

In a solar cell one region is made very thin so that most of the light incident on it reaches the depletion region. In this diode (selenium is used as semiconductor) when photons of visible light incident to depletion region, electrons jump from valence band to conduction band producing electron-hole pairs. These free electrons under the influence of barrier electric field moves to *n* region and holes move to *p* region, so the potential of *p* region increases and that of *n* region decreases. A net potential difference develops across the junction. Hence when a load resistance is connected to *p*-*n* junction, electrons flow in the resistor from *B* to *A* resulting into a net current from *A* to *B* as shown in figure.



Note that the *I*-*V* characteristics of solar cell is drawn in the fourth quadrant of the co-ordinate axes. This is because a solar cell does not draw current but supplies the same to the load.

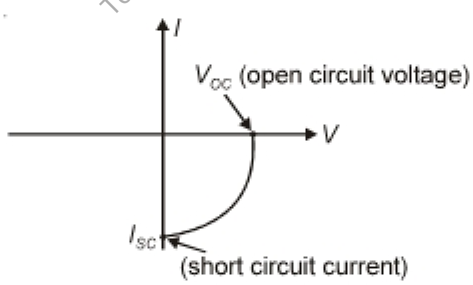


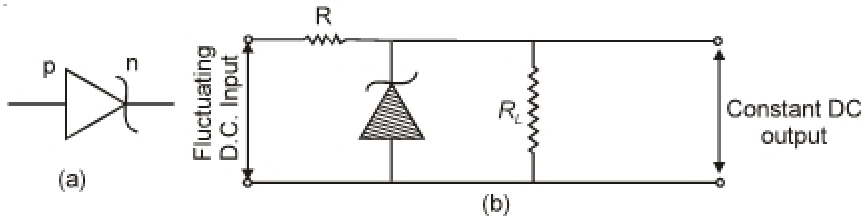
Fig : *I*-*V* characteristics of solar cell

Since solar radiation spectrum has maximum intensity at 1.5 eV, therefore, semiconductors with band gap close to 1.5 eV are ideal materials for solar cell fabrication. Materials used are Si, GaAs, CdTe, Cu In Se_2 etc. Materials should have high optical absorption, electrical conductivity, low cost and availability. Solar cells are extensively used to power electronic devices in satellites and space vehicles, in calculators etc.

Zener diode

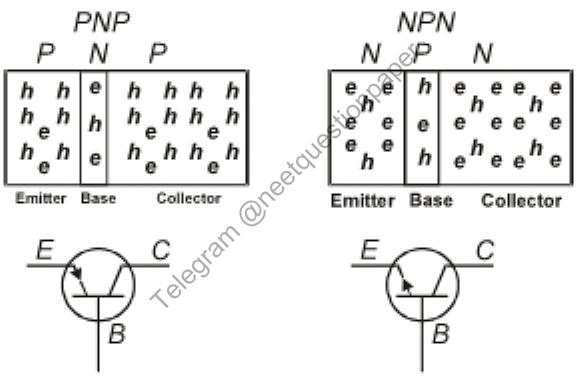
In the usual junction diodes, the reverse current increases rapidly at large reverse breakdown voltage. The junction diodes of low power rating are destroyed by reverse breakdown voltage. The specially designed junction diodes which can operate in the reverse breakdown voltage region continuously without being damaged, are called Zener diodes. These are generally highly doped Silicon diodes. Silicon is preferred over germanium because of its higher thermal stabilities.

A Zener diode is represented by the symbol shown in figure (a)



An important application of Zener diode is that it can be used as a voltage regulator. The regulating action takes place because of the fact that in reverse breakdown region, a very small change in voltage produces a very large change in current. In the Zener region, the resistance of the Zener diode drops considerably. Let us consider a Zener diode and a dropping resistor R connected to a fluctuating dc supply such that Zener diode is reverse biased [figure (b)]. When the applied voltage is such that the voltage across Zener is less than Zener voltage, the diode will not conduct. Hence the output voltage will be proportional to the input voltage and is given by $V_{out} = \frac{R_L}{R+R_L}V_{in}$, but when input voltage is such that the voltage developed across the Zener is more than Zener voltage, the diode will conduct and will offer very small resistance. Hence it will allow all the extra current and the output voltage will be equal to Zener voltage *i.e.*, $V_{out} = V_z$. But every Zener diode has a certain value of current limit and corresponding power limit. If the current in the Zener diode exceeds this limit, the diode will burn out. Note that Zener diode is always used in reverse bias.

Junction Transistor



(1) Arrow represents the direction of flow of emitter current or flow of majority charge carriers.

(2) Emitter is very heavily doped.

(3) Base is made thin and very lightly doped.

(4) Doping (base) < Doping (collector) < Doping (emitter) and collector is wider than emitter.

Transistor Action

(1) Active state : When *E-B* junction is forward biased and *C-B* junction is reverse biased.

(2) Saturation state : When *E-B* junction is forward biased and *C-B* junction is also forward biased.

(3) Cut off state : When both *E-B* and *C-B* junction are reverse biased.

Transistor is used in active state as an amplifier.

Current equation for transistor is $\boxed{I_e = I_b + I_c}$

Characteristics of a Transistor

In CE configuration, the input is between the base and the emitter and the output is between the collector and the emitter. The variation of the base current I_b with base-emitter voltage E_{be} is called the 'input characteristic'. Similarly, the variation of the collector current I_c with the collector-emitter voltage E_{ce} is called the output characteristic. Note that if base current is increased or decreased then collector (as well as emitter)current increases and decreases respectively.

The typical input characteristic graph between I_b and E_{be} is shown below in Fig (a). The collector emitter voltage E_{ce} is kept fixed while studying the dependence of I_b on E_{be}. It will be like forward biased diode graph as expected, because emitter base junction in a transistor is forward biased

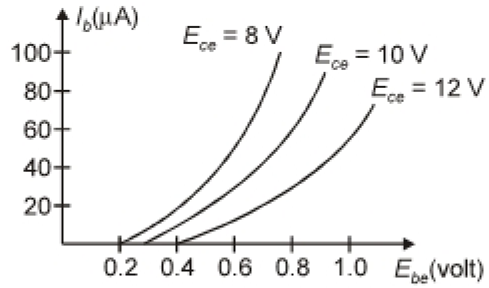


Fig (a) : Typical input characteristic of CE configuration

Since the increase in E_{ce} appears as increase in E_{cb}, its effect on I_b is negligible. As a consequence, input characteristics for various values of E_{ce} will give almost identical curves. Hence, it is enough to determine only one input characteristic curve.

The output characteristic is obtained by observing the variation of I_c as E_{ce} is varied keeping I_b constant. It is obvious that if E_{be} is increased by a small amount, both hole current from the emitter region and the electron current from the base region will increase. As a consequence both I_b and I_c will increase proportionately. This shows that when I_b increases I_c also increases. The plot of I_c versus E_{ce} for different fixed values of I_b gives one output characteristic. So there will be different output characteristics corresponding to different values of I_b as shown in Fig (b).

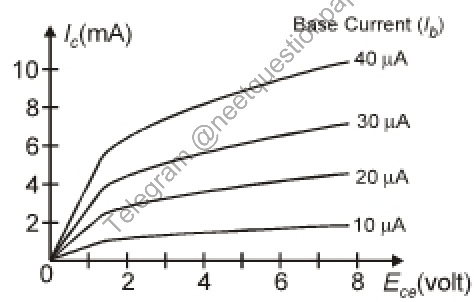
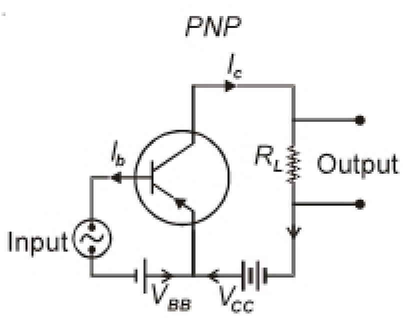
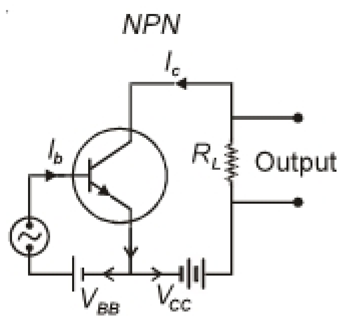


Fig (b) : Output characteristics of CE configuration

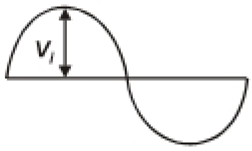
Transistor as an amplifier (Common Emitter Configuration)

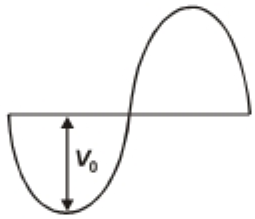
$$\boxed{I_e = I_b + I_c}$$





Input $V_i = V_i \sin \omega t$ Output $V_0 = V_0 \sin (\omega t \quad \pi)$





(1) There is phase reversal of 180°.

(2) DC current gain $\beta = \frac{I_c}{I_b}$.

(3) AC current gain $\beta_{ac} = \frac{\Delta I_c}{\Delta I_b}$.

(4) AC voltage gain $A_v = \frac{\Delta V_0}{\Delta V_i}$.

(5) Resistance gain $R_g = \frac{R_L}{R_i}$ (R_i = input resistance).

(6) Power gain $P_g = A_v \times \beta_{ac}$.

(7) $A_V = -\beta_{ac} \times R_g$. (negative sign shows a phase difference of 180°)

(8) Trans conductance $g_m = \frac{\Delta I_c}{\Delta V_i}$

(9) $A_v = -g_m \times R_L$

Some other related points

(1) For amplifiers in series, voltage gains get multiplied.

(2) $\frac{1}{\alpha} - \frac{1}{\beta} = 1$ $\left(\alpha = \frac{I_C}{I_E}\right)$

(3) $\alpha = \frac{\beta}{\beta + 1}$

(4) $\beta = \frac{\alpha}{1 - \alpha}$

(5) $\alpha < 1$, $\beta > 1$

Transistor as a Switch

Consider CE configuration of transistor as shown below in figure (A)

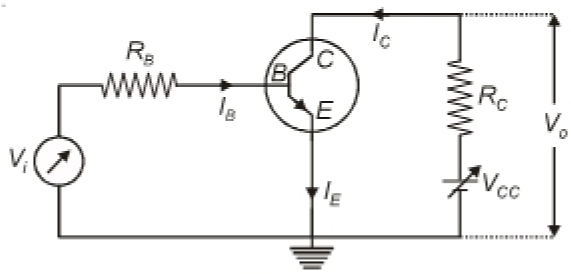


Figure (A)

Applying Kirchhoff's voltage rule to the input and output sides of this circuit we get

$V_i = I_B \cdot R_B + V_{BE}$ (V_i = dc input voltage)

and $V_o = V_{CC} - I_C \cdot R_C$ (V_o = dc output voltage)

Now we can analyse how V_o changes as V_i increases from zero onwards.In case of Silicon transistor, if V_i is less than 0.6 V, I_B will be zero, hence I_C will be zero and transistor will be said to be in cut-off state, and $V_o = V_{CC}$. When V_i becomes greater than 0.6 V, some I_B flows, so some I_C flows (transistor is in active state now) and output V_o decreases as the term $I_C \cdot R_C$ increases. With increase in V_i, the I_C increases almost linearly and so V_o decreases linearly till its value becomes less than about 1.0 volt.

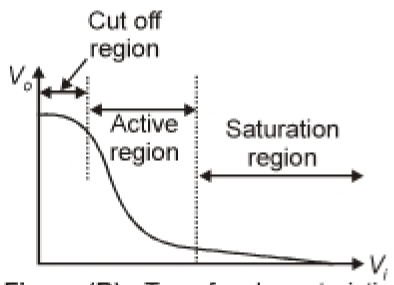


Figure (B) : Transfer characteristic

Beyond this, the change becomes non linear and transistor goes into saturation state. With further increase in V_i the output voltage is found to decrease further towards zero (however, it may never become zero). If we draw the V_o versus V_i curve [Figure-(B)], we see that between cut off state and active state and also between active state and saturation state there are regions of non-linearity showing that the transition from cut-off state to active state and from active state to saturation state are not sharply defined.

Now the operation of transistor as a switch is understood the following way. When V_i is low (in cut off region), V_o is high. If V_i is high (in saturation region), then V_o is low, almost zero. If we define low and high states as below and above certain voltage levels corresponding to cutoff and saturation of the transistor, then we can say that a low input switches the transistor off and high input switches it on. Alternatively, we can say that a low input to the transistor gives a high output and a high input gives a low output. The switching circuits are designed in such a way that the transistor does not remain in active state.

Transistor as an Oscillator

The purpose of this circuit is to generate large energy sinusoidal wave of desired frequency.

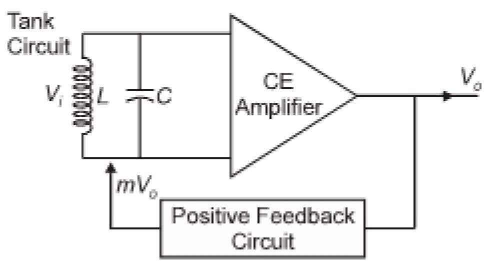


Figure (a) : Block diagram of feedback oscillator circuit

As shown in the block diagram of Figure (a), we have a tank circuit which is essentially an L-C oscillation circuit. It generates electrical oscillation (of low energy) of desired frequency given by $f = \frac{1}{2\pi\sqrt{LC}}$.

This oscillating signal is then fed into a CE transistor amplifier where its power increases and it is sent as output V_o. In a practical tank circuit, there are resistive and radiation losses in the coil L and dielectric losses in capacitor C. During each cycle, a small part of the originally imparted energy is used up to overcome these losses. The result is that the amplitude of oscillating current decreases gradually and eventually it becomes zero when all the energy is consumed as losses. However, in practice, we need continuous undamped oscillations for the successful operation of electronics equipment. In order to make the oscillations in the tank circuit undamped, it is necessary to supply correct amount of energy to the tank circuit at the proper time intervals to meet the losses. This is done by taking small fraction of output energy (mV_o) and feeding to the tank circuit with the help of positive feedback circuit. 'Positive' word implies that the applied feedback energy is in phase with the tank circuit oscillations. Also the applied feedback energy has the same energy as that of the oscillations in the tank circuit.

Here $\frac{V_o}{V_i} = A_{fb}$ (gain of the complete amplifier with positive feedback)

If A is the gain of transistor CE amplifier (without feedback) then you can see $A = \frac{V_o}{V_i + mV_o}$, where m is feedback fraction. This gives $A_{fb} = \frac{V_o}{V_i} = \frac{A}{1 - mA}$. In order to produce continuous undamped oscillations at the output terminals of the amplifier, the positive feedback should be such that $m \cdot A = 1$. Once this condition is set in the amplifier with positive feedback, continuous undamped oscillations can be obtained at the output immediately after connecting the necessary power supplies.

In actual practice, a CE transistor amplifier is used with LC oscillation as the input signal. Variable capacitor ensures signal frequency of desired value as shown in Figure (b). The output of CE amplifier is 180° out of phase with the input signal. So, it can't be directly used as a feedback signal, as it will work as negative feedback. So the output is passed through another inductor L_2 which is mutually inducted with inductor L_1 of tank circuit. As per Lenz's law the current induced in L_1 is again 180° out of phase (opposing nature of induced emf) of L_2. So now current induced in L_1 is in phase with itself and that is the way 'positive feedback' is ensured in the tank circuit. (Here M is the coefficient of mutual induction between L_1 and L_2). Value of M will decide the feedback fraction m. Now the final output will be put into load resistance R_L from where it can be used as high energy wave of desired frequency $f = \frac{1}{\sqrt{2\pi L_1 C}}$.

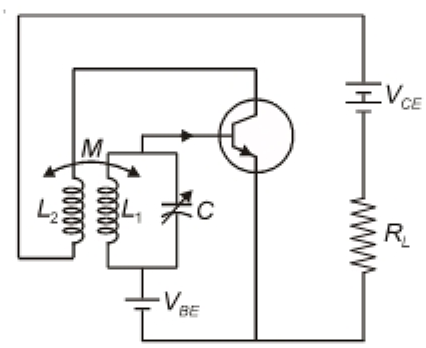


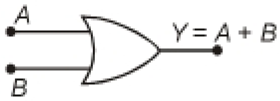
Figure (b) : Transistor as an oscillator

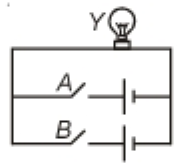
There are many other types of tank circuits (say RC) or feedback circuits giving different types of oscillators like Colpitt's oscillator, Hartley oscillator, RC-oscillator.

Logic Gates

OR Gate : $Y = A + B$

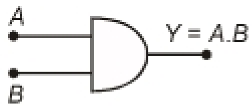
A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

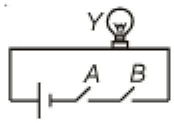




AND Gate : $Y = A.B$

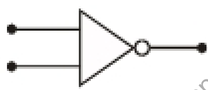
A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

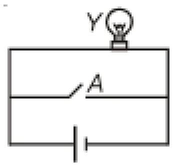




NOT Gate : $Y = \overline{A}$

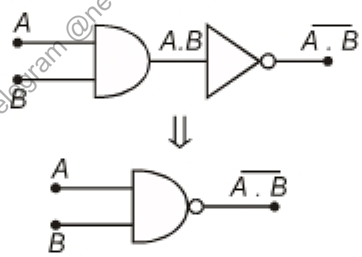
A	Y
0	1
1	0

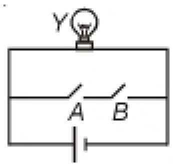




NAND : $Y = \overline{A.B} = \overline{A} + \overline{B}$

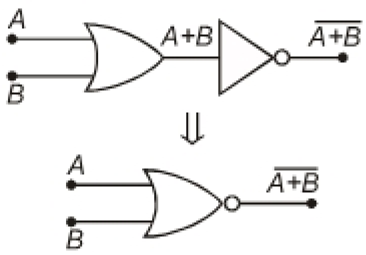
A	B	$A.B$	$\overline{A.B}$
0	0	0	1
0	1	0	1
1	0	0	1
1	1	1	0

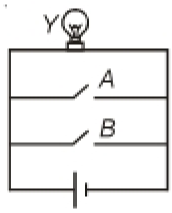




NOR : $Y = \overline{A+B} = \overline{A}.\overline{B}$

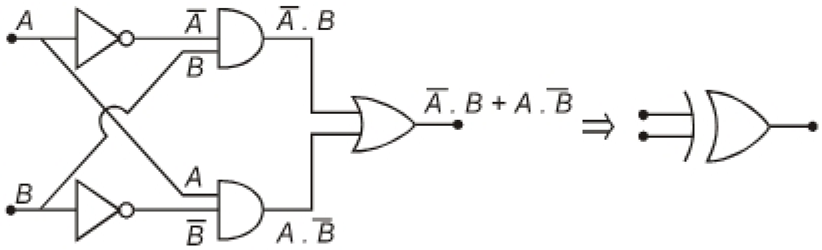
A	B	$A + B$	$\overline{A+B}$
0	0	0	1
0	1	1	0
1	0	1	0
1	1	1	0





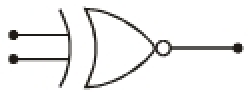
XOR Gate : $Y = \overline{A}.B + A.\overline{B}$

A	B	$\overline{A}$	$\overline{B}$	$\overline{A}.B$	$A.\overline{B}$	$\overline{A}.B + A.\overline{B}$
0	0	1	1	0	0	0
0	1	1	0	1	0	1
1	0	0	1	0	1	1
1	1	0	0	0	0	0



XNOR Gate : $Y = \overline{(\bar{A}.B + A.\bar{B})} = \bar{A}.\bar{B} + A.B = (\bar{A} + B).(A + \bar{B})$

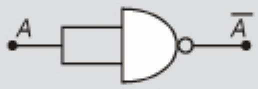
A	B	Y
0	0	1
0	1	0
1	0	0
1	1	1



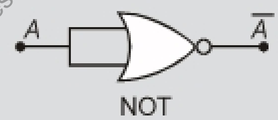
Note :

NAND or NOR (called universal gates) alone can be used to realise NOT, AND and OR gate.

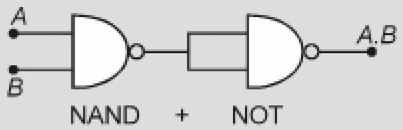
(1) NOT Gate :



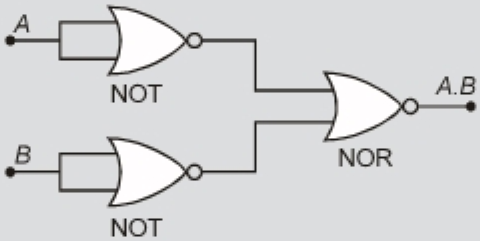
or



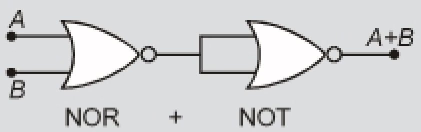
(2) AND Gate :



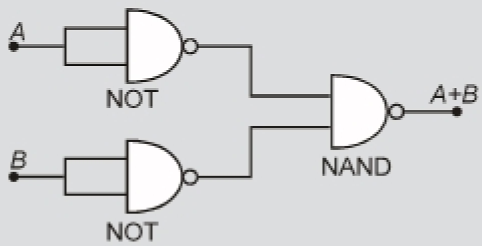
or

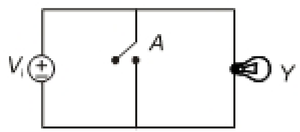
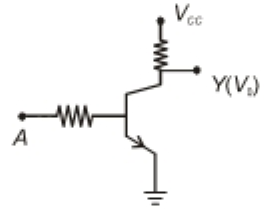
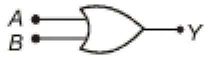
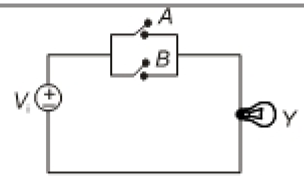
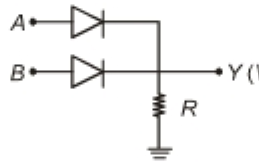
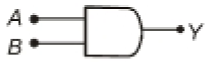
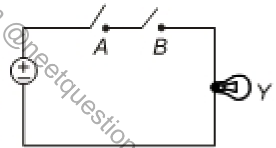
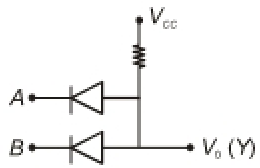
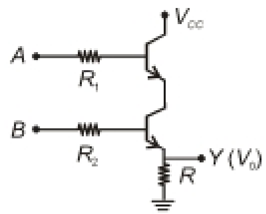
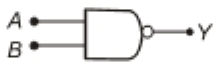
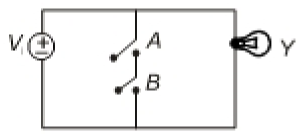
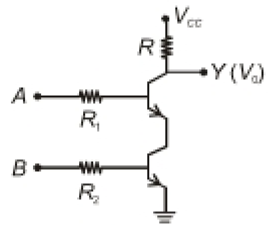
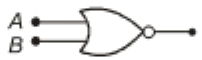
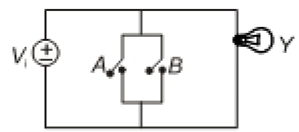
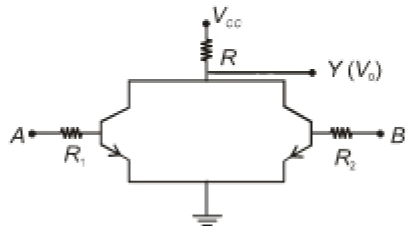


(3) OR Gate :



or



<table>
<tr><th>Logic gate</th><th>Symbol</th><th>Characteristic equation</th><th>Truth table</th><th colspan="3">Realization circuit</th></tr>
<tr><td>NOT</td><td></td><td>$Y = \overline{A}$</td><td><table><tr><th>A</th><th>Y</th></tr><tr><td>0</td><td>1</td></tr><tr><td>1</td><td>0</td></tr></table></td><td></td><td colspan="2"></td></tr>
<tr><td>OR</td><td></td><td>$Y = A + B$</td><td><table><tr><th>A</th><th>B</th><th>Y</th></tr><tr><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>1</td></tr><tr><td>1</td><td>0</td><td>1</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table></td><td></td><td colspan="2"></td></tr>
<tr><td>AND</td><td></td><td>$Y = A \bullet B$</td><td><table><tr><th>A</th><th>B</th><th>Y</th></tr><tr><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>0</td></tr><tr><td>1</td><td>0</td><td>0</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table></td><td></td><td></td><td></td></tr>
<tr><td>NAND</td><td></td><td>$Y = \overline{A \bullet B}$</td><td><table><tr><th>A</th><th>B</th><th>Y</th></tr><tr><td>0</td><td>0</td><td>1</td></tr><tr><td>0</td><td>1</td><td>1</td></tr><tr><td>1</td><td>0</td><td>1</td></tr><tr><td>1</td><td>1</td><td>0</td></tr></table></td><td></td><td colspan="2"></td></tr>
<tr><td>NOR</td><td></td><td>$Y = \overline{A + B}$</td><td><table><tr><th>A</th><th>B</th><th>Y</th></tr><tr><td>0</td><td>0</td><td>1</td></tr><tr><td>0</td><td>1</td><td>0</td></tr><tr><td>1</td><td>0</td><td>0</td></tr><tr><td>1</td><td>1</td><td>0</td></tr></table></td><td></td><td colspan="2"></td></tr>
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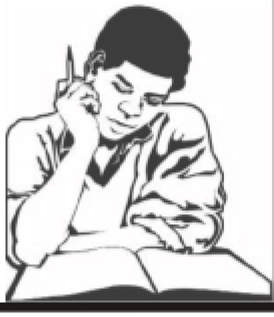
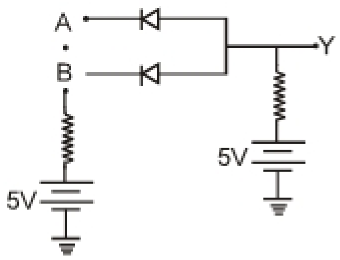


Try Yourself

SECTION - A

Objective Type Questions

1. The following circuit constructed using PN junctions denote (input - *A* and *B*, output - *Y*)



(1) OR gate

(2) AND gate

(3) NOT gate

(4) XOR gate

2. In case of an unbiased PN junction

(1) N side is at higher potential than P side

(2) N side is at lower potential than P side

(3) There is no potential difference exists

(4) No electric field is present

3. For a transistor amplifier circuit

(1) Current gain in case of CE mode is larger than CB mode

(2) Power gain in case of CE mode is larger than CB mode

(3) In both CB and CE mode, base current is very small

(4) All of these

4. For a transistor (α = 0.96) operating in CE mode, if input resistance and load resistance are respectively 1Ω and 1 kΩ, the voltage gain is

(1) 960 (2) 60×10^{-5}

(3) 24000 (4) 3720

5. For a P-type semiconductor

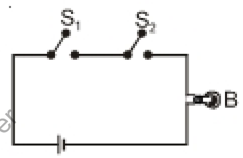
(1) Free electrons are the majority charge carrier

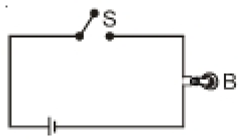
(2) Impurity atoms are known as donor atom

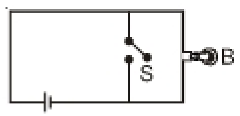
(3) Conductivity is more than N-type semiconductor

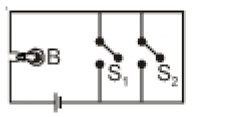
(4) Impurity atoms are known as acceptor atom

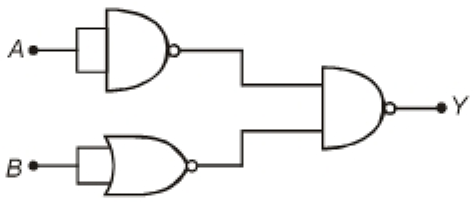
6. The analogus equivalent circuit for NOT gate is

(1) 

(2) 

(3) 

(4) 

7. 

For the above circuit, *Y* is

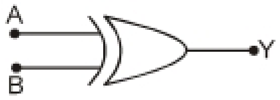
(1) *A*

(2) *B*

(3) *A* + *B*

(4) *A*·*B*

8. The truth table for following gate with A, B as inputs and Y as output is



(1)

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

(2)

A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

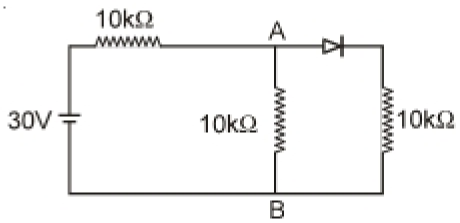
(3)

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	1

(4)

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	0

9. In the following figure, assuming the diode to be ideal, potential difference between *A* and *B* is



(1) 0
(2) 5 V
(3) 10 V
(4) 15 V

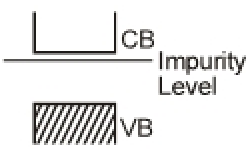
10. In a common emitter transistor amplifier, using output resistance of 5000 Ω and input resistance of 2000 Ω, if the peak value of input signal voltage is 10 mV and β = 50, then the peak value of output voltage is

(1) 5×10^{-6} V
(2) 12.5×10^{-4} V
(3) 125 V
(4) 1.25 V

11. The electrical conductivity of a pure germanium can be increased by

(1) Dopping acceptor/donor impurities
(2) Increasing the temperature
(3) Irradiating infrared light on it
(4) All of these

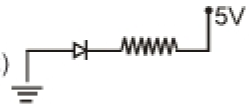
12. The shown band diagram at absolute zero is for



(1) P-type semiconductor
(2) N-type semiconductor
(3) Intrinsic semiconductor
(4) Conductor

13. Which of the following diode is forward biased?

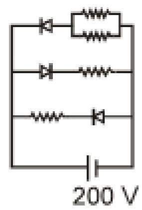
(1) 

(2) 

(3) 

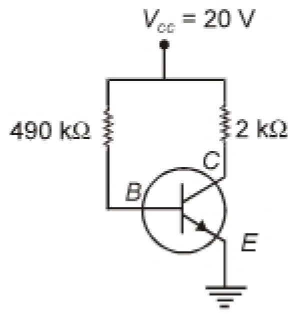
(4) 

14. Calculate the current from the cell in the following circuit, if all the diodes are ideal. All the resistances are of 200 Ω.



(1) Zero
(2) 1 A
(3) 2 A
(4) 4 A

15. In a common emitter transistor circuit, the current amplification factor β is 50 and I_c = 2 mA, calculate V_{BE}



(1) 2 V
(2) 1 V
(3) 0.4 V
(4) 0.3 V

16. Copper has face centred cubic lattice with interatomic spacing 2.5 Å. The value of lattice constant will be about.

(1) 0.35 Å
(2) 3.5 Å
(3) 7.0 Å
(4) 1.5 Å

17. Distance between body centred atom and a corner atom in sodium is (where *a* = lattice constant)

(1) $\frac{a\sqrt{3}}{2}$
(2) $a\sqrt{3}$
(3) $\frac{a\sqrt{3}}{4}$
(4) $a\sqrt{2}$

18. Liquid crystal display monitors are made of

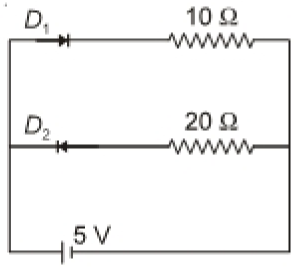
(1) Monocrystals (2) Single crystals

(3) Liquid crystals (4) Polycrystals

SECTION - B

Previous Years Questions

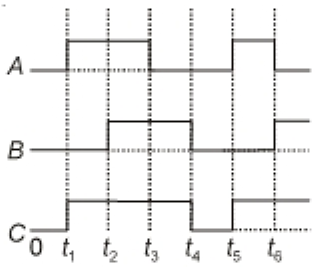
1. Two ideal diodes are connected to a battery as shown in the circuit. The current supplied by the battery is **[AIPMT 2012]**



(1) 0.25 A (2) 0.5 A

(3) 0.75 A (4) Zero

2. The figure shows a logic circuit with two inputs *A* and *B* and the output *C*. The voltage wave forms across *A*, *B* and *C* are as given. The logic circuit gate is **[AIPMT 2012]**



(1) AND gate (2) NAND gate

(3) OR gate (4) NOR gate

3. In a CE transistor amplifier, the audio signal voltage across the collector resistance of 2 kΩ is 2 V. If the base resistance is 1 kΩ and the current amplification of the transistor is 100, the input signal voltage is **[AIPMT 2012]**

(1) 1 mV

(2) 10 mV

(3) 0.1 V

(4) 1.0 V

4. C and Si both have same lattice structure, having 4 bonding electrons in each. However, C is insulator whereas Si is intrinsic semiconductor. This is because **[AIPMT 2012]**

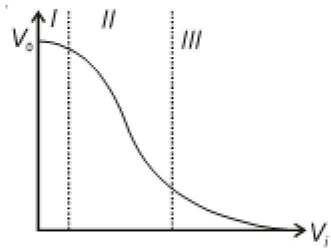
(1) The four bonding electrons in the case of C lie in the second orbit, whereas in the case of Si they lie in the third.

(2) The four bonding electrons in the case of C lie in the third orbit, whereas for Si they lie in the fourth orbit.

(3) In case of C the valance band is not completely filled at absolute zero temperature.

(4) In case of C the conduction band is partly filled even at absolute zero temperature.

5. Transfer characteristics [output voltage (V_0) vs input voltage (V_i)] for a base biased transistor in CE configuration is as shown in the figure. For using transistor as a switch, it is used **[AIPMT 2012]**



(1) In region II

(2) In region I

(3) In region III

(4) Both in region (I) and (III)

6. In a *n*-type semiconductor, which of the following statement is true? **[NEET-2013]**

(1) Electron are minority carriers and pentavalent atoms are dopants

(2) Holes are minority carriers and pentavalent atoms are dopants

(3) Holes are majority carriers and trivalent atoms are dopants

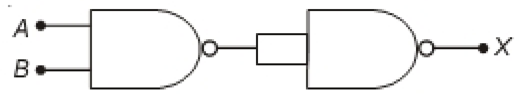
(4) Electrons are majority carriers and trivalent atoms are dopants

7. In a common emitter (CE) amplifier having a voltage gain *G*, the transistor used has transconductance 0.03 mho and current gain 25. If the above transistor is replaced with another one with transconductance 0.02 mho and current gain 20, the voltage gain will be **[NEET-2013]**

(1) 1.5 *G* (2) $\frac{1}{3}G$

(3) $\frac{5}{4}G$ (4) $\frac{2}{3}G$

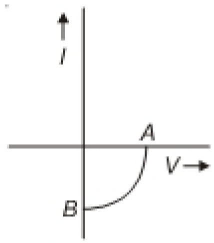
8. The output (X) of the logic circuit shown in figure will be **[NEET-2013]**



(1) $X = \overline{A.B}$ (2) $X = A.B$

(3) $X = \overline{A+B}$ (4) $X = \overline{\overline{A}}.\overline{\overline{B}}$

9. The given graph represents $V - I$ characteristic for a semiconductor device.



Which of the following statement is **correct**? **[AIPMT 2014]**

(1) It is $V - I$ characteristic for solar cell where point A represents open circuit voltage and point B short circuit current

(2) It is for a solar cell and points A and B represent open circuit voltage and current, respectively

(3) It is for a photodiode and points A and B represent open circuit voltage and current, respectively

(4) It is for a LED and points A and B represents open circuit voltage and short circuit current respectively

10. The barrier potential of a p-n junction depends on:

a. Type of semiconductor material

b. Amount of doping

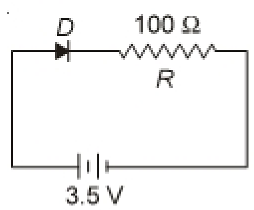
c. Temperature

Which one of the following is correct? **[AIPMT 2014]**

(1) a and b only (2) b only

(3) b and c only (4) a, b and c

11. In the given figure, a diode D is connected to an external resistance R = 100 Ω and an e.m.f. of 3.5 V. If the barrier potential developed across the diode is 0.5 V, the current in the circuit will be



[Re-AIPMT-2015]

(1) 35 mA (2) 30 mA

(3) 40 mA (4) 20 mA

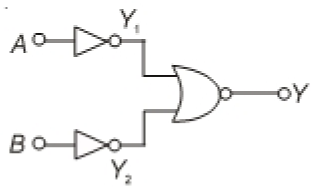
12. The input signal given to a CE amplifier having a voltage gain of 150 is $V_i = 2\cos\left(15t + \frac{\pi}{3}\right)$. The corresponding output signal will be

[Re-AIPMT-2015]

(1) $300\cos\left(15t + \frac{4\pi}{3}\right)$ (2) $300\cos\left(15t + \frac{\pi}{3}\right)$

(3) $75\cos\left(15t + \frac{2\pi}{3}\right)$ (4) $2\cos\left(15t + \frac{5\pi}{6}\right)$

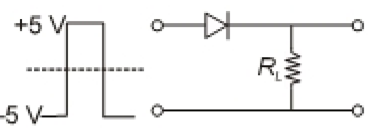
13. Which logic gate is represented by the following combination of logic gates? **[AIPMT-2015]**



(1) NOR (2) OR

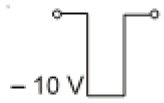
(3) NAND (4) AND

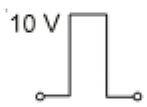
14. If in a p-n junction, a square input signal of 10 V is applied, as shown

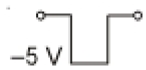


then the output across R_L will be **[AIPMT-2015]**

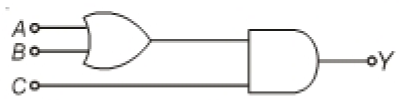
(1) 

(2) 

(3) 

(4) 

15. To get output 1 for the following circuit, the correct choice for the input is **[NEET-2016]**



(1) A = 1, B = 0, C = 1

(2) A = 0, B = 1, C = 0

(3) A = 1, B = 0, C = 0

(4) A = 1, B = 1, C = 0

16. Consider the junction diode as ideal. The value of current flowing through *AB* is **[NEET-2016]**

(1) 10^{-3} A (2) 0 A

(3) 10^{-2} A (4) 10^{-1} A

17. A *npn* transistor is connected in common emitter configuration in a given amplifier. A load resistance of 800 Ω is connected in the collector circuit and the voltage drop across it is 0.8 V. If the current amplification factor is 0.96 and the input resistance of the circuit is 192 Ω, the voltage gain and the power gain of the amplifier will respectively be **[NEET-2016]**

(1) 4, 3.69 (2) 4, 3.84

(3) 3.69, 3.84 (4) 4, 4

18. For CE transistor amplifier, the audio signal voltage across the collector resistance of 2 kΩ is 4 V. If the current amplification factor of the transistor is 100 and the base resistance is 1 kΩ, then the input signal voltage is

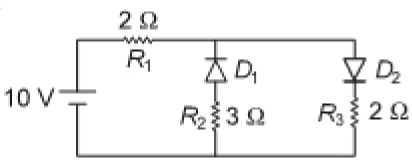
[NEET (Phase-2) 2016]

(1) 10 mV (2) 20 mV

(3) 30 mV (4) 15 mV

19. The given circuit has two ideal diodes connected as shown in the figure below. The current flowing through the resistance R_1 will be

[NEET (Phase-2) 2016]



(1) 2.5 A (2) 10.0 A

(3) 1.43 A (4) 3.13 A

20. What is the output *Y* in the following circuit, when all the three inputs *A*, *B*, *C* are first 0 and then 1?

[NEET (Phase-2) 2016]

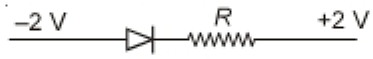
(1) 0, 1 (2) 0, 0

(3) 1, 0 (4) 1, 1

21. Which one of the following represents forward bias diode? **[NEET - 2017]**

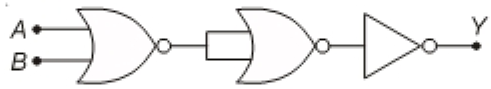
(1) 

(2) 

(3) 

(4) 

22. The given electrical network is equivalent to **[NEET - 2017]**



(1) AND gate (2) OR gate

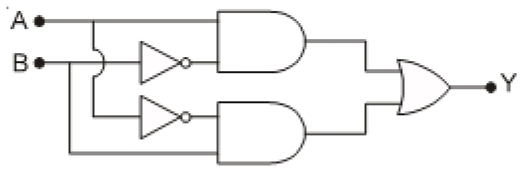
(3) NOR gate (4) NOT gate

23. In a common emitter transistor amplifier the audio signal voltage across the collector is 3 V. The resistance of collector is 3 kΩ. If current gain is 100 and the base resistance is 2 kΩ, the voltage and power gain of the amplifier is **[NEET - 2017]**

(1) 200 and 1000 (2) 15 and 200

(3) 150 and 15000 (4) 20 and 2000

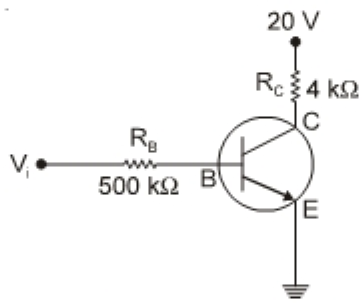
24. In the combination of the following gates the output Y can be written in terms of inputs A and B as **[NEET - 2018]**



(1) $\overline{A\cdot B}$ (2) $A\cdot\overline{B}+\overline{A}\cdot B$

(3) $\overline{A+B}$ (4) $\overline{A\cdot B}+A\cdot B$

25. In the circuit shown in the figure, the input voltage V_i is 20 V, V_{BE} = 0 and V_{CE} = 0. The values of I_B, I_C and β are given by **[NEET - 2018]**



(1) I_B = 40 μA, I_C = 10 mA, β = 250

(2) I_B = 25 μA, I_C = 5 mA, β = 200

(3) I_B = 40 μA, I_C = 5 mA, β = 125

(4) I_B = 20 μA, I_C = 5 mA, β = 250

26. In a p-n junction diode, change in temperature due to heating **[NEET - 2018]**

(1) Affects only reverse resistance

(2) Affects only forward resistance

(3) Affects the overall V - I characteristics of p-n junction

(4) Does not affect resistance of p-n junction

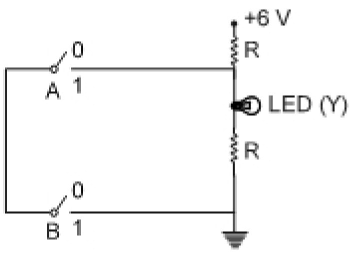
27. For a *p*-type semiconductor, which of the following statements is true ? **[NEET-2019]**

(1) Electrons are the majority carriers and trivalent atoms are the dopants.

(2) Holes are the majority carriers and trivalent atoms are the dopants.

(3) Holes are the majority carriers and pentavalent atoms are the dopants.

(4) Electrons are the majority carriers and pentavalent atoms are the dopants.

28. 

The correct Boolean operation represented by the circuit diagram drawn is **[NEET-2019]**

(1) AND (2) OR

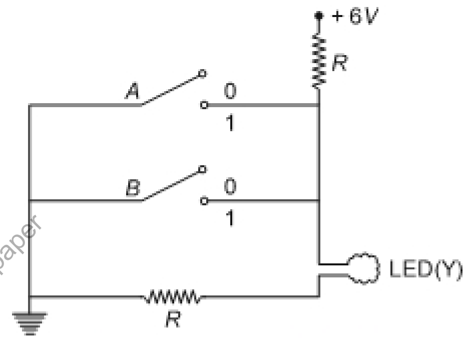
(3) NAND (4) NOR

29. An LED is constructed from a p-n junction diode using GaAsP. The energy gap is 1.9 eV. The wavelength of the light emitted will be equal to **[NEET-2019 (Odisha)]**

(1) 654×10^{-11} m (2) 10.4×10^{-26} m

(3) 654 nm (4) 654 Å

30. The circuit diagram shown here corresponds to the logic gate **[NEET-2019 (Odisha)]**



(1) NAND (2) NOR

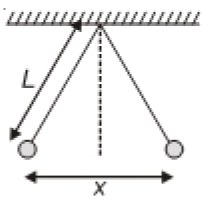
(3) AND (4) OR

❑ ❑ ❑

Sample Question Paper-1

Choose the correct answer :

1. Two small equally charged spheres, each of mass *m*, are suspended from the same point by silk threads of length *L* as shown below ($x << L$). The rate with which the charge leaks off each sphere if their approach velocity varies as $V = \frac{c}{\sqrt{x}}$ (c is constant) is



(1) $\frac{1}{2}c\sqrt{2\pi\varepsilon_0 \frac{mg}{l}}$ (2) $\frac{5}{2}c\sqrt{2\pi\varepsilon_0 \frac{l}{mg}}$

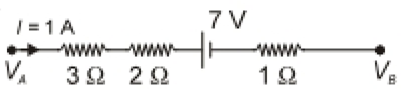
(3) $\frac{1}{2}c\sqrt{4\pi\varepsilon_0 \frac{l}{mg}}$ (4) $\frac{3}{2}c\sqrt{2\pi\varepsilon_0 \frac{mg}{l}}$

2. An electric dipole of length 1 cm is placed at an angle 60°C with an electric field intensity 0.1×10^6 N/C. It experience a torque equal to $2\sqrt{3}$ N-m. The charge on dipole is

(1) 4 mC (2) 3 mC

(3) 2 mC (4) 8 mC

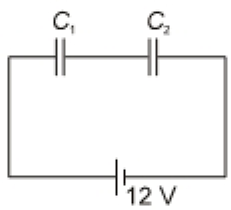
3. The potential difference ($V_A - V_B$) in the given figure is



(1) 13 V (2) 12 V

(3) 11 V (4) 10 V

4. Two capacitors C_1 and C_2 of capacitance 3 μF and 9 μF are connected to a cell of emf 12 V as shown in figure. The ratio of electrostatic energy stored in capacitor C_1 and capacitor C_2 is



(1) 1 : 1 (2) 1 : 3

(3) 3 : 1 (4) 3 : 4

5. Which of the following statement is true?

(1) The cause of charging is actual transfer of protons from one material to the other

(2) Protons are transferred from material of lower work function to the material whose work function is higher

(3) Electrons are transferred from material of lower work function to the material whose work function is higher

(4) All of these

6. A long wire carrying a steady current is bent into a circular loop of two turns. The magnetic field at centre is 10 T. It is then bent into a circular loop of 10 turns. The magnetic field at the centre of this coil of 10 turns will be

(1) 250 T (2) 100 T

(3) 10 T (4) Zero

7. A 20 Ω resistance and a capacitor of 20 Ω reactance are connected in series across 220 V. The value of displacement current is

(1) $\frac{11}{\sqrt{2}}$ A (2) 11 A

(3) $\frac{10}{\sqrt{2}}$ A (4) 10 A

8. An inductor 200 mH and resistor 20 Ω are connected in series across a source of 220 V, 50 Hz. The impedance of the AC circuit is

(1) 10π (2) $20\sqrt{\pi}$ Ω

(3) $10\sqrt{1+\pi}$ Ω (4) $20\sqrt{1+\pi^2}$ Ω

9. A charged particle carrying a charge 3.2×10^{-19} C is moving in a magnetic field of $(5\hat{i} + 4\hat{j})$ T with velocity $(3\hat{i} + 2\hat{j})$ m/s. The magnetic force acting on charged particle is

(1) 3.4×10^{-20} N (2) 6.0×10^{19} N

(3) 6.0×10^{-18} N (4) 6.4×10^{-19} N

10. The magnetic field at centre O of a coil bent in the form of a square of side $a = \sqrt{2}$ m carrying current I in clockwise direction is

(1) $\frac{\sqrt{2}\mu_o I}{\pi}$; vertically upwards

(2) $\frac{2\mu_o I}{\pi}$; vertically downwards

(3) $\frac{2\mu_o I}{\pi}$; vertically upwards

(4) $\frac{\mu_o I}{2\pi}$; vertically downwards

11. If two bulbs (30 W, 220 V) and (70 W, 220 V) are connected in series with 220 V supply, then effective wattage is

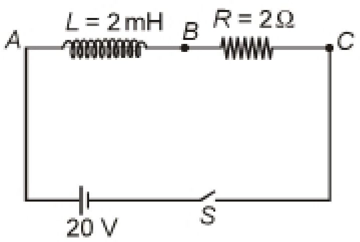
(1) 21 W

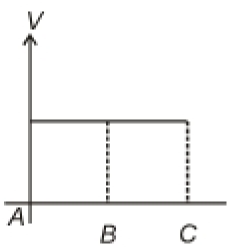
(2) 100 W

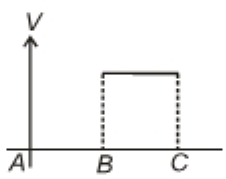
(3) 30 W

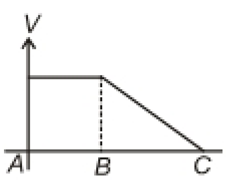
(4) 40 W

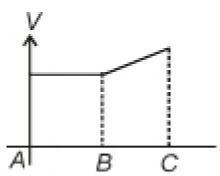
12. An electric circuit containing a wire of resistance 2 Ω, inductor and battery is shown. At t = 0 switch is closed. In steady state variation of potential drop as one moves from A to C is correctly shown in



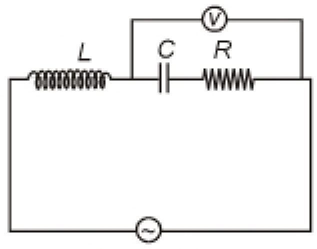
(1)


(2)


(3)


(4)


13. The given LCR series circuit is at resonance. Potential across the inductor capacitor and resistor are 40 V, 40 V and 30 V respectively. The reading of voltmeter will be



$V = V_0 \sin\omega t$

(1) 30 V (2) Zero

(3) 50 V (4) 40 V

14. Select incorrect statement

(1) For a given change in magnetic flux linked with a closed coil, the amount of charge flow in it is inversely proportional to its resistance

(2) Electromagnetic induction is based on the law of conservation of energy

(3) The metallic cores of transformer is laminated to minimize eddy current

(4) A time varying magnetic field can't exert a force on the stationary charge

15. In a common emitter configuration collector current and emitter current are 3.09 mA and 3.19 mA respectively. The current gain in this configuration is

(1) 3.09 (2) 31.9

(3) 30.9 (4) 1.003

16. If λ is de Broglie wavelength of electron moving in n^{th} orbit, then the radius of 3^{rd} orbit in hydrogen atom is

(1) $\frac{3\lambda}{n}$ (2) $\frac{2\lambda}{n}$

(3) $\frac{\lambda}{n}$ (4) 3λ

17. A gamma ray may be emitted

(1) When nucleus returns to ground state from excited state

(2) After α-decay

(3) After β–decay

(4) All of these

18. The refracting angle of a prism is A and the critical angle for the medium of the prism is Q_C. There will be no emergent ray when

(1) $A = 2Q_C$ (2) $A < Q_C$

(3) $A > 2Q_C$ (4) $Q_C < A < 2Q_C$

19. An unpolarised light of intensity I_0 is incident on a pair of two polaroids held coaxially such that their transmission axes make an angle of 30° with each other. The fraction of intensity of light emerging from the pair is

(1) $\frac{1}{2}$ (2) $\frac{3}{8}$

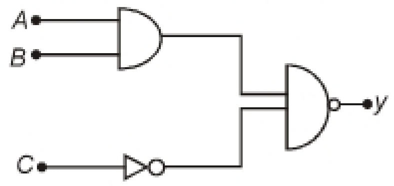
(3) $\frac{1}{8}$ (4) $\frac{9}{16}$

20. In YDSE the fringe width is 0.06 mm. If the wave-length of light used is increased by 25% and the slit separation is decreased by 25% then fringe width will be

(1) 0.06 mm (2) 0.03 mm

(3) 0.05 mm (4) 0.10 mm

21. In the given circuit the output y is given by



(1) $\overline{(A+B)}.C$ (2) $(A+B).C$

(3) $(\overline{A}+\overline{B})+C$ (4) $(\overline{A}.\overline{B})+C$

22. Which of the following is a correct statement?

(1) Energy of thermal neutrons is approximately 0.025 eV

(2) The electron emitted in beta radiation originates from inner orbits of atom

(3) Fast neutrons can be slowed down by elastic collision with heavy nuclei

(4) The rest mass of a stable nucleus is more than the sum of the rest masses of separated nucleons

23. Energy of the photon produced by annihilation of an electron and a positron is approximately

(1) 1.02 MeV (2) 1.02 keV

(3) 1.02 eV (4) 1.02 GeV

24. During transition of an electron from higher energy level to lower energy level in hydrogen atom photon emitted has frequency f. The recoil energy of atom is

(1) $\propto f^2$ (2) $\propto f$

(3) $\propto \frac{1}{f^2}$ (4) $\propto \frac{1}{f^{3/2}}$

25. In a photo cell, if a line source of light is placed at a distance 20 m, the photoelectric current is 2 μA. If distance of the source is halved then photoelectric current will become

(1) 2 μA (2) 4 μA

(3) 16 μA (4) 8 μA

26. After three half lives, 8 g of radioactive material remains in a sample. What will be the amount of substance at t = 0 s?

(1) 48 g (2) 64 g

(3) 20 g (4) 44 g

27. An inductor of inductance 10 mH and a capacitor of capacitance 5 μF are in LC oscillation. If the maximum energy stored in the capacitor is 2 J, the maximum current in the circuit is

(1) 0.2 A (2) 2 A

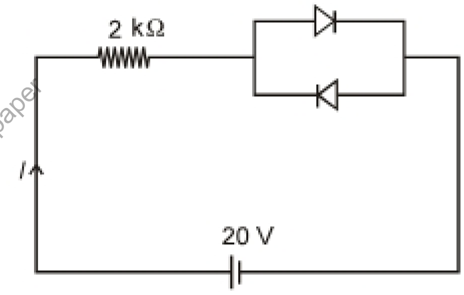
(3) 20 A (4) 5 A

28. Two antenna are radiating electromagnetic waves of frequency 80 MHz and 160 MHz. The ratio of power radiated by these is

(1) 1 : 2 (2) 2 : 1

(3) 1 : 4 (4) 4 : 1

29. Current in the following circuit will be



(1) Zero (2) 10 mA

(3) 1 mA (4) 9.6 mA

30. Two slits, 4 mm apart are illuminated by light of wavelength 6000 Å. Position of 2nd bright fringe on the screen will be

(1) 0.24 mm (2) 0.6 mm

(3) 6 mm (4) 8 mm

31. Which of the following has/have zero average value in a plane electromagnetic wave?

(1) Magnetic energy

(2) Magnetic energy and electric energy both

(3) Electric field only

(4) Both magnetic and electric fields

32. The material of a permanent magnet has

	Retentivity	**Coercivity**
(1)	High	low
(2)	High	high
(3)	Low	high
(4)	Low	low

33. If a galvanometer of resistance 25 Ω is shunted by a resistance of 2.5 Ω then fraction of total current that flows through the galvanometer is

(1) $\frac{1}{10}$ (2) $\frac{3}{11}$

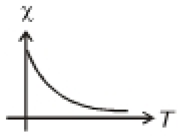
(3) $\frac{3}{10}$ (4) $\frac{1}{11}$

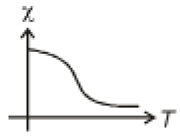
34. A photon of energy 3.4 eV is incident on a metal of work function 2 eV. The stopping potential is equal to

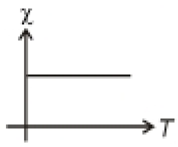
(1) 1.7 V (2) 5.4 V

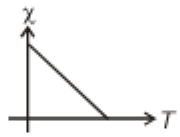
(3) 6.8 V (4) 1.4 V

35. The variation of magnetic susceptibility (χ) with absolute temperature T for a ferromagnetic material is

(1) 

(2) 

(3) 

(4) 

36. Select the correct statement about PN junction

(1) The potential is same everywhere if it is not connected to any circuit

(2) The width of the depletion zone is independent of density of impurities

(3) The electric field in the depletion zone is produced by the ionized impurities atoms.

(4) Potential barrier doesn't depend on temperature

37. A ray of light passes through the equilateral prism such that angle of incidence is equal to angle of emergence. If angle of incidence is 45° then angle of deviation will be

(1) 15° (2) 75°

(3) 60° (4) 30°

38. The sun is rotating about its own axis. The spectral lines emitted from the two ends of its equator for an observer on the earth will show

(1) Shift towards violet end

(2) Shift towards red end

(3) No shift

(4) Shift towards red end by one line and towards violet end by other line

39. In a full wave rectifier, input ac current has a frequency f then output frequency of current is

(1) f (2) $2f$

(3) $\frac{f}{2}$ (4) $4f$

40. In photoelectric effect, the electrons are ejected from metals if the incident light has certain maximum

(1) Amplitude (2) Wavelength

(3) Frequency (4) Intensity

41. A conducting sphere of radius 5 cm and carrying charge q is joined to a conducting sphere of radius 10 cm and carrying a charge $-2q$. The charge flowing between them will be

(1) $\frac{4q}{3}$ (2) q

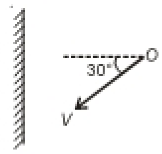
(3) $\frac{q}{3}$ (4) $\frac{q}{6}$

42. An arc of radius R is charged. The linear density of charge is λ and the arc subtends an angle $\frac{\pi}{3}$ at the centre. What is electric potential at the centre?

(1) $\frac{\lambda}{4\varepsilon_0}$ (2) $\frac{\lambda}{8\varepsilon_0}$

(3) $\frac{\lambda}{6\varepsilon_0}$ (4) $\frac{\lambda}{12\varepsilon_0}$

43. An object moves towards a plane mirror with a speed V at an angle of 30° to the perpendicular of the mirror. Velocity of object with respect to its image will be



(1) $\frac{v\sqrt{3}}{2}$ (2) v

(3) $\sqrt{3}\,v$ (4) $\frac{v}{2}$

44. A simple microscope has maximum magnifying power of 7. The minimum magnifying power of the microscope will be

(1) 6 (2) 5

(3) 3 (4) 2

45. The energy released when 3α-particles combine to form a C^{12} nucleus is, (mass of $_2He^4$ = 4.002603 u)

(1) 23.67 MeV (2) 0.961 MeV

(3) 1.3674 MeV (4) 7.27 MeV

❑ ❑ ❑

Sample Question Paper-2

Choose the correct answer :

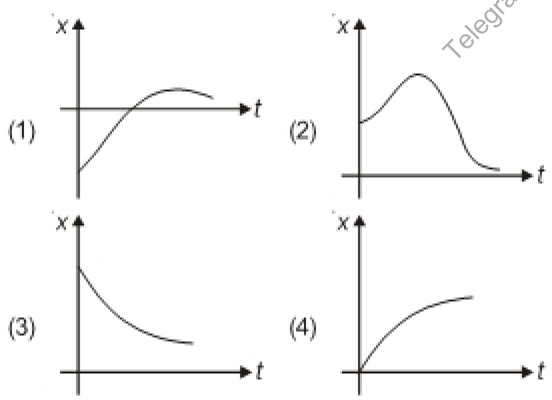
1. The refractive index of a material is given by the equation, $\mu = A + \frac{B}{\lambda^2}$,where A and B are constant. The dimensional formula of B is

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

2. In an experiment three quantities a, b and c are measured with percentage error 1%, 2% and 3% respectively. Quantity P is calculated as follows $P = \frac{a^3b^2}{c}$. % error in P is

(1) 14% (2) 10%
(3) 7% (4) 6%

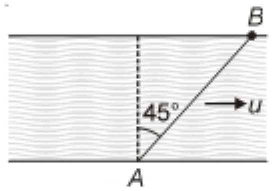
3. Among the four graphs, there is only one graph for which average velocity over the time interval (0, T) can vanish for suitably chosen T. Which one is it?



4. Under the action of a force $F = kx$, the position of a body changes from 0 to x. The work done is

(1) $\frac{kx^2}{2}$ (2) kx^2
(3) kx (4) $\frac{kx}{2}$

5. A man wants to reach point B on the opposite bank of a river flowing at a speed as shown in figure. What minimum speed relative to water should the man have, so that he can reach point B?



(1) $u\sqrt{2}$ (2) $\frac{u}{\sqrt{2}}$
(3) $2u$ (4) $\frac{u}{2}$

6. A missile is fired for maximum range with an initial velocity of 20 m/s. If g = 10 m/s^2, the range of missile is

(1) 50 m (2) 60 m
(3) 20 m (4) 40 m

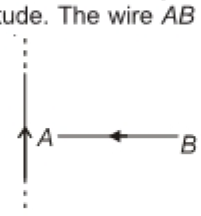
7. A aircraft executes a horizontal loop of radius 1 km with a speed of 900 km/h. Ratio of centripetal acceleration to acceleration due to gravity is

(1) 12.3 (2) 3.3
(3) 6.4 (4) None of these

8. Bar magnet is cut in two equal parts along its length and in this case magnetic moment of individual part is M_1. Another identical bar magnet is cut in two equal parts perpendicular to its length and in this case magnetic moment of each part becomes M_2. The ratio $M_1 : M_2$ is

(1) 1 : 1 (2) 1 : 2
(3) 2 : 1 (4) $\sqrt{2}:1$

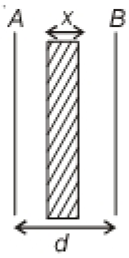
9. A wire AB carrying a current is kept close to uniform wire of infinite length carrying current of same magnitude. The wire AB will



(1) Remains stationary
(2) Experience torque only
(3) Accelerate downward
(4) Move towards infinitely long wire

10. A charge particle enters in a uniform magnetic field by making an angle of 30°. Which of the following quantity will change?
    (1) Speed of charge particle
    (2) Kinetic energy of charge particle
    (3) Linear momentum of charge particle
    (4) All of these

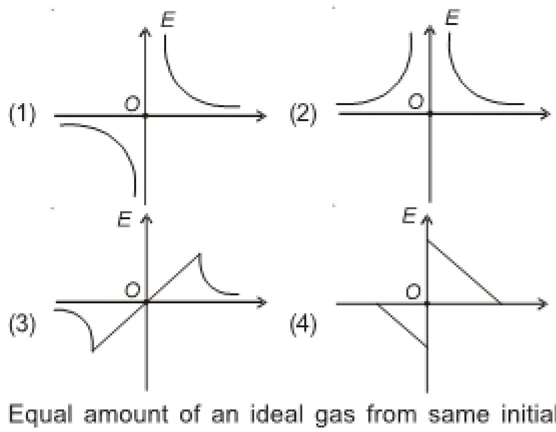
11. A dielectric of dielectric constant K is filled between plates of a parallel plate capacitor. When it is kept closed to A, midway between A & B and closed to B, capacitance in these cases are C_1, C_2 and C_3 respectively, then



    (1) $C_1 = C_2 = C_3$
    (2) $C_1 > C_2 > C_3$
    (3) $C_1 < C_2 < C_3$
    (4) $C_1 = C_3 < C_2$

12. Force acting on an electron kept between plates of a charged capacitor is F. If one of the plate of the capacitor is removed, force acting on the electron will becomes
    (1) Zero (2) F
    (3) $2F$ (4) $\frac{F}{2}$

13. Which of the following graph correctly shows the variation in electric field due to an infinitely long charged wire, at a perpendicular distance r from it?

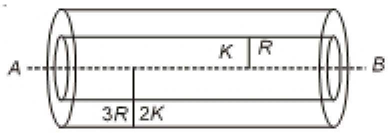


14. Equal amount of an ideal gas from same initial state are expanded through three different process A, B and C to same final volume. A is isobaric, B is isothermal and C is adiabatic expansion. If P_A, P_B and P_C are final pressure, then
    (1) $P_A = P_B = P_C$ (2) $P_A > P_B > P_C$
    (3) $P_A < P_B < P_C$ (4) $P_A > P_B = P_C$

15. The coefficient of performance of an ideal heat pump working between 27°C and 327°C is
    (1) 2 (2) 1
    (3) 0.5 (4) 0.67

16. 1 g ice at 0°C is mixed with 1 g water at 40°C. In equilibrium ratio of mass of ice and mass of water mixture is
    (1) 1 : 1 (2) 1 : 3
    (3) 1 : 2 (4) Zero

17. Find equivalent thermal conductivity of arrangement between A and B.



    (1) $\frac{17K}{9}$ (2) $\frac{3K}{2}$
    (3) $\frac{18K}{11}$ (4) $3K$

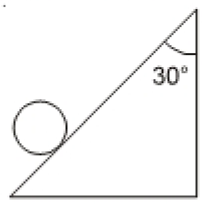
18. A cylindrical tube open at both ends has fundamental frequency f in air. Now the tube is dipped vertically in water, so that one fourth of it is in outside the water. The fundamental frequency of air column is now
    (1) $2f$ (2) f
    (3) $\frac{3f}{4}$ (4) $\frac{f}{4}$

19. A simple pendulum is suspended from the roof of a trolley which moves in a horizontal direction with an acceleration g. The time period of oscillation is given by $T = 2\pi\sqrt{\frac{l}{a}}$, where a is given by
    (1) g (2) $2g$
    (3) $\frac{g}{2}$ (4) $\sqrt{2}\,g$

20. A rod of length 3 m is suspended about its one end and is made to oscillate simple harmonically. The effective length of simple pendulum having same time period as the rod is
    (1) 2 m (2) 3 m
    (3) 6 m (4) 1.5 m

21. Two particles of mass m and $4m$ are initially at rest. They start moving towards each other due to their mutual gravitational attraction. At an instant velocity of mass m is $v\hat{i}$, then velocity of mass $4m$ at that instant is
    (1) Zero (2) $-v\hat{i}$
    (3) $-\frac{v}{4}\hat{i}$ (4) $4v\hat{i}$

22. A disc is rolling down on rough inclined plane starting from rest. Assuming the condition of pure rolling, choose the wrong statement



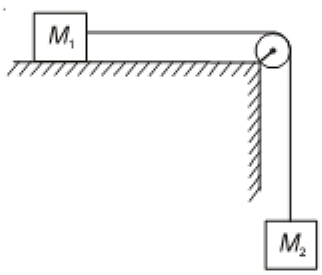
(1) Acceleration of center of mass of disc is constant
(2) Friction force acting on disc is in backward direction
(3) Disc possess translational as well as rotational energy
(4) Friction force acting on disc is $\frac{Mg}{6}$

23. A rod of length L and mass M is bent in the form of a ring. The gravitational potential at center of ring is

(1) $\frac{-GM}{L}$ (2) $\frac{-GM}{L}.2\pi$
(3) $\frac{-GM}{2\pi L}$ (4) $\frac{-GM\pi}{L}$

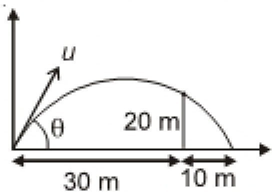
24. Choose the wrong statement
(1) A body in gravitational field has maximum binding energy, when it is at rest
(2) g is minimum on the mercury among the planets
(3) Geostationary satellite revolves around the earth from west to east
(4) Variation of g inside the uniform earth is non-linear with distance from centre of earth

25. All surfaces are smooth and string is ideal. Choose the correct statement.



(1) If $M_1 = M_2$, then acceleration of M_2 is zero
(2) If $M_1 > M_2$, then acceleration of M_2 is zero or upward
(3) If $M_1 < M_2$, then acceleration of M_2 is downward
(4) All of these

26. In the adjacent diagram shown for a projectile, what is the angle of projection?



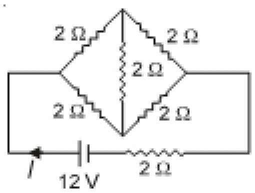
(1) $\tan^{-1}(1)$ (2) $\tan^{-1}\left(\frac{8}{3}\right)$
(3) $\tan^{-1}\left(\frac{4}{3}\right)$ (4) $\tan^{-1}\left(\frac{5}{3}\right)$

27. A ball falls from 20 m height on a surface and rebounds. The coefficient of restitution between ball and surface is $\frac{1}{2}$. What is the maximum height attained after collision?
(1) 20 m (2) 10 m
(3) 15 m (4) 5 m

28. A force $\vec{F} = 2\hat{i} + 3\hat{j} - \hat{k}$ acts at point (1, 2, 3) m and due to this point of application changes to (1, –2, –3) m. Work done by the agent applying force is
(1) –6 J (2) 6 J
(3) 3 J (4) 10 J

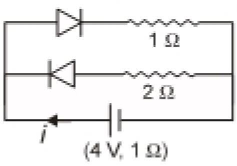
29. Sand is being dropped on a conveyor belt at the rate of M kg/s and a force of F newton is acting on moving belt so that belt is moving with a constant velocity. What is the velocity of belt?
(1) $\frac{F}{M}$ (2) $\frac{2F}{M}$
(3) Zero (4) $\frac{F}{2M}$

30. In the given circuit, find current supplied by cell



(1) 3 A (2) 4 A
(3) 2 A (4) 1 A

31. All diodes shown in figure are ideal, find i



(1) 2 A (2) 1 A
(3) 1.33 A (4) Zero

32. When all the inputs of a NAND gate are connected together, the resulting circuit is

(1) NOT gate (2) AND gate

(3) OR gate (4) NOR gate

33. A *p*-type and *n*-type semiconductor can be obtained by doping pure silicon or germanium with

(1) Aluminium and Boron

(2) Indium and Aluminium

(3) Arsenic and Phosphorus

(4) Galium and Antimony

34. The nuclei that has a radius half the radius of $_{26}Fe^{56}$ is

(1) $^{7}_{3}Li$ (2) $^{14}_{7}N$

(3) $^{28}_{14}Si$ (4) $^{40}_{20}Ca$

35. The probability of survival of a sample of radioactive nuclei for one mean life is

(1) $\frac{1}{e}$ (2) $\frac{\log 2}{e}$

(3) $1-\frac{1}{e}$ (4) e

36. The longest wavelength in Balmer series of hydrogen atom will have wavelength (R = Rydberg's constant)

(1) $\frac{36}{5R}$ (2) $\frac{4}{R}$

(3) $\frac{1}{4R}$ (4) $\frac{5}{36R}$

37. In Rutherford's α particle scattering experiment, the ratio of α particles scattered through an angle of 60° and 120° is

(1) 1 : 2 (2) 1 : 3

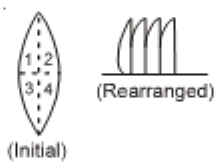
(3) 2 : 1 (4) 9 : 1

38. Threshold wavelength for a metal having work function ϕ_0 is λ. What is the threshold wavelength for a metal whose work function is $2\phi_0$?

(1) λ (2) 2λ

(3) $\frac{\lambda}{2}$ (4) $\frac{\lambda}{4}$

39. The given thin lens is broken into four identical parts 1, 2, 3 and 4 and are rearranged as shown. If the initial focal length is *f*, then after rearrangement, the equivalent focal length is



(1) f (2) $\frac{f}{2}$

(3) $\frac{f}{4}$ (4) $4f$

40. In plane electromagnetic wave if average electric energy density is u, then average magnetic energy density is

(1) u (2) $2u$

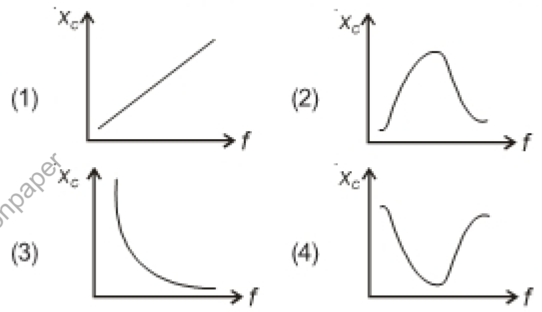
(3) $\frac{u}{2}$ (4) $\sqrt{2}u$

41. The power factor of LCR series circuit cannot be

(1) 1 (2) Zero

(3) 0.5 (4) 0.75

42. Which of the following graph correctly shows the variation of capacitive reactance X_C with frequency f?



43. Magnetic flux through a closed loop changes according to equation (ϕ) = $3t^2 - 6t$, where ϕ is in weber and t is in second. At what time instantaneous emf induced is zero?

(1) 1 second

(2) 2 second

(3) 4 second

(4) 3 second

44. A wire of fixed length is wound on a solenoid of length l and radius r and its self inductance is found to be L. Now if same wire is wound on a solenoid of length $\frac{l}{2}$ and radius $\frac{r}{2}$, then the self inductance will be

(1) $2L$ (2) L

(3) $4L$ (4) $8L$

45. If the horizontal component of earth's magnetic field is more than vertical component of earth's magnetic field at a place, then angle of true dip at that place can be

(1) 45° (2) 22°

(3) 90° (4) 51°

❑ ❑ ❑

ANSWERS

Chapter 1 : Electric Charges and Fields

Section A : Objective Type Questions

1.	(2)	2.	(4)	3.	(4)	4.	(3)	5.	(1)	6.	(3)	7.	(4)
8.	(2)	9.	(1)	10.	(2)	11.	(4)	12.	(3)	13.	(2)	14.	(2)
15.	(1)	16.	(1)	17.	(3)	18.	(3)	19.	(3)	20.	(3)		

Section B : Previous Years Questions

1.	(4)	2.	(1)	3.	(4)	4.	(2)	5.	(3)	6.	(2)	7.	(1)
8.	(2)	9.	(3)										

Chapter 2 : Electrostatic Potential and Capacitance

Section A : Objective Type Questions

1.	(2)	2.	(4)	3.	(3)	4.	(1)	5.	(3)	6.	(1)	7.	(3)
8.	(3)	9.	(4)	10.	(2)	11.	(4)	12.	(2)	13.	(4)	14.	(1)
15.	(4)	16.	(4)	17.	(1)	18.	(2)	19.	(3)	20.	(3)	21.	(1)
22.	(2)	23.	(3)	24.	(1)	25.	(4)						

Section B : Previous Years Questions

1.	(3)	2.	(3)	3.	(1)	4.	(3)	5.	(2)	6.	(4)	7.	(3)
8.	(1)	9.	(3)	10.	(2)	11.	(2)	12.	(1)	13.	(1)	14.	(4)

Chapter 3 : Current Electricity

Section A : Objective Type Questions

1.	(2)	2.	(3)	3.	(1)	4.	(4)	5.	(1)	6.	(3)	7.	(4)
8.	(3)	9.	(2)	10.	(3)	11.	(3)	12.	(1)	13.	(4)	14.	(1)
15.	(4)	16.	(4)	17.	(3)	18.	(3)	19.	(1)	20.	(3)	21.	(1)
22.	(1)	23.	(1)	24.	(1)	25.	(1)	26.	(3)	27.	(2)	28.	(1)
29.	(1)	30.	(1)	31.	(3)	32.	(1)	33.	(2)	34.	(3)	35.	(4)
36.	(3)	37.	(2)	38.	(1)	39.	(4)						

Section B : Previous Years Questions

1.	(2)	2.	(1)	3.	(4)	4.	(3)	5.	(1)	6.	(1)	7.	(2)
8.	(2)	9.	(3)	10.	(3)	11.	(2)	12.	(2)	13.	(2)	14.	(2)
15.	(1)	16.	(2)	17.	(4)	18.	(3)	19.	(3)	20.	(3)	21.	(4)
22.	(2)	23.	(1)	24.	(1)	25.	(2)	26.	(4)	27.	(3)	28.	(1)

Chapter 4 : Moving Charges and Magnetism

Section A : Objective Type Questions

1.	(3)	2.	(2)	3.	(4)	4.	(1)	5.	(3)	6.	(2)	7.	(2)
8.	(3)	9.	(1)	10.	(2)	11.	(2)	12.	(2)	13.	(4)	14.	(4)

15.	(3)	16.	(3)	17.	(4)	18.	(3)	19.	(2)	20.	(1)	21.	(3)
22.	(3)	23.	(4)	24.	(4)	25.	(1)	26.	(3)	27.	(1)	28.	(1)
29.	(3)	30.	(2)	31.	(3)	32.	(1)						

Section B : Previous Years Questions

1.	(3)	2.	(3)	3.	(1)	4.	(3)	5.	(1)	6.	(3)	7.	(4)
8.	(4)	9.	(3)	10.	(4)	11.	(1)	12.	(3)	13.	(2)	14.	(2)

Chapter 5 : Magnetism and Matter

Section A : Objective Type Questions

1.	(2)	2.	(2)	3.	(4)	4.	(1)	5.	(1)	6.	(3)	7.	(3)
8.	(3)	9.	(4)	10.	(3)	11.	(3)	12.	(1)	13.	(2)	14.	(3)
15.	(1)	16.	(1)										

Section B : Previous Years Questions

1.	(4)	2.	(1)	3.	(3)	4.	(4)	5.	(2)	6.	(2)	7.	(2)
8.	(1)	9.	(1)	10.	(1)	11.	(3)	12.	(3)	13.	(3)		

Chapter 6 : Electromagnetic Induction

Section A : Objective Type Questions

1.	(2)	2.	(4)	3.	(1)	4.	(2)	5.	(3)	6.	(4)	7.	(2)
8.	(4)	9.	(2)	10.	(3)	11.	(3)	12.	(1)	13.	(3)	14.	(1)
15.	(4)	16.	(1)	17.	(2)	18.	(1)	19.	(2)	20.	(2)	21.	(1)
22.	(4)	23.	(1)	24.	(4)								

Section B : Previous Years Questions

1.	(3)	2.	(2)	3.	(1)	4.	(4)	5.	(1)	6.	(1)	7.	(4)
8.	(3)	9.	(3, 4)	10.	(4)	11.	(3)						

Chapter 7 : Alternating Current

Section A : Objective Type Questions

1.	(2)	2.	(3)	3.	(2)	4.	(4)	5.	(3)	6.	(2)	7.	(1)
8.	(2)	9.	(2)	10.	(1)	11.	(1)	12.	(3)	13.	(1)	14.	(2)
15.	(4)	16.	(3)	17.	(1)	18.	(3)						

Section B : Previous Years Questions

1.	(1)	2.	(3)	3.	(2)	4.	(3)	5.	(3)	6.	(2)	7.	(2)
8.	(3)	9.	(3)	10.	(3)	11.	(3)	12.	(1)	13.	(3)	14.	(2)

Chapter 8 : Electromagnetic Waves

Section A : Objective Type Questions

1.	(4)	2.	(2)	3.	(2)	4.	(3)	5.	(3)	6.	(1)	7.	(2)
8.	(3)	9.	(1)	10.	(1)	11.	(4)	12.	(3)	13.	(3)	14.	(2)

Section B : Previous Years Questions

1.	(3)	2.	(4)	3.	(2)	4.	(2)	5.	(3)	6.	(1)	7.	(1)
8.	(2)	9.	(2)	10.	(1)	11.	(2)	12.	(2)				

Chapter 9 : Ray Optics and Optical Instruments

Section A : Objective Type Questions

1.	(2)	2.	(1)	3.	(1)	4.	(1)	5.	(1)	6.	(1)	7.	(1)
8.	(1)	9.	(2)	10.	(2)	11.	(4)	12.	(4)	13.	(1)	14.	(2)
15.	(4)	16.	(4)	17.	(1)	18.	(1)	19.	(3)	20.	(1)	21.	(4)
22.	(4)	23.	(4)	24.	(1)								

Section B : Previous Years Questions

1.	(1)	2.	(3)	3.	(1)	4.	(3)	5.	(2)	6.	(2)	7.	(4)
8.	(2)	9.	(1)	10.	(1)	11.	(3)	12.	(4)	13.	(2)	14.	(1)
15.	(3)	16.	(4)	17.	(3)	18.	(2)	19.	(1)	20.	(2)	21.	(2)
22.	(4)	23.	(2)	24.	(2)	25.	(3)	26.	(4)	27.	(1)	28.	(4)

Chapter 10 : Wave Optics

Section A : Objective Type Questions

1.	(1)	2.	(1)	3.	(1)	4.	(1)	5.	(3)	6.	(3)	7.	(1)
8.	(1)	9.	(3)	10.	(1)	11.	(3)	12.	(3)	13.	(1)	14.	(4)
15.	(4)	16.	(1)	17.	(2)	18.	(4)	19.	(4)	20.	(2)		

Section B : Previous Years Questions

1.	(1)	2.	(2)	3.	(4)	4.	(3)	5.	(4)	6.	(2)	7.	(2)
8.	(2)	9.	(1)	10.	(1)	11.	(2)	12.	(4)	13.	(3)	14.	(4)
15.	(3)	16.	(2)	17.	(2)	18.	(2)	19.	(3)	20.	(4)		

Chapter 11 : Dual Nature of Matter and Radiation

Section A : Objective Type Questions

1.	(2)	2.	(4)	3.	(2)	4.	(1)	5.	(3)	6.	(1)	7.	(2)
8.	(1)	9.	(1)	10.	(1)	11.	(2)	12.	(2)				

Section B : Previous Years Questions

1.	(2)	2.	(1)	3.	(3)	4.	(2)	5.	(4)	6.	(2)	7.	(2)
8.	(1)	9.	(4)	10.	(2)	11.	(3)	12.	(3)	13.	(1)	14.	(2)
15.	(1)	16.	(4)	17.	(2)	18.	(1 & 2)	19.	(1)	20.	(1)	21.	(2)
22.	(1)	23.	(2)										

Chapter 12 : Atoms

Section A : Objective Type Questions

1.	(4)	2.	(3)	3.	(1)	4.	(3)	5.	(1)	6.	(2)	7.	(2)
8.	(1)	9.	(4)	10.	(1)	11.	(2)	12.	(2)				

Section B : Previous Years Questions

1.	(2)	2.	(3)	3.	(4)	4.	(3)	5.	(3)	6.	(2)	7.	(4)
8.	(3)	9.	(3)	10.	(3)	11.	(4)						

Chapter 13 : Nuclei

Section A : Objective Type Questions

1.	(3)	2.	(2)	3.	(1)	4.	(3)	5.	(1)	6.	(1)	7.	(3)
8.	(2)	9.	(4)										

Section B : Previous Years Questions

1.	(1)	2.	(2)	3.	(2)	4.	(1)	5.	(4)	6.	(3)	7.	(2)
8.	(3)	9.	(4)	10.	(2)	11.	(2)	12.	(1)	13.	(1)	14.	(1)

Chapter 14 : Electronic Devices

Section A : Objective Type Questions

1.	(2)	2.	(1)	3.	(4)	4.	(3)	5.	(4)	6.	(3)	7.	(3)
8.	(4)	9.	(3)	10.	(4)	11.	(4)	12.	(2)	13.	(4)	14.	(2)
15.	(3)	16.	(2)	17.	(1)	18.	(3)						

Section B : Previous Years Questions

1.	(2)	2.	(3)	3.	(2)	4.	(1)	5.	(4)	6.	(2)	7.	(4)
8.	(2)	9.	(1)	10.	(4)	11.	(2)	12.	(1)	13.	(4)	14.	(1)
15.	(1)	16.	(3)	17.	(2)	18.	(2)	19.	(1)	20.	(3)	21.	(1)
22.	(3)	23.	(3)	24.	(2)	25.	(3)	26.	(3)	27.	(2)	28.	(3)
29.	(3)	30.	(2)										

Sample Question Paper-1

1.	(4)	2.	(1)	3.	(1)	4.	(3)	5.	(3)	6.	(1)	7.	(1)
8.	(4)	9.	(4)	10.	(2)	11.	(1)	12.	(3)	13.	(3)	14.	(4)
15.	(3)	16.	(1)	17.	(4)	18.	(4)	19.	(2)	20.	(4)	21.	(3)
22.	(1)	23.	(1)	24.	(1)	25.	(2)	26.	(2)	27.	(3)	28.	(3)
29.	(2)	30.	(2)	31.	(4)	32.	(2)	33.	(1)	34.	(4)	35.	(2)
36.	(3)	37.	(4)	38.	(4)	39.	(2)	40.	(2)	41.	(1)	42.	(4)
43.	(3)	44.	(1)	45.	(4)								

Sample Question Paper-2

1.	(4)	2.	(2)	3.	(2)	4.	(1)	5.	(2)	6.	(4)	7.	(3)
8.	(1)	9.	(3)	10.	(3)	11.	(1)	12.	(4)	13.	(1)	14.	(2)
15.	(1)	16.	(2)	17.	(1)	18.	(1)	19.	(4)	20.	(1)	21.	(3)
22.	(4)	23.	(2)	24.	(4)	25.	(3)	26.	(2)	27.	(4)	28.	(1)
29.	(1)	30.	(1)	31.	(1)	32.	(1)	33.	(4)	34.	(1)	35.	(1)
36.	(1)	37.	(4)	38.	(3)	39.	(2)	40.	(1)	41.	(2)	42.	(3)
43.	(1)	44.	(1)	45.	(2)								

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