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Popular Master Guide

CUET-UG
PHYSICS

Section-II:
Domain Specific Subject

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R. Gupta's®

Popular Master Guide

NATIONAL TESTING AGENCY (NTA)

CUET-UG

Common University Entrance Test for
Under Graduate Courses/Programmes

SECTION-II

DOMAIN SPECIFIC SUBJECT

PHYSICS

By

RPH Editorial Board

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EXAMINATION STRUCTURE

SECTION-II: DOMAIN SPECIFIC SUBJECTS

No. of Questions	Subject	Time
40 Questions to be attempted out of 50	• Input text can be used for MCQ Based Questions • MCQs based on NCERT Class XII Syllabus only	45 minutes for each Domain Specific Subjects

- **Mode of the Test** : Computer Based Test (CBT)
- **Test Pattern** : Objective type with Multiple Choice Questions
- **Medium of Exam** : **13 Languages** (Tamil, Telugu, Kannada, Malayalam, Marathi, Gujarati, Odiya, Bengali, Assamese, Punjabi, English, Hindi and Urdu)

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PHYSICS

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SAMPLE PAPER (SOLVED)

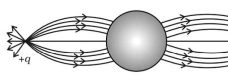
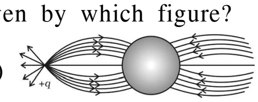
CUET-UG

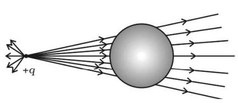
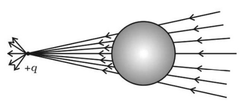
(Common University Entrance Test for UG Programmes)

PHYSICS*

SECTION-II : DOMAIN SPECIFIC SUBJECT

1. A point positive charge is brought near an isolated conducting sphere as shown in the following figures. The electric field is best given by which figure?

(*i*)  (*ii*) 

(*iii*)  (*iv*) 

A. Fig. (*i*) B. Fig. (*ii*)
C. Fig. (*iii*) D. Fig. (*iv*)

2. A positively charged particle is released from rest in an uniform electric field. The electric potential energy of the charge:
A. remains a constant because the electric field is uniform.
B. increases because the charge moves along the electric field.
C. decreases because the charge moves along the electric field.
D. decreases because the charge moves opposite to the electric field.

3. The electrostatic potential on the surface of a charged conducting sphere is 100 V. Two statements are made in this regard:
S_1 : At any point inside the sphere, electric intensity is zero.
S_2 : At any point inside the sphere, the electrostatic potential is 100 V.
Which of the following is a correct statement?
A. S_1 is true but S_2 is false
B. Both S_1 & S_2 are false
C. S_1 is true, S_2 is also true and S_1 is the cause of S_2
D. S_1 is true, S_2 is also true but the statements are independant

4. Equipotentials at a great distance from a collection of charges whose total sum is not zero are approximately:
A. spheres B. planes
C. paraboloids D. ellipsoids

5. A resistance R is to be measured using a meter bridge. Student chooses the standard resistance S to be 100 Ω. He finds the null point at l_1 = 2.9 cm. He is told to attempt to improve the accuracy.
Which of the following is a useful way?
A. He should measure l_1 more accurately
B. He should change S to 1000 Ω and repeat the experiment
C. He should change S to 3 Ω and repeat the experiment
D. He should give up hope of a more accurate measurement with a meter bridge

6. Which of the following characteristics of electrons determines the current in a conductor?
A. Drift velocity alone
B. Thermal velocity alone
C. Both drift velocity and thermal velocity
D. Neither drift nor thermal velocity

7. Biot-Savart law indicates that the moving electrons (velocity v) produce a magnetic field B such that:
A. $B \perp v$
B. $B \,||\, v$
C. it obeys inverse cube law
D. it is along the line joining the electron and point of observation

8. An electron is projected with uniform velocity along the axis of a current carrying long solenoid. Which of the following is true?
A. The electron will be accelerated along the axis.
B. The electron path will be circular about the axis.
C. The electron will experience a force at 45° to the axis and hence execute a helical path.
D. The electron will continue to move with uniform velocity along the axis of the solenoid.

9. A circular current loop of magnetic moment M is in an arbitrary orientation in an external magnetic field B. The work done to rotate the loop by 30° about an axis perpendicular to its plane is:
A. MB B. $\sqrt{3}\dfrac{MB}{2}$
C. $\dfrac{MB}{2}$ D. zero

10. In a permanent magnet at room temperature:
A. magnetic moment of each molecule is zero
B. the individual molecules have non-zero magnetic moment which are all perfectly aligned
C. domains are partially aligned
D. domains are all perfectly aligned

*40 Questions to be attempted out of 50

11. A paramagnetic sample shows a net magnetisation of 8 Am^{-1} when placed in an external magnetic field of 0.6 T at a temperature of 4 K. When the same sample is placed in an external magnetic field of 0.2 T at a temperature of 16 K, the magnetisation will be:

A. $\frac{32}{3}$ Am^{-1} B. $\frac{2}{3}$ Am^{-1}
C. 6 Am^{-1} D. 2.4 Am^{-1}

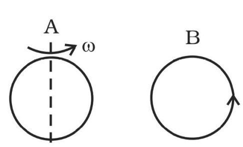
12. A square of side L meters lies in the *x-y* plane in a region, where the magnetic field is given by $B = B_0(2\hat{i} + 3\hat{j} + 4\hat{k})T$, where B_0 is constant. The magnitude of flux passing through the square is:

A. 2 B_0 L^2 Wb   B. 3 B_0 L^2 Wb
C. 4 B_0 L^2 Wb   D. $\sqrt{29}$ B_0 L^2 Wb

13. A loop, made of straight edges has six corners at A (0, 0, 0), B (L, O, 0), C (L, L, 0), D (0, L, 0), E (0, L, L) and F (0, 0, L). A magnetic field $\mathbf{B} = B_0(\hat{i} + \hat{k})T$ is present in the region. The flux passing through the loop ABCDEFA (in that order) is:

A. B_0 L^2 Wb   B. 2 B_0 L^2 Wb
C. $\sqrt{2}$ B_0 L^2 Wb   D. 4 B_o L^2 Wb

14. Same as problem 4 except the coil A is made to rotate about a vertical axis as shown in the following figure. No current flows in B if A is at rest. The current in coil A, when the current in B (at t = 0) is counter clockwise and the coil A is as shown at this instant, t = 0, is:



A. constant current clockwise
B. varying current clockwise
C. varying current counterclockwise
D. constant current counterclockwise

15. The self inductance L of a solenoid of length l and area of cross-section A, with a fixed number of turns N increases as

A. l and A increase
B. l decreases and A increases
C. l increases and A decreases
D. both l and A decrease

16. If the rms current in a 50 Hz ac circuit is 5 A, the value of the current 1/300 seconds after its value becomes zero is:

A. $5\sqrt{2}$ A   B. $5\sqrt{3/2}$ A
C. 5/6 A   D. $5/\sqrt{2}$ A

17. To reduce the reasonant frequency in an LCR series circuit with a generator:

A. the generator frequency should be reduced
B. another capacitor should be added in parallel to the first
C. the iron core of the inductor should be removed
D. dielectric in the capacitor should be removed

18. Which of the following combinations should be selected for better tuning of an LCR circuit used for communication?

A. R = 20 Ω, L = 1.5 H, C = 35 μF
B. R = 25 Ω, L = 2.5 H, C = 45 μF
C. R = 15 Ω, L = 3.5 H, C = 30 μF
D. R = 25 Ω, L = 1.5 H, C = 45 μF

19. An inductor of reactance 1 Ω and a resistor of 2 Ω are connected in series to the terminals of a 6 V (rms) a.c. source. The power dissipated in the circuit is:

A. 8 W   B. 12 W
C. 14.4 W   D. 18 W

20. One requires 11 eV of energy to dissociate a carbon monoxide molecule into carbon and oxygen atoms. The minimum frequency of the appropriate electromagnetic radiation to achieve the dissociation lies in:

A. visible region   B. infrared region
C. ultraviolet region   D. microwave region

21. The electric field intensity produced by the radiations coming from 100 W bulb at a 3 m distance is E. The electric field intensity produced by the radiations coming from 50 W bulb at the same distance is:

A. $\frac{E}{2}$ B. 2E
C. $\frac{E}{\sqrt{2}}$ D. $\sqrt{2}E$

22. The ratio of contributions made by the electric field and magnetic field components to the intensity of an EM wave is:

A. c : 1   B. c^2 : 1
C. 1 : 1   D. $\sqrt{c} : 1$

23. A short pulse of white light is incident from air to a glass slab at normal incidence. After travelling through the slab, the first colour to emerge is:

A. blue   B. green
C. violet   D. red

24. A passenger in an aeroplane shall:

A. never see a rainbow
B. may see a primary and a secondary rainbow as concentric circles
C. may see a primary and a secondary rainbow as concentric arcs
D. shall never see a secondary rainbow

25. The phenomena involved in the reflection of radiowaves by ionosphere is similar to:

A. reflection of light by a plane mirror
B. total internal reflection of light in air during a mirage
C. dispersion of light by water molecules during the formation of a rainbow
D. scattering of light by the particles of air

26. In a Young's double slit experiment, the source is white light. One of the holes is covered by a red filter and another by a blue filter. In this case:

A. there shall be alternate interference patterns of red and blue

B. there shall be an interference pattern for red distinct from that for blue
C. there shall be no interference fringes
D. there shall be an interference pattern for red mixing with one for blue

27. A particle is dropped from a height H. The de Broglie wavelength of the particle as a function of height is proportional to:
A. H B. $H^{1/2}$
C. H^0 D. $H^{-1/2}$

28. The wavelength of a photon needed to remove a proton from a nucleus which is bound to the nucleus with 1 MeV energy is nearly:
A. 1.2 nm B. 1.2×10^{-3} nm
C. 1.2×10^{-6} nm D. 1.2×10^{1} nm

29. A proton, a neutron, an electron and an α-particle have same energy. Then their de Broglie wavelengths compare as:
A. $\lambda_p = \lambda_n > \lambda_e > \lambda_\alpha$ B. $\lambda_\alpha < \lambda_p = \lambda_n > \lambda_e$
C. $\lambda_e < \lambda_p = \lambda_n > \lambda_\alpha$ D. $\lambda_e = \lambda_p = \lambda_n = \lambda_\alpha$

30. Taking the Bohr radius as a_0 = 53 pm, the radius of Li^{++} ion in its ground state, on the basis of Bohr's model, will be about:
A. 53 pm B. 27 pm
C. 18 pm D. 13 pm

31. The simple Bohr model cannot be directly applied to calculate the energy levels of an atom with many electrons. This is because:
A. of the electrons not being subject to a central force
B. of the electrons colliding with each other
C. of screening effects
D. the force between the nucleus and an electron will no longer be given by Coulomb's law

32. O_2 molecule consists of two oxygen atoms. In the molecule, nuclear force between the nuclei of the two atoms:
A. is not important because nuclear forces are short-ranged
B. is as important as electrostatic force for binding the two atoms
C. cancels the repulsive electrostatic force between the nuclei
D. is not important because oxygen nucleus have equal number of neutrons and protons

33. Two H atoms in the ground state collide inelastically. The maximum amount by which their combined kinetic energy is reduced is:
A. 10.20 eV B. 20.40 eV
C. 13.6 eV D. 27.2 eV

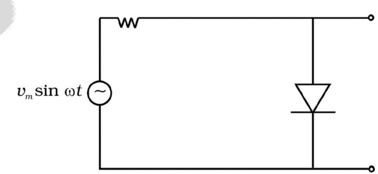
34. When a nucleus in an atom undergoes a radioactive decay, the electronic energy levels of the atom:
A. do not change for any type of radioactivity
B. change for α and β radioactivity but not for γ-radioactivity
C. change for α-radioactivity but not for others
D. change for β-radioactivity but not for others

35. Heavy stable nuclei have more neutrons than protons. This is because of the fact that:
A. neutrons are heavier than protons
B. electrostatic force between protons are repulsive
C. neutrons decay into protons through beta decay
D. nuclear forces between neutrons are weaker than that between protons

36. The conductivity of a semiconductor increases with increase in temperature because:
A. number density of free current carriers increases
B. relaxation time increases
C. both number density of carriers and relaxation time increase
D. number density of current carriers increases, relaxation time decreases but effect of decrease in relaxation time is much less than increase in number density

37. Hole is:
A. an anti-particle of electron
B. a vacancy created when an electron leaves a covalent bond
C. absence of free electrons
D. an artifically created particle

38. The output of the given circuit in Fig.



A. would be zero at all times
B. would be like a half wave rectifier with positive cycles in output
C. would be like a half wave rectifier with negative cycles in output
D. would be like that of a full wave rectifier

39. A speech signal of 3 kHz is used to modulate a carrier signal of frequency 1 MHz, using amplitude modulation. The frequencies of the side bands will be:
A. 1.003 MHz and 0.997 MHz
B. 3001 kHz and 2997 kHz
C. 1003 kHz and 1000 kHz
D. 1 MHz and 0.997 MHz

40. A message signal of frequency ω_m is superposed on a carrier wave of frequency ω_c to get an amplitude modulated wave (AM). The frequency of the AM wave will be
A. ω_m B. ω_c
C. $\frac{\omega_c + \omega_m}{2}$ D. $\frac{\omega_c - \omega_m}{2}$

41. A male voice after modulation-transmission sounds like that of a female to the receiver. The problem is due to:
A. poor selection of modulation index (selected $0 < m < 1$)
B. poor bandwidth selection of amplifiers
C. poor selection of carrier frequency
D. loss of energy in transmission

42. A basic communication system consists of:
(*a*) transmitter (*b*) information source
(*c*) user of information (*d*) channel
(*e*) receiver

Choose the correct sequence in which these are arranged in a basic communication system:
A. (*a*), (*b*), (*c*), (*d*), (*e*) B. (*b*), (*a*), (*d*), (*e*), (*c*)
C. (*b*), (*d*), (*a*), (*c*), (*e*) D. (*b*), (*e*), (*a*), (*d*), (*c*)

43. Which of the following is NOT the property of equipotential surface?
A. They do not cross each other
B. The rate of change of potential with distance on them is zero
C. For a uniform electric field they are concentric spheres
D. They can be imaginary spheres

44. Three capacitors 2 μF, 3 μF and 6 μF are joined in series with each other. The equivalent capacitance is:
A. 1/2 μF B. 1 μF
C. 2 μF D. 11 μF

45. Which statement is true for Gauss law?
A. All the charges whether inside or outside the gaussian surface contribute to the electric flux
B. Electric flux depends upon the geometry of the gaussian surface
C. Gauss theorem can be applied to non-uniform electric field
D. The electric field over the gaussian surface remains continuous and uniform at every point

46. An electric current is passed through a circuit containing two wires of same material, connected in parallel. If the lengths and radii of the wires are in the ratio of 3 : 2 and 2 : 3, then the ratio of the current passing through the wire will be:
A. 2 : 3 B. 3 : 2
C. 8 : 27 D. 27 : 8

47. We use alloys for making standard resistors because they have
A. low temperature coefficient of resistivity and high specific resistance
B. high temperature coefficient of resistivity and low specific resistance
C. low temperature coefficient of resistivity and low specific resistance
D. high temperature coefficient of resistivity and high specific resistance

48. Given below are two statements labelled as Assertion (A) and Reason (R):
Assertion (A) : An electron has a high potential energy when it is at a location associated with a more negative value of potential, and a low potential energy when at a location associated with a more positive potential.
Reason (R) : Electrons move from a region of higher potential to region of lower potential.

Select the most appropriate answer from the options given below:
A. Both (A) and (R) are true and (R) is the correct explanation of (A)
B. Both (A) and (R) are true, but (R) is not the correct explanation of (A).
C. (A) is true, but (R) is false.
D. (A) is false and (R) is also false.

49. Given below are two statements labelled as Assertion (A) and Reason (R).
Assertion (A) : A magnetic needle free to rotate in a vertical plane, orients itself (with its axis) vertical at the poles of the earth.
Reason (R) : At the poles of the earth the horizontal component of earth's magnetic field will be zero.

Select the most appropriate answer from the options given below:
A. Both (A) and (R) are true and (R) is the correct explanation of (A)
B. Both (A) and (R) are true, but (R) is not the correct explanation of (A).
C. (A) is true, but (R) is false
D. (A) is false and (R) is also false

50. Given below are two statements labelled as Assertion (A) and Reason (R).
Assertion (A) : On increasing the current sensitivity of a galvanometer by increasing the number of turns, may not necessarily increase its voltage sensitivity.
Reason (R) : The resistance of the coil of the galvanometer increases on increasing the number of turns.

Select the most appropriate answer from the options given below:
A. Both (A) and (R) are true and (R) is the correct explanation of (A)
B. Both (A) and (R) are true, but (R) is not the correct explanation of (A)
C. (A) is true, but (R) is false
D. (A) is false and (R) is also false

ANSWERS

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
A	C	C	A	C	A	A	D	D	C
11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
B	C	B	A	B	B	B	C	C	C
21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
D	C	D	B	B	C	D	B	B	C
31	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
A	A	A	B	B	D	B	C	A	B
41	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**
B	B	C	B	D	C	A	C	A	A

PHYSICS

CHAPTER

1

ELECTROSTATICS

INTRODUCTION

The branch of physics, which deals with the study of charges at rest, the forces between the static charges, fields and potentials due to these charges is called electrostatics or static electricity.

ELECTRIC CHARGE

The addition property of electrons, which gives rise to electric force between two electrons is called electric charge. The SI unit of charge is coulomb (C).

Charge on electron (e) = 1.6×10^{-19} C.

There are two types of electric charge positive and negative commonly carried by protons and electrons respectively. Like charges repel each other and unlike charges attract each other.

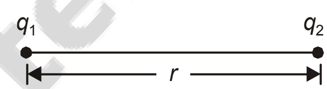
CONSERVATION OF CHARGE

It states that for an isolated system, the net charge always remains constant. In any physical process, the charge it may get transferred from one part of the system to another, but net charge will always remain same. It means charge can be neither be created nor destroyed.

In mechanics, the total linear momentum of an isolated system always remains constant, the electric charge also obeys a similar law. It is called law of conservation of charge.

COULOMB'S LAW FORCES BETWEEN TWO POINT CHARGES

It states that the force of attraction or repulsion between two point charges is directly proportional to the product of the charges and inversely proportional to the square of the distance between them and its direction is along the line joining the two charges.



$$F \propto \frac{q_1 q_2}{r^2} = \frac{1}{4\pi \epsilon_0}\frac{q_1 q_2}{r^2} = \frac{k q_1 q_2}{r^2}$$

where, k is constant and also written as $1/4\ \pi\varepsilon_0$

where ε_0 = Permittivity of free space

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

Coulomb's Law in Vector Space: In Vector form of Coulomb's Law

$$\vec{F}_{12} = \frac{k q_1 q_2}{r^2}\hat{r}_{21}$$

or,

$$= \frac{k q_1 q_2}{r^3}\vec{r}$$

where,

F = Force between charges q_1 and q_2

$\vec{F}_{12}$ = Force on q_1 because of q_2,

r = Distance between q_1 and q_2,

$\hat{r}_{21}$ = Unit vector in the direction from 2 to 1

k = Constant of proportionality

$= 9 \times 10^9\ Nm^2C^{-2}$

Coulomb's Law in Some Medium

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

where, ε = Permittivity of the medium = $\varepsilon_0\ \varepsilon_r$

ε_r = Relative Permittivity of the medium

If the medium is some insulating medium, then ε_r is also written as capital K and, then, it is called "Dielectric Constant" of the medium. The medium is called 'dielectric'.

Notes:

(*i*) This 'K' (Dielectric Constant) and the previous '*k*'. (Constant of proportionality in the Coulomb's Law) are different quantities. The first is capital K and the second is small *k*.

(*ii*) Coulomb's Law is a universal law, but it is applicable only to *point charges* whether stationary or in motion.

FORCES BETWEEN MULTIPLE CHARGES

The force acting on a charge is directly proportional to the magnitude of the charge and inversely proportional to the square of the distance between them. The force acting on a point charge due to multiple charges is given by the vector sum of all individual forces acting on the charges.

i.e. $$F_{in} = \frac{1}{4\pi\varepsilon_0}\left[\frac{q_1q_2}{r_{12}^2}\hat{F}_{12} + \frac{q_1q_2}{r_{13}^2}\hat{r}_{13} + \ldots + \frac{q_1q_2}{r_{ln}^2}\hat{r}_{ln}\right]$$

$$= \frac{q_2}{4\pi\varepsilon_0}\sum_{j=2}^{n}\frac{q_1}{r_{1r}^2}\hat{r}_{1r}$$

SUPERPOSITION PRINCIPLE AND CONTINUOUS CHARGE DISTRIBUTION

It states that when a number of charges are interacting the total force an a given charge is the vector sum of the forces acted on it by all other charges.

$$\vec{F}_0 = \vec{F}_{01} + \vec{F}_{02} + \vec{F}_{03} + \ldots + \vec{F}_{0n}$$

Continuous Charge Distribution: The continuous charge distribution may be one-dimensional, two dimensional or three dimentional. The charge distribution called linear, surface and volume distributions respectively.

ELECTRIC FIELD

It is the space around a charge in which if a test charge is placed, experiences some force which it would not have experienced otherwise. So be sure, 'electric field' is the *space* around the charge in which any other charge is acted upon by an electrostatic force.

Electric Field Strength ($\vec{E}$) : The electric field strength at a point is the electric force per unit charge which a small positive test charge will experience if placed there. It applies only to a point.

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

where,

$\vec{E}$ = Electric Field Strength

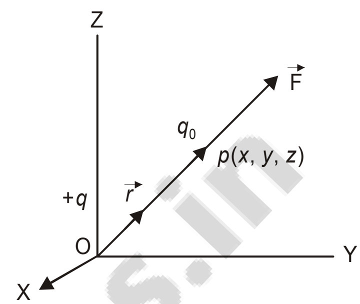
$\vec{F}$ = Force experienced by the test charge

q_0 = test charge

The SI Unit of E is NC^{-1}

ELECTRIC FIELD DUE TO A POINT CHARGE (q)

To find electric field at point P, place a vanishingly small positive test charge q_0 at point p. According to Coulomb's law, force on test charge q_0 due to charge q_0 is given by



$$\vec{F} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q_0}{r^2}\hat{r}$$

The magnitude of electric field at point p, is given by

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

$$E = \frac{kq}{r^2}$$

or, $$\vec{E} = \frac{kq}{r^3}\cdot\vec{r}$$

Near a Plane Sheet of Charge

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

i.e., it does not depend upon the distance of the point from the sheet of charge.

Near a Conducting Charged Plate

$$E = \frac{\sigma}{\varepsilon_0}$$

σ = Surface charge density of the sheet = $\frac{q}{A}$

$$= \frac{\text{Total charge on the sheet}}{\text{Total area of the sheet}}$$

At a Distance r from a Charged Metal Sphere

When the point is on or outside the sphere

$$E = \frac{kq}{r^2}$$

When the point is inside the sphere:

$$E = 0$$

Due to a Charged Non-metal Sphere

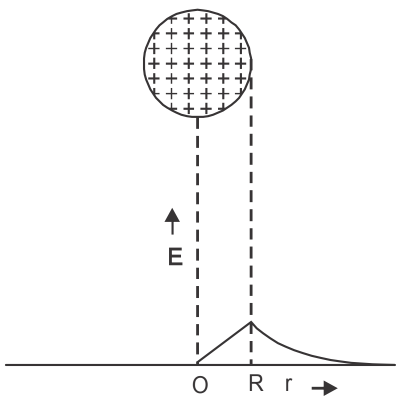
When the point is outside the sphere

$$E = \frac{kq}{r^2}$$

When the point is inside the sphere:

$$E = \frac{kqr}{R^3}$$

where, R = radius of the sphere



On the Axis of a Uniformly Charged Circular Ring

$$E = \frac{kqr}{(R^2 + r^2)^{3/2}}$$

where,

R = radius of the ring

r = distance of the point from the centre of the ring

$\therefore$ E = 0, at the centre

$$\text{E is max. when } r = \pm\frac{R}{\sqrt{2}}$$

On the Axis of a Uniformly Charged Disc

$$E = \frac{\sigma}{2\varepsilon_0}\left[1 - \frac{r}{(R^2 + r^2)}\right]$$

At a Point Due to an Infinitely Long Line of Charge

$$E = \frac{\lambda}{2\pi\varepsilon_0 r}$$

where,

λ = linear charge density *i.e.*, charge per unit length.

r = perpendicular distance of the point

On the Axis of a Dipole

$$E = \frac{2kpr}{\left(r^2 - l^2\right)^2}$$

where,

r = distance of the point from the centre of the dipole

p = dipole moment

$2l$ = length of the dipole

If $l << r$, then

$$E = \frac{2kp}{r^3} \quad \text{or, } E \propto \frac{1}{r^3}$$

On Equatorial Line of a Dipole

$$E = \frac{kp}{(r^2 + l^2)^{3/2}}$$

In the direction parallel to the axis of the dipole, from positive towards negative poles.

If $r >> l$, then

$$E = \frac{kp}{r^3}$$

At a point lying on a line making an angle θ *with the dipole axis*

$$= p\frac{\sqrt{(3\cos^2\theta + 1)}}{4\pi\varepsilon_0}$$

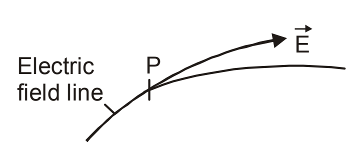
Force on the Surface of a Charged Conductor

In a charged conductor, charge resides on its surface. As same nature charges repel each other, so the entire charged surface experiences an outward force (F) all the time.

$$\text{This force/unit surface area} = \frac{\sigma^2}{2\varepsilon_0}$$

ELECTRIC FIELD LINES

It is defined as the path straight or curved such that tangent to it any point gives the direction of electric field intensity at that point. Infact, it is the path along which a unit a positive charge actually moves in electric field, if free to do so.



ELECTRIC DIPOLE

A system of two equal and opposite charges separated by a certain distance is called an electric dipole.

Electric Dipole moment is defined as the product of the magnitude of either change and the length of the electric dipole.

$$\vec{p} = q \times 2\vec{l}$$

Dipole Placed in an Electric Field

$\vec{\tau}$ = torque on the dipole

$= \vec{p} \times \vec{E}$

Potential Energy of the dipole

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

Note: The electric dipole moment $\vec{p}$ is directed from negative charge to the positive charge.

Work Done in Rotating a Dipole in a Uniform Electric Field

If the dipole is rotated through an angle θ from its equilibrium position in the field (which will be when the axis of the dipole, *i.e.* the direction from its negative charge to its positive charge is the direction of the electric field), then the total work done, W will be

$$W = \int_0^{\theta} pE \sin\theta \cdot d\theta$$

$$= pE\,(1 - \cos\theta)$$

where, p = dipole moment

E = Electric field strength

If the dipole is rotated through 90° *i.e.,* it becomes perpendicular to the direction of field, then

$$W_{90^\circ} = p.E$$

If it is rotated through 180°, then

$$W_{180^\circ} = 2p.E$$

Potential Energy of an Electric Dipole Placed in a Uniform Electric Field (U)

It is defined as the work done in bringing the dipole from infinity to inside the filed in the given orientation.

If dipole is parallel to the field, then,

$$U = -p.E$$

If it is at angle θ

$$U_0 = -p.E \cos\theta$$

If $\theta = 90^\circ$,

$$U_{90^\circ} = 0$$

Electric field intensity and potential at a point $(t_1 + t_2)$ distance away from a charge Q such that up to t_1 distance medium has a relative permittivity $\in_{r_1}$ and then in t_2 distance $\in_{r_2}$.

$$E = \frac{1}{4\pi \in_0} \cdot \frac{Q}{\left[\sqrt{\in_{r_1}} \cdot t_1 + \sqrt{\in_{r_2}} \cdot t_2\right]^2}$$

$$V = \frac{1}{4\pi \in_0} \cdot \frac{Q}{\left[\sqrt{\in_{r_1}} \cdot t_1 + \sqrt{\in_{r_2}} \cdot t_2\right]}$$

esu and emu units of electrical & magnetic quantities.

ELECTRIC FIELD DUE TO A DIPOLE

The direction of electric field due to an electric dipole at a point on its axial line is same as that of the electric dipole moment.

Electric field on axial line of the electric dipole: At the point at a distance r from the centre of the dipole,

$$E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2pr}{(r^2 - a^2)^2}$$

For dipole of small length ($2a << r$),

$$\therefore \quad E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2p}{r^3}$$

Electric field on equitorial line of the electric dipole: At the point at a distance r from the centre of the elecric dipole,

$$\vec{E} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{p}{(r^2 + a^2)^{3/2}}$$

For dipole of small lengh ($2a << r$)

$$\therefore \quad E = \frac{1}{2\pi\varepsilon_0} \cdot \frac{p}{r^3}.$$

TORQUE ON A DIPOLE IN A UNIFORM ELECTRIC FIELD

Consider a dipole with charges $+q$ and $-q$ forming a dipole since they are a distance d away from each other. Let it be placed in a uniform electric field of strength E such that the axis of the dipole forms and angle θ with the electric field.

For an electric dipole of dipole moment $\vec{p}$ placed in electric field $\vec{E}$,

$$\vec{\tau} = \vec{p} \times \vec{E}$$

If θ be the angle between the directions of $\vec{p}$ and $\vec{E}$,

the, $\tau = pE \sin\theta$.

ELECTRIC FLUX

The electric flux through a small surface is defined as the electric lines force passing through that area, when normally to the lines of force.

$\oint \vec{E} \cdot \vec{ds} = E\, ds \cos\theta$ is called the electric flux through (or passing through or linked with or cutting across) the surface *'ds'*, θ being the angle *between 'the normal to the surface 'ds', and 'direction of electric field'.*

The sign of these lines which are coming out of the closed surface is taken as (+) and of those going in as (–).

As far as counting, the number of lines is concerned, $\frac{q}{\epsilon_0}$ electric lines of the force are supposed to be emanating from a charge q when placed in free space.

If there is no net charge placed within the closed surface, the total electric flux linked with the surface will be zero.

GAUSS'S LAW AND ITS APPLICATIONS

It states that the surface integral of the electric field along any closed surface is proportional to the charge contained by the closed surface, *i.e.,*

$$\oint \vec{E} \cdot \vec{ds} = \frac{q}{\varepsilon_0}$$

Hence, Gauss's theorem may be stated as below:

If a closed surface encloses a charges, then surface integral of the electric field (due to enclosed charge) over the closed surface is equal to $\frac{1}{\varepsilon_0}$ times the charged enclosed.

Applications of Gauss's Law

(*i*) The electric field $\vec{E}$ is resulting from all charge, both inside and those outside the Gaussian surface.

(*ii*) The electric in $\oint \vec{E}.d\vec{A}$ is complete electric field. It may be partly due to charge with in the surface and partly due to charge outside the surface. However, if these is no charge enclosed in the Gaussian surface, then

$$\oint \vec{E}.d\vec{A} = 0$$

(*iii*) If a closed body is placed in an electric field (either uniform or non-uniform) total flux linked with it will be zero.

Electric Field due to Infinitely Long Uniformly Straight Wire

Let us consider an uniformly charged wire of infinite length having a constant linear charge density (λ). A cylinder of length (l), radius (r) closed at each end by plane caps normal to the axis is chosen as Gaussian surface. Consider a very small area ds on the Gaussian surface. By symmetry, the magnitude of the electric field will be the same at all points on the surface of the cylinder and directed radially outward $\vec{E}$ and $\vec{ds}$ are along the same direction.

By Gauss's law, the field due to infinitely long straight wire is,

$$E = \frac{\lambda}{2\pi\varepsilon_0 r}$$

UNIFORMLY CHARGED INFINITE PLANE SHEET AND UNIFORMLY CHARGED THIN SPHERICAL SHELL

Electric Field due to an Infinite Plane Sheet of Charge: Consider an infinite sheet thin plane sheet of positive charge having a uniform surface charge density (σ) on both sides of the sheet. By symmetry, it follows that the electric field is perpendicular to the plane sheet of charge and direction outward direction.

Then, electric field, $E = \frac{\sigma}{2\varepsilon_0}$

The magnitude of the electric field at a point due to an infinite plane sheet of charge is independent of its distance from the sheet of charge.

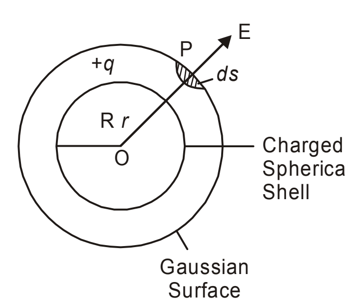
Electric Field due to two Infinite Plane Parallel Sheets of Charge: In case of two infinite plane sheets of charge having equal and opposite surface charge densities, the field is non-zero only in the space between the two sheets and it is constant *i.e.*, uniforms Further, the field is in dependent of the distance between the infinite plane sheets of charge.

The electric field is given by

$$E = \frac{\sigma}{\varepsilon_0}$$

Electric Field due to a Uniformly Charged Spherical Shell:

(*i*) **When point P lies outside the spherical shell:** Draw the gaussian surface through point P. It will be a spherical shell of radius r and centre O. Let $\vec{E}$ be the electric field at point P due to charge of on the spherical shell.



$\therefore$ Total electric flux through the gaussian surface,

$$\phi = E \cdot 4\pi r^2$$

Since the charge enclosed by the gaussian surface q, then from Gauss' law.

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2} \text{ (for } r > R) \; [\because q = 4\pi R^2\sigma]$$

$$= \frac{\sigma}{\varepsilon_0} \cdot \frac{R^2}{r^2} \text{ (for } r > R)$$

(*ii*) When point P lies on the surface of spherical shell: According to Gauss's theorem

$$E = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{R^2} \qquad \text{(for } r = R\text{)}$$

Since $q = 4\pi R^2\sigma$

Then, electrical field,

$$E = \frac{\sigma}{\varepsilon_0} \quad \text{(for } r = R\text{)}$$

(*iii*) When point P lies inside the spherical Shell: The gaussian surface through point P will not enclose any charge and hence according to Gauss's theorem

$$E \times 4\pi r^2 = \frac{0}{r^2}$$

$\therefore$ $E = 0$. (for $r < R$)

Thus, at a point inside the charged spherical shell, electric field is zero.

ELECTRIC POTENTIAL AND ITS CALCULATION FOR A POINT CHARGE

The electric potential at a point is an elecric field is defined as the amount of work done per unit positive test charge in moving the test charge from infinity to that point against the electrostatic force due to the field.

i.e., $$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$$

It is a scalar quantity. It's unit is volt (V) and dimensions are $[ML^2T^{-3}A^{-1}]$.

Potential Gradient: Potential gradient between two points is the rate of change of potential as we go from one point to another

$$\vec{E} = -\frac{dV}{d\vec{r}}$$

Electric Field Strength at a point is equal to negative of the potential gradient at that point.

(–) sign indicates that the direction of E is opposite to the direction in which potential is increasing, *i.e.,* the direction of field is towards the point having smaller potential.

Potential at a Point Due to Different Charges

(i) Due to a point charge (q) at a point at distance r

$$V = \frac{kq}{r}$$

where,

K = Proportionality constant in the equation of Coulomb's law.

(ii) On the axis of a dipole

$$V = \frac{kp}{r^2}$$

(iii) A point on the equatorial axis of the dipole

V = zero

(iv) At a point on a line inclined at an angle θ with the axis of a dipole and passing through the mid-point of dipole.

$$V = \frac{kp\cos\theta}{(r^2 - l^2\cos\theta)}$$

where, 1 = half the length of dipole.

If $r >> l$, then

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

(v) On the axis of a charged ring

$$V = \frac{kq}{(R^2 + r^2)^{1/2}}$$

where,

R = radius of charged ring

r = distance of the point from the centre of charged ring

q = total charge on ring

k = Proportionally constant of Coulomb's Law.

(vi) Due to uniformly charged conducting sphere

(*a*) This sphere behaves like a point charge placed at its centre for all points lying on it's surface and outside

$$V = \frac{kq}{r}$$

(*b*) For all points within the sphere, potential is same and is

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

$\therefore$ Electric Field at its centre = zero.

where, R is the radius of the sphere.

(vii) Due to uniformly charged non-conducting sphere

(*a*) This sphere too behaves like a point charged placed at its centre for all points lying on its surface and outside

$$V = \frac{kq}{r}$$

(*b*) For points within the sphere

$$V = \frac{kq(3R^2 - r^2)}{2R^3}$$

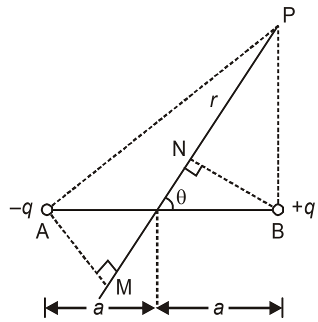
$\therefore$ Potential at its centre.

$$V = \frac{3kq}{2R}$$

where, R is the radius of the sphere.

ELECTRIC DIPOLE AND SYSTEM OF CHARGES

A dipole is a pair of opposite charges with equal magnitudes separated by a distance '*d*'. The electric potential due to a point charge q at a distance of r from that charge is given by



$$V = \frac{1}{4\pi\varepsilon_0} \cdot \frac{p\cos\theta}{(r^2 - a^2\cos^2\theta)}$$

The electric potential due to the dipole in the following two cases:

(*i*) **When point P lies on the axial line of the dipole:** In this case,

$$\theta = 0° \text{ and } \cos\theta = \cos 0° = 1$$

$$\therefore \quad V_{axial} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{p}{(r^2 - a^2)} \quad (\text{for } a << r)$$

$$= \frac{1}{4\pi\varepsilon_0} \cdot \frac{p}{r^2}$$

(*ii*) **When point *p* lies on the equatorial line of the dipole:** In such case,

$$\theta = 90° \text{ and } \cos\theta = \cos 90° = 0$$

$$\therefore \quad V_{equi} = 0.$$

EQUIPOTENTIAL SURFACES

It is any surface on which potential is same everywhere. Work done in moving a charge (any charge) from any point to any point on the equipotential surface is zero.

Two equipotential surfaces never intersect each other.

Electric lines of force, whether emanating from or entering into an equipotential surface, are always normal to the equipotential surface.

Closer the two equipotential surfaces having the same potential difference, more is the electric field between them.

ELECTRICAL POTENTIAL ENERGY OF A SYSTEM OF TWO POINT CHARGES IN AN ELECTROSTATIC FIELD

The electrical potential energy of a system of point charges is defined as the work required to be done to bring the charges constituting the system to their respective locations from infinity.

The work done in bringing the two charges to their respective positions in stored as the potential energy of the configuration of two charges i.e.,

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

CONDUCTORS AND INSULATORS

Conductors: The elements, in which the valence shell is filled less than half, are found to be good conductors. For example, in metals such as copper, aluminium, silver etc. the valence shell contains three or less electrons.

There is net flow of electrons through the metal. It is found that as the strength of the applied electric field is increased, more and more free electrons cross through a section of the metal. As such, the metals are termed as conductor for electricity.

Insulators: The materials which do not have free electrons in them are unable to conduct electricity and are termed as insulators. An insulator may behave in the following two ways.

1. It may not conduct electricity through it and as such it is called insulator.
2. It may not conduct electricity through it but on applying electric field, induced charges are produced on its faces. Such an insulator is called dielectric.

The dielectrics do not conduct electricity. On applying electric field, induced charges of opposite kinds develop on their opposite faces.

DIELECTRICS AND ELECTRIC POLARIZATION

Dielectrics: Dielectrics are insulating (non-conducting) materials which transmits electric effect without conducting. These are two types

1. **Polar dielectrics:** A polar molecule has permanent electric dipole moment $(\vec{P})$ is the absence of electric field. But polar dielectric has net dipole moment zero in the absence of electric field. In the presence of the electric field polar molecules tends to line up in the direction of electric field and the substance has finite dipole moment. CO_2, NH_3, HCl etc. are made of polar molecules.
2. **Non-polar dielectric:** In non-polar molecules, each molecule has zero dipole moment in its normal state. Benzene, methane etc. are made of non-polar molecules.

Electric Polarisation: Electric polarisation occurs, when a non-polar substance placed between two parallel plates with an applied electric field. The electric field tends to attract the negatively charged electron particles on clouds towards the positive plate and positive charge nucleus towards a negative plate.

CAPACITOR (CAPACITANCES)

A capacitor is a combination of two conductors (with any geometry) isolated from each other so that they can be given equal but opposite charge. The conductors of a capacitor are called plates. (Whether they are spherical, cylindrical or even rolled sheets, the conductors are still called plates.)

A simple capacitor consists of a pair of parallel plates of area is separated by a small distance d. A capacitor is represented by the symbol .

The charge stored in a capacitor is given by

$$Q = CV$$

Where, V is the potential difference between two plates. The constant C is called the capacitance of the capacitor. The capacitance depends on the particular geomerty of the two conductors consitituting the capacitor. Capacitance does not depend on the charge nor on the potential difference V.

The unit of capacitance is the farad (F).

$$1F = 1\frac{C}{V}$$

$$\text{Farad} = \frac{\text{Coulomb}}{\text{Volt}}$$

In SI system, unit of capacitor is farad and its dimensions is $[A^2T^4M^{-1}L^{-2}]$.

Capacitance of an Isolated Conductor

When a charge q is given to a conductor, it spreads over the outer surface of the conductor. The whole conductor comes to the same potential.

According to Coulomb's law,

$$\text{Potential} \propto \text{charge}$$

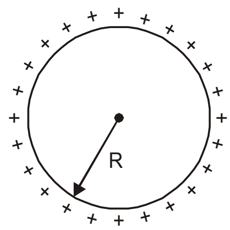
or $\quad V \propto q$ or $V = \frac{1}{C}q$

Where C is a constant called capacitance of the conductors.

$$q = CV \text{ or } C = \frac{q}{V}$$

Capacitance of a Spherical Conductor

When a charge q is given to a spherical conductor of radius R, the potential on its is



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

But $\quad C = \frac{q}{V} = \frac{q}{\frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{R}}$

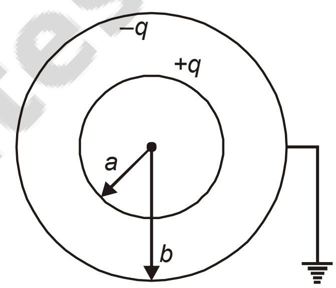
$$= 4\pi\varepsilon_0 R$$

Capacitance of Spherical Capacitor

If the charge q is given to the inner spherical conductor it spreads over the outer surface of it and a charge $-q$ appears on the inner surface of the shell. The electric field is produced only between the two. Here

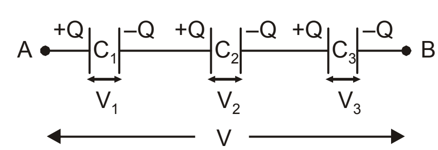
$$V = \frac{q}{4\pi\varepsilon_0}\left(\frac{1}{a} - \frac{1}{b}\right)$$

or $\quad C = \frac{q}{V} = 4\pi\varepsilon_0\left(\frac{ab}{b-a}\right)$



COMBINATION OF CAPACITORS IN SERIES AND PARALLEL

Series Combination of Capacitors: Let three capacitors are connected in series as shown in figure. Let their capacitances be C_1, C_2 and C_3. The total potential difference across V between the point A and B is the potential difference across each capacitor.



The charge on each plate has same magnitude Q. A single equivalent capacitor that can be placed between points A and B to maintain same potential difference would have capacitance C_{eq} where,

$$Q = C_{eq.}V$$

$$V = V_1 + V_2 + V_3 + V_4 \quad ...(i)$$

$$Q = C_1V_1 = C_2V_2 = C_3V_3 = C_4V_4.$$

So we substitute for V_1, V_2, V_3 and V_4 and V into equation (i), we get

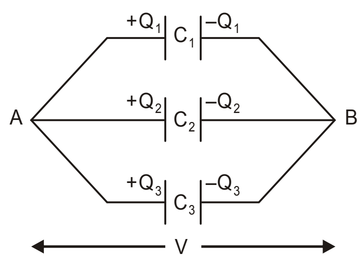
$$\frac{Q}{C_{eq.}} = \frac{Q}{C_1} + \frac{Q}{C_2} = \frac{Q}{C_3} + \frac{Q}{C_4}$$

$$\frac{1}{C_{eq.}} = \frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}+\frac{1}{C_4}$$

The equivalent capacitance $C_{eq.}$ is smaller than the smallest contributing capacitance.

Parallel Combination of Capacitors: Consider a collection of three capacitors in parallel as shown in the figure.

$$C_1 = \frac{Q_1}{V}, C_2 = \frac{Q_2}{V}, C_3 = \frac{Q_3}{V}$$



The magnitude of charge on each plate of the equivalent capacitor must be

$$Q = Q_1 + Q_2 + Q_3 + Q_4$$

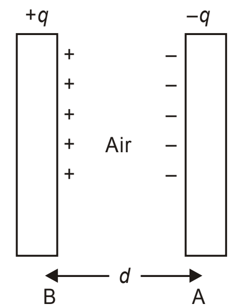
$$C_{eq.}V = C_1V + C_2V + C_3V + C_4V$$

$$C_{eq.} = C_1 + C_2 + C_3+ C_4$$

The equivalent capacitance is the sum of the individual capacitances.

CAPACITANCE OF PARALLEL PLATE CAPACITOR

Let, A = Area of each plate, d = separation between plates, then its capacitance,



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

If instead of air some other insulator of dielectric constant K is inserted between the plates then the capacitance becomes K times that of air.

i.e., $C_{medium} = KC_{air}$

Charges are not stored by a parallel plate capacitor but only the electric energy is stored in the form of potential energy. The total charge in a capacitor is zero.

ENERGY STORED IN CAPACITOR

Work has to be done in charging a conductor against the force of repulsion by already existing charge on it. The work is stored as potential energy in the electric field of the conductor. Let a conductor of capacity C is charged to a potential V and let q be the charge on the conductor at this instant.

Hence, stored potential energy,

$$U = \frac{1}{2}CV^2 = \frac{1}{2}\frac{q^2}{C} = \frac{1}{2}qV$$

EXERCISE

1. n small drops of the same size are charged to V volt each. If they coalesce to form a single large drop, then its potential will be

A. $\frac{V}{n}$ B. Vn

C. $Vn^{1/3}$ D. $Vn^{2/3}$

2. Two conducting spheres of radii r_1 and r_2 are equally charged. The ratio of their potentials is

A. $\frac{r_1^2}{r_2^2}$ B. $\frac{r_2^2}{r_1^2}$

C. $\frac{r_1}{r_2}$ D. $\frac{r_2}{r_1}$

3. If the electric field is given by $6\hat{i}+3\hat{j}+4\hat{k}$, determine the electric flux through a surface of area 20 units lying in yz plane.

A. 80 units B. 100 units

C. 120 units D. 150 units

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

A. 2 volt B. $\frac{1}{2}$ volt

C. 4 volt D. 1 volt

5. A tin nucleus has charge + 50 e. If the proton is at 10^{-12} m from the nucleus, then the potential at this position is (charge on proton is 1.6×10^{-19} C)

A. 14.4×10^4 V B. 7.2×10^4 V

C. 7.2×10^8 V D. 14.4×10^8 V

6. The electric potential at the surface of an atomic nucleus (Z = 50) of radius 9.0×10^{-15} m is

A. 80 volt B. 8×10^6 volt

C. 9 volt D. 9×10^5 volt

7. A proton has a mass of 1.67×10^{-27} kg and charge 1.6×10^{-19} C. If the proton be accelerated through a potential difference of one million volts, then the KE is:

A. 1.6×10^{-15} J B. 1.6×10^{-13} J
C. 1.6×10^{-25} J D. 3.2×10^{-13} J

8. Electrons are caused to fall through a potential difference of 1500 volt. If they were initially at rest, their final speed is:

A. 4.6×10^{7} ms^{-1} B. 2.3×10^{7} ms^{-1}
C. 0.23×10^{2} ms^{-1} D. 5.1×1.9 ms^{-1}

9. If the force exerted by a small spherical charged object on another charged object at 8.00 cm is 2.0 N. What will be the force exerted when the second object is moved to 4.0 cm?

A. 4 N B. 8 N
C. 16 N D. 2 N

10. In bringing an electron towards another electron, the electrostatic potential energy of system:

A. Increases B. Decreases
C. Becomes zero D. Remains unchanged

11. A spherical droplet having a potential of 2.5 V is obtained as a result of merging of 125 identical droplets. Find the potential of constituent droplet.

A. 0.4 V B. 0.5 V
C. 0.2 V D. 0.1 V

12. A hollow metallic sphere of radius 12 cm has been given a charge 8×10^{-7} coulomb. The electric potential at a point 9 cm from the centre of the sphere is

A. $9\times10^{9}\left(\frac{8\times10^{-7}}{0.09}\right)$ V B. $9\times10^{9}\left(\frac{8\times10^{-7}}{(0.09)^2}\right)$ V

C. $9\times10^{9}\left(\frac{8\times10^{-7}}{0.12}\right)$ V D. zero

13. The insulation property of air breaks down at intensity of electric field 3×10^{6} V/m. The maximum charge that can be given to a sphere of diameter 5 m is

A. 2×10^{-2} C B. 2×10^{-3} C
C. 2×10^{-4} C D. 2×10^{-5} C

14. 1 g of solid, there are 5×10^{21} atoms. If one electron is removed from every one atom of the solid, the charge gained by the solid in 1 mg is

A. 0.08 C B. 0.8 C
C. –0.08 C D. –0.8 C

15. The potential difference between two points if 2J of work must be done to move a 4 mC charge from one point to another is

A. 50 V B. 500 V
C. 5 V D. 5000 V

16. The radius of a charged metal sphere R is 10 cm and its potential is 300 V. Find the charge density on the surface of the sphere.

A. 2×10^{-3} cgs esu B. 4×10^{-3} cgs esu
C. 6×10^{-3} cgs esu D. 8×10^{-3} cgs esu

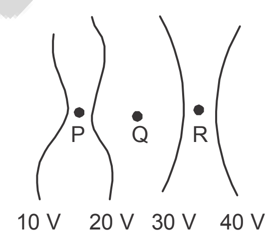
17. If a glass rod is rubbed with silk, it acquires a positive charge because

A. protons are added to it
B. protons are removed from it
C. electrons are added to it
D. electrons are removed from it

18. What is the area of the plates of a 2F parallel capacitor, given that the separation between the plates is 0.5 cm?

A. 0.53×10^{8} m^2 B. 1.01×10^{8} m^2
C. 2.13×10^{8} m^2 D. 1.13×10^{9} m^2

19. The following figure shows contours of potential distribution. At which point out of P, Q and R is the electric field strength is minimum?



A. P B. Q
C. R D. cannot be determined

20. Two metal balls of radii 5 cm and 4 cm are charged to the same potential, the surface densities of charge on the two spheres are in the ratio

A. 4 : 5 B. 5 : 4
C. 16 : 25 D. 25 : 16

21. If an electron has an initial velocity in a direction different from that of an electric field, the path of the electron is

A. a straight line B. a circle
C. an ellipse D. a parabola

22. To move a unit positive charge from one point to another on an equipotential surface

A. work is done by the charge
B. work is done on the charge
C. no work is done
D. work done is a constant

23. As one penetrates a uniformly charged conducting sphere, the electric field strength E

A. increases
B. decreases
C. remains the same as at the surface
D. is zero at all points

24. The surface density on a solid steel sphere of radius r is σ. What is the electric field strength on its surface?

A. $k\dfrac{\sigma}{\varepsilon_0 r}$ B. $\dfrac{\sigma}{\varepsilon_0}$

C. $\dfrac{\sigma}{\varepsilon_0 r}$ D. $\dfrac{2\sigma}{\varepsilon_0}$

25. Two free protons are kept at a distance of 1Å. and released, then the K.E. of each proton when at infinite separation is

A. 5.6×10^{-12} joule B. 11.5×10^{-19} joule

C. 23×10^{-19} joule D. 46×10^{-19} joule

26. A system has two charges $q_A = 2.5 \times 10^{-7}$C and $q_B = -2.5 \times 10^{-7}$ C are located at a points A (0, 0, –15 cm) and B (0, 0, + 15 cm) respectively. The electric dipole moment of the system is

A. 7.5×10^{-8} cm B. 3.5×10^{-7} cm

C. 1.5×10^{-8} cm D. 0.15×10^{-8} cm

27. An oil drop of 12 excess electrons is held stationary under a constant electric field of 2.55×10^4 NC^{-1} in millikan's oil drop experiment. The density of oil is 1.26 gcm^{-3}. Find the radius of the drop

(Given g = 9.8 m/sec^2, $e = 1.6 \times 10^{-19}$ C)

A. 3.57×10^{-7} m B. 9.81×10^{-7} m

C. 1.81×10^{-7} m D. 0.81×10^{-7} m

28. The potential difference applied on X-ray tube is 5kV and connect through it is 3.2 mA. Then, the number of electrons striking the target per second is

A. 1×10^{16} B. 4×10^{17}

C. 2×10^{16} D. 3×10^{15}

29. Two equal point charges are fixed at $x = -a$ and $x = \pm a$ on the x-axis. Another point charge Q is placed at the origin. The change in electrical potential energy of Q. When it is displaced by a small distance x-along the x-axis is near proportional to

A. x^{-2} B. x^2

C. x D. $x^{1/2}$

30. The ratio of the coulomb forces between two small sphere carrying constant charge when placed at a given distance (a) in air (b) in a medium of dielectric constant k

A. $1 : k^2$ B. $k : 1$

C. $1 : k$ D. $k^2 : 1$

31. Under the influence of the coulomb field of charge +Q, a charge $-q$ is moving around in it an elliptical orbit. Find out the correct statement (s)

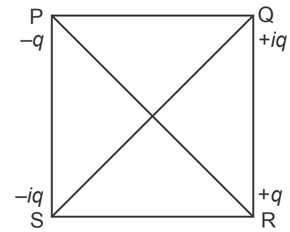
A. The linear momentum of charge $-q$ is constant

B. The angular momentum of charge $-q$ is constant

C. The linear speed of the charge $-q$ is constant

D. The angular velocity of the charge $-q$ is constant

32. Four charges are arranged at the corners of squares PQRS, as shown in fig. The force on the positive charge kept at centre O is



A. along the diagonal QS

B. along the diagonal PR

C. perpendicular to side PQ

D. Zero

33. On moving a charge 20 C by 2 cm, 2J of work is done, then the potential difference between the points is

A. 0.3 V B. 0.1 V

C. 0.8 V D. 0.4 V

34. If the force between the electron in the first Bohr orbit and the nucleus (proton) in hydrogen atom is F, then the force between them, when the electron is in the second orbit is

A. $\dfrac{F}{12}$ B. $\dfrac{F}{16}$

C. $\dfrac{F}{2}$ D. $\dfrac{F}{4}$

35. Two charges q and $-3q$ are placed fixed on X-axis separated by distance 'd'. Where should a third change zq be placed such that, it will not experience any force

A. $\dfrac{d}{2}\left(1+\sqrt{3}\right)$ to the left of q

B. $d\left(1+\sqrt{3}\right)$ to the right of q

C. $\dfrac{d}{4}\left(1+\sqrt{3}\right)$ to the right of q

D. $\dfrac{d}{3}\left(1+\sqrt{3}\right)$ to the left of q

36. Two copper balls each weighing 10 g are kept in air 10 cm apart. If one electron from every 10^6 atoms is transferred from one ball to the other ball, the coulomb force between them is (atomic wt. of copper is 63.5)

A. 2×10^6 N B. 2×10^8 N

C. 2×10^7 N D. 2×10^9 N

37. Three charges each of magnitude q are placed at the corners of an equilateral triangle, the electrostatic force on the charge placed at the centroid is (each side of triangle is L)

A. $\dfrac{1}{4\pi \epsilon_0} \dfrac{q^2}{L^2}$ B. $\dfrac{1}{4\pi \epsilon_0} \dfrac{2q^2}{L^2}$

C. $\dfrac{1}{6\pi \epsilon_0} \dfrac{2q^2}{2L^2}$ D. Zero

38. A particle 'A' having a charge of 2×10^{-8} C and a mass of 100 g is fixed at a bottom of smooth inclined plane of inclination 30°. Where should another particle β, having same charge and mass be placed on the inclined so that it remains in equilibrium?
A. 27 cm B. 22 cm
C. 26 cm D. 31 cm

39. Two identical conductors of Cu and Al are placed in an identical electric field. The magnitude of induced charge in the Al will be
A. equal to Cu B. zero
C. less than Cu D. greater than Cu

40. Two identical particles each of mass 10 g and carrying a charge 2.0×10^{-4} C each are kept at a seperation of 10 cm and then released. What would be the speed of the particles, when separation becomes large?
A. 500 m/s B. 300 m/s
C. 600 m/s D. 400 m/s

41. Two identical charges repel each other with a force equal to 10 mg wt, when they are 0.6 m apart in air, g = 10 m/sec^2. The value of each charge is
A. 3 μC B. 5 μC
C. 2 μC D. 6 μC

42. If a body gives out 10^9 electrons every second, how much time is required to get the total charge of 1 C from it?
A. 132.32 years B. 198.18 years
C. 215.05 years D. 98.34 years

43. Two point charges placed at a certain distance r in air exert a force F on each other. Then the distance r at which these charges will exert the same force in a medium of dielectric constant k is given by
A. $r\sqrt{k}$ B. $\frac{r}{\sqrt{k}}$
C. r D. $\frac{r}{k}$

44. Two particles of equal mass m and charge q are palced at a distance of 16 cm. They do not experience any force. The value of $\frac{q}{m}$ is
A. $\sqrt{4\pi \epsilon_0 G}$ B. $\sqrt{2\pi \epsilon_0 G}$
C. $\sqrt{3\pi \epsilon_0 G}$ D. $\sqrt{5\pi \epsilon_0 G}$

45. Equal charges q are placed at each of A, B, C, and D of a square of side length 'a'. The magnitude of force on the charge at B will be
A. $\left(\frac{1+2\sqrt{2}}{2}\right)\frac{q^2}{4\pi \epsilon_0 a^2}$ B. $\left(1+\frac{1}{\sqrt{2}}\right)\frac{q^2}{4\pi \epsilon_0 a^2}$
C. $\left(1+\sqrt{2}\right)\frac{q^2}{4\pi \epsilon_0 a^2}$ D. $\left(2+\sqrt{2}\right)\frac{q^2}{4\pi \epsilon_0 a^2}$

46. The ratio of electrostatic and gravitational force acting between electron and proton separated by a distance 5×10^{-11} m, will be charge one = 1.6×10^{-19} C, mass of electron = 9.1×10^{-31} kg, mass of p^+ = 1.6×10^{-27} kg and G = 6.7×10^{-11} Nm^2/kg^2
A. 1.37×10^{37} B. 1.76×10^{19}
C. 2.98×10^{22} D. 3.54×10^{16}

47. Four point charges –Q, $-q$, $2q$ and 2Q are placed, one of the each corner of square. The relation between Q and q for which the potential at the centre of the square is zero is
A. $\frac{1}{q}$ B. $-\frac{1}{q}$
C. q D. $-q$

48. A ball with charge $-50\,e$ is placed at the centre of hollow spherical shell which carries a net charge of $-50\,e$. The charge on the shell in outer surface is
A. $-100\,e$ B. $-50\,e$
C. $+100\,e$ D. 0

49. A ring of radius r carries a charge Q uniformly distributed over its length. A charge q is placed at its centre will experience a force equal to
A. 0 B. $\frac{qQ}{4\pi \epsilon_0 r^2}$
C. $\frac{2qQ}{3\pi \epsilon_0 r^2}$ D. $\frac{qQ}{6\pi \epsilon_0 r^2}$

50. An infinite number of charge, each of charge 1μC are placed on X-axis with co-ordinates x = 1, 2, ...∞. If a charge of 1C is kept at the origin, then the net force acting on 1C charge is
A. 1×10^4 N B. 3.5×10^4 N
C. 1.2×10^4 N D. 4.0×10^4 N

51. A polythene piece rubbed with wool is formed to have a negative charge of -3×10^{-7} C. The number of electrons transferred from the wool to polythene is
A. 1.8×10^{12} B. 1.9×10^{15}
C. 1.5×10^{13} D. 1.8×10^{10}

52. A copper ball 1 cm in diameter is immersed in oil with a density 800 kgm^{-3}. What is the charge of ball, if the ball moves downwards with constant speed with homogeneous electric field it is applied in oil? The electric field is directed vertically upward and its intensity E = 36000 V/m and density of Cu = 8600 kgm^{-3}.
A. 3.6×10^{-6}C B. 3.2×10^{-7}C
C. 2.1×10^{-9}C D. 1.1×10^{-8}C

53. Two point charges repel each other with a force 100 N. One of the charges increased by 10% and other is reduced by 10%. The new force of repulsion at the same distance would be

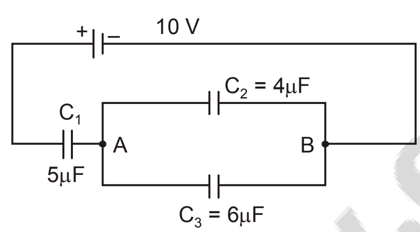
A. 101 N B. 100 N
C. 99 N D. 110 N

54. The two charges identical metal spheres A and B repel each other with a force 3×10^{-5}N. Another identical uncharged sphere C is touched with A and then placed at the mid point A and B, Net force on C is
A. 3×10^{-5} N B. 1×10^{-5} N
C. 2×10^{-5} N D. 11.5×10^{-5} N

55. Two point charges +3 μC and +8 μC repel each other with a force of 40 N. If a charge of –5 μC is added to each of them, then the force between them will become
A. 20 N B. 15 N
C. 18 N D. 10 N

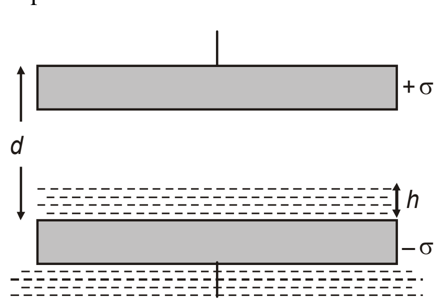
56. A parallel plate capacitor is connected to a battery. The plates are pulled apart with uniform speed. If x is the separation between the plates then rate of change of electrostatic energy of the capacitor is proportional to
A. x^2 B. x
C. $\frac{1}{x}$ D. $\frac{1}{x^2}$

57. The charge on C_1 capacitor and potential difference across points A and B is



A. $\frac{50}{6}\mu C, \frac{33}{9}V$ B. $\frac{10}{3}\mu C, \frac{100}{3}V$
C. 50μC, 5V D. 0, 0

58. A parallel plate capacitor of plate area A and separation between the plates d, is submerged into a non-conducting liquid of dielectric constant K, and density ρ. If the capacitor plates get charges of charge density σ, then for the idealized situation shown in figure, the height h of the level of liquid that rises in the capacitor is:



A. zero B. $\frac{K\sigma^2}{\varepsilon_0 \rho g}$
C. $\frac{\sigma^2}{K\varepsilon_0 \rho g}$ D. $\frac{\sigma^2(K-1)}{K\varepsilon_0 \rho g}$

59. A capacitor of capacitance 1μF withstands a maximum voltage of 6 kV, while another capacitor of capacitance 2 μF, the maximum voltage 4 kV. If they are connected in series, the combination can with stand a maximum of
A. 6 kV B. 4 kV
C. 10 kV D. 9 kV

60. The capacity of a parallel plate air capacitor is 10 μF and is given a charge of 40 μC. The electrical energy stored in the capacitor (in erg) is
A. 500 B. 800
C. 900 D. 200

61. An air capacitor is given a charge of 2 μC raising its potential to 200 V. If on inserting a dieletric medium, its potential falls to 50 V, what is the dielectric constant of the medium?
A. 1 B. 2
C. 3 D. 4

62. An electric dipole is formed by + 6 μC and –6 μC charges at 5 mm distance. The dipole moment is
A. 2×10^{-7}C m B. 3×10^{-8}C m
C. 2.5×10^{-6}C m D. 4×10^{-7}C m

63. An electric dipole of dipole moment 4×10^{-5}C m is placed in a uniform electric field of 10^{-3} NC^{-1} making an angle of 30° from the direction of electric field. Then, the torque exerted by the electric field on the dipole is
A. 1.5×10^{-7} Nm B. 0.5×10^{-8} Nm
C. 2×10^{-8} Nm D. 2.8×10^{-7} Nm

64. The electric potential at 0.1 m from a point charge is 50 V. What is the magnitude of the charge?
A. $\frac{5}{9} \times 10^{-9}$C B. $\frac{1}{3} \times 10^{-8}$C
C. $\frac{3}{7} \times 10^{-7}$C D. $\frac{5}{9} \times 10^{-8}$C

65. A box encloses an electrical dipole consisting of charge 5 μC and –5 μC and of length 10 cm. What is the total electric flux through the box?
A. 0 B. ∞
C. 10 D. 100

66. The electric flux through each face of a hollow cube of side 10 cm, if a charge of 8.854 μC is placed at its centre is
A. 2.13×10^5 Nm^{2}C^{-1} B. 1.67×10^5 Nm^{2}C^{-1}
C. 0.13×10^6 Nm^{2}C^{-1} D. 3.05×10^4 Nm^{2}C^{-1}

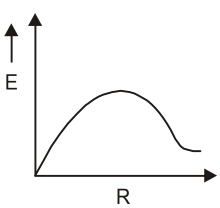
67. A capacitor charged from a 50 V dc supply is found to have a charge of 10 μC. What is energy stored in a capacitor?

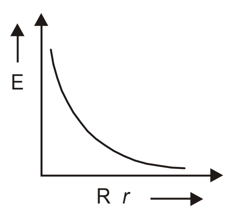
A. 1.2×10^{-4} J B. 2.0×10^{-3} J
C. 2.5×10^{-4} J D. 4.0×10^{-3} J

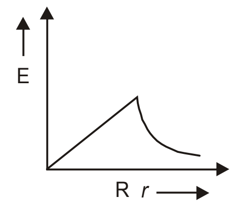
68. The potential at a point 0.1 m from an isolated point charge is +100 V. What is the nature and magnitude of the point charge?

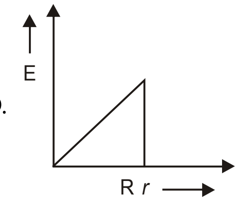
A. 1.11×10^{-9}C (Positive)
B. 2.11×10^{-9}C (Negative)
C. 0.14×10^{-8}C (Negative)
D. 2.51×10^{-9}C (Positive)

69. In a uniformly charged sphere of total charge Q and radius R, the electric field E is plotted as a function of distance from the centre. The graph which would correspond will be

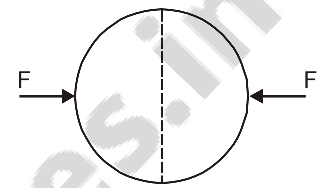
A. 

B. 

C. 

D. 

70. A uniformly charged this spherical shell of radius R carries uniform surface charge density of σ per unit area. It is made of two hemispherical shells, held together by pressing them with force (in fig.), F is proportional to



A. $\frac{1}{\varepsilon_0}\sigma R$ B. $\frac{1}{\varepsilon_0}\sigma^2 R^2$
C. $\frac{1}{\varepsilon_0}\frac{\sigma}{R^2}$ D. $\frac{1}{\varepsilon_0}\frac{\sigma^2}{R^2}$

ANSWERS

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
D	D	C	B	B	B	B	B	B	A
11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
D	C	B	B	B	D	D	D	B	A
21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
D	C	D	B	B	A	B	C	B	B
31	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
B	A	B	B	A	B	D	A	A	C
41	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**
C	B	B	A	A	B	D	A	A	C
51	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**
A	D	C	A	D	D	A	D	D	B
61	**62**	**63**	**64**	**65**	**66**	**67**	**68**	**69**	**70**
D	B	C	A	A	B	C	A	C	B

EXPLANATORY ANSWERS

1. As, $n\frac{4}{3}\pi r^3 = \frac{4}{3}\pi R^3, R = n^{1/3}r$

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

$V' = \frac{nq}{4\pi\varepsilon_0 R} = \frac{nq}{4\pi\varepsilon_0 n^{1/3} r}$

$\therefore$ $V' = n^{2/3}\ V$

2. As, $V_1 = \frac{q}{4\pi\varepsilon_0 r_1}$

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

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

3. Given, $\vec{E} = 6\hat{i} + 3\hat{j} + 4\hat{k}$

The area vector denoted the surface of area 20 units is *yz* plane.

$$\vec{S} = 20\hat{i}$$

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

$$= \left(6\hat{i} + 3\hat{j} + 4\hat{k}\right)\cdot 20\hat{i}$$

$$= 120 \text{ units.}$$

4. We have, $W = QV$

$\therefore$ $5 = 10 \times V \Rightarrow V = \frac{1}{2}\text{volt}$

5. Potential $= \frac{1}{4\pi\varepsilon_0}\left(\frac{Q}{r}\right)$

$$= \frac{9\times10^9 \times 50\times1.6\times10^{-19}}{10^{-12}}\text{V}$$

$$= 7.2 \times 10^4 \text{ V}$$

6. As, $V = \frac{Q}{4\pi\varepsilon_0 r}$

$$= \frac{Ze}{4\pi\varepsilon_0 r}$$

$$= \frac{9\times10^9 \times 50\times1.6\times10^{-19}}{9\times10^{-15}}\text{V}$$

$$= 8 \times 10^6 \text{ V}$$

7. As, $KE = \frac{1}{2}mv^2 = eV$

$$= 1.6 \times 10^{-19} \times 10^6$$

$$= 1.6 \times 10^{-13} \text{ J.}$$

8. Use $eV = \frac{1}{2}mv^2$

$\therefore$ $v = \sqrt{\frac{2eV}{m}}$

$$= \sqrt{\frac{2\times1.6\times10^{-19}\times1500}{9\times10^{-31}}}\text{ m/s}$$

$$= 2.3 \times 10^7 \text{ ms}^{-1}.$$

9. Distance changes from 8 cm to 4 cm, *i.e.*, distance is halved force becomes 4 times, hence new force is 8 N.

10. Work has to be done agaist the force as repulsion in bringing an electron towards another electron. This increases the electrostatic potential energy of system.

11. We have, $V.n^{2/3} = 2.5$

or, $V.(125)^{2/3} = 2.5$

or, $25V = 2.5$, or $V = 0.1$ V

12. We have, $V_{inside} = V_{on}$

$$= \frac{1}{4\pi\varepsilon_0}\frac{q}{r} = 9 \times 10^9 \times \frac{8\times10^{-7}}{0.12}\text{V}$$

13. As, $E = \frac{Q}{4\pi\varepsilon_0 R^2}$

$$3 \times 10^6 = \frac{Q}{4\pi\varepsilon_0 R^2} = \frac{9\times10^9\times Q}{\left(\frac{5}{2}\right)^2}$$

$\therefore$ $Q = \frac{25\times3\times10^6}{4\times9\times10^9} = 2 \times 10^{-3}$ C

14. As, $Q = ne = 5 \times 10^{21} \times 1.6 \times 10^{-19} \times 10^{-3}\text{C} = 0.8$ C

15. As, $dW = qdV$

$$2 = 4 \times 10^{-3}dV$$

$\therefore$ $dV = \frac{2}{4}\times10^3 = 500$ V

16. We have, 300 V = 1 stat volt

$\frac{Q}{R} = \frac{Q}{10} = 1$ $\{\because K = 1 \text{ in CGS esu}\}$

Q = 10 stat coulomb

As, $\sigma = \frac{Q}{4\pi R^2} = \frac{10}{4\pi(10)^2}$

$\therefore$ $\frac{1}{40\pi} = 8 \times 10^{-3}$ c.g.s. esu.

17. When electrons are removed from metal plate, it becomes deficit of electrons and hence positively charged Q must be negative.

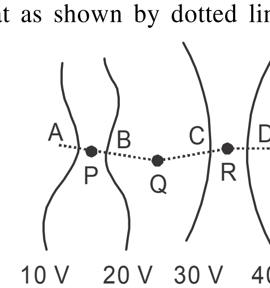
18. Given, $C = 2F$, $d = 0.5 \text{ cm} = 0.5 \times 10^{-2}$ m

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

or $A = \frac{Cd}{\varepsilon_0} = \frac{2\times0.5\times10^{-2}}{8.854\times10^{-12}}$

$$= 1.13 \times 10^9 \text{ m}^2$$

19. The electric field lines are perpendicular to equipotential surfaces. Hence, one of them will be somewhat as shown by dotted line. Further,



$$E = \frac{-dV}{dr}$$

$$\therefore \quad E_P = -\frac{10}{AB}$$

$$E_Q = -\frac{10}{BC}$$

$$E_R = -\frac{10}{CD}$$

As BC > AB as well as CD,

$\therefore$ EQ is minimum.

20. As, $\frac{q_1}{5} = \frac{q_2}{4} \quad \therefore \quad \frac{q_1}{q_2} = \frac{5}{4}$

$$\frac{\sigma_1}{\sigma_2} = \frac{q_1}{4\pi(5)^2} \Big/ \frac{q_2}{4\pi(4)^2}$$

$$= \frac{q_1}{q_2} \times \frac{4^2}{5^2} = \frac{5}{4} \times \frac{4^2}{5^2} \times \frac{4}{5} = \frac{16}{25}$$

21. Uniform motion in one direction and uniformly accelerated motion at right angles to it gives a parabola.

22. $dW = qdV$

V = constant, $dV = 0$

$dW = 0$

23. Electric intensity at a point distant d from a dipole is inversely proportional to the cube of the distance.

24. As, $E = \frac{kQ}{r^2} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{\sigma \cdot 4\pi r^2}{r^2} = \frac{\sigma}{\varepsilon_0}$

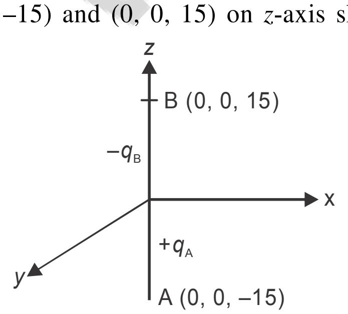
25. P.E. of protons at 1Å = K.E. of 2 protons at ∞.

$$\frac{(e)(e)}{4\pi \epsilon_0 r} = \text{(K.E. of each proton)} \times 2$$

K.E. of each proton $= \frac{9 \times 10^9 \times (1.6 \times 10^{-19})^2}{2 \times 1 \times 10^{-10}}$

$= 11.5 \times 10^{-19}$ joule.

26. Two charges q_A and q_B are located at point A(0, 0, –15) and (0, 0, 15) on z-axis shown in Fig.



$q = q_A + q_B$

$= 2.5 \times 10^{-7} - 2.5 \times 10^{-7}$ cm $= 0$

$= AB = 15 + 15 = 30$ cm $= 30 \times 10^{-2}$ m

Electric dipole moment

$P = \text{Charge} \times AB$

$= 2.5 \times 10^{-7} \times (30 \times 10^{-2}) = 7.5 \times 10^{-8}$ m.

27. Given, $n = 12$, $E = 2.55 \times 10^{14}$ V/m

$\rho = 1.26 \text{ gcm}^{-3} = 1.26 \times 10^3 \text{ kg/m}^3$

As the drop is stationary

$\therefore$ Weight of droplet = force due to electric field

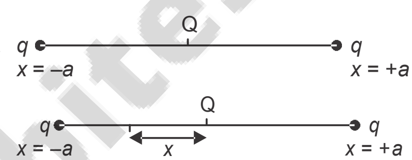
$$\frac{4}{3\pi r^3 \rho g} = E_{ne}$$

$$r^3 = \frac{3E_{ne}}{4\pi\rho g} = \frac{3 \times 2.55 \times 10^4 \times 12 \times 1.6 \times 10^{-19}}{4 \times 3.14 \times 1.26 \times 10^3 \times 9.8}$$

$\therefore \quad r = 9.8 \times 10^{-7}$ m.

28. As, $i = \frac{q}{t} = \frac{ne}{t} \Rightarrow n = \frac{i \times t}{e} = \frac{3.2 \times 10^{-3}}{1.6 \times 10^{-19}} = 2 \times 10^{16}$.

29.



initial position

Final position $x = -a$

PE at Q, $U_i = \frac{2Qq}{4\pi \epsilon_0 a}$ ...(i)

Final PE of Q is

$$U_f = \frac{Qq}{4\pi \epsilon_0}\left[\frac{1}{a+x} + \frac{1}{a-x}\right]$$

$$= \frac{Qq}{4\pi \epsilon_0}\left[\frac{a-x+a+x}{a^2-x^2}\right]$$

$$U_f = \frac{2Qq_a}{4\pi \epsilon_0 (a^2-x^2)} \quad ...(ii)$$

Now, $\Delta U = U_f - U_i = \frac{2Qq}{4\pi \epsilon_0}\left[\frac{a}{a^2-x^2} - \frac{1}{a}\right]$

$$= \frac{2Qq}{4\pi \epsilon_0}\left[\frac{a^2-a^2+x^2}{a(a^2-x^2)}\right]$$

$$= \frac{2Qq}{4\pi \epsilon_0} \frac{x^2}{a(a^2-x^2)},$$

$$\Delta U = \frac{2Qqx^2}{4\pi \epsilon_0 a^3}$$

$\therefore \quad \Delta U \propto x^2$

30. Given, $F_a = \frac{q_1 q_2}{4\pi \epsilon_0 r^2}$ ...(i)

$F_b = \frac{q_1 q_2}{k 4\pi \epsilon_0 r^2}$ ...(ii)

From (i) & (ii), we get $F_a : F_b = k : 1$

31. A torque about Q of charge $-q$ is zero, then angular momentum of charge $-q$ is constant but distance between charges is changing, so force is changing. Therefore, the velocity and speed are also changing.

32. There is positive charge at O. The resultant force due to the charges placed at P and Q is zero and resultant force due charge at Q and S is towards S along the diagonal QS.

33. The potential difference between two points in an electric field is $V_A - V_B = \dfrac{W}{q_0}$

Where, W is work done by moving charge q_0 from the point A to B.

Given, $\quad W = 2J,\ q_0 = 20\ C$

$$\therefore \quad V_A - V_B = \frac{2}{20} = 0.1\ V$$

34. As, $\quad F = \dfrac{1}{4\pi \in_0}\dfrac{q_1 q_2}{r_1^2}$ and $F_1 = \dfrac{1}{4\pi \in_0}\dfrac{q_1 q_2}{r_2^2}$

Where, r_2 is the radius of 2nd orbit

$$r_n^2 \propto n^2 \qquad r_2 = 4r_1$$

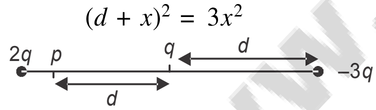
$$F_1 = \frac{1}{4\pi \in_0}\frac{q_1 q_2}{(4r_1)^2} = \frac{F}{16}$$

35. On the charge $2q$ placed at p.

Force due to q is to the left and that due to $-3q$ is to the right

$$\frac{2q^2}{4\pi \in_0 x^2} = \frac{6q^2}{4\pi \in_0 (d+x)^2}$$

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

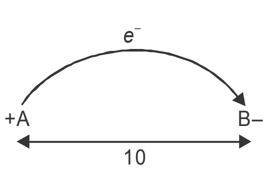


$$\Rightarrow \quad 2x^2 - 2dx - d^2 = 0$$

$$\therefore\ x = \frac{d}{2} \pm \frac{\sqrt{3}d}{2} = \frac{d}{2}(1+\sqrt{3}) \text{ to left of } q.$$

36. No. of atoms in given mass $= \dfrac{10}{63.5} \times 6.02 \times 10^{23}$

$$= 6.48 \times 10^{22}$$



Transfer of electrons between balls

$$= \frac{9.48 \times 10^{22}}{10^6} = 9.48 \times 10^{16}$$

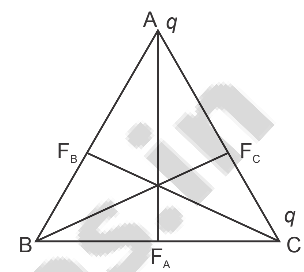
$\therefore$ Magnitude of charge gained by each ball.

$$Q = 9.48 \times 10^{16} \times 1.6 \times 10^{-19} = 0.015C$$

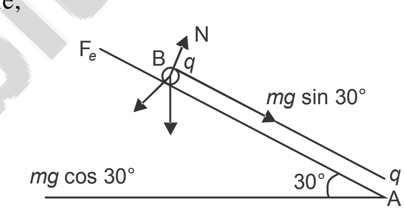
$\therefore$ Force of attraction between the two balls

$$F = 9 \times 10^9 \times \frac{(0.015)^2}{(0.1)^2} = 2 \times 10^8\ N.$$

37. From the figure, we see $|\vec{F}| = |\vec{F}_B| = |\vec{F}_C|$ and are equally inclined with each other. Thus, the resultant force will be zero.



38. The forces acting on charge B are shown in fig. Resolving perpendicular and parallel to the inclined plane,



$$N = mg \cos 30° \qquad ...(i)$$

$$F_e = mg \sin 30° \qquad ...(ii)$$

From (*i*) and (*ii*)

$$\frac{kq^2}{x^2} = \frac{mg}{2}$$

Using the given value and solving, we get

$$x = \sqrt{\frac{2kq^2}{mg}} = 27 \text{ cm.}$$

39. Since Cu and Al are both metals, equal amount of charge will be induced on them.

40. When the separation of particles becomes large, the entire PE is converted into KE.

$$\therefore \quad 2 \times \left(\frac{1}{2}mv^2\right) = \frac{q_1 q_2}{4\pi \in_0 r}$$

$$10^{-2}v^2 = \frac{9 \times 10^9 \times (2 \times 10^{-4})^2}{10^{-1}} = 3600$$

$$v^2 = \frac{3600}{10^{-2}} = 36 \times 10^4$$

$$\therefore \quad v = 600 \text{ m/sec.}$$

41. As, $\quad F = \dfrac{1}{4\pi \in_0}\dfrac{q_1 q_2}{r^2}$

$$\therefore \quad q_1 = q_2 = q$$

$\therefore \quad (10 \times 10^{-3}) \times 10 = \dfrac{9\times10^9 \times q^2}{(0.6)^2}$

$\Rightarrow \quad q^2 = 4 \times 10^{-12}$

$\therefore \quad q = 2 \times 10^{-6}$ C = 2 μC.

42. Given, $n = 10^9$ electrons/sec

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

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

Since total charge = 1C

$\therefore$ Time required $= \dfrac{Q}{q} = \dfrac{1}{1.6\times10^{-10}}$ s

$= 6.25 \times 10^9 s$

$= \dfrac{6.25\times10^9}{3600\times24\times365}$ year

= 198.18 years.

43. F = F′

$$\frac{Q_1Q_2}{4\pi \in_0 r^2} = \frac{Q_1Q_2}{4\pi \in_0 r'^2 k}$$

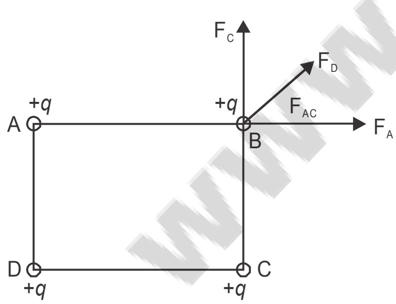
$\Rightarrow \quad r' = \dfrac{r}{\sqrt{k}}$

44. Here, when $|\vec{F}_a| = |\vec{F}_e|$

$\Rightarrow \quad \dfrac{G\cdot m^2}{(16\times10^{-2})^2} = \dfrac{1}{4\pi \in_0}\dfrac{q^2}{(16\times10^{-2})^2}$

$\Rightarrow \quad \dfrac{q}{m} = \sqrt{4\pi \in_0 G}$

45.



$\because \quad F_A = F_C = \dfrac{kq^2}{a}$ and $F_D = \dfrac{kq^2}{(a\sqrt{2})^2}$

$\therefore \quad F_{net} = \dfrac{\sqrt{2}kq^2}{a^2} + \dfrac{kq^2}{2a^2}$

$= \dfrac{kq^2}{a^2}\left(\sqrt{2}+\dfrac{1}{2}\right)$

$= \dfrac{q^2}{4\pi \in_0 a^2}\left(1+\dfrac{2\sqrt{2}}{\sqrt{2}}\right)$

46. Electrostatic force

$F_e = \dfrac{1}{4\pi \in_0}\dfrac{e^2}{r^2} = \dfrac{9\times10^9\times(1.6\times10^{-19})^2}{(5\times10^{-11})^2}$

$= 9.22 \times 10^{-8}$ N

and gravitational force.

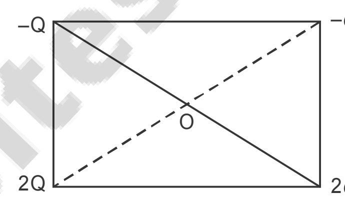
$F_G = \dfrac{Gm_em_p}{r^2}$

$F_G = \dfrac{6.7\times10^{-11}\times9.1\times10^{-31}\times1.6\times10^{-27}}{(5\times10^{-11})^2}$

$= 5.24 \times 10^{-27}$ N

$\therefore \quad \dfrac{F_e}{F_G} = \dfrac{9.22\times10^{-8}}{5.24\times10^{-27}} = 1.76 \times 10^{19}$

47. Consider the side of square b 'a', then potential at centre O is

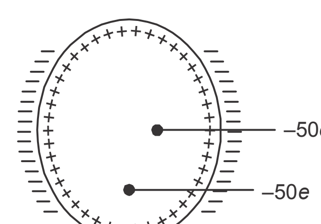


$$V = \frac{k(-Q)}{\left(\frac{a}{\sqrt{2}}\right)} + \frac{k(-q)}{\left(\frac{a}{\sqrt{2}}\right)} + \frac{k(2q)}{\frac{a}{\sqrt{2}}} + \frac{k(2Q)}{\frac{a}{\sqrt{2}}} = 0$$

$-Q - q + 2q + 2Q = 0 \Rightarrow Q + q = 0 \Rightarrow Q = -q$.

48. From Fig, total charge on outer surface

$= -50e - 50e = -100e$



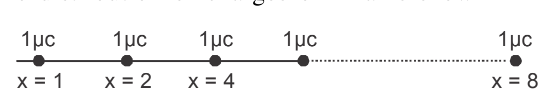
Induced charge on inner surface of shell = $+50e$

Induced charge on outer surface of shell = $-50e$

49. The electric field at the centre of the circular charged ring of radius R is zero.

$\therefore \quad$ Force = qE = 0

50. The distribution of charges on X-axis shown in fig.



$\therefore$ Total force acting on 1C charge is given as

$F = \dfrac{1}{4\pi \in_0}$

$= \left[\dfrac{1\times1\times10^{-6}}{(1)^2} + \dfrac{1\times1\times10^{-6}}{(2)^2} + \dfrac{1\times10^{-6}}{(4)^2} + \dfrac{1\times1\times10^{-6}}{(8)^2} + ...\infty\right]$

$$= \frac{10^{-6}}{4\pi \in_0}\left(1+\frac{1}{4}+\frac{1}{16}+...\infty\right)$$

$$= 9 \times 10^9 \times 10^{-6}\left(\frac{1}{1-\frac{1}{4}}\right)$$

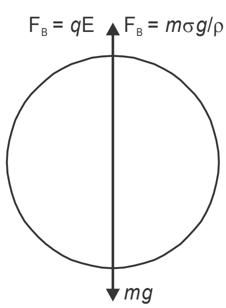
$$= 9 \times 10^9 \times 10^{-6} \times \frac{4}{3}$$

$$= 9 \times \frac{4}{3} \times 10^3 = 1.2 \times 10^4 \text{ N.}$$

51. Total charge $q = -3 \times 10^{-7}$ C
Charge on the electron $= -1.6 \times 10^{-19}$C
As, $q = ne$

or, $$n = \frac{q}{e} = \frac{-3\times10^{-7}}{-1.6\times10^{-19}}$$
$$= 1.8 \times 10^{12}.$$

52. Here, mass of Cu ball, $m = \frac{4}{3}\pi r^3\rho$



The ball is immersed in oil and a uniform electric field exists in the upwards direction.

Here, three forces acts on the ball.

For the equilibrium of Cu ball

$$mg = F_E + F_B = qE + m\sigma g$$

$$\Rightarrow \quad q = \frac{mg}{E}\left(1-\frac{\sigma}{\rho}\right)$$

$$= \frac{4}{3}\frac{\pi r^3 \rho g}{E}\left(1-\frac{\sigma}{\rho}\right)$$

$$= \frac{4\pi(0.5\times10^{-2})^3(8600\times9.8)}{3\times36000\times100}\left(1-\frac{800}{8600}\right)$$

$$= 1.1 \times 10^{-8}\text{C.}$$

53. As, $F = \frac{1}{4\pi \in_0}\frac{q_1q_2}{r^2}$

For the new force $q_1' \cdot q_2' = q_1\left(\frac{110}{100}\right)q_2\left(\frac{90}{100}\right)$

Thus, new force F′ is $\frac{99}{100}$ times of F

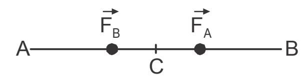
$$\therefore \quad \frac{99}{100} \times 100 = 99 \text{ N.}$$

54. There is same charge q on the sphere A and B

$$\therefore \quad F = \frac{1}{4\pi \in_0}\frac{q^2}{r^2} = 3 \times 10^{-5} \text{ N}$$

Now, on touching the sphere A and C

Final charges on these spheres $q'_A = q'_C = \frac{q}{c}$



$\therefore$ Net force on C, $\vec{F} = \vec{F}_A + \vec{F}_B$

$$F = \frac{1}{4\pi \in_0}\frac{\left(\frac{q}{2}\right)\left(\frac{q}{2}\right)}{\left(\frac{r}{2}\right)^2} - \frac{1}{4\pi \in_0}\frac{\left(\frac{q}{2}\right)q}{\left(\frac{r}{2}\right)^2}$$

$$= -\left(\frac{1}{4\pi \in_0}\frac{q}{r^2}\right) = -3\times10^{-5} \text{ N}$$

55. Given F = 40

$$F = \frac{k(3)(8)}{r^2} = \frac{24k}{r^2} \qquad ...(i)$$

$$F' = \frac{k(3-5)(8-5)}{r^2} = \frac{-6k}{r^2} \qquad ...(ii)$$

From equation (i) & (ii), we get

$$\frac{F'}{F} = \frac{-6k}{r^2}\times\frac{r^2}{24k} = -\frac{1}{4}$$

$$\therefore \quad F' = -\frac{F}{4} = -\frac{40}{4} = -10 \text{ N (attractive)}$$

56. As, $$U = \frac{1}{2}qV = \frac{1}{2}\frac{\varepsilon_0 AV^2}{x}$$

$$\frac{dU}{dt} = \frac{1}{2}\varepsilon_0 AV^2\left(-\frac{1}{x^2}\right)\frac{dx}{dt}$$

$$= \frac{1}{2}\varepsilon_0 AV^2 v\left(-\frac{1}{x^2}\right)$$

$$\therefore \quad \frac{dU}{dt} \propto \frac{1}{x^2}$$

57. The effective capacitance of the parallel combination of C_2 and C_3 is 10μF and that of the entire combination C_1, C_2, C_3 is $\left(\frac{50}{15}\right)$μF. Thus the charge on the equivalent capacitor is

$$Q = CV = \frac{50}{15}\times10 - \frac{100}{3}\mu C$$

The same charge appears on C_1 capacitor,

Now, $$V_{AB} = \frac{Q}{C_{AB}} = \frac{100}{3}\times\frac{10^{-6}}{10\times10^{-6}} = \frac{10}{3}\text{V}$$

58. Surface charge on liquid surface

$$= \sigma A\left(1-\frac{1}{K}\right)$$

The upward force of attraction

$$= E\cdot\sigma A\left(1-\frac{1}{K}\right)$$

with $\quad E = \dfrac{\sigma}{K\,\varepsilon_0}$

This is balanced by $mg = Ah\rho g$

59. Here, $\quad C = \dfrac{2\times 1}{2+1} = \dfrac{2}{3}\mu F$

As, $\quad Q = CV$

$\therefore \quad Q = \dfrac{2}{3}E$

$$V_1 = \frac{Q}{C_1} = \frac{2}{3}E < 6kV$$

or $\quad E < \dfrac{3}{2}\times 6$

i.e., $\quad E < 9kV$

60. As, $\quad \text{Energy} = \dfrac{Q^2}{2C} = \dfrac{(40\times10^{-6})^2}{2\times10\times10^{-6}}$

$$= \frac{40\times40\times10^{-12}}{2\times10\times10^{-6}}\,J$$

$$= 80\times10^{-6}\times10^{7}\text{ erg}$$

$$= 800\text{ erg}$$

61. The potential between the plates of the capacitor decreases by a factor equal to dielectric constant

$\therefore \quad k = \dfrac{V}{V'} = \dfrac{200}{50} = 4.$

62. Given, $\quad q = +6\mu C = \pm 6\times10^{-6}\,C$

$2a = 5\text{ mm} = 5\times10^{-3}\text{ m}$

$\therefore$ Electric dipole moment

$$P = q(2a) = 6\times10^{-6}\times5\times10^{-3}$$

$$= 3\times10^{-8}C\text{ m.}$$

63. As $\quad \tau = PE\sin\theta$

$$= 4\times10^{-8}\times10^{-3}\sin 30^\circ$$

$$= 2\times10^{-8}\text{ Nm.}$$

64. As $\quad V = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q}{r}$

$\therefore \quad q = 4\pi\varepsilon_0 Vr$

$$= \frac{1}{9\times10^{9}}\times50\times0.1 = \frac{5}{9}\times10^{-9}C.$$

65. Since, net charge enclosed by the box is zero, electric flux through the box is also zero.

66. Total electric flux through each face of the cube

$$\phi = \frac{q}{\varepsilon_0} = \frac{8.854\times10^{-6}}{8.854\times10^{-12}} = 10\text{ Nm}^2C^{-1}$$

$\therefore$ Electric flux through each face of the cube.

$$\phi = \frac{1}{6}\phi = \frac{1}{6}\times10^{6}$$

$$= 1.67\times10^{5}\text{ Nm}^2C^{-1}$$

67. As, $\quad C = \dfrac{q}{V} = \dfrac{10}{50} = 0.2\mu F$

$\therefore$ Energy stored, $U = \dfrac{1}{2}CV^2$

$$= \frac{1}{2}\times0.2\times10^{-6}\times(50)^2$$

$$= 2.5\times10^{-4}\text{ J}$$

68. As, $\quad V = \dfrac{1}{4\pi\varepsilon_0}\cdot\dfrac{q}{r}$

or $\quad q = 4\pi\varepsilon_0 rV = \dfrac{0.1\times100}{9\times10^{9}}$

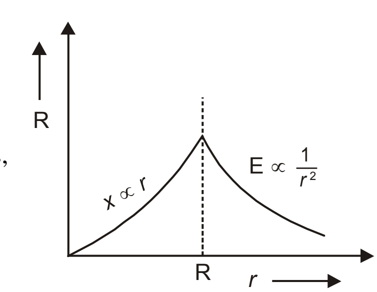
$$= 1.11\times10^{-9}\text{ (Positive)}$$

69. For uniform charge sphere

$$E = \frac{kqr}{R^3}(r<R)$$

$$= \frac{kq}{R^3}(r=R) = \frac{kq}{r^3}(r>R)$$

Hence graph is,



70. Since equilibrium of hemispherical shell,

we have, $\quad F = \dfrac{\sigma^2}{2\varepsilon_0}\times\pi R^2$

$\Rightarrow \quad F = \dfrac{\pi}{2\varepsilon_0}\sigma^2R^2$

$\therefore \quad F \propto \dfrac{\sigma^2R^2}{\varepsilon_0}$

CHAPTER

2

CURRENT ELECTRICITY

ELECTRIC CURRENT (I)

Electric current is rate of flow of charge. Charge carriers can be electrons, ions, holes (as in semi-conductors), etc. If dq be the net charge transported at a section of the conductor in time dt, then, current,

$$I = \frac{dq}{dt}$$

where q = charge

t = time

Electric Current Density (J): It is the current flowing per unit area of cross-section of the conductor.

$$J = \frac{I}{A}$$

For irregular shapes of cross-sections,

$$I = \int \vec{J} \cdot d\vec{A}$$

Although I, J and A are all scalar quantities, they can be so defined as to be represented as vector quantities for the limited purpose under consideration.

Free Electrons: Valence shell and conduction shell in the atoms of conductors, overlap. Thus, the electrons in the valence shell can also be considered as of conduction shell. Now, the electrostatic-cum-gravitational pull of the nucleus on the electrons is felt only upto the conduction shell. As soon as an electron comes in the conduction shell level (which is the shell next and outer to the valence shell), it becomes free of the nucleus pull of any particular atom. Hence, it becomes free to travel from one atom to another within the body of the conductor. It is then called a free electron.

In almost all cases, these free electrons flow from one direction to another (because of some electric field acting on them) and constitute current. If there is not net (*i.e.,* external) field acting on these free or conduction electrons, then they do move in irregular random motion, striking other electrons/atoms/molecules in the process. Then their speed is given by:

$$v_{rms} = \sqrt{\left(\frac{3kT}{m}\right)}$$

$$\simeq 10^{+5} \text{ m/s.}$$

Here

v_{rms} = Root mean square velocity

k = Boltzmann constant and

T = Absolute temperature

DRIFT VELOCITY

When some electric field is applied between the ends of a conductor, its free electrons start *drifting* in a direction according to the direction of the applied field, though they still keep on colliding with their neighbouring fundamental particles, Order of the drift speed is only 10^{-4} m/s.

$$v_d = \left(\frac{eV\tau}{ml}\right) \text{ or } \left(-\frac{e\vec{E}\tau}{m}\right)$$

where,

v_d = Drift speed

E = External field applied to the conductor

e = Charge on electron

V = Potential difference applied between the two ends of the conductor

l = Length of the conductor

m = Mass of an electron

The electric current (I) will be:

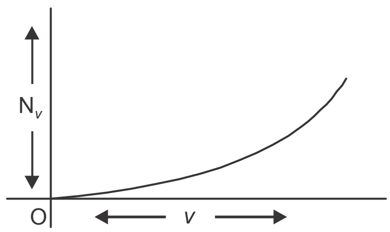
$I = neAv_d$

where,

A = Area of cross-section

n = No. of electrons per unit volume

Distribution of Electrons as per their Velocities



where,

v = velocity

N_v = No. of electrons, having a particular velocity V.

OHM'S LAW

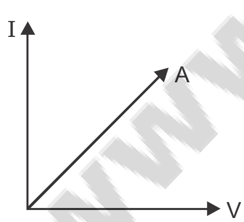
It states that the physical conditions (temperature) mechanical strain etc. remain same, then current (I) flowing through the conductor is proportional to the potential difference (V) applied between its ends."

$$I \propto V$$

or $$\frac{V}{I} = \text{a constant, R}$$

The constant 'R' is called the *resistance* of the conductor. It's reciprocal $\frac{1}{R}$ is called *Conductance (G).*

From the Ohm's law the variation of potential difference (V) and current (I) through a conductor is straight line.



Validity of OHM's Law

(*i*) Ohm's Law is not a universal law.

(*ii*) Ohm's Law is followed by ohmic conductors (metals) only under normal working conditions.

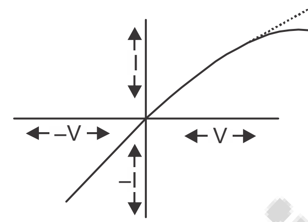
(*iii*) The following materials/devices do not follow Ohm's Law

1. Vacuum Tubes
2. Crystal Rectifiers
3. Thermisters, Thyristors
4. Transistors
5. Super-conductors

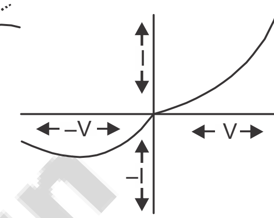
(*iv*) Ohm's law is not followed under following conditions:

1. At very high temperatures
2. At very low temperatures
3. At very high potential differences

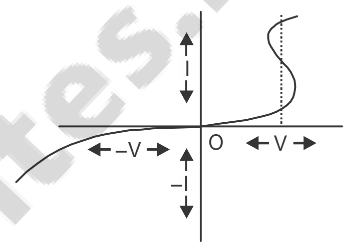
(*v*) **V-I Curves**



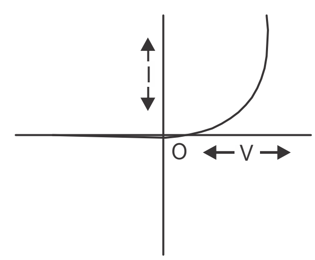
For Semi-conductors



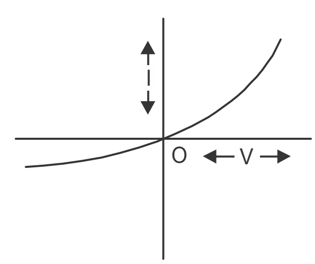
For Diode Junction



For Thyrister



For Vacuum Tube



For Semi-conductor Diode

ELECTRICAL RESISTANCE

It is defined as the ratio of the potential difference applied across the conductor to the current through it.

i.e., $$R = \frac{V}{I}$$

The SI unit of electrical resistance is ohm. It is denoted by Ω.

$$1\Omega \text{ (ohm)} = \frac{1 \text{ volt}}{1 \text{ amp}} = 1VA^{-1}$$

The electrical resistance of a conductor is said to be 1 Ω, if 1 A of current flows through it, when a p.d. of 1V is applied across it.

RESISTANCE OF DIFFERENT MATERIALS

These are classified into three parts.

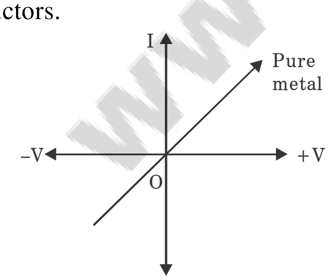
1. Conductor: The materials which conductor electric current fairly well are called conductors. Metals are good conductors. They have low resistivities in the range of 10^{-8} Ω to 10^{-6} Ω. Copper (Cu) and aluminium (Al) have lowest resistivities while nicrome has a resistivity of about 60 times that of copper.

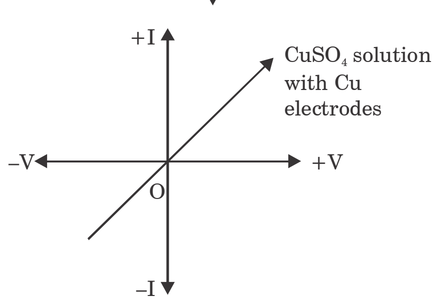
2. Insulators: The materials which do not conduct electric current are called insulators. They have high resistivity more than 10^4 Ω m. Insulators like glass, mica, bakelite and hard rubber have very high resistivities in the range of 10^4 Ωm to 10^6 Ωm.

3. Semiconductor: Those materials whose resistivities lies between conductors and insulators *i.e.*, between 10^{-6} Ωm to 10^4 Ωm. Germanium and silicon are semiconductors.

V-I CHARACTERISTIC OF OHMIC AND NON-OHMIC CONDUCTORS

Ohmic Conductors: The conductors which obeys Ohm's law are called Ohmic conductors. For these conductors, the linear relationship between voltage and current ($V \propto I$) holds good. The resistance $R = \frac{V}{I}$ is independent of the current I through conductor. The V^- characteristics graph for VI ohmic conductors is a straight line passing the origin. The metallic conductor of small currents and electrolyte like $CuSO_4$ solution with copper electrodes are Ohmic conductors.





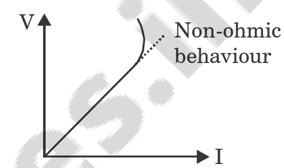
Non-ohmic Conductors: The conductors which do not obey Ohm's law are called non-ohmic conductors. The resistance such conductors is not constant even at a given temperature, rather it is current dependent. It may be following types.

(*i*) The straight line V-I graph does not pass through the origin.

(*ii*) V-I relationship is non-linear.

(*iii*) V-I relationship depends upon the sigh of V for same absolute value of V.

(*iv*) V-I relationship is non-unique.



Non-Ohmic conductor

The V-I characteristics of non ohmic conductor is given alongside.

ELECTRICAL ENERGY AND POWER

Electrical Energy: Electrical energy is the total work done by an electric current in a given time. It is equal to the total energy consumed in an electric current in a given time. The SI unit of electrical energy is joule (J). The commercial unit of electrical energy is kilowatt-hour (kWh) or Board of Trade Unit (BTU).

One kilowatt-hour is the amount of electrical energy consumed, when an electrical appliances having a power rating of 1 kW is used for 1 hours.

$$1 \text{ kWh} = 1 \text{ kilowatt} \times \text{hours}$$
$$= 3.6 \times 10^6 \text{ watts}$$
$$\therefore \quad 1 \text{ kWh} = 3.6 \times 10^6 \text{ J}$$

Electrical Power: The rate at which electrical energy dissipated into other forms of energy is called electrical power *i.e.*,

$$P = \frac{W}{t} Vi = i^2 R = \frac{V^2}{R}$$

It's SI unit is joule/s or watt (W) watt is a small unit, so some bigger units are used. In domestic or commercial purposes kilowatt unit is used

$$1 \text{ kW} = 1000 \text{ W}$$

In Mechanics, the unit of power is often written in horse power (HP)

$$1 \text{ HP} = 746 \text{ W}$$

If work is done, an equal amount of energy is consumed. When an electrical appliance consumes electrical energy at the rate of 1 joule/sec, its power is said to be 1 watt.

ELECTRICAL RESISTIVITY

The resistance of a conductor depends upon the following:

(*i*) It is directly proportional to the length of the conductor

i.e., $R \propto l$ ...(*i*)

(*ii*) It is inversely proportional to the area of cross-section of the conductor *i.e.*,

$$R \propto \frac{l}{A} \qquad ...(ii)$$

Combining (*i*) & (*ii*), we get

$$R \propto \frac{l}{A}$$

$$\Rightarrow \qquad R = \rho\frac{l}{A} \qquad \text{(where } \rho \text{ is constant)}$$

where ρ is called electrical resistivity or specific resistance. Its SI unit is ohm m (Ω–m)

Electrical conductivity: The reciprocal of resistivity (ρ) is called electrical conductivity.

$$R = \rho\cdot\frac{1}{A}$$

where,

R = Resistance (unit: ohm, Ω)

ρ = Resistivity (unit: ohm meter, Ω m)

l = Length of the conductor

A = Area of cross-section of conductor

$$G = \frac{1}{R} \quad \Rightarrow \quad \sigma = \frac{1}{\rho}$$

where, G = Conductance

[unit mho which is ohm written in reverse order); also siemens, s]

σ = Conductivity (unit mho^{-1} m^{-1})

Stretching of a conductor wire and change in its resistance

If a conductor wire of length l_1, radius r_1 and resistance R_1 is stretched to length l_2, then its new resistance R_2 can be calculated as below:

As volume remains same,

$$\therefore \qquad \pi r_1^2 l_1 = \pi r_2^2 l_2$$

$$\text{or} \qquad r_2 = r_1 \times \sqrt{\left(\frac{l_1}{l_2}\right)} \qquad ...(1)$$

$$\text{Now, as} \qquad R_1 = \rho\cdot\frac{l_1}{\pi r_1^2} \qquad ...(2)$$

$$R_2 = \rho\cdot\frac{l_2}{\pi r_2^2} = \rho\cdot\frac{l_2}{\pi\cdot\frac{l_1 r_1^2}{l_2}} \text{ from eq (1)}$$

$$= \rho\cdot\frac{l_2^2}{\pi\cdot r_1^2 l_1} \qquad ...(3)$$

Dividing (3) by (2), we get,

$$\frac{R_2}{R_1} = \frac{l_2^2}{l_1^2} \quad \text{or} \quad R_2 = \left(\frac{l_2}{l_1}\right)^2 R_1$$

$$\text{or as} \qquad \pi r_1^2 l_1 = \pi r_2^2 l_2$$

$$\therefore \qquad \frac{l_2}{l_1} = \left(\frac{r_1}{r_2}\right)^2$$

$$\therefore \qquad R_2 = \left(\frac{r_1}{r_2}\right)^4 \cdot R_1$$

If $l_2 = 2l_1$, then $R_2 = 4R_1$

COLOUR CODE FOR RESISTANCES

The value of resistances used in electric and electronic circuits vary over a very wide range. Such high resistances are marked on them according to colour code.

Colour Code for Carbon Resistors

The colour code is used to indicate the resistance value of a carbon resistor and its percentage accuracy. The colour code is given in table.

Colour	Letter as an old to memory	Figure	Multiplier
Black	B	0	10^0
Brown	B	1	10^1
Red	R	2	10^2
Orange	O	3	10^3
Yellow	Y	4	10^4
Green	G	5	10^5
Blue	B	6	10^6
Violet	V	7	10^7
Grey	G	8	10^8
White	W	9	10^9

To read the value of carbon resistance:

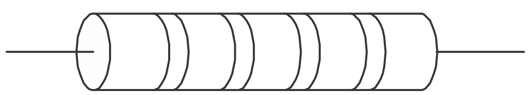
B	B	R	O	Y	Great	Britain	Very	Good	Wife
↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
0	1	2	3	4	5	6	7	8	9

The systems of marking the colour codes:

A set of coloured coaxial rings or bands is printed on the resistor which reveals the following facts:

1. The first band (A) indicates—the first significant figure.

2. The second band (B) indicates—the second significant figure.
   0, 1, 2, 3, 4, 5 6, 7, 8, 9
3. The third band (C) indicates—the power of ten with which the above two significant figures.
   i.e., 10^0, 10^1, 10^2, 10^3, 10^4, 10^5, 10^6, 10^7, 10^8, 10^9.
4. The fourth band (D) indicates— the tolerance variation in per cent of the indicated value. In case, there is no fourth band, then its tolerance value is 20%.



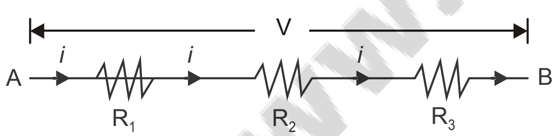
Consider the carbon resistance, for which the bands A, B, and C are colours brown, green and orange respectively and fourth band (D) is silver colour.

The corresponding to colours bands A and B, which are brown or green, the fig. are 1 and 5. The corresponding to third band of orange colour, the multiplier is 10^3. Therefore, resistance is of the $15 \times 10^3\ \Omega$. Since silver colour of the fourth band corresponds to a tolerance of 10%, the value of given resistance, $R = 15 \times 10^3\ \Omega \pm 10\%$.

SERIES AND PARALLEL COMBINATION OF RESISTORS

(*i*) Resistances in series

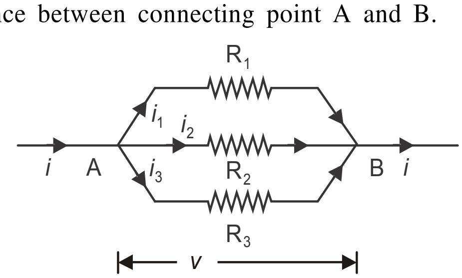
The such type combination, same current passes through all the resistances.



$$R_{AB} = R_1 + R_2 + R_3$$

(*ii*) Resistance in parallel

In this type of combination, potential difference across each resistance is the same and is equal to the potential difference between connecting point A and B.



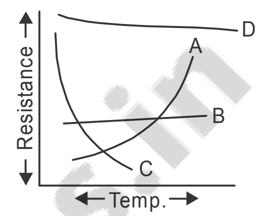
$$\frac{1}{R_{AB}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

If two resistances are parallel, then,

$$R_{eq} = \frac{R_1 R_2}{R_1 + R_2}$$

TEMPERATURE DEPENDENCE OF RESISTANCE

The variation of resistance of a conductor, an alloy, a semiconductor or an insulator with increase in temperature is not same in the all case.



$$R_T = R_0\,[1 + \alpha(T - T_0)]$$

where,

R_T = Resistance at temperature T
R_0 = Resistance at temperature T_0
α = Temperature Coefficient of Resistance. (It is a constant for a given metal).
= (+) for metals,
= (+) but very small for alloys like manganin, nichrome, constantan, eureka;
= (–) for semiconductors and insulators.
A = For conductors
B = For alloys, *e.g.*, manganin
C = For semiconductors and electrolytes
D = Insulators

This means that when temperature is increased then,

S.No.	In case of	Resistance	Conductivity
1.	Metals	Increases	Decreases
2.	Insulators	Decreases slightly	Increases slightly
3.	Semi-conductors	Decreases appreciably	Increases appreciably
4.	Alloys like constantan, manganin, eureka etc.	Increases but negligibly	Decreases but negligibly
5.	Super-Conductors	Increases abruptly at transition or critical temp.	Decreases abruptly at transition or critical temp.

Temperature Coefficient of Resistivity (ρ)

For conductors:

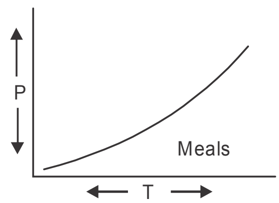
$$\rho_r = \rho_0\,[1 + \alpha(T - T_0)]$$

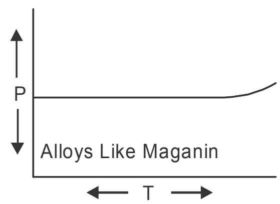
For Insulators:

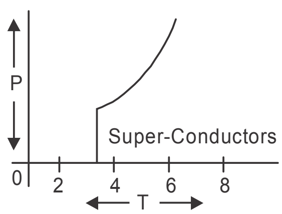
$$\rho_T = \rho_0 e^{\frac{E_g}{kT}}$$

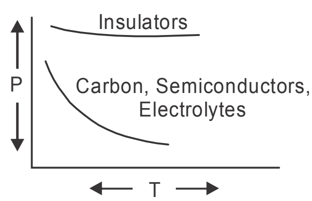
where,

E_g = Energy gap between conduction and valance bands









k = Boltzmann constant

T = Absolute temperature

ELECTRICAL CELL AND ITS INTERNAL RESISTANCE

Electrical Cell: The device which converts chemical energy into electrical energy is called electric cell. Electric cell is a source of constant emf but not constant current. A battery is one or more cells, connected. This cell is also known as electrochemical cell. Electrical cell has two terminals, which are made up of metal, one terminal is positive, while other one is negative. It two terminals are connected to an electrical device, electric current flows through it.

Internal Resistance of a cell (*r*): When cell is connected in a circuit, it drives the charge in the circuit. The rate of flow of charge is termed as current. If the current flows through the cell, its electrolyte offers resistance to the flow of current. The resistance offered by the electrolyte of the cell, if the electric current flows through it, is known as internal resistance of the cell. It is denoted by r.

The internal resistance, $r = \left(\frac{E}{V} - 1\right)R$.

Cells provide e.m.f. to the circuit. Combination of cells is called a **battery**.

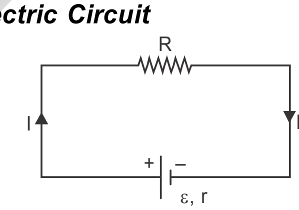
EMF (Electromotive Force) of Cell: The potential difference (P.d.) between the two poles of the cell in an open circuit. (when no current is drawn from the cell) is called the emf of the cell.

It is concerned with the energy required to move charge carries around the circuit again and again. It's definition is 'energy required to move I unit of charge around the circuit once.' There are other definitions as well *e.g.,* "potential difference between the terminals of a cell in open circuit".

e.m.f. = electromotive force, but emf is *not* a force.

This 'energy' to move the charge carriers (generally electrons) is always supplied by some external agency which converts some other form of energy into electrical energy and supplies it to the circuit. For instance, electro-chemical cells (the ordinary cells), photo cells, generators, dynamos etc.

Simplest Electric Circuit



e = emf of the cell

r = Internal resistance of the cell

R = External resistance

The guiding formula is:

$$\text{Circuit current} = \frac{\text{Total e.m.f. applied to the circuit}}{\text{Total resistance of the circuit}}$$

Here R and r are connected in series, therefore equivalent resistance is $(R + r)$

Total emf applied to the circuit = ε

$$\therefore \text{ Circurt current, } I = \frac{\varepsilon}{(R + r)}$$

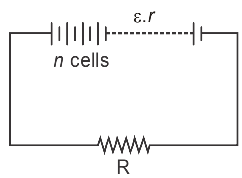
POTENTIAL DIFFERENCE AND EMF (E) OF A CELL

Potential Difference: The voltage across the terminal of a cell, when it is supplying current to external resistance is called potential difference. The potential difference (pd) is equal to the product of current and resistance. *i.e.* $V = iR$.

COMBINATION OF CELLS IN SERIES AND IN PARALLEL

(*i*) *Cells in Series*

Let n cells each of emf (ε) and internal resistance (r) are connected in series as shown in Fig.



Total emf = $n\varepsilon$

Total resistance = $nr + R$

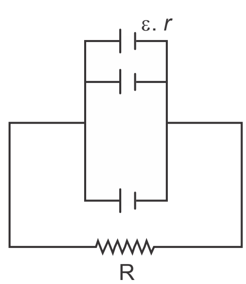
$\therefore$ Circuit current, I = $\dfrac{n\varepsilon}{nr + R}$

If R >> r, then I = $\dfrac{n\varepsilon}{R}$ = n times the current which a single cell will give. So, it is good.

If R << r then I = $\dfrac{n\varepsilon}{nr} = \dfrac{\varepsilon}{r}$ = the current which a single cell alone can provide. (of no use)

(*ii*) *Cells in parallel*

Let n cells of emf (ε) and internal resistance (r) are connected in parallel as shown in Fig.



Circuit emf = ε

Circuit resistance = $\dfrac{r}{n} + R = \dfrac{r + nR}{n}$

$\therefore$ Circuit current, I = $\dfrac{n\varepsilon}{r + nR}$

$\therefore$ If R >> r, then I = $\dfrac{n\varepsilon}{nR} = \dfrac{\varepsilon}{R}$

and If R << r, then I = $\dfrac{n\varepsilon}{r}$ = n times the current which can be provided by a single cell. Therefore,

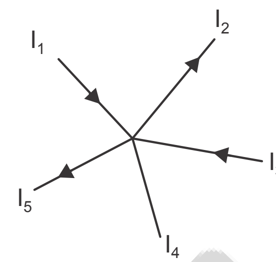
* Series combination is used, when R (external resistance) is much greater than r or nr (total internal resistance).
* Parallel combination is used, when r (internal resistance) is much greater than R (external resistance).

KIRCHHOFF'S LAWS AND THEIR APPLICATIONS

Kirchhoff's First Law (Junction Law)

The algebraic sum of the currents meeting at a junction in a closed circuit is zero. *i.e.*, $\Sigma i = 0$

It is based on the principle of conservation of electric charge. It says, "the sum of all the currents entering any junction point is equal to the sum of all the currents leaving that point."



$\therefore$ Sum of currents entering = $I_1 + I_3$

and Sum of current leaving = $I_2 + I_4 + I_5$

$\therefore$ $I_1 + I_3 = I_2 + I_4 + I_5$

Kirchhoff's Second Law (Loop Law)

It is based on the law of conservation of energy. It states that, "The algebraic sum of changes in potential around any closed loop must be zero."

i.e., $\sum \varepsilon + \sum IR = 0$

Note: IR is the potential drop across the resistance R through which current I is flowing.

Important Points in Applying Second Law

Different authors use different methods and conventions. They are all correct but thoroughly confusing in the sense that they clash with each others notations. Hence, be forwarded, use the following method and conventions which are most rational and can be applied even mechanically.

Closed Circuit

It means, when current flows through the circuit.

Open Circuit

When no current flows through the circuit.

Kirchhoff's rules apply only to closed circuits.

How to apply 2nd rule?

(*i*) Assume any direction of flow of current in the closed loop.

(*ii*) Now travel along this loop once completely, *i.e.,* start from any point of the loop and come back there, either moving in clock-wise or in anti-clockwise direction as per your desire.

(*iii*) ***Sign Convention For 'IR' Products***

When you are crossing over some resistance (R) through which you have assumed that some current (I) is flowing, then if your direction of traverse (*i.e.,* travel) is same as the assumed direction of flow of current, then this 'IR' is (–), otherwise (+).

This must be applied to all the internal resistances of cells and armature resistances of motors also in the same way.

(*iv*) **Sign Convention of ε**

Note: While dealing with ε the assumed or actual direction of flow of current does not matter at all. Only your direction of travel matters.

If you are moving from negative terminal to the positive terminal, then take sign of ε (emf) of that cell as (+); and vice-versa.

All other devices like *electric motors* should be treated as 'emf eating devices' *i.e.,* having 'negative emf' if your direction of travel is same as the assumed direction of flow of current through that device. Otherwise, (+).

How to calculate this emf of these devices?

Motors are generally given with their 'HP' (horse-power) or 'wattage' or 'kilowattage' rating.

We know,

$$1 \text{ HP} = 746 \text{ W}$$

and $\quad 1 \text{ W} = 1 \text{ volt} \times 1 \text{ amp.}$

or $\quad \text{wattage} = \text{voltage} \times \text{amperage}$

$$\therefore \quad \text{Voltage} = \frac{\text{Wattage}}{\text{Amperage}}$$

∴ Thus, emf of the motor

$$= \frac{[\text{Power of the motor in watts right}]}{\left[\begin{array}{c}\text{Its current rating in amperes or current}\\ \text{flowing through it in amps}\end{array}\right]}$$

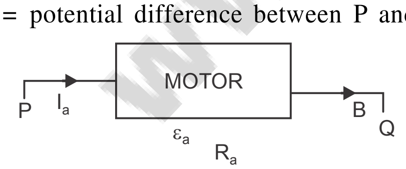
Consider all electric motors as equivalent to cells which are put in the circuit so as to try to obstruct the flow of current, whose emf = x/I and internal resistance = resistance of their armature, where,

x = Power of the motor in watts

I = Current through the motor in amps.

Example:

If V = potential difference between P and Q.



ε_α = emf drop

R_a = Armature resistance, then

I_a (Armature current) = ?

Applying Kirchhoff's rule from P to Q:

$$P_p - I_a \cdot R_a - \varepsilon_a = P_Q$$

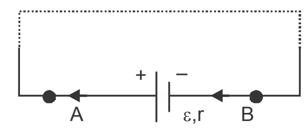
$$(P_p - P_Q) - \varepsilon_a = I_a \cdot R_a$$

$$\therefore \text{ or } \quad V - \varepsilon_a = I_a \cdot R_a$$

$$\text{or} \quad I_a = \frac{V - \varepsilon_a}{R_a}$$

Charging and Discharging Cells

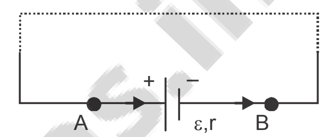
(*i*) When a cell is supplying current to the circuit, we say that it is being discharged because its chemical energy is being used up. In this stage, the current flows through the cell as given below:



Here, $P_A - P_B = \varepsilon - Ir$.

where p stands for the potential.

(*ii*) When a cell is being charged then following happens

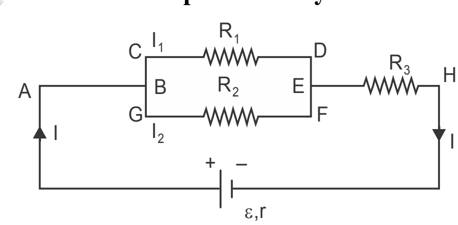


Note the direction of flow of current.

Here, $P_A - P_B = \varepsilon + Ir$

***Important*:** Thus, in either case, potential of positive terminal is higher than the potential of the negative terminal.

How to use Kirchhoff's Rules to find out potential difference between two points in any branch of a Circuit.



Suppose R_1, R_2, R_3, ε and r are given and we want to find out p.d. (*i.e.,* potential difference) between any two points of the circuit.

Let we want to find out p.d. between B and H.

Solution:

We can solve it any of the following three ways.

***1st way*:** Proceed from B to H in clockwise direction through the branch CD. Then,

$$P_B - I_1R_1 - IR_3 = P_H$$

$$\text{or} \quad P_B - P_H = I_1R_1 + IR_3 \qquad \text{...(1)}$$

***2nd way*:** Proceed from B to H in clockwise direction through the branch GF. Then,

$$P_B - I_2R_2 - IR_3 = P_H$$

$$\text{or} \quad P_B - P_H = I_2\,R_2 + IR_3 \qquad \text{...(2)}$$

3rd way: Proceed from B to H in anti-clockwise direction through the cell. Then,

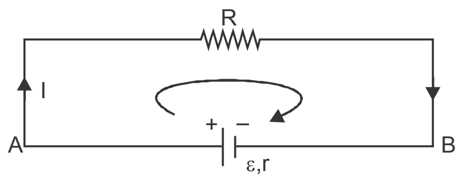
$$P_B - \varepsilon + Ir = P_H$$

$$\text{or} \quad P_B - P_H = \varepsilon - Ir \qquad \text{... (3)}$$

Equations (1), (2) or (3) will give the same result.

Applications of Kirchhoff's Law

Let us traverse the closed loop starting from A in clockwise direction.



$$-IR - Ir + \varepsilon = 0$$

or $$\varepsilon = IR + Ir$$

or $$I = \frac{\varepsilon}{R + r} \qquad \text{... (1)}$$

Now, suppose we want to find out potential difference V, between A and B, *i.e.,* potential difference between the terminals of the cell in closed circuit (In open circuit, it will be, ε).

Let $\quad P = \text{Potential}$

We can find it out either by going from A to B via R, or via the cell.

1st way:

$$P_A - IR = P_B$$

or $$P_A - P_B = IR$$

i.e., $$V = IR \qquad \text{... (2)}$$

2nd way:

$$P_A - \varepsilon + Ir = P_B$$

$$P_A - P_B = \varepsilon - Ir$$

or $$V = \varepsilon - Ir$$

Accordingly, we can say that:

It total energy supplied by cell = ε, then of this ε, IR is used up in the external circuit and Ir within the cell.

And also, I can be written in the following 3 ways:

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

$$I = \frac{\varepsilon - V}{r}$$

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

Hence, if ε, V and R are known, the r can be calculated as below

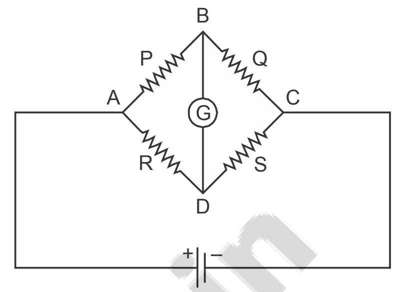
$$r = \frac{\varepsilon - V}{I} \quad \text{from 2nd relation}$$

$$r = \frac{\varepsilon - V}{V/R} \quad \text{from 3rd relation}$$

or, $$r = \frac{(\varepsilon - V)R}{V}$$

WHEATSTONE BRIDGE

A wheatstone bridge is an electrical circuit used to measured an unknown resistance by balancing two legs of a bridge circuit one leg of which includes unknown component.



Principle

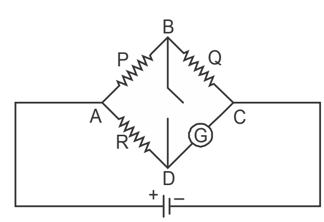
Wheatstone bridge principle states that the four resistances P, Q, R and S are connected as shown, are such that $\frac{P}{Q} = \frac{R}{S}$, then potential drop between A and B is same as between A and D. Points B and D are at the same potential. Hence, in these circumstances, no current will pass through the galvanometer G.

This configuration of resistances is called Wheatstone Bridge, and in this state when $\frac{P}{Q} = \frac{R}{S}$, it is called balanced Wheatstone Bridge. Thus, if 3 resistance of the 4 : P, Q, R and S are known, the 4th unknown resistance can be calculated from the relation

$$\frac{P}{Q} = \frac{R}{S}.$$

Example:

If the bridge is balanced, what will be the change in the deflection of the galvanometer needle when the key 'k' is pressed?



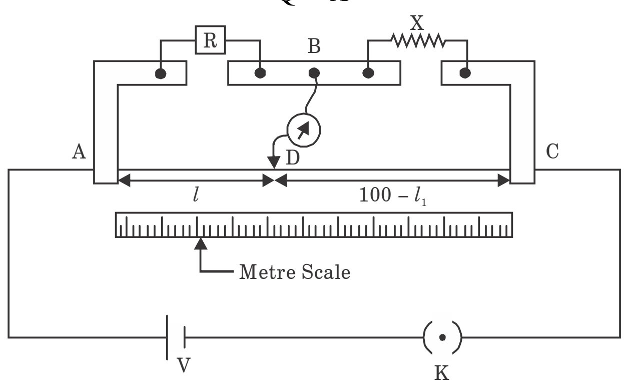
Answer:

Because the bridge is balanced, points B and D are at the same potential. Therefore, no current will flow between B and D on pressing the key. Hence, no re-distribution of currents will take place. Thus, the reading of G will remain the same.

METRE BRIDGE

A metre bridge is also known as slide wire bridge. It can be used to measure an unknown resistance to compare the values of two unknown resistance. When bridge is balanced, then

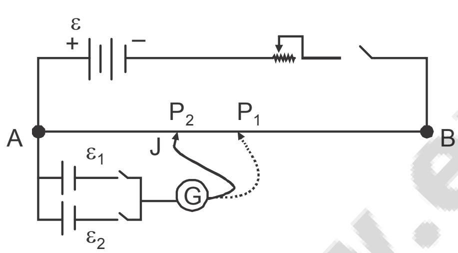
$$\frac{P}{Q} = \frac{R}{X}$$



POTENTIOMETER PRINCIPLE AND ITS APPLICATIONS

The device is used to measure emf of a cell, internal resistance of a cell and potential difference between any two points of a circuit.

Potentiometer is used mainly to compare emfs of two cells. Or, if one of these two emfs is known, to calculate the emf of the other cell.



AB is a long resistance wire of length l with uniform cross-section. If p.d. = ε is applied across it, then potential drop per unit length along AB will be

$$= \frac{\varepsilon}{l} \qquad \text{... (1)}$$

Suppose ε is to be measured, just slide jockey (J)[1] along the length AB and find out the balance length AP_1, *i.e.,* if the key of the jockey is pressed on the wire AB at P_1, there is no deflection in the galvanometer G.

If $AP_1 = l_1$, then $\varepsilon_1 = l_1 \times \frac{\varepsilon}{l}$

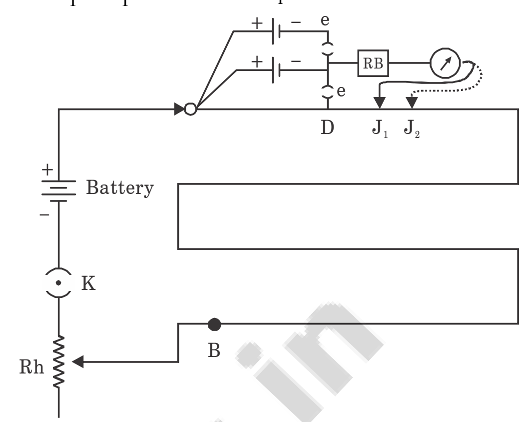
So $\frac{\varepsilon_1}{\varepsilon_2}$ will be $= \frac{l_1}{l_2}$

Applications of Potentiometer

Comparison of emfs of two primary cells: From Fig. we see that, the comparing emfs of two cells are given below. Let emf of two primary cells are ε_1 and ε_2.

We have $\varepsilon_1 = kl_1$ and $\varepsilon_2 = kl_2$

$$\therefore \quad \frac{\varepsilon_2}{\varepsilon_1} = \frac{l_2}{l_1} \Rightarrow \varepsilon_2 = \frac{l_2}{l_1} \cdot \varepsilon_1$$



In order to set the null point on the potentiometer wire, it is necessary that emf. ε of auxiliary battery must be greater than both ε_1 and ε_2.

Internal resistance of a primary cell by potentiometer

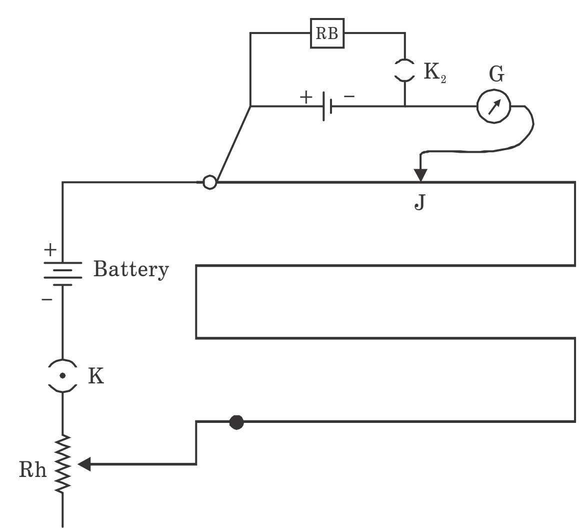
We have, $\varepsilon = kl_1$ ...(*i*)

and $V = kl_2$ ...(*ii*)

From (*i*) and (*ii*), we get

$$\frac{\varepsilon}{V} = \frac{l_1}{l_2}$$

Now from Ohm's law, we get



$$\varepsilon = I(R + r) \quad \text{and} \quad V = IR$$

$$\therefore \quad \frac{\varepsilon}{V} = \frac{R+r}{R} = \frac{l_1}{l_2}$$

$$\Rightarrow \quad 1 + \frac{r}{R} = \frac{l_1}{l_2} \Rightarrow \frac{r}{R} = \frac{l_1 - l_2}{l_2}$$

$$\therefore \text{ Internal resistance } r = R\left[\frac{l_1 - l_2}{l_2}\right].$$

EXERCISE

1. The resistance across two opposite faces of a cube of side 2 cm is 2×10^{-6} ohm. The specific resistance of its material in ohm cm is

A. 10^{-6} B. 2×10^{-6}

C. 4×10^{-6} D. $\frac{1}{2} \times 10^{-6}$

2. A piece of wire of resistance 4 ohm is bent through 180° at its mid point and the two halves are twisted together. Then the resistance is

A. 8 ohm B. 1 ohm

C. 2 ohm D. 5 ohm

3. The current flowing through a wire depends on time as $I = 3t^2 + 2t + 5$. The charge flowing through the cross-section of wire in time from $t = 0$ to $t = 2$ second is

A. 12 C B. 15 C

C. 20 C D. 22 C

4. The internal resistance of a cell of e.m.f. 2.0 volts is 0.1 Ω. It is connected to a resistance of 3.9 Ω. The voltage across the cell will be (in volts)

A. 0.5 B. 1.9

C. 1.95 D. 2.0

5. When a piece of aluminium wire of finite length is drawn through a series of dyes to reduce its diameter to half its original value, its resistance will become

A. two times B. four times

C. eight times D. sixteen times

6. The resistance of 20 cm long wire is 5 Ω. The wire is stretched to a uniform wire of 40 cm length. The resistance now will be (in ohms)

A. 5 B. 10

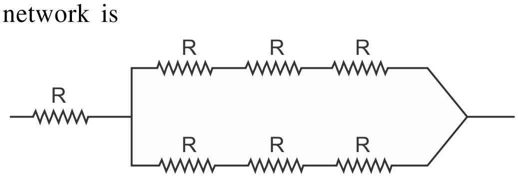
C. 20 D. 200

7. The e.m.f. of a source which is equivalent to two batteries connected in parallel, whose e.m.f.'s are equal to 8V and 6V having internal resistance of 1.4 Ω and 0.6 Ω respectively.

A. 7 volt B. 14 volt

C. 6.6 volt D. 2 volt.

8. In the figure below the effective resistance of the network is



A. 2R B. 4R

C. 10R D. 5R/2

9. Two resistors of 15 Ω and 30 Ω are connected in parallel. What should be the value of R to be connected in series with the other two so that the net resistance will be 20 Ω

A. 5 Ω B. 10 Ω

C. 15 Ω D. 20 Ω

10. What is the number of equal parts into which a conductor having a resistance R_0 = 100 Ω should be cut to obtain the resistance R = 1 Ω, if the parts are connected in parallel

A. 5 B. 10

C. 20 D. 2

11. When a resistor of 4 Ω is connected across a cell the potential difference across the resistor in 8V, but this falls to 6V when a second 4 Ω resistor is connected in parallel with the first. Calculate the e.m.f. and internal resistance of the cell.

A. 6V, 4 Ω B. 12V, 4 Ω

C. 12V, 2 Ω D. 6V, 2 Ω

12. Two conductors when connected in series give 27 Ω and in parallel 6 Ω. The two resistance are

A. 21 Ω, 6 Ω B. 9 Ω,18 Ω

C. 24 Ω, 3 Ω D. 15 Ω, 12 Ω

13. A metal wire is subjected to a constant potential difference. When the temperature of the metal wire increases, the drift velocity of the electrons is

A. Increases, thermal velocity of the electrons increases

B. Decreases, thermal velocity of the electrons increases

C. Increases, thermal velocity of the electrons decreases

D. Decreases, thermal velocity of the electrons decreases

14. A primary cell has e.m.f. 2 volt. When short circuited it gives a current of 4 amp. What is its terminal p.d.?

A. 0 B. $\propto$

C. 2V D. 5V

15. A primary cell has an e.m.f. of 1.5 volt. When short circuited it gives a current of 3 ampere. The internal resistance of the cell is

A. 4.5 ohm B. 2 ohm

C. 0.5 ohm D. 1/4.5 ohm

16. Four wires of equal length and of resistance 10 Ω each are connected in the form of a square. The equivalent resistance between two opposite corners of the square is

A. 10 Ω B. 40 Ω

C. 20 Ω D. 10/4 Ω

17. Three 2 ohm resistors are connected to form a triangle. The resistance between any two corners is

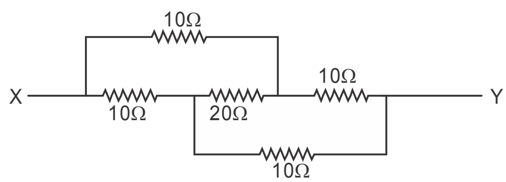
A. 6 Ω B. 2 Ω

C. 3/4 Ω D. 4/3 Ω

18. A piece of wire is cut into four equal parts and the pieces are bundled together side by side to form a thick wire. Compared with that of original wire, the resistance of the bundle is

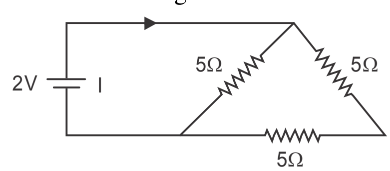
A. The same B. 1/4
C. 1/8 D. 1/16

19. Five resistance have been connected as shown in the circuit diagram. The equivalent resistance between the points X and Y will be equal to



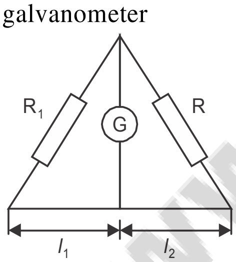
A. 10 Ω B. 20 Ω
C. 22 Ω D. 50 Ω

20. The current I in the given circuit is



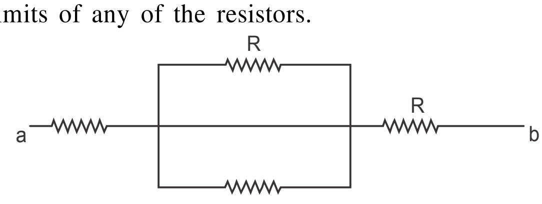
A. 1/45 amp B. 1/15 amp
C. 1/10 amp D. 3/5 amp

21. Determine the resistance R measured with a Wheatstone bridge as shown in figure, if at $R_1 = 1.5\ \Omega$, $l_1 = 20$ cm, $l_2 = 80$ cm there is no current through the galvanometer



A. 3 Ω B. 6 Ω
C. 9 Ω D. 12 Ω

22. Three 10 Ω, 2W resistors are connected as in figure. Find the maximum possible voltage between points *a* and *b* without exceeding the power dissipation limits of any of the resistors.



A. $5\sqrt{3}$ V B. $3\sqrt{5}$ V
C. 15 V D. 5/3 V

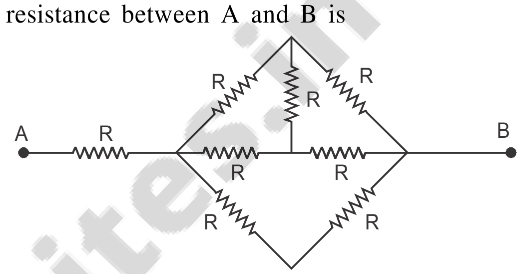
23. Two cells each of e.m.f. E and internal resistance *r*, are connected in parallel across a resistor R. The power delivered to the resistor is maximum if R is equal to

A. *r*/2 B. *r*
C. 2 *r* D. 0

24. A current of 4.8 ampere is flowing in a conductor. The number of electrons flowing per second through the conductor will be

A. 3×10^{19} electrons per sec
B. 76.8×10^{20} electrons per sec
C. 7.68×10^{20} electrons per sec
D. 3×10^{20} electrons per sec

25. In the following network of resistance, the effective resistance between A and B is

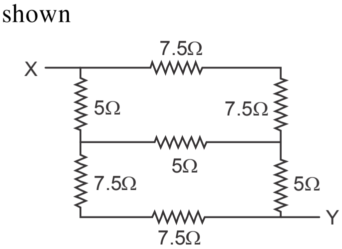


A. 5/3 R B. 8/3 R
C. 5 R D. 8 R

26. If 2% of the main current is to be passed through the galvanometer of resistance G, the resistance of shunt required is

A. G/49 B. 49 G
C. G/50 D. 50 G

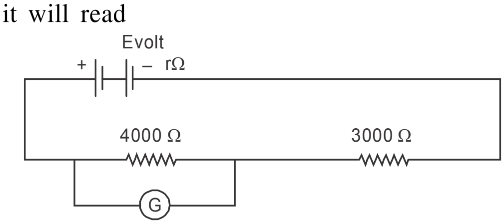
27. The resistance between points *x* and *y* of the following circuit shown



A. $\dfrac{10}{3}\Omega$ B. 7 Ω

C. $\dfrac{25}{3}\Omega$ D. $\dfrac{50}{3}\Omega$

28. In the figure, when an ideal voltameter is connected across 4000 ohm resistance, it reads 30 volt. If the voltmeter is connected across 3000 ohms resistance, it will read



A. 20 volt B. 22.5 volt
C. 35 volt D. 40 volt

29. When the current (i) is flowing through conductor, the drift velocity is v. If $2i$ current is flowed through the same metal but having double the area of cross section, then the drift velocity will be

A. v B. $2v$

C. $\frac{v}{2}$ D. $3v$

30. Every atom makes one free electron in Cu. If 1.1 A current is flowing in the wire of Cu having 1 mm diameter, then the drift velocity will be (density of Cu = 9×10^3 kg/m^3 and atomic weight = 63)

A. 0.2 mm/sec B. 0.1 mm/sec

C. 0.3 mm/sec D. 0.4 mm/sec

31. The specific resistance of manganin is 50×10^{-8} Ωm. The resistance of a cube of length 50 cm will be

A. 10^{-4} Ω B. 10^{-6} Ω

C. 10^{-8} Ω D. 10^{-5} Ω

32. The resistance of a wire is 20 Ω. It is so stretched that the length become three times, then the new resistance of the wire will be

A. 180 Ω B. 220 Ω

C. 250 Ω D. 132 Ω

33. A wire of a certain material is stretched slowly by ten per cent. Its new resistance and specification resistance become respectively

A. 1.21 times, same B. 2.21 times, same

C. 3.21 times, same D. 1.1 times, same

34. Two conductors are made of the same material and have the same length. Conductor A is a solid wire of diameter 1 mm. Conductor B is a hollow tube of outer diameter 2 mm and inner diameter 1 mm. Then, the ratio of resistance R_A to R_B is

A. 1 : 3 B. 3 : 1

C. 1 : 2 D. 2 : 1

35. When a piece of aluminium wire of finite length is drawn through a series of dies to reduce its diameter to half its original value, its resistance will became.

A. eighteen times B. sixteen times

C. three times D. five times

36. In hydrogen atom, the electron makes 6.6×10^{15} revolutions per second around the nucleus in an orbit of radius 0.5×10^{-10} m. It is equivalent to current nearly

A. 1 mA B. 2 mA

C. 0.1 mA D. 0.5 mA

37. A metallic block has no potential different applied across it, then the mean velocity of free electrons is (T = absolute temperature of the block)

A. proportional to $\sqrt{T}$

B. proportional to T

C. finite but in dependent of temperature

D. zero

38. The resistance of wire uniform diameter d and length L is R. The resistance of another wire of the same material but diameter $2d$ and length 4L will be

A. $\frac{R}{4}$ B. $\frac{R}{2}$

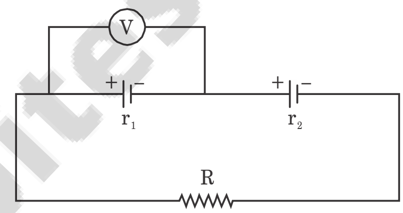
C. R D. 2R

39. A metal wire of specific resistance of 64×10^{-6} Ωm, and length 198 cm has a resistance of 7Ω, then, the radius of the wire will be

A. 0.024 cm B. 0.011 cm

C. 0.033 cm D. 0.02 cm

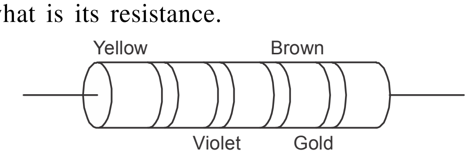
40. The emf of two cells is equal but their internal resistances are r_1 and r_2. The cells are connected as shown in Fig. If the reading of the voltmeter is zero, then relation among R, r_1 and r_2 is



A. $R = \frac{(r_1 + r_2)}{2}$ B. $R = \frac{(r_1 - r_2)}{2}$

C. $R = r_1 + r_2$ D. $R = r_1 - r_2$

41. A carbon resistor has coloured steps as shown in Fig. what is its resistance.



A. 470 Ω ± 5% B. 350 Ω ± 3%

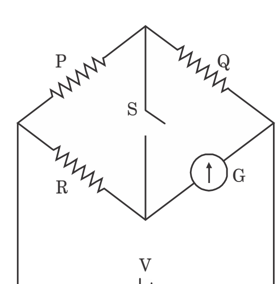
C. 120 Ω ± 10% D. 250 Ω ± 5%

42. A potentiometer consists of a wire of length 4 m and resistance 10 Ω. It is connected to a cell of emf 2V. The potential difference per unit length of the wire will be

A. 0.25 Vm^{-1} B. 0.5 Vm^{-1}

C. 1.5 Vm^{-1} D. 2 Vm^{-1}

43. In the circuit shown P ≠ R, the reading of the galvanometer is same with switch s open or closed. Then



A. $I_R = I_G$ B. $I_P = I_G$
C. $I_Q = I_G$ D. $I_Q = I_R$

44. A moving coil galvanometer of resistance 100 Ω is used as an ammeter using a resistance 0.1 Ω. The maximum deflection current in the galvanometer is 1002 A. Find the minimum current in the circuit so that the ammeter shows maximum deflection

A. 1.01 mA B. 100.1 mA
C. 105.5 mA D. 0.99 mA

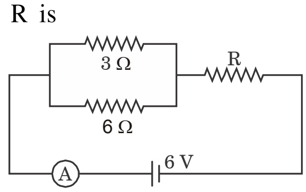
45. A set of n identical resistors each of resistance RΩ, when connected in series have an effective resistance of x Ω and when the resistors are connected in parallel, the effective resistance is y Ω. Then the relation between R, x and y is

A. $R = (xy)^{3/2}$ B. $R = xy$
C. $R = \sqrt{xy}$ D. $R = \frac{xy}{2}$

46. If an ammeter is connected in parallel to a circuit, it is likely to be damaged due to excess

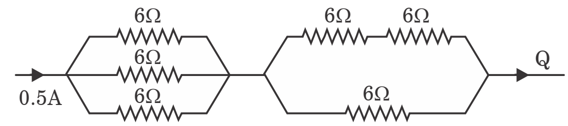
A. voltage B. current
C. resistance D. power

47. If the ammeter in the given circuit reads 2A, the resistance R is



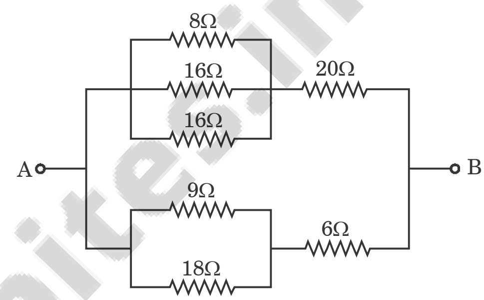
A. 1 Ω B. 2 Ω
C. 3 Ω D. 4 Ω

48. Resistances of 6 Ω each one connected in the manner shown in adjoining Fig. with the current 0.5 A as shown in Fig., the p.d. $V_P - V_Q$ is



A. 6.0 V B. 7.2 V
C. 3.6 V D. 3.0 V

49. The equivalent resistance of the arrangement of resistances shown in adjoining Fig. between the points A and B is



A. 24 Ω B. 10 Ω
C. 6 Ω D. 8 Ω

50. Three resistances P, Q, R each of 2 Ω and an unknown resistance S from the four arm S of a Wheatstone bridge circuit where resistance of 60 Ω is connected in parallel to S the bridge gets balanced. What is the value of S?

A. 1 Ω B. 6 Ω
C. 2 Ω D. 3 Ω

ANSWERS

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
C	B	D	C	D	C	C	D	B	B
11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
C	B	B	A	C	A	D	D	A	D
21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
B	B	A	A	A	A	C	B	A	B
31	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
B	A	A	B	B	A	A	C	A	D
41	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**
A	B	A	B	C	B	A	D	D	D

EXPLANATORY ANSWERS

1. As, $R = \rho \frac{l}{A}$

$$2 \times 10^{-6}\ \Omega = \rho \times \frac{2\text{ cm}}{2\text{ cm} \times 2\text{ cm}}$$

$\therefore$ $\rho = 4 \times 10^{-6}\ \Omega$ cm.

2. We have, $R = \frac{2 \times 2}{2+2} = 1\ \Omega.$

3. Given, $I = 3t^2 + 2t + 5$

$\because$ $I = \frac{dq}{dt} = 3t^2 + 2t + 5$

$$\therefore \qquad dq = (3t^2 + 2t + 5)dt$$

$$= \left[\frac{3t^3}{3} + \frac{2t^2}{2} + 5t\right]_0^2$$

$$= \left[t^3 + t^2 + 5t\right]_0^2$$

$$= 8 + 4 + 10 = 22 \text{ C}$$

4. As, $\quad V = E - Ir$

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

$$= 2 - \frac{2 \times 0.1}{3.9 + 0.1} = 1.95 \text{ V.}$$

5. Diameter is reduced to half, length increases 4 times as mass of material remains the same.

$$R = \rho\frac{l}{A} = 4\rho\frac{1}{\pi D^2}$$

$$\therefore \qquad R' = \frac{4\rho \times 4l}{\pi\left(\frac{D}{2}\right)^2} = 16 \text{ R.}$$

6. Length is doubled. Area is reduced to half

$$R = \rho\frac{l}{a}, \; R' = \frac{\rho(2l)}{\left(\frac{a}{2}\right)} = 4R$$

$$= 4 \times 5 = 20\,\Omega.$$

7. As, $\quad E = \dfrac{E_1 r_2 + E_2 r_1}{r_1 + r_2}$

$$= \frac{8 \times 0.6 + 6 \times 1.4}{1.4 + 0.6} = 0.6 \text{ V.}$$

8. As, $\quad R_{eft} = R + \dfrac{3R \times 3R}{3R + 3R} = \dfrac{5R}{2}.$

9. We have, $\dfrac{15 \times 30}{15 + 30} + X = 20 \quad \therefore X = 10\,\Omega.$

10. Let n parts be made thin, each part has resistance $\dfrac{R_0}{n}$

Connecting them parallel gives

$$\frac{R_0}{n} \times \frac{1}{n}\Omega$$

$$\therefore \qquad \frac{R_0}{n^2} = \frac{100}{n^2} = l$$

$$\therefore \qquad n = 10.$$

11. Use $E - \dfrac{E}{R + r}r = V$

$$\therefore \quad E - \frac{E}{4 + r} \times r = 8 \qquad \text{...}(i)$$

$$E - \frac{E}{\frac{4 \times 4}{4 + 4} + r} \times r = 6 \qquad \text{...}(ii)$$

From equations (i) and (ii), we get

$$\frac{\frac{E(4)}{4 + r}}{\frac{E \times 2}{2 + r}} = \frac{8}{6}$$

On solving $r = 2\ \Omega$

$E = 12$ V.

12. We have, $\quad r_1 + r_2 = 27$

$$\frac{r_1 r_2}{r_1 + r_2} = 6$$

$$r_1 r_2 = 6 \times 27 = 162$$

On solving $r_1 = 9$, $r_2 = 18$.

13. If the temperature increases, resistance increases. As the emf applied is the same, the current density decreases. But the rms velocity of electrons due to thermal motion is proportional to $\sqrt{T}$. The thermal velocity increases.

14. $\dfrac{E}{r} = I$ (on short circuiting)

$$\frac{2}{r} = 4, \quad r = \frac{2}{4} = 0.5\,\Omega$$

$\therefore$ V = E – Ir = 2 – 4 × 0.5 = 2 – 2 = 0.

15. We have, $\dfrac{E}{r} = I \Rightarrow \dfrac{1.5}{r} = 3, \; r = \dfrac{1}{2} = 0.5\,\Omega.$

16. $R_{eq} = \dfrac{20 \times 20}{20 + 20} = 10\,\Omega.$

17. We have, $\dfrac{1}{R} = \dfrac{1}{4} + \dfrac{1}{2} = \dfrac{3}{4} \;\therefore\; R = \dfrac{4}{3}\Omega.$

18. As, $\quad R' = \dfrac{1}{4} \times \dfrac{R}{4} = \dfrac{R}{16}$

$$\therefore \qquad \frac{R'}{R} = \frac{1}{16}.$$

19. It is balanced Wheatstone bridge, so 20 Ω resistance is superfluous, effective resistance = 10 Ω.

20. Total resistance of the circuit is

$$\frac{5 \times 10}{5 + 10} = \frac{50}{15} = \frac{10}{3}\Omega$$

$$\text{Current, } I = \frac{2}{\left(\frac{10}{3}\right)} = \frac{2 \times 3}{10} = \frac{3}{5}\text{A}.$$

21. For balance Wheatstone bridge,

$$\frac{R_1}{R}=\frac{rl_1}{rl_2}=\frac{l_1}{l_2}\Rightarrow\frac{1.5}{R}=\frac{20}{80}=\frac{1}{4},\ R=6\,\Omega.$$

22. Total resistance of circuit is = 15 Ω

Current through R = $\left(\frac{V}{15}\right)$

Power = $\left(\frac{V}{15}\right)^2\times 10=2$

V = $\sqrt{45}=3\sqrt{5}$ volt.

23. Power is maximum if external resistance R is equal to total internal resistance which is $\frac{r}{2}$ for two cells in parallels.

$\therefore$ R = $\frac{r}{2}$ for a maximum power.

24. As, $\frac{n}{\text{second}}e$ = I,

$$\therefore \quad \frac{n}{\text{second}}=\frac{I}{e}=\frac{4.8}{1.6\times10^{-19}}$$

$= 3 \times 10^{19}$.

25. Resistance R is in series with a balanced Wheatstone bridge in parallel with a series combination of two resistors of resistance R each.

$$\therefore \quad R+\frac{R\times 2R}{R+2R}=\frac{5R}{3}$$

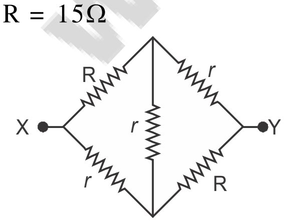
26. As, $I_g = I\left(\frac{S}{S+G}\right)$

$$\frac{I_g}{I}=\frac{2}{100}=\frac{S}{S+G}$$

$$\frac{1}{50}=\frac{S}{S+G}\Rightarrow S=\frac{G}{49}.$$

27. Given, $r = 5\Omega$

R = 15Ω



In such a case, please remember,

$$R_{XY}=\frac{r(3R+r)}{3r+R}$$

$$=\frac{5(3\times15+5)}{3\times5+15}=\frac{5\times50}{3}=\frac{25}{3}\Omega.$$

28. Let I be current in the circuit then I × 4000 = 30 volt Voltmeter is put across 3000 Ω

$$I\times 3000=\frac{30}{4000}\times3000$$

$$=\frac{90}{4}=22.5\ \text{V}.$$

29. As, $v_d=\frac{J}{ne}\Rightarrow v_d\propto J$ (current density)

$J_1=\frac{i}{A}$ and $J_2=\frac{2i}{2A}=\frac{i}{A}J_1$

$(v_d)_1=(v_d)_2=v$.

30. The density of Cu = 9×10^3 kgm^{-3}

$\because$ 6×10^{23} atom has a mass = 63×10^{-3} kg

$\therefore$ No. of electrons per m^3 are = $\frac{6\times10^{23}}{63\times10^{-3}}\times9\times10^3$

$= 8.5\times10^{28}$

Now, drift velocity $v_d=\frac{i}{neA}$

$$=\frac{1.1}{8.5\times10^{28}\times1.6\times10^{-19}\times\pi\times10.5\times10^{-32}}$$

$\therefore$ $v_d = 0.1\times10^{-3}$ m/sec.

31. As, $R=\frac{\rho l}{A}=50\times10^{-8}\times\frac{50\times10^{-12}}{(50\times10^{-2})^2}=10^{-6}\,\Omega.$

32. In case of stretching of wire, R ∝ l^2.

If length becomes 3 times so, resistance becomes 9 times

R = 9 × 20 = 180 Ω.

33. In stretching wire, R ∝ $l^2\Rightarrow\frac{R_1}{R_2}=\left(\frac{l_1}{l_2}\right)^2$

If l_1 = 100, then l_2 = 110 $\Rightarrow\frac{R_1}{R_2}=\left(\frac{100}{110}\right)^2$

$R_2 = 1.21\ R_1$

Resistivity does it change with stretching.

34. We have, $R_A=\frac{\rho l}{\pi(\pi^{-3}\times0.5)^2}$ ...(*i*)

and $R_B=\frac{\rho l}{\pi[(10^{-3})^2-(0.5\times10^{-3})^2]}$ ...(*ii*)

From equation (*i*) & (*ii*), we get

$$\frac{R_A}{R_B}=\frac{(10^{-3})^2-(0.5\times10^{-3})^2}{(10.5\times10^{-3})^2}=3:1.$$

35. In stretching of wire, R ∝ $\frac{1}{d^4}$

Where, d = diameter of wire

$\therefore$ R = $(2)^4$ = 16 times.

36. As, $i = qv$

$= 1.6\times10^{-19}\times6.6\times10^{15}$

$= 10.56\times10^{-4}$A = 1 mA.

37. In the absence of external field, mean velocity of free electron (v_{rms}) is given by

$$v_{rms} = \sqrt{\frac{3kT}{m}} \Rightarrow v_{rms} \propto \sqrt{T}\ .$$

38. We have, $R \propto \frac{l}{A} \propto \frac{1}{d^2} \Rightarrow \frac{R_1}{R_2} = \frac{l_1}{l_2} \times \left(\frac{d_2}{d_1}\right)^2$

$$= \frac{L}{4L}\left(\frac{2d}{d}\right)^2 = 1$$

$\Rightarrow \qquad R_2 = R_1 = R.$

39. As, $\qquad R = \rho\frac{l}{A}$

$$7 = \frac{64 \times 10^{-6} \times 198}{\frac{21}{7} \times r^2}$$

$\Rightarrow \qquad r = 0.024$ cm.

40. The current passing through the circuit be iA (say) Evidently potential drop in the first cell will be ir_1

Therefore, $\quad V = E - ir_1 = 0$ (given)

or $\qquad \frac{E}{r_1} = i \qquad$ ...(i)

Applying Ohm's law, for the complete circuit,

$$i = \frac{2E}{R + r_1 + r_2} = \frac{E}{r_1} \text{ (from eqn. } (i))$$

$$2r_1 = R + r_1 + r_2$$

or $\qquad R = r_1 - r_2.$

41. Corresponding the first two colour bands of yellow and violet colours, the figures are 4 & 7 corresponding to the third band of brown colour, the multiplier is 10′ *i.e.*, 10.

Hence, the given carbon resistor is of the value

47 × 10 *i.e.,* 470 Ω

Since the band showing the tolerance is golden, the value of resistor, R = 470 Ω ±5%.

42. Since potential difference of full length of wire = 2V

$\therefore$ P.D. for unit wire = $\frac{2}{4}$ = 0.5 Vm^{-1}.

43. The reading of galvanometer remains constant whether switch S is open/closed then, no current will flow through the switch *i.e.*, R and G will be in series and same current will flow through them *i.e.*, $I_R = I_G$.

44. We have, $\quad I_g \times G = (I - I_G)S$

$\Rightarrow \qquad I = \left(1 + \frac{G}{S}\right)I_G \Rightarrow I = 100.1$ mA.

45. When n resistors, each of resistance R connected in series, then

$x = nR \qquad$ ...(i)

$y = \frac{R}{n} \qquad$ ...(ii)

Multiplying equations (i) and (ii) we get,

$$xy = nR \times \frac{R}{n} = R^2 \quad \therefore\ R = \sqrt{xy}$$

46. If the ammeter is connected in parallel to the circuit, net resistance of the circuit decreases. Then, more current is drawn from the battery, which can damage the ammeter.

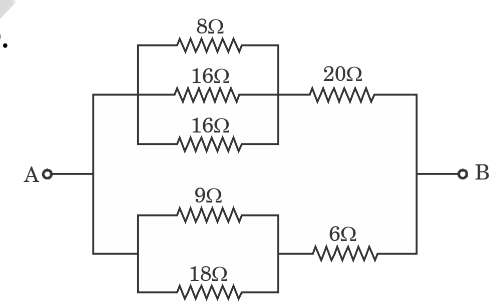
47. As $\qquad i = \frac{V}{R} \Rightarrow 2 = \frac{6}{\frac{6 \times 3}{6+3} + R} = \frac{6}{2+R}$

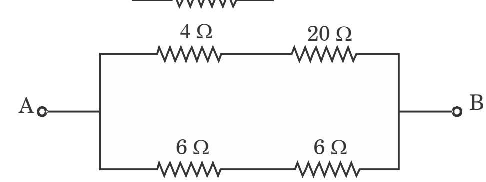
$\Rightarrow \qquad R = 1\Omega.$

48. We have, $\quad V_P - V_Q = \left(\frac{6}{3} + \frac{12 \times 6}{12+6}\right)(0.5)$

$= (2 + 4)0.5 = 6 \times 0.5V = 3V.$

49.





$\therefore \qquad R_{AB} = \frac{24 \times 12}{24 + 12} = 8\Omega.$

50. As, $\qquad \frac{P}{Q} = \frac{R}{S} \Rightarrow \frac{2}{2} = \frac{2}{\frac{6S}{6+S}}$

$\Rightarrow \qquad 1 = \frac{2(6+S)}{6S} \Rightarrow 6S = 12 + 2S$

$S = 3\ \Omega.$

CHAPTER

3

MAGNETIC EFFECTS OF CURRENT AND MAGNETISM

INTRODUCTION

The electronic current in a conductor is due to the charges in motion, such charges produced magnetic interaction. The magnetic field produced due to current through the conductor interacts with – magnetic needle and deflects it.

Magnetic Field: It is the region in which a magnetic force can be observed; *i.e.*, a small magnet or a small loop of wire carrying current will experience a torque.

It is used as synonym of 'Magnetic Flux Density' whose other name is 'Magnetic Induction' also.

Magnetic Field Strength $(\vec{H})$: If refers to a physical quantity that is used as one of the basic measures of the intensity of magnetic field. Its Unit is A/m.

Its is given as

$$\vec{B} = \mu_0 \vec{H}$$

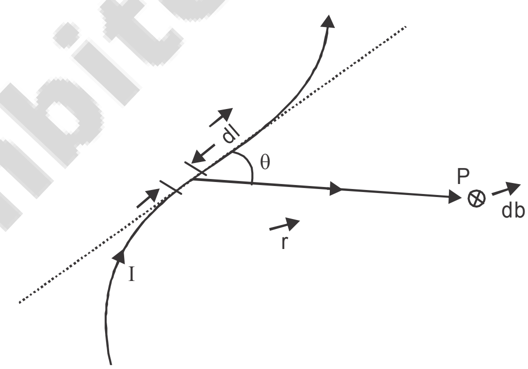
where μ_0 is called 'Permeability' of free space.

BIOT-SAVART LAW AND ITS APPLICATION TO CURRENT CARRYING CIRCULAR LOOP

Biot-Savart Law: A current carrying conductor produces a magnetic field around it. The magnitude and direction of this field at a point can be expressed by means of a law determined experimentally by Biot and Savart as Biot-Savart Law.

Magnetic field $(d\vec{B})$ due to a current carrying element $d\vec{l}$ at a point P is given by:

$$dB = \frac{\mu_0}{4\pi}\frac{I \cdot dl \cdot \sin\theta}{r^2}$$



or in vector form as

$$d\vec{B} = \frac{\mu_0 I}{4\pi} \cdot \frac{d\vec{l} \times \vec{r}}{r^3}$$

where,

$d\vec{l}$ = Current element whose direction is same as that of current passing through it.

$\vec{r}$ = Position vector of P with respect to origin at the mid point of $d\vec{l}$

θ = Angle between $d\vec{l}$ and $\vec{r}$ and

I = Current flowing through $d\vec{l}$.

The direction of $(d\vec{B})$ is given by the Right Hand Screw rule when direction of $d\vec{l}$ (*i.e.,* of I) is rotated towards the direction of $\vec{r}$ through the angle θ. In the figure shown, it is perpendicular to the plane of the paper, going inside the paper.

Application of Current Carrying Circular Loop

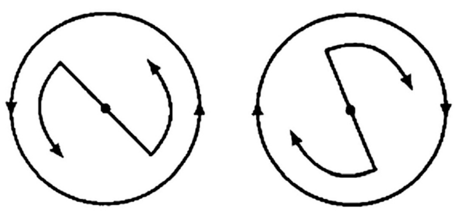
According to Biot-Savart law, the magnetic field at a point due to the current loop is given by

$$B = \frac{\mu_0}{4\pi} \cdot \frac{2\pi I}{a}$$

If circular loop has n turns, then,

$$B = \frac{\mu_0}{4\pi} \cdot \frac{2\pi n I}{a}$$

When the current flows through a circular loop (Fig) in the direction of magnetic field. The face of the loop in which the current appears to flow anticlockwise Fig. (*a*) acts as magnetic north pole. While if the current appears to flow through the face of the loop in clockwise direction Fig. (*b*), then the face acts as magnetic south pole. In the both cases, the magnetic field at the centre of loop is directed along the normal to the plane of the loop.



(*a*) (*b*)

Vector Representation of vectors having direction perpendicular to the plane of the paper

- $\odot$ represents a vector perpendicular to the plane of paper, coming out of the paper towards you.
- $\otimes$ represents a vector perpendicular to the plane of paper, going into the paper.

S.I. unit of Magnetic Field ($\vec{B}$)

It is tesla (T), named after Nikola Tesla (1870-1943)

$$\mu_0 = 4\pi \times 10^{-7}\ \text{TmA}^{-1} \text{ (in S.I. system)}$$
$$= 1 \text{ (in CGS emu system)}$$

AMPERE'S LAW

It states that for any closed loop path, the sum of the length elements times the magnetic field in the direction of the length element is equal to the permeability times the electric current enclosed in the loop.

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 I$$

(*i*) Magnetic Field due to an Infinitely long Current Carrying Straight Wire

The line integral of magnetic field along the circular path $= \oint \vec{B} \cdot \vec{dl}$

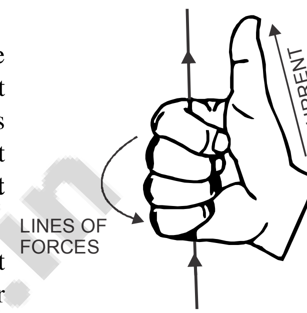
Since $\oint \vec{B} \cdot \vec{dl} = \mu_0 I$

But $\oint dl = 2\pi r$

$\therefore \quad \oint \vec{B} \cdot \vec{dl} = B \times 2\pi r$

$\therefore \quad B = \dfrac{\mu_0 I}{2\pi r} = \dfrac{\mu_0}{4\pi} \cdot \dfrac{2F}{r}$

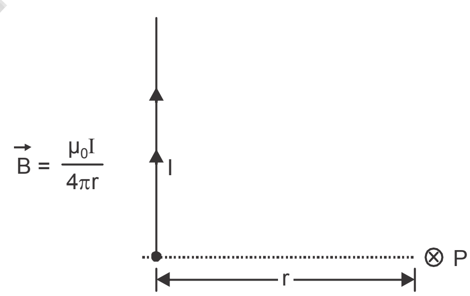
Its gives the strength of the magnetic field due to an infinitely long current carrying wire at a point at distance r from it.



Its direction can be found out by the Right Hand Screw Rule as already explained, but easiest is to use **Right Hand Thumb Rule.**

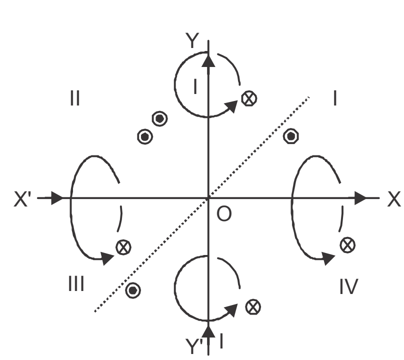
If you hold the current carrying wire in your right hand so that your right hand thumb indicates the direction of current, then your right hand fingers (which are now surrounding the wire) give the direction of magnetic lines of force.

(*ii*) Magnetic Field ($\vec{B}$) due to an infinitely long wire carrying current I, whose one end is right in front of you while the other at infinity



(*iii*) Magnetic Field due to two long wires carrying current placed at right angles to each other

Circular loops shown indicate the directions of magnetic field lines due to the two wires X′ OX and Y′ OY. From this we see that the directions of these field lines are $\odot$, $\otimes$ in

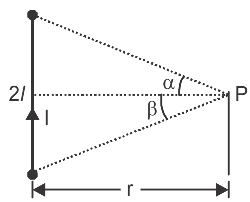


I-quadrant, $\odot$, $\odot$, in II-quadrant, $\otimes$, $\odot$ in III-quadrant and $\otimes$, $\otimes$ in IV-quadrant. Hence, these 2 fields will cancel each other out on the dashed line shown. The equation of this dashed line obviously is

$$y = x$$

(*iv*) **Magnetic Field $\vec{B}$ due to straight wire of finite length**

$$\vec{B} = \frac{\mu_0 I}{4\pi r}(\sin\alpha + \sin\beta)$$



(*v*) **Magnetic field $(\vec{B})$ due to circular current carrying loop having N turns**

(I) **At Centre** $\vec{B} = \frac{\mu_0 NI}{2a}\frac{Wb}{m^2}$

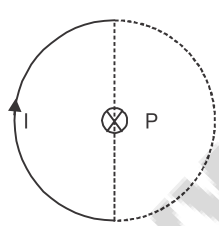
where a = radius of the circular loop.

So $\vec{B}$ at centre $\propto \frac{1}{\text{radius of coil}}$

(II) **On its axis at a distance r**

$$\vec{B} = \frac{\mu_0 NIa^2}{2(r^2 + a^2)^{3/2}}$$

(*vi*) **Magnetic field $(\vec{B})$ due to a half circle coil having N turns**



$$\vec{B} = \frac{\mu_0 NI}{4a}$$

(*vii*) **Magnetic Field due to a long Current Carrying Straight Solenoid**

A solenoid consists of an insulated long wire closely wound in the form of a helix. Its length is very large as compared to its diameter.

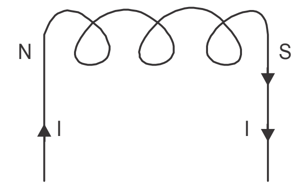
$$B = \mu_0 nI$$

where n = number of turns per unit length.

It does not matter whether the solenoid is toroidal or straight.

Magnetic Moment of a Circular Coil Having N Turns $(\vec{m})$: It is defined as $\vec{m} = NI\vec{A}$

Accordingly it behaves like a magnet having one of its faces acting like a North pole, while, the other as a South pole.



If you look at the face of any end from outside and the current's direction is anti-clockwise, then that face acts as a North pole as shown and vice-versa.

FORCE ON A MOVING CHARGE IN UNIFORM MAGNETIC AND ELECTRIC FIELDS

Force (F) on a Moving Charge (q) in a Magnetic Field (B)

The force acting an a charged particle q moving with velocity v in magnetic field B making an angle θ with the direction of field is

$$\vec{F} = a(\vec{v} \times \vec{B})$$

$$|\vec{F}| = qvB \sin\theta$$

where, $\vec{v}$ = Velocity of the charge

θ = Angle between $\vec{v}$ and $\vec{B}$

Hence, force does not depend upon the mass of the charged particle.

If the particle moves parallel to the magnetic field, then θ = 0; hence F becomes zero.

Magnetic field B is said to be 1 tesla if a charge of 1 C moving with a speed of 1 m/s at right angles to the magnetic field experiences a force of 1 N.

Force on Moving Charge in a Uniform Electric Field

When the charged particle having charge q is at rest moving in the direction of electric field $\vec{E}$, it experience a force $q\vec{E}$ in the direction of $\vec{E}$ and hence the particle is accelerated in the direction of $\vec{E}$. When the charged particle moves perpendicular to electric field $\vec{E}$, it describes a parabolic path in the electric field.

CYCLOTRON

The basic principle of cyclotron operation is a process called resonance acceleration. In this process, the particle can be accelerated to acquire high engines of several million electron volts.

Cyclotron Frequency: In a cyclotron the frequency of applied alternating electric field is equal to frequency of oscillation of the positive ion and this frequency is called cyclotron frequency. It is given by

$$\nu = \frac{Bq}{2\pi m}$$

FORCE (F) ON A STRAIGHT CURRENT (I) CARRYING CONDUCTOR IN A UNIFORM MAGNETIC FIELD (B)

Force on a current carrying conductor uniform in a magnetic force on a current carrying conductor placed in magnetic field is

$$\vec{F} = i(\vec{l} \times \vec{B}) \text{ or } F = ilB \sin\theta$$

When B and l are parallel, then $\theta = 0$ and F = 0 when l and B are mutually perpendicular, then $\theta = 90°$ and $F = Bil = F_{max}$

where,

$\vec{l}$ = length of current carrying conductor. Its direction being taken as the direction of current flowing through it.

FORCE BETWEEN TWO PARALLEL CURRENT CARRYING CONDUCTOR AND DEFINITION OF AMPERE

When two infinitely long parallel conductors carrying currents I_1 and I_2 are flowing though conductors then,

$$F = \frac{\mu_0 I_1 I_2}{2\pi r}$$

where,

F = force per unit length

I_1 & I_2 = current in wire 1 & 2

r = distance between wires

If $I_1 = I_2 = I$, then this formula becomes

$$F = \frac{\mu_0 I^2}{2\pi r}$$

Direction of F : Attractive if directions of I_1 and I_2 are same and repulsive if directions of I_1 and I_2 are opposite to each other.

Definition Ampere: "One ampere is the strength of that steady current which, when flowing in two parallel infinitely long conductors of negligible cross-section placed in vacuum at a distance of 1m from each other, produces between the two conductors a force of 2×10^{-7} Newton per metre length."

Force between two Electron or Proton Beams Running Parallel in Space

This is different than two long wires carrying current, in the sense that current carrying wires do not produce any electrostatic field while these beams do. This additional electrostatic force between these beams will be roughly 10^{27} times larger than the magnetic force. This means magnetic force will become negligible now. Hence, whether these beams are running in the same direction or opposite, the net force between them will be repulsive.

Lorentz Force: It is the force experienced by a charge moving in free space where both electric and magnetic fields exit.

Lorentz Force, $\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$.

$q\vec{E}$ is called Lorentz electric force and $q(\vec{v} \times \vec{B})$ is called Lorentz magnetic force.

Relative magnitudes of electric & magnetic forces

$$\mu_0 \varepsilon_0 = \frac{1}{C^2}$$

where, μ_0 = Permeability of free space

ε_0 = Permittivity of free space

C = Velocity of light in free space $= 3 \times 10^8$ m/s.

$$\therefore \quad \frac{F_e}{F_m} = 10^{27}$$

where, F_e = Lorentz electric force

F_m = Lorentz magnetic force

So, F_m is 10^{27} times smaller than F_e.

TORQUE EXPERIENCED BY A CURRENT LOOP IN UNIFORM MAGNETIC FIELD

The torque on the whole coil is given by

$$\tau = NIAB \sin\theta$$

In vector form, $\vec{\tau} = \vec{P}_m \times \vec{B}$

Torque τ on a Rectangular Current Loop Placed in a Magnetic Field. We have,

$$\tau = NIAB \sin\theta$$

or $\vec{\tau} = N(\vec{m} \times \vec{B})$

where, τ = torque, N = No. of turns, I = Current, A = Area of the loop, B = Magnetic Field, ϕ = Angle between $\vec{m}$ *i.e.,* perpendicular to the loop and $\vec{B}$

Hence, if a coil is placed in a magnetic field, and is rotated by some external agency, then emf will be produced in it. This is the principle of AC generator. However, if a current carrying coil is placed in a magnetic field, then it experience a torque alone.

MOVING COIL GALVANOMETER ITS CURRENT SENSITIVITY AND CONVERSION TO AMMETER TO VOLTMETER

It is an instrument used for the detection and measurement of current. Its action is based on the torque acting on the current carrying coil placed in a magnetic field.

We have, $I = \frac{K}{NBA} \cdot \frac{\alpha}{\sin\theta}$

In case of radial magnetic field, $\theta = 90°$

$\therefore \quad I = \frac{K}{NBA} \cdot \alpha$

Higher the sensitivity of the galvanometer, higher will be the value of α for the same I.

Hence, Sensitivity $\propto \frac{1}{K}$

$\propto$ N, B and A

Here, I = Current flowing through galvanometer
K = Torque required to produce unit angular twist in the suspension strip
N = No. of turns
B = Magnetic field
A = Area of coil
α = Angle between 'perpendicular to the face of the galvanometer coil' and $\vec{B}$

$\frac{K}{NBA}$ is written as C and is called the galvanometer constant.

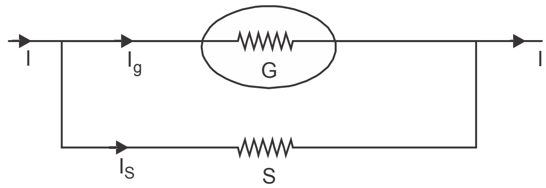
Current Sensitivity: It is defined as the deflection produced in the galvanometer, when a unit current flow through it. If *d* be the deflection in the galvanometer, when current I is passed through it, then, $I_s = \frac{\phi}{I} = \frac{NBA}{K}$.

Conversion of Galvanometer into Ammeter and Voltmeter

(*i*) ***Galvanometer:*** It is an instrument with two terminals. If current passes through it, it's needle gets deflected from it's zero position which is at the centre of the scale. The direction of deflection will depend upon the direction of flow of current through it. The amount of deflection is proportional to the value of the current. Even commercially available galvanometers are very sensitive. They respond to as small currents as may be a few micro amperes.

Galvanometers can easily be converted into ammeters (to measure currents) or voltmeters (to measure potential differences).

(*ii*) ***Ammeter*:** A galvanometer can be converted into an ammeter by connecting a low resistance in parallel with the galvanometer. This resistance is called *shunt resistance*



If S = Shunt Resistance
G = Resistance of the galvanometer
I = Total current which is to be measured.
I_g = Galvanometer current *i.e.,* that value of current which will cause the galvanometer needle give full deflection.
I_s = Current which would flow through shunt resistance then,

$$S = G \cdot \frac{I_g}{I - I_g} \quad \text{or} \quad I_g = \frac{S}{(S+G)} \cdot I$$

Note: Ideal ammeter will have zero resistance.

(*iii*) ***Voltmeter*:** To convert a galvanometer into a voltmeter, a high resistance R is connected in series with the galvanometer. The value is the high resistance for the voltmeter to have range 0 to V volts is given by

$$R = \frac{V}{I_g} - G.$$

where, V = Max. p.d. to be measured.
I_g = Galvanometer current, *i.e.*, that current which will give full-scale deflection to the galvanometer needle.
G = Galvanometer resistance.
R = Resistance which should be connected to the galvanometer in series.

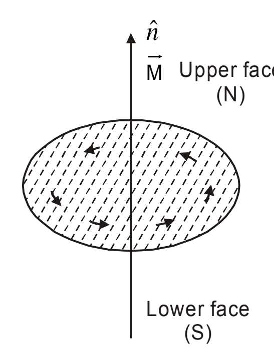
CURRENT LOOP AS A MAGNETIC DIPOLE AND MAGNETIC DIPOLE MOMENT

The magnetic dipole moment of the current loop (M) is directly proportional to strength of current (I) through the loop and (*ii*) area (A) enclosed by the loop.

i.e., $M \propto I$ or $M \propto A$

$\therefore \quad M = KIA$

where K is constant of proportionality.



When we define unit of magnetic dipole moment as that of small one turn loop of unit area carrying unit current.

As, $M = IA$

$M = NIA$

In vector form, $\vec{M} = NIA\hat{n}$

Magnetic Dipole Moment: It is the product of strength of either pole (m) and the magnetic length ($2\vec{l}$) of the magnet. It is represented by $\vec{M}$.

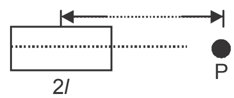
Magnetic dipole moment = strength of either pole × magnetic length

$$\vec{M} = m(2\vec{l})$$

Potential due to a Magnetic Dipole

(*i*) At a point in end-side on position

$$V = \frac{\mu_0}{4\pi}\frac{M}{(r^2 - l^2)}$$



For a very short magnet

$l^2 << r^2$, hence

$$V = \frac{\mu_0}{4\pi}\frac{M}{r^2}$$

(*ii*) At a point in the broad side on position V = 0

Terrestrial Magnetism

$B_e = \sqrt{H^2 + V^2} \rightarrow$ Earth's magnetic field

$H = B_e \cos\theta \rightarrow$ Horizontal component of earth's magnetic field

$V = B_e \sin\theta \rightarrow$ Vertical component of earth's magnetic field

$$\tan\theta = \frac{V}{H}$$

$$\theta = \tan^{-1}\left(\frac{V}{H}\right) \rightarrow \text{Angle of dip.}$$

Vibration Magnetometer: We have,

$$\alpha = -\frac{MH}{K}\theta$$

$\theta \rightarrow$ Angular displacement of the magnet from the magnetic meridian.

$\alpha \rightarrow$ Angular acceleration

$K \rightarrow$ moment of inertia of the magnet about its axis of vibration.

$M \rightarrow$ Magnetic moment of the magnet.

$H \rightarrow$ Horizontal component of earth's magnetic field, in the direction of magnetic meridian.

$$\omega = \sqrt{\frac{MH}{K}}.$$

$\omega \rightarrow$ Angular frequency of vibrating magnet.

$$T = 2\pi\sqrt{\left(\frac{K}{MH}\right)}$$

$T \rightarrow$ Time period.

Comparison of two Magnetic Fields: We have

$$\frac{B_1}{B_2} = \frac{(T^2 - T_1^2)T^2}{(T^2 - T_2^2)T_1^2}$$

$T \rightarrow$ time-period of the magnetometer under the influence of the earth's magnetic field above.

$T_1 \rightarrow$ time period of the magnet which vibrates in the resultant magnetic field $(H + B_1)$.

$T_2 \rightarrow$ time period of the magnet which vibrates in the resultant magnetic field $(H + B_2)$.

Comparison of Magnetic Moments of two Magnets: We have,

$$\frac{M_1}{M_2} = \frac{K_1}{K_2}\cdot\frac{T_2^2}{T_1^2} \quad \text{(Substitution method)}$$

$$\frac{M_1}{M_2} = \frac{T_1^2 + T_2^2}{T_2^2 - T_1^2} \quad \text{(Sum and difference method)}$$

BAR MAGNET AS AN EQUIVALENT SOLENOID

A system composed of two poles, equal in magnitude but opposite in polarity, placed at a small distance is known as bar magnet.

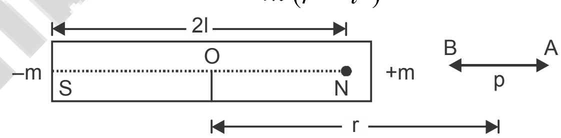
The magnetic field lines for a bar magnet and the current carrying solenoid resemble very closely. So that bar magnet can be thought of as a large number of circulating currents in analogy with a soil.

To demonstrate the similarity of a current carrying solenoid to a bar magnet.

Field due to a small bar magnet

(i) In end on position

$$B = \frac{\mu_0}{4\pi}\frac{2Mr}{(r^2 - l^2)^2}$$



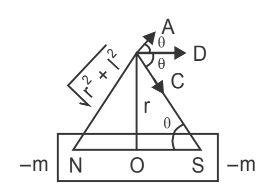
For a small magnet $r^2 >> l^2$

$$B = \frac{\mu_0}{4\pi}\cdot\frac{2M}{r^3}$$

(ii) Broad side on position

$$B = \frac{\mu_0}{4\pi}\cdot\frac{2ml}{(r^2 + l^2)^{3/2}}$$

$$= \frac{\mu_0}{4\pi}\frac{M}{(r^2 + l^2)^{3/2}}$$



when $r^2 >> l^2$

$$B = \frac{\mu_0}{4\pi}\cdot\frac{M}{r^3} \quad M \rightarrow \text{Magnetic dipole moment}$$

Direction of $\vec{B}$ is parallel to the axis from N pole to S-pole.

Couple on a Bar Magnet in a Magnetic Field

$\tau = MB\sin\theta$ Scalar form

$\vec{\tau} = \vec{M}\times\vec{B}$ vector form

work done in rotating a magnetic dipole in a magnetic field

$$W = \int_{\theta_1}^{\theta_2}\tau\, d\theta$$

when $\theta_1 = 0$ & $\theta_2 = \theta$

$W = MB[1 - \cos\theta]$

Potential energy of a magnetic dipole placed in a magnetic field

$$= -MB\ (\cos\theta_2 - \cos\theta_1)$$

when $\theta_1 = 90°$ and $\theta_2 = \theta$

$$U = -MB(\cos\theta - \cos 90°)$$

or $\quad U = -MB\ \cos\theta$

In vector notation $U = -\vec{M}\cdot\vec{B}$

Couple Between Two Small Magnets

Case I $\rightarrow$ The magnet being in the end-on position

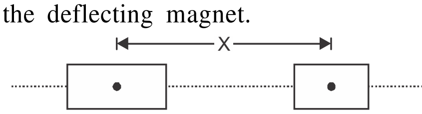
$$\text{Couple} = \frac{\mu_0}{4\pi} - \frac{2MM'}{r^3}$$

Case II $\rightarrow$ The magnet being in the Broad side-on position (two magnets are at right angle)

$$\text{Couple} = \frac{\mu_0}{4\pi}\frac{2MM'}{r^3}$$

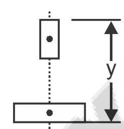
Force Between Two Small Magnets:

(*i*) The magnet being in the End-on position with respect to the deflecting magnet.



$$F = \frac{\mu_0}{4\pi}\left[\frac{6MM'}{x^4}\right],\ \text{in rationalized MKS system}$$

(*ii*) The magnet being in the broad side on position with respect to the deflating magnet



$$F = \frac{\mu_0}{4\pi}\left[\frac{3MM'}{y^4}\right],\ \text{in rationalized MKS system}$$

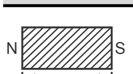
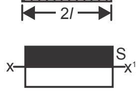
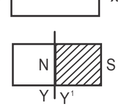
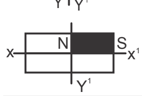
Magnetic Potential: We have,

$$V = -\int B\,dx$$

Magnetic potential due to a point pole, at a distance r from the pole of strength m

$$V = \frac{\mu_0}{4\pi}\cdot\frac{m}{r}\frac{\text{Joule}}{\text{Weber}}$$

Corresponding values of pole strength and magnetic moments

Magnet	*Pole strength*	*Effective Length after cutting*	*Magnetic Moment*
	m	$2l$	$M = 2ml$
	$\frac{m}{2}$	$2l$	$M' = \frac{m}{2}\times 2l = ml = \frac{M}{2}$
	m	l	$M'' = ml = \frac{M}{2}$
	$\frac{m}{2}$	l	$M''' = \frac{ml}{2} = \frac{M}{4}$

MAGNETIC FIELD LINES

According to Faraday, magnetic line is an imaginary curve, the tangent to which at any point gives us the direction of magnetic field $\vec{B}$ at that point.

Magnetic field lines are closed curves *i.e.*, they appear to converge or diverge at poles.

EARTH'S MAGNETIC FIELD AND MAGNETIC ELEMENTS

Out earth behaves as powerful magnet within it, whose south pole is towards the earth's north pole and the north pole is towards the earth's south pole.

Elements of the Earth's Magnetism

Angle of Declination: The acute angle between magnetic meridian and the geographical meridian at any place is called as the angle of declination.

Angle Dip: The angle of dip at a place is the angle between the direction of earth's magnetic field and the horizontal. Angle of dip at poles is 90°, while at the equator is 0°.

Apparent Dip: The angle made by needle with horizontal is called apparent dip.

Horizontal component of Earth's Magnetic Field: It is the component of total intensity of earth's magnetic field in the horizontal direction in magnetic meridian.

PARA, DIA AND FERRO-MAGNETIC SUBSTANCES

Paramagnetic Substances: Those substances, when placed in a magnetic field are feebly magnetised in the direction of the field. These substances, when brought near the poles of strong magnet, show weak attraction. For example, bismuth, zinc, copper, silver, gold etc.

Diamagnetic Substances: Those substances, when placed in the magnetic field are feebly magnetised in a direction opposite to that of the field. Those substances, when brought near the poles of strong magnet, show weak repulsion. Examples of diamagnetic substances are copper, zinc, bismuth, silver, gold etc.

Ferromagnetic Substances: Those substances, which when placed in a magnetic field are strongly magnetised in the direction of the magnetising field, are called ferromagnetic substances. The ferromagnetic behaviour of a substance becomes temperature dependent above certain temperature, which is characteristic of that substance. It is called curie temperature. For example, the ferromagnetic materials are nickel, cobalt, alnico etc.

Magnetisation (I): It defined as the magnetic moment developed per unit volume, when a magnetic specimen is subjected to magnetising field. It is given by

$$I = \frac{M}{V} = \frac{\text{Magnetic moment}}{\text{Volume}}$$

$$= \frac{m}{A} = \frac{\text{Magnetic pole strength}}{\text{Area of cross section}}$$

Relative permeability of a medium

$$\mu_r = \frac{B}{B_0}$$

$B \rightarrow$ the magnetic flux density in a material medium.

and $B_0 \rightarrow$ the magnetic flux density in a vacuum.

MAGNETIC SUSCEPTIBILITY AND PERMEABILITY

Magnetic Susceptibility: Magnetic susceptibility is measured by the ratio of the intensity of magnetisation (I) of a substance to the magnetising force (H).

$$\chi_m = \frac{I}{H}$$

The susceptibility is greater for soft iron than for steel.

Magnetisation I α H (H $\rightarrow$ Magnetic field intensity).

or, $\vec{I} = \chi_m \vec{H}$

$\chi_m \rightarrow$ magnetic susceptibility.

If χ_m is +ve and small, material is paramagnetic

If χ_m is –ve, material is diamagnetic

If χ_m is +ve and very large, material is ferromagnetic

Relation between B and HI:

$$\frac{B}{H} = \mu \text{ (Permeability)}$$

Relation between μ and χ

$$\mu_r = 1 + \chi$$

and $\mu_r = \dfrac{\mu}{\mu_0}$ also $= \dfrac{B}{B_0}$

Magnetic Permeability: Magnetic permeability is the conducting power of a medium for magnetic lines of force as compared to that for air and is measured by the ratio of the number of lines of force passing normally through a unit area placed within the substance.

HYSTERESIS

The area of the hysteresis loop for a ferromagnetic material is equal to the energy loss per cycle of magnetisation and demagnetisation per unit volume.

Energy loss in material = Volume of material × area of hysteresis curve × frequency × time.

Hysteresis loss per cycle per unit volume is equal to the area of I – H loop.

ELECTROMAGNETS AND PARMANENT MAGNETS

Magnets: The phenomenon of attraction of small bits, iron, steel, cobalt, nickel etc. towards the ores are called magnetism. The iron ore showing this effect is called a natural magnet.

Electromagnets: The core electromagnets are made or ferromagnetic material which have high permeability and law retentively. Soft iron is a suitable material for this purpose when soft iron rod is placed in a solenoid and current is passed through the solenoid, magnetism of the solenoid is increased by a thousand fold. Electric bells, loudspeakers, cranes etc. are electromagnets.

Permanent Magnets: Permanent Magnets are materials which retain at room temperature, the ferromagnetic properties for the long time.

The inverse square law in magnetism

In rationalised MKS system

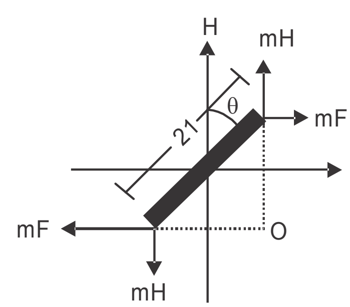
$$F = \frac{\mu_0 \mu}{4\pi} \frac{m_1 m_2}{r^2} \text{ newtons}$$

In C.G.S. system $F = \dfrac{\mu_0 \mu m_1 m_2}{r^2}$ dynes

$$\mu\mu_0 = \mu_a \rightarrow \text{absolute permeability}$$

In air (or strictly speaking in vacuum) $\mu = 1$

in C.G.S. system equation reduces to



$$F = \frac{m_1 m_2}{r^2}$$

Intensity of magnetic field

$$H = \frac{\mu_0}{4\pi} \cdot \frac{m}{r^2}$$

Tangent Law: If a small magnet pivoted at its centre is acted upon by 2 magnetic fields F and H perpendicular to each other, it rotates and stabilises itself making an angle θ, say, with H. Then,

$$F = H \tan\theta \text{ or } \tan\theta = \frac{F}{H}$$

EXERCISE

1. A helium nucleus makes a full rotation in a circle of radius 0.8 metre in two seconds. The value of the magnetic field B at the centre of the circle will be

A. $\dfrac{10^{-19}}{\mu_0}$ B. $10^{-19}\ \mu_0$

C. $2 \times 10^{-19}\ \mu_0$ D. $\dfrac{2\times10^{-19}}{\mu_0}$

2. Two thin long parallel wires separated by a distance 'b' are carrying a current i ampere each. The magnitude of the force per unit length exerted by one wire on the other is

A. $\dfrac{\mu_0 i^2}{b^2}$ B. $\dfrac{\mu_0 i^2}{2\pi b}$

C. $\dfrac{\mu_0 i}{2\pi b}$ D. $\dfrac{\mu_0 i}{2\pi b^2}$

3. A solenoid of 1.5 metre length and 0.4 cm diameter possesses 10 turns per cm. A current of 5 ampere is flowing through it. The magnetic induction at axis inside the solenoid is

A. $2\pi \times 10^{-3}$ tesla B. $2\pi \times 10^{-5}$ tesla

C. $2\pi \times 10^{-2}$ gauss D. $2\pi \times 10^{-5}$ gauss

4. A uniform magnetic field acts at right angles to the direction of motion of electrons. As a result, the electrons moves in a circular path of radius 2 cm. If the speed of the electron is doubled the radius of the circular path will be

A. 2.0 cm B. 0.5 cm

C. 4.0 cm D. 1.0 cm

5. If a long copper rod carries a direct current, the magnetic field associated with the current will be

A. only inside the rod

B. only outside the rod

C. both inside and outside the rod

D. neither inside nor outside the rod.

6. A wire of length Lm carrying a current i ampere is bent in the form of a circle. The magnitude of magnetic moment is

A. $\dfrac{iL^2}{4\pi}$ B. $\dfrac{iL^2}{2\pi}$

C. $4\pi^2 L^2 i$ D. $\pi L^2 i$

7. An electric current of 30 A is flowing in each of two parallel conducting wires placed 5 cm apart. The force acting per unit length on either of the wires will be:

A. 1.5×10^{-5} N/m B. 2.4×10^{-3} N/m

C. 3.6×10^{-3} N/m D. 4.8×10^{-4} N/m

8. The strength of the magnetic field at a point distance r near a long straight current carrying wire is B. The field at a distance $\dfrac{r}{2}$ will be

A. $\dfrac{B}{2}$ B. $\dfrac{B}{4}$

C. 2B D. 4B

9. The number of turns and radius of cross section of the coil of a tangent galvanometer are doubled, its reduction factor is K. The new reduction factor K′ will be

A. K B. 2K

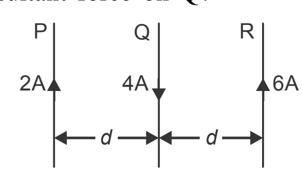
C. 4K D. $\dfrac{K}{4}$

10. A long wire carries a current of 20 A along the axis of a solenoid. The field due to the solenoid is 4 mT. The resultant field at a point 3 mm from the solenoid axis is

A. 1.33 mT B. 4.2 mT

C. 5.33 mT D. 2.87 mT

11. P, Q and R are long parallel straight wires in air, carrying currents as shown below. What is the direction of the resultant force on Q?



A. To the left

B. To the right

C. The same as that of current in Q

D. Perpendicular to this page

12. Suppose that a proton travelling in vacuum with velocity V_1 at right angles to a uniform magnetic field experiences twice the force that an α-particle experience when it is travelling along into same path with velocity V_2. The ratio $\dfrac{V_1}{V_2}$ is

A. 0.5 B. 1

C. 2 D. 4

13. A particle carrying a charge equal to 100 times the charge of the electrons is rotating per second in a circular path of radius 0.8 m. The value of magnetic field produced at the centre will be (μ_0 = permeability for vacuum)

A. $\dfrac{10^{-7}}{\mu_0}$ B. $10^{-6}\ \mu_0$

C. $10^{-17}\ \mu_0$ D. $10^{-7}\ \mu_0$

14. In hydrogen atom the electron moves in an orbit of radius 0.5 Å making 10^{16} revolutions per second. The magnetic moment associated with the orbital motion of the electron in A – m^2 is

A. 1.25×10^{-18} B. 1.25×10^{-23}
C. $25\pi \times 10^{-23}$ D. $25\pi \times 10^{-38}$

15. In hydrogen atom, the electron is making 6.6×10^{15} rev/sec around the nucleus of radius 0.53 Å. The magnetic field produced at the centre of the orbit is nearly

A. 0.14 Wb/m^2 B. 1.4 Wb/m^2
C. 14 Wb/m^2 D. 140 Wb/m^2

16. The magnetic field at a distance r from a long wire carrying current 'i' is 0.4 tesla. The magnetic field at a distance '$2r$' is

A. 0.2 tesla B. 0.8 tesla
C. 0.1 tesla D. 1.6 tesla

17. A circular current carrying coil has a radius R. The distance from the centre of the coil on the axis where the magnetic induction will be $\frac{1}{8}$th of its value at the centre of the coil is

A. $\frac{R}{\sqrt{3}}$ B. $R\sqrt{3}$
C. $2R\sqrt{3}$ D. $\left(\frac{2}{\sqrt{3}}\right)R$

18. A conducting circular loop of radius (r) carries a constant current (i). It is placed in uniform magnetic field $\vec{B}$, such that $\vec{B}$ is perpendicular to the plane of the loop. The magnetic force acting on the loop is

A. $\pi ri\vec{B}$ B. $ir\vec{B}$
C. zero D. $2\pi ir\vec{B}$

19. What is the force on each single electron assuming that each electron experiences the same force

A. 7.5×10^{-11} N B. 8×10^{-13} N
C. 7.25×10^{-15} N D. 2.5×10^{-17} N

20. A period of oscillation of a magnet in a vibration magnetometer is 2 seconds. The period of oscillation of a magnet whose magnetic moment is four times that of the first magnet is

A. 1 sec B. 4 sec
C. 8 sec D. 0.5 sec

21. At a certain place, horizontal component of earth's magnetic field is $\sqrt{3}$ times the vertical component. The angle of dip at the place is

A. 75° B. 60°
C. 45° D. 30°

22. If the magnet is suspended at an angle 30° to the magnetic meridian the dip needle makes an angle at 60° with the horizontal. The true value of dip is

A. $\tan^{-1}\left(\frac{2}{3}\right)$ B. $\tan^{-1}\left(\frac{3}{2}\right)$
C. $\tan^{-1}(3)$ D. $\tan^{-1}(2)$

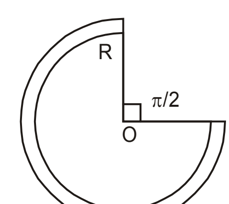
23. A steady current I goes through a wire loop ABC having shape of right angle with AB = $3x$, AC = $4x$ and BC = $5x$. If the magnitude of the magnetic field at A due to this loop is $k\left(\frac{\mu_0 I}{48\pi x}\right)$. Find the value of k.

A. 7 B. 5
C. 4 D. 3

24. A current of 4×10^{-3} A is flowing in a long straight conductor. The value of the internal of magnetic field around the closed path enclosing the straight conductor will be

A. $1.2\ \pi \times 10^{-9}$ Wb/m^2 B. $1.6\ \pi \times 10^{-9}$ Wb/m^2
C. $2.4\ \pi \times 10^{-8}$ Wb/m^2 D. 1.6×10^{-9} Wb/m^2

25. A current i amp flows in a circular arc of wire whose radius is R, which subtends an angle $\frac{B\pi}{2}$ radian at its centre. The magnetic induction B at the centre is



A. $\frac{\mu_0 ni}{R}$ B. $\mu_0 niR$
C. $\frac{3\mu_0 i}{8R}$ D. $\frac{2\mu_0 ni}{8R}$

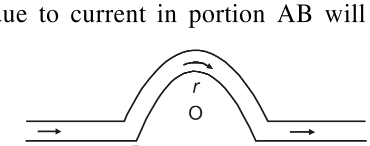
26. The magnetic field B within a solenoid having n turns per metre length and carrying a current of i amp is given by

A. $\frac{\mu_0 ni}{R}$ B. $\mu_0 ni$
C. $2\mu_0 ni$ D. $4\mu_0 ni$

27. The strength of the magnetic field at a point r near a long straight current carrying wire is B. The field at a distance $\frac{r}{2}$ will be

A. 2 B B. B
C. $\frac{B}{2}$ D. 3 B

28. In the Fig. the magnetic induction at the centre of the area due to current in portion AB will be



A. $\frac{\mu_0 i}{r}$ B. $\frac{2\mu_0 i}{r}$

C. Zero D. $\frac{\mu_0 i}{3r}$

29. Magnet of magnetic moment m and pole strength M is divided in two parts, then magnetic moment of each part will be

A. $\frac{M}{2}$ B. m

C. $\frac{m}{2}$ D. 2 M

30. A galvonometer has a resistance of 50 Ω. A resistance of 5 Ω is connected across its terminals. What part of total current will flow through the galvonometer?

A. $\frac{1}{9}$ B. $\frac{1}{10}$

C. $\frac{1}{11}$ D. $\frac{1}{15}$

31. Ratio of magnetic intensities for an axial point and a point on broad side on position at equal distance d from the centre of magnet. The magnetic field at a distance d from a short bar magnet in longitudinal and transverse positions are in the ratio.

A. 2 : 1 B. 3 : 2
C. 1 : 1 D. 2 : 3

32. The magnetic field at a point x on the axis of a small bar magnet is equal to the field at point y on the equator of the same magnet. The ratio of the distance of x and y from the centre of the magnet is

A. 2^3 B. $2^{-1/3}$
C. 2^{-3} D. $2^{1/3}$

33. The magnetic field due to short magnet at a point on its axis at distance x cm from the middle point of the magnet is 200 gauss. The magnetic field at a point from the middle of the magnet is

A. 50 gauss B. 200 gauss
C. 100 gauss D. 400 gauss

34. A beam of ions with velocity 2×10^5 ms^{-1} enters nearly into a uniform magnetic field of 4×10^{-2}T. If the specific charge of the ion is 5×10^7 C/kg, then the radius of the circular path described will be

A. 0.25 m B. 0.10 m
C. 0.16 m D. 0.20 m

35. The vertical component of the earth's magnetic field at a place is $0.16\sqrt{3}$ oersted. Calculate the value of B_H, if the dip at the place is 30°.

A. 0.48 oersted B. 0.32 oersted
C. 0.52 oersted D. 0.60 oersted

36. A bar magnet made of steel has magnetic moment of 2.5 Am^2 and a mass of 6.6×10^{-3} kg. If the density of steel is 7.9×10^3 kg m^{-3}. Then, the intensity of magnetisation of the magnet is

A. 2.0×10^4 Am^{-1} B. 2.5×10^{-5} Am^{-1}
C. 3.0×10^6 Am^{-1} D. 3.5×10^{-7} Am^{-1}

37. A magnet 10 cm long and having a pole strength 2Am is deflected through 30° from the magnetic meridian. The horizontal component of earth's induction is 0.32×10^{-4}T. The value of the deflecting couple is

A. 12×10^{-7} Nm B. 32×10^{-7} Nm
C. 42×10^{-6} Nm D. 64×10^{-7} Nm

38. A circular coil of 200 turns has a radius of 5 cm and carries a current of 5A. The magnetic field at the centre of the coil is

A. 1.26×10^{-2} T B. 1.32×10^{-3} T
C. 1.57×10^{-2} T D. 1.83×10^{-2} T

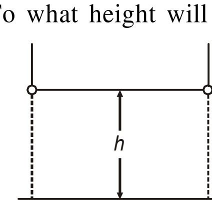
39. The magnetic field applied in a cyclotron is 0.7T and radius is 1.8 m. The energy of emergent deuterons will be

A. 12 MeV B. 38 MeV
C. 102 MeV D. 118 MeV

40. A galvanometer gives full scale deflection when a current of 2 mA flows through it and the potential difference across its terminals is 4 mV. Which of the following would be most suitable to convert, it to give a full scale deflection for a current of 1A?

A. 0.002 Ω in series B. 0.002 Ω in parallel
C. 0.004 Ω in series D. 0.006 Ω in parallel

41. A long straight wire carrying current of 25 A rests on a table as shown in Fig. Another wire AB of length 1 m, mass 2.5 g carries the same current but in the opposite direction. The wire AB is free to slide up and down. To what height will AB rise?



A. 0.21 cm B. 0.31 cm
C. 0.41 cm D. 0.51 cm

42. A wire placed along north-south direction carries a current of 10 A from south to north. Find the magnetic field due to a 1 cm piece of wire at a point 200 cm north east from the piece.

A. 1.8×10^{-9} T B. 2.5×10^{-8} T
C. 3.1×10^{-9} T D. 2.9×10^{-7} T

43. A closely wound solenoid, 80 cm long has 5 layers of windings of 400 turns each. The diameter of the solenoid is 1.8 cm. If the current carried in 8.0 A, estimate the magnitude of $\vec{B}$ inside the solenoid near its centre.

A. 1.2×10^{-3} T B. 2.5×10^{-2} T
C. 2.3×10^{-3} T D. 4.5×10^{-2} T

44. A 60 cm long wire (mass 10 gm) is hanged by two flexible wires in a magnetic field of 0.40 Wbm^{-2}. Find the magnitude and direction of current required to be flown by neutralize the tension of the hanging wires. (Take $g = 10\ ms^{-2}$)
A. 0.315 A B. 0.405 A
C. 0.416 A D. 0.215 A

45. A cyclotron has an oscillatory frequency of 12×10^6 Hz and dee of radius 50 cm. The magnetic induction required to accelerate neutron of mass 3.3×10^{-27} kg and charge 1.6×10^{-19} C is
A. 1.6 T B. 3.2 T
C. 4.0 T D. 4.5 T

46. By mistake, a voltmeter is connected in series and an ammeter is connected in parallel with a resistance in an electrical circuit. What will happen to the instruments?
A. Voltmeter is damaged
B. Ammeter is damaged
C. Both are damaged
D. None is damaged

47. A bar magnet is placed in a magnetic meridian with its N pole pointing towards geographical north. Two neutral points are obtained on the equatorial line of the magnet. Given length of magnet = 8 cm, distance between neutral points = 6 cm and horizontal component of earth's magnetic field = 0.32 gauss. The pole strength of the magnet is
A. 5 abA cm B. 7 abA cm
C. 9 abA cm D. 11 abA cm

48. A bar magnet of magnetic moment 200 Am^2 is suspended in a magnetic field intensity 0.25 N/Am. The couple required to deflect it through 30° is
A. 15 Nm B. 20 Nm
C. 25 Nm D. 50 Nm

49. The work done in turning a magnetic moment M by an angle of 90° from the meridian is n times the corresponding work done to turn through an angle of 60°, the value of n is
A. 1 B. $\frac{1}{2}$
C. 4 D. 2

50. A short bar magnet of magnetic moment 0.4 JT^{-1} is placed in a uniform magnetic field of 0.16 T. The magnet is in stable equilibrium, when the potential energy is
A. –0.64 J B. 0
C. –0.082 J D. 0.064 J

51. If the magnetic dipole moment of an atom of a diamagnetic material and ferromagnetic material are denoted by μ_d, μ_p & μ_f respectively. Then,
A. $\mu_d = 0$ and $\mu_p \neq \mu_f$ B. $\mu_d \neq 0$ and $\mu_p = 0$
C. $\mu_p = 0$ and $\mu_f \neq 0$ D. $\mu_d \neq 0$ and $\mu_f \neq 0$

52. A short bar magnet placed with its axis at 30° with a uniform external magnetic field of 0.25 T experiences a torque of magnitude equal to 4.5×10^{-2} J. The magnetic moment of the magnet is
A. 0.36 JT^{-1} B. 0.12 JT^{-1}
C. 0.48 JT^{-1} D. 0.28 JT^{-1}

53. A magnetic needle free to rotate in a vertical plane parallel to the magnetic meridian has its north tip pointing down at 22° with the horizontal. The horizontal component of the earth's magnetic field at the place is known to be 0.35 G. The magnitude of earth's magnetic field at the place is
A. 0.48 G B. 0.55 G
C. 0.38 G D. 0.28 G

54. A closely wound solenoid of 2000 turns and area of cross section 1.6×10^{-4} m^2, carrying a current of 4A is suspended through its centre allowing it to turn in a horizontal plane. What is the magnetic moment associated with the solenoid?
A. 1.28 Am^2 B. 0.28 Am^2
C. 2.28 Am^2 D. 1.92 Am^2

55. A closely wound solenoid of 800 turns and area of cross-section 2.5×10^{-4} m^2 carry a current of 3A. What is associated magnetic moment?
A. 0.60 JT^{-1} B. 0.50 JT^{-1}
C. 0.55 JT^{-1} D. 0.45 JT^{-1}

56. A short bar magnet has a magnetic moment of 0.48 JT^{-1}. Find the direction and magnitude of the magnetic field produced by the magnet at a distance of 10 cm from the centre of the magnet on the axis of the magnet?
A. 0.56 G along S-N direction
B. 0.96 G along S-N direction
C. 0.90 G along S-N direction
D. 0.54 G along S-N direction

57. A long straight horizontal cable carries a current of 2.5 A in the direction 10° south of west of 10° north of east. The magnetic meridian of the place happens to be 10° west of the geographic meridian. The earth's magnetic field at the location is 0.33G, and the angle of dip is zero. Locate the natural points.
A. 1.0 cm B. 0.9 cm
C. 2.1 cm D. 1.5 cm

58. A long straight wire carries a current of 35 A. What is the magnitude of the field $\vec{B}$ at a point 20 cm from the wire?

A. 3.5×10^{-5} T B. 5.4×10^{-6} T
C. 4.2×10^{-3} T D. 8.5×10^{-4} T

59. A galvanometer coil has a resistance of 12 Ω and metre shows full deflection for a current of 3 mA. How will you convert the metre into a voltmeter of range 0 to 18 V?
A. 4852 Ω B. 5988 Ω
C. 6432 Ω D. 2163 Ω

60. A suspended magnet oscillates with the periodic time T in the earth's horizontal field. When a bar magnet is brought near it, the periodic time is found to have been decreased to $\frac{T}{2}$. Find the ratio of the field of magnet to earth's horizontal field.
A. 1 : 3 B. 3 : 1
C. 1 : 2 D. 2 : 1

ANSWERS

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
B	B	A	C	C	A	C	C	A	B
11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
A	D	C	B	C	A	B	B	B	A
21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
D	B	A	B	C	B	A	C	C	D
31	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
A	D	C	B	A	C	B	A	B	C
41	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**
D	A	B	C	A	D	A	C	D	D
51	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**
A	A	C	A	A	B	D	A	B	B

EXPLANATORY ANSWERS

1. As, $B = \frac{\mu_0}{4\pi}\frac{2\pi I}{r} = \frac{\mu_0}{2}\times\frac{2eV}{0.8}$

$= \frac{\mu_0}{0.8}\times\frac{1.6\times10^{-19}}{2} = \mu_0\times10^{-19}$

2. As, $F = \frac{\mu_0}{4\pi}\frac{2(i\times i)}{b} = \frac{\mu_0 i^2}{2\pi b}$

3. As, $B = \mu_0 n I = 4\pi\times10^{-7}\times\left(\frac{10}{1/100}\right)\times5$

$= 2\pi\times10^{-3}$ T

4. As, $F = evB = \frac{mv^2}{r}$

$r = \frac{mv}{eB}$, $V \to 2v$, $r \to 2r$

Hence, radius becomes 4 cm.

5. Inside as well as outside as $\int \vec{B}\cdot\vec{dl} = \mu_0 I$

B is non zero inside as well as outside.

6. Magnetic moment, $p_m = IA = I\pi r^2$

where $2\pi r = L \Rightarrow r = \frac{L}{2\pi}$

$p_m = I\pi\left(\frac{L}{2\pi}\right)^2 = \frac{IL^2}{4\pi}$

7. As, $F = \frac{\mu_0 I_1 I_2}{2\pi r}$

$= \frac{4\pi\times10^{-7}\times30\times30}{2\times\pi\times5\times10^{-2}}$

$= 3.6\times10^{-3}$ N/m

8. As, $B = \frac{\mu_0 2I}{4\pi r}$ or $B \propto \frac{1}{r}$

$r \to \frac{2}{r}$, $B' \to 2B$

9. Reduction factor $K = \frac{2rH}{\mu_0 n}$

$K' = \frac{2\times2r\times H}{\mu_0(2n)} = K.$

10. Field due to wire,

$B_w = B_{wire} = \frac{\mu_0}{4\pi}\times\frac{2I}{4\pi}$

$= \frac{10^{-7}\times2\times20}{3\times10^{-3}} = 1.33\times10^{-3}$

$T = \frac{4}{3}$ mT

Field due to solenoid $B_s = 4$ mT

Net magnetic field $= \sqrt{B_w^2 + B_s^2}$

$= \sqrt{\left(\frac{4}{3}\right)^2 + (4)^2}\, mT = 4.2$ mT

11. Unlike parallel currents repel, Force that P exerts on Q is $= \frac{\mu_0}{4\pi}\frac{I_P \times I_Q}{d}$

$= 10^{-7} \times \frac{2 \times 4}{d}$N towards right

Force that R exerts on Q is $10^{-7} \times \frac{4 \times 6}{d}$N towards left.

$\therefore$ Net force is towards left.

12. As, $F = qvB$

For proton : $F_p = eV_1B$

For α particle : $F_\alpha = 2eV_2B$

$$F_p = 2F\alpha$$
$$eV_1B = 2 \times 2eV_2B$$
$$\frac{V_1}{V_2} = \frac{4}{1}$$

13. As, $B = \frac{\mu_0}{4\pi}\frac{2\pi I}{r}$

$$= \frac{\mu_0}{4\pi} \times 2\pi \times \frac{100 \times 1.6 \times 10^{-19}}{0.8}$$

$$= \frac{\mu_0}{2} \times \frac{100 \times 1.6 \times 10^{-19}}{0.8} = \mu_0 \times 10^{-17}.$$

14. As, $P_m = IA = evA$

$= evr^2$

$= 1.6 \times 10^{-19} \times 10^{16} \times \pi(.5 \times 10^{-10})^2 Am^2$

$= 1.25 \times 10^{-23} Am^2$

15. As, $B = \frac{\mu_0}{4A}\frac{2\pi I}{r}$

$$= 10^{-7} \times \frac{2\pi \times eV}{r}$$

$$= 10^{-7} \times \frac{2\pi \times 1.6 \times 10^{-19} \times 6.6 \times 10^{15}}{0.53 \times 10^{-10}} T$$

$= 14\ W^b/m^2$

16. As, $B = \frac{\mu_0}{4\pi}\frac{2I}{r}$

$$0.4 = \frac{\mu_0}{4\pi}\frac{2I}{r} \quad \therefore B' = \frac{\mu_0}{4\pi}\frac{2I}{2r} = \frac{0.4}{2} = 0.2T$$

17. As, $B_x = \frac{B_{centre}}{8}$

$$\frac{\mu_0}{4\pi}\frac{2\pi IR^2}{(R^2 + x^2)^{1/2}} = \frac{1}{8}\frac{\mu_0}{4\pi}\frac{2\pi I}{R}$$

$$8R^3 = (R^2 + x^2)^{3/2}$$
$$(2R)^3 = (R^2 + x^2)^{3/2}$$
$$2R = (R^2 + x^2)^{1/2}$$
$$4R^2 = (R^2 + x^2) \text{ or } x^2 = 3R^2$$
$$x = \sqrt{3}\,R.$$

18. Net force on a current carrying closed loop is always zero, when it is placed in a uniform magnetic field.

19. As, $F = evB = 1.6 \times 10^{-19} \times 5 \times 10^5 \times 10$ N

$= 8 \times 10^{-13}$ N

20. As, $T = 2\pi\sqrt{\frac{I}{MH}}$

$$2 = 2\pi\sqrt{\frac{I}{MH}} \quad ...(i)$$

$$T' = 2\pi\sqrt{\frac{I}{MH}} \quad ...(ii)$$

Divide by $\frac{(ii)}{(i)}$, we get $\frac{T'}{2} = \frac{1}{2}$, $\quad T' = 1$

21. As, $H = \sqrt{3}V$

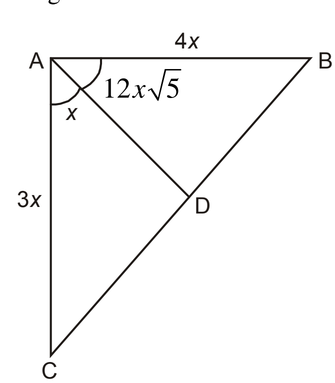
$\therefore \quad \tan\theta = \frac{V}{H} = \frac{1}{\sqrt{3}} \quad \therefore \quad \theta = 30°$

22. As, $\tan\delta' = \frac{V}{H\cos 30°} = \tan 60° = \sqrt{3}$

$$\frac{V}{H}\tan\delta = \sqrt{3} \times \frac{\sqrt{3}}{2} = \frac{3}{2}$$

$$\tan\delta = \tan^{-1}\left(\frac{3}{2}\right)$$

23. Magnetic field at point A due to AC and AB is zero, then the magnetic field at A due to BC.



$$B = \frac{\mu_0}{4\pi} \cdot \frac{I}{AD} (\sin\alpha + \sin\beta)$$

where, $$B = \frac{\mu_0}{4\pi} \cdot \frac{I}{\frac{12x}{5}} \left(\frac{3}{5} + \frac{4}{5}\right)$$

$\Rightarrow$ $$B = \frac{\mu_0}{4\pi} \cdot \frac{I}{12x} \times 7 = \frac{7\mu_0 I}{48\pi x}$$

$\therefore$ $k = 7$

24. As, $\oint B \cdot dl = \mu_0 i$

$$= 4\pi \times 10^{-7} \times 4 \times 10^{-3}$$

$$= 1.6\pi \times 10^{-9} \text{ W}b/\text{m}^2$$

25. As, $B = \frac{\mu_0}{4\pi} \frac{(2\pi - \theta)}{R} = \frac{\mu_0}{4\pi} \left(\frac{2\pi - \pi/2}{R}\right) \times i = \frac{3\mu_0 i}{8R}$

26. Magnetic field inside the solenoid, $B_{in} = \mu_0 ni$.

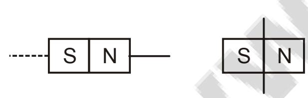
27. As, $B = \frac{1}{r} \Rightarrow \frac{B_1}{B_2} = \frac{r_2}{r_1} \Rightarrow \frac{B}{B_2} = \frac{r/2}{r}$

$$\Rightarrow B_2 = 2B$$

28. The magnetic induction at centre (O) due to the electric current in part AB, will be zero, because centre (O) lies on AB, when it extended.

29. When cut along the axis of magnet of length l, then new pole strength $m' = \frac{m}{2}$ and new length $l' = l$

$\therefore$ New magnetic moment $M' = \frac{m}{2} \times l = \frac{ml}{2} = \frac{m}{2}$



When cut $\perp$ to the axis of magnet, so that the new pole strength $m' = m$ and new length's $l' = \frac{l}{2}$

$\therefore$ New magnetic moment $m' = m \times \frac{l}{2} = \frac{ml}{2} = \frac{m}{2}$

30. As, $$S = \frac{I_g G}{I - I_g} \text{ or } \frac{I_g}{I} = \frac{S}{G+S}$$

Here, $G = 50\ \Omega$ and $S = 5\ \Omega$

$\therefore$ $$\frac{I_g}{I} = \frac{5}{50+5} = \frac{1}{11}$$

31. We have, $$B_1 = \frac{2M}{d^3} \quad ...(i)$$

and $$B_2 = \frac{M}{d^3} \quad ....(ii)$$

Dividing equation (i) by (ii), we get

$$\frac{B_1}{B_2} = \frac{\frac{2M}{d^3}}{\frac{M}{d^3}} = 2:1$$

32. We have, $B_1 = \frac{2M}{x^3}$ and $B_2 = \frac{M}{y^3}$

As, $B_1 = B_2 \Rightarrow \frac{2M}{x^3} = \frac{M}{y^3}$ or $\frac{x^3}{y^3} = 2$

$\therefore$ $$\frac{x}{y} = 2^{1/3}$$

33. Axis along the magnet $B_a = \frac{2M}{x^3} = 200$ gauss

Therefore, $B_a = \frac{M}{x^3} = 100$ gauss

34. As, $$r = \frac{mv}{Bq} = \frac{U}{(g/m)B}$$

$$= \frac{2 \times 10^5}{5 \times 10^7 \times 4 \times 10^{-2}} = 0.10 \text{ m}$$

35. As, $B_v = B \sin\theta$

Here, $B_v = 0.16\sqrt{3}$, $\theta = 30°$

$\therefore$ $0.16\sqrt{3} = B \sin 30°$

or $0.16\sqrt{3} = \frac{B}{2}$

$\Rightarrow$ $B = 0.32\sqrt{3}$ oersted

Also, $B_H^2 + B_v^2 = B^2$

or $$B_H = \sqrt{(B^2 - B_v^2)}$$

$$= \sqrt{(0.32\sqrt{3}) - (0.16\sqrt{3})^2}$$

$$= \sqrt{0.2304} = 0.48 \text{ oersted}$$

36. The volume of the bar magnet,

$$V = \frac{\text{mass}}{\text{density}} = \frac{6.6 \times 10^{-3}}{7.9 \times 10^3} = 8.3 \times 10^{-7} \text{ m}^3$$

$\therefore$ Intensity of magnetisation,

$$I = \frac{M}{V} = \frac{2.5}{8.3 \times 10^{-7}} = 3.0 \times 10^6 \text{ Am}^{-1}$$

37. As, $\tau = MB \sin\theta$

$$= \frac{10}{100} \times 2 \times 0.32 \times 10^{-4} \sin 30°$$

$$= 32 \times 10^{-7} \text{ N-m}$$

38. Magnetic field at the centre of the coil,

$$B = \frac{\mu_0 N_i}{2R}$$

Given, N = 200, R = 5 cm = 0.05 m, i = 5A

$$\therefore \quad B = \frac{4\pi \times 10^{-7} \times 200 \times 5}{2 \times 0.05} T$$
$$= 1.26 \times 10^{-2} \text{ T}$$

39. Required energy $= \dfrac{q^2 B^2 r^2}{2m}$

$$= \frac{(1.6 \times 10^{-19}) \times (0.7)^2 \times (1.8)^2}{2 \times (2 \times 1.67 \times 10^{-27}) \times 1.6 \times 10^{-13}}$$
$$= 38 \text{ MeV.}$$

40. As, $\quad G = \dfrac{4 \times 10^{-3}}{2 \times 10^{-3}} = 2\Omega$

As, $\quad S = \dfrac{GI_g}{I - I_g}$

$$= \frac{2 \times 2 \times 10^{-3}}{(1-2) \times 10^{-3}} = \frac{4 \times 10^{-3}}{(1 - 0.002)}$$
$$= 0.004 \ \Omega$$

41. As, F = BIl sin θ = BIl

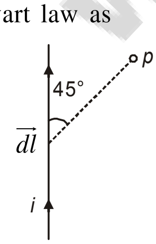
or $\quad B = \dfrac{\mu_0 I}{2\pi h}$

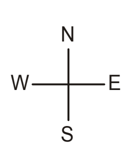
$\therefore \quad F = mg = \dfrac{\mu_0 I^2 l}{2\pi h}$

or $\quad h = \dfrac{\mu_0 I^2 l}{2\pi mg}$

$$= \frac{4\pi \times 10^{-7} \times 250 \times 25 \times 1}{2\pi \times 2.5 \times 10^{-3} \times 9.8}$$
$$h = 0.51 \text{ cm.}$$

42. The situation is shown in fig. The magnetic field due to a small current element of length $\vec{dl}$ is given by Biot-Savart law as





As, $\quad dB = \dfrac{\mu_0}{4\pi} \cdot \dfrac{idl \sin\theta}{r^2}$

$$= \frac{10^7 \times 10 \times 10^{-2} \sin 45°}{2^2}$$
$$= 1.8 \times 10^{-9} \text{ T.}$$

43. Given l = 80 cm = 0.8 m, N = 5 × 400 = 2000, i = 8.0 A, D = 1.8 cm

As, $B = \dfrac{\mu_0 N i}{l} = \dfrac{4\pi \times 10^{-7} \times 2000 \times 80}{0.80}$

$$= 8\pi \times 10^{-3}\text{T} = 2.5 \times 10^{-2} \text{ T}$$

44. The tension in the wires vanishes, if the downward force due to the weight of the conductor is annulled by the magnetic force. Hence, the magnetic conductor should act vertically upwards. The direction of current given by Flemming's left hand rule and is from left to right.

$\therefore \quad 1Bl = mg$

or $\quad i = \dfrac{mg}{Bl} = \dfrac{10 \times 10^{-3} \times 10}{0.4 \times 0.6}$

$$= 0.416\text{A}$$

45. Given, $v = 12 \times 10^6$ Hz, r = 0.5 m, B = ?

$m = 3.3 \times 10^{-27}$ kg, $q = 1.6 \times 10^{-19}$ C

As, $\quad v = \dfrac{Bq}{2\pi m}$

or $\quad B = \dfrac{2\pi m v}{q}$

$$= \frac{2 \times 3.14 \times 3.3 \times 10^{-27} \times 12 \times 10^6}{1.6 \times 10^{-19}}$$
$$= 1.6 \text{ T}$$

46. Due to high resistance of voltmeter connected in series, the effective resistance of circuit will increase and hence, the current in the circuit will decrease, due to which the ammeter and voltmeter will not be damaged.

47. As, $\quad \dfrac{M}{(r^2 + l^2)^{3/2}} = 0.32$

$\Rightarrow \quad \dfrac{p \times 8}{(9+16)^{3/2}} = 0.32$

$\Rightarrow \quad \dfrac{p \times 8}{125} = 0.32$

$\therefore \quad p = \dfrac{0.32 \times 125}{8} = 5$ abAcm

48. As, torque, $\quad \tau = MB \sin \theta$

$$= 200 \times 0.25 \times \sin 30°$$
$$= 200 \times 0.25 \times \frac{1}{2} = 25 \text{ Nm.}$$

49. As, $\quad W = MB(1 - \cos\theta)$

For $\quad \theta = 90°$

$\therefore \quad W_1 = MB\ (1 - \cos 90°) = MB \quad ...(i)$

For $\quad \theta = 60°$

$\therefore \quad W_2 = MB\,(1 - \cos 60°) = \dfrac{MB}{2} \quad ...(ii)$

From (*i*) and (*ii*), we get

Since, $\quad n = \dfrac{W_1}{W_2}$

$$\frac{W_1}{W_2} = n$$

$$\Rightarrow \quad \frac{MB}{\frac{MB}{2}} = n$$

$$\therefore \quad n = 2$$

50. For unstable equilibrium

$$U = -MB$$

$$U = -(0.4) \times (0.16) = -\,0.064 \text{ J}$$

51. The magnetic dipole moment of diamagnetic material is zero as each of its pair of electrons have opposite spins *i.e.*, $\mu_d = 0$

Paramagnetic substances have dipole moment > 0 *i.e.*, $\mu_d \neq 0$

Ferromagnetic substances are very strong magnetic moment *i.e.*, $\mu_f \neq 0$.

52. Given, $\theta = 30°$, $B = 0.25$ T, $\tau = 4.5 \times 10^{-2}$ J, $m = ?$

As, $\quad \tau = mB \sin \theta$

$$\Rightarrow \quad m = \frac{\tau}{B \sin \theta} = \frac{4.5 \times 10^{-2}}{0.25 \times \sin 30°}$$

$$= 0.36 \text{ JT}^{-1}$$

53. Given, $\delta = 22°$, $B_H = 0.35$ G

As, $\quad B = \dfrac{B_H}{\cos \delta}$

$$= \frac{0.35 \text{ G}}{\cos 22°} = \frac{0.35 \text{ G}}{0.9272} = 0.38\text{G}$$

54. Given, N = 2000, A = 1.6×10^{-4} m^2, I = 4A

Magnetic moment of solenoid turns N, area of cross section A and carrying current I is

$$m = NIA = 2000 \times 0.4 \times 4.6 \times 10^{-4} \text{ Am}^2$$

$$= 1.28 \text{ Am}^2$$

This magnetic moment acts along the axis of the solenoid in the direction related to the sense of current via right-handed screw rule.

55. Given, N = 800, A = 2.5×10^{-4} m^2 , I = 3 A

As, $m = NIA = 800 \times 3 \times 2.5 \times 10^{-4} = 0.60 \text{ JT}^{-1}$

56. Given, $m = 0.48 \text{ JT}^{-1}$, $r = 10$ cm = 0.10 m

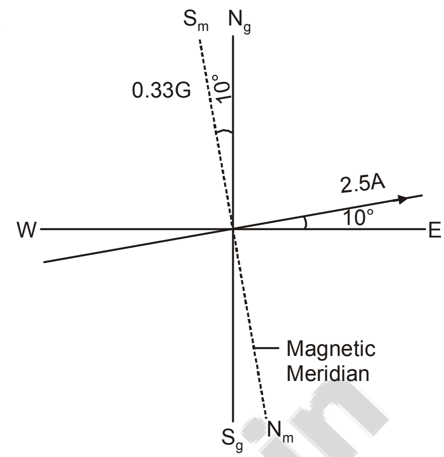
For a short magnet,

$$B_{\text{axial}} = \frac{\mu_0}{4\pi} \cdot \frac{2m}{r^3} = \frac{4\pi \times 10^{-7}}{4\pi} \times \frac{2 \times 0.48}{(0.10)^3}$$

$$= 0.96 \times 10^{-4} \text{ T} = 0.96 \text{ G}$$

This field acts along S-N direction.

57.



Let the neutral point lies at a distance r from the cable. Then, at the neutral point,

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

or, $\quad r = \dfrac{\mu_0 I}{2\pi B_H} = \dfrac{4\pi \times 10^{-7} \times 2.5}{2\pi \times 0.33 \times 10^{-4}}$

$$= 1.5 \times 10^{-2} \text{ m} = 1.5 \text{ cm}$$

As the direction of the magnetic field of the cable is opposite to that of $\vec{B}_H$ at points above the cable, so the line of neutral points lies parallel to the above the cable at the distance of 1.5 cm from it.

58. Given, I = 35 A, r = 20 cm = 0.20 m

$$\mu = 4\pi \times 10^{-7} \text{ TmA}^{-1}$$

As, $\quad B = \dfrac{\mu_0 I}{2\pi r} = \dfrac{4\pi \times 10^{-7} \times 35}{2\pi \times 0.20}$

$$= 3.5 \times 10^{-5} \text{ T}$$

59. Given, $R_g = 12\ \Omega$, $I_g = 3$ mA $= 3 \times 10^{-3}$ A, V = 18 V

As, $\quad R = \dfrac{V}{I_g} - R_g = \dfrac{18}{3 \times 10^{-3}} - 12$

$$= 6000 - 12 = 5988\ \Omega$$

60. As, $\quad T = 2\pi \sqrt{\dfrac{I}{MH}} \quad ...(i)$

and $\quad \dfrac{T}{2} = 2\pi \sqrt{\dfrac{I}{M(H+B)}} \quad ...(ii)$

Squaring and dividing equation (*i*) by (*ii*), we get

$$4 = \frac{H+B}{H}$$

or $\quad \dfrac{B}{H} = 3 \quad \therefore \quad B : H = 3 : 1.$

CHAPTER

4

ELECTROMAGNETIC INDUCTION AND ALTERNATING CURRENT

ELECTROMAGNETIC INDUCTION

The phenomena of generating current emf by changing magnetic fields is called electromagnetic induction.

FARADAY'S LAW, INDUCED emf AND CURRENT

Faraday's Laws of Electromagnetic Induction

1. Whenever there is a change in magnetic lines of force in an electrical circuit, an emf is induced in the circuit. If the circuit is closed, a current called induced current flows through the circuit.
2. The induced emf around a closed path is equal to the negative of the time rate of change of the magnetic flux through the same path.

Rate of change of magnetic flux $= \dfrac{\phi_2 - \phi_1}{t_2 - t_1} = \dfrac{\Delta\phi}{\Delta t}$

INDUCED EMF

When a closed conducting loop is placed (at rest) in a changing magnetic field, then an electric field is induced in the loop, which is called induced electric field $\vec{E}$. If e be the developed induced emf in the loop, then $e = \oint \vec{E} \cdot \vec{dl}$

or $$\oint \vec{E} \cdot \vec{dl} = -\frac{d\phi}{dt} \text{ (Faraday's law)}$$

$$\varepsilon = -\frac{\Delta\phi}{\Delta t},\ \Delta t \to 0 \text{ or } \varepsilon = -\frac{d\phi}{dt}$$

If the coil has N turns

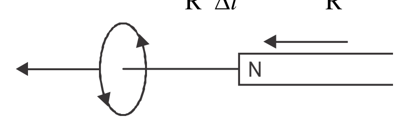
$$\varepsilon = -N\frac{\Delta\phi}{\Delta t} = -\frac{\Delta(N\phi)}{\Delta t}$$

Where, Nϕ is called the number of 'flux linkage' in the coil. If the coil is closed and the total resistance of its circuit be R, then the induced current in the circuit will be

$$i = \frac{\varepsilon}{R} = \frac{N\,\Delta\phi}{R\,\Delta t}$$

The charge flowed through the circuit in time interval Δt.

$$q = i\Delta t = \frac{N}{R}\frac{\Delta\phi}{\Delta t} \times \Delta t = \frac{N}{R}\Delta\phi$$



$$= \frac{\text{number of turns} \times \text{change in mag. flux}}{\text{resistance}}$$

LENZ'S LAW

Lenz's rule is a convenient method to determine the direction of induced current produced in a circuit. It is related to the principle of conservation of energy.

It states that "the direction of an induced current is such as to oppose the cause producing it."

EDDY CURRENT

Eddy currents are the current induced in the bulk pieces of conductors, when the amount of magnetic flux linked with the conductor changes. These currents are called Foucalt currents. The magnitude of eddy currents, $i = -\dfrac{d\phi}{dt}$.

SELF AND MUTUAL INDUCTANCE

Self Inductance: It is defined as the induction of voltage in a current carrying wire, when the current in the wire itself is changing. In case of self inductance, the magnetic field created by a changing current in the circuit itself induced a voltage in the same circuit.

Coefficient of self inductance (L): We have,

$$L = \frac{N\phi}{i}$$

where, N $\rightarrow$ Number of turns in the coil

ϕ $\rightarrow$ Flux linked with each turn

and i $\rightarrow$ The current flowing through the coil.

According to Faraday's law of electromagnetic induction

$$\varepsilon = -\frac{\Delta(N\phi)}{\Delta t} = -\frac{\Delta(Li)}{\Delta t}$$

or $$\varepsilon = L\frac{\Delta i}{\Delta t}$$

L of a plane coil

$$L = \frac{\mu_0}{2}\pi N^2 R$$

If a rod of ferromagnetic material be placed inside the coil.

$$L = \frac{\mu_0 \mu_r \pi N^2 R}{2}$$

where

μ_r = relative permeability of ferromagnetic material

R = radius of plane coil

Coefficient of self inductance of a solenoid: We have,

$$L = \frac{\mu_0 N^2 A}{l}$$

where, $l \rightarrow$ Length and A $\rightarrow$ Area = πr^2

Mutual Inductance: Mutual inductance is the property of two coils by virtue of which each opposes any changes in the strength of current flowing through the other by developing an induced emf.

Co-efficient of mutual induction (M): We have,

$$M = \frac{N_2\phi_2}{i_1}$$

$N_2 \rightarrow$ number of turns in the secondary coil

$\phi_2 \rightarrow$ magnetic flux linked with each turn of the secondary coil.

$i_1 \rightarrow$ current flowing in the primary coil.

$$\varepsilon_2 = -M\frac{\Delta i_1}{\Delta t}$$

$\varepsilon_2 \rightarrow$ induced emf in secondary coil.

$$M = \frac{-\varepsilon_2}{\Delta i_1 / \Delta t}$$

If $\frac{\Delta i_1}{\Delta t} = 1$, then

M = ε_2, Co-efficient of mutual induction between two coils.

Mutual Inductance Between Two Plane Coils:

We have,

$$B = \frac{\mu_0 N_1 i_1}{2R_1}$$

$$\phi_2 = \frac{\mu_0 N_1 i_1}{2R_1} \times \pi R_2^2$$

$$M = \frac{\mu_0 N_1 N_2 \pi R_2^2}{2R_1}$$

In an iron rod be placed inside the coil

$$M = \frac{\mu_r \mu_0 N_1 N_2 \cdot \pi R_2^2}{2R_1}$$

where,

B = magnetic field at the centre of the primary coil

R_1 and R_2 = radii of primary and secondary coils

N_1 and N_2 = Number of turns in primary and secondary coils

A = πR_2^2, area of secondary coil

ϕ_2 = magnetic flux linked with secondary coil

μ_r = Relative Permeability of iron, if an iron rod is placed as a core

The co-efficient of coupling (K) between two coils having self-induction L_1 and L_2 and co-efficient of mutual inductance = M, then

$$K = \sqrt{\frac{M}{L_1 L_2}}$$

Energy stored in a self-inductance coil.

$$W = \int_0^{i_0} L i\, di = \frac{L i_0^2}{2}$$

ALTERNATING CURRENTS

An alternating current is that which changes continuously in magnitude and periodically in direction. It can be represented by a sine curve or a cosine curve, *i.e.*, $I = I_0 \sin \omega t$ or $I = I_0 \cos \omega t$.

where, $I \rightarrow$ instantaneous value of the current at time t.

and $I_0 \rightarrow$ peak value (maximum) value of the current.

Mean Value of Alternating Current : We have

$$I_{mean} = \frac{1}{T/2}\int_0^{T/2} I\, dt$$

$$= \frac{\omega}{\pi}\int_0^{\pi/\omega} I_0 \sin\omega t\, dt = \frac{2I_0}{\pi}$$

PEAK AND RMS VALUES OF ALTERNATING CURRENT/VOLTAGE

Peak Value of Alternating current/voltage: The sum of maximum value of AC in positive half cycle and maximum value in negative half cycle is defined as the peak value of AC.

$$I_p = 2\sqrt{2}\, I_{rms} = 2.828\, I_{rms}$$

RMS (Root mean square) value of alternating current/voltage: The steady current, when passed through a resistance for a given time will produce the same amount of heat as the alternating current does in the same resistance and in the same time is called rms value of alternating current.

$$I_{rms} = \frac{I_0}{\sqrt{2}} = 0.71\, I_0$$

Similarly, root-mean-square value of the alternating valtage.

$$E_{rms} = \frac{E_0}{\sqrt{2}} = 0.71\, E_0$$

Accordingly

$$RMS = \frac{E_0}{\sqrt{2}} \times \frac{I_0}{\sqrt{2}} = \frac{E_0 I_0}{2}$$

$$= \frac{1}{2}\text{ (Peak power)}$$

When an alternating current $I = I_0 \sin \omega t$ passes through a resistance R, the instantaneous rate of heating is $I^2 R$.

Average rate of heating during a cycle

$$= \frac{1}{T}\int_0^T I^2 R\, dt = \frac{I_0^2 R}{2} = (I_{rms})^2 R$$

Also, $$I_{virtual} = \frac{I_0}{\sqrt{2}} = I_{rms}$$

and $$E_{virtual} = \frac{E_0}{\sqrt{2}} = E_{rms}$$

REACTANCE AND IMPEDENCE

Reactance (X): The opposition offered by the coil or condenser or both to flow of AC through it is defined as reactance (X).

$$X = \frac{E}{I} = \frac{E_0}{I_0} = \frac{E_{rms}}{I_{rms}}$$

(Inductive reactance $\rightarrow X_L$ and
Inductive capacitance $\rightarrow X_C$)

Impedance (Z): The opposition offered by the condenser, inductor and conductor to the flow of AC through it is called as impedance.

Circuit Containing Inductance (L): Instantaneous voltage across L

$$E = L\frac{dI}{dt}$$

or $$dI = \frac{E_0}{L}\sin\omega t\, dt$$

$$I = \frac{E_0}{\omega L}\sin\left(\omega t - \frac{\pi}{2}\right)$$

$$\Rightarrow \quad I = \frac{E_0}{X_L}\sin\left(\omega t - \frac{\pi}{2}\right)$$

where, $2\pi f L = \omega L = X_L \rightarrow$ inductive reactance

[It has the unit of resistance]

Peak value of alternating current

$$I_0 = \frac{E_0}{X_L}$$

The inductive reactance is zero for D.C.

Circuit Containing a Capacitor (C):

We have, $q = CE_0 \sin \omega t$

$$I = CE_0 (\cos \omega t)(\omega)$$

$$I = \frac{E_0}{1/\omega C}\sin\left(\omega t + \frac{\pi}{2}\right)$$

$$I_0 = \frac{E_0}{1/\omega C}$$

The peak value of alternating current

$$I_0 = \left(\frac{E_0}{X_c}\right)$$

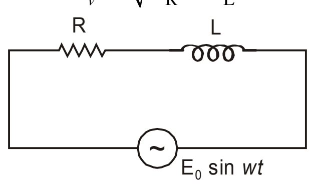
The capacitive reactance:

$$\left[X_c = \frac{1}{\omega C} = \frac{1}{2\pi f\, C}\right].$$ It is infinite for D.C.

LCR SERIES CIRCUIT

L-R Series Circuit: We have

$$E_v = \sqrt{V_R^2 + V_L^2}$$



where, $E_v \to$ an A.C. source of e.m.f.

$V_R \to$ R.M.S. values of voltage across resistance

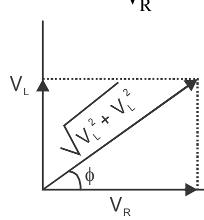
$V_L \to$ R.M.S. values of voltage across inductance.

$$E_v = I_v\sqrt{(V^2 + X_L^2)}$$

$$dr_v = \frac{E_v}{\sqrt{(R^2 + X_L^2)}}$$

and $$I_0 = \frac{E_0}{\sqrt{(R^2 + \omega^2 L^2)}}$$

$$\tan\phi = \frac{V_L}{V_R} = \frac{X_L}{R} = \frac{\omega L}{R}$$



If Z is the effective resistance offered by L and R to A.C., then

$$I_v = \frac{E_v}{Z}$$

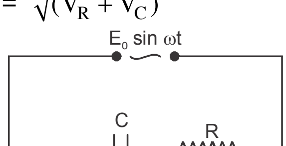
$$Z = \sqrt{(R^2 + X_L^2)} = \sqrt{(R^2 + \omega^2 L^2)}$$

The effective resistance Z offered by L and R to A.C. is called the impedance of L - R circuit.

The eqn. of current $I = \dfrac{E_0 \sin(\omega t - \phi)}{\sqrt{X_L^2 + R^2}}$

C-R Series Circuit: Let an alternating soure of e.m.f. of r.m.s. value E_v connected to a series combination of a capacitor or capacitance C and a resistance R.

$$E_v = \sqrt{(V_R^2 + V_C^2)}$$



$E_v \to$ The r.m.s. value of alternating e.m.f. of the source.

V_R and $V_C \to$ r.m.s. values of voltage across R and C respectively.

$V_R = I_v R$ and $V_C = I_v \times C$

$I_v \to$ r.m.s value of current

$X_C = \dfrac{1}{\omega C}$ is reactance due to capacitor C.

$$E_v = I_v\sqrt{(R^2 + X_C^2)}$$

$$= \frac{E_v}{\sqrt{[R^2 + (1/\omega^2 C^2)]}}$$

For phase ϕ

$$\tan\phi = \frac{X_C}{R} = \frac{1/\omega C}{R}$$

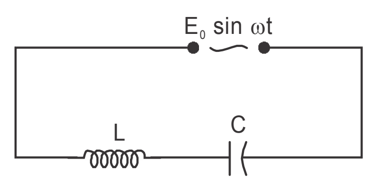
Impedence, $Z = \sqrt{(R^2 + X_C^2)}$

$$= \sqrt{\left(R^2 + \frac{1}{\omega^2 C^2}\right)}$$

Thus, the equation of current becomes

$$i = \frac{E_0}{\sqrt{\left(R^2 + \frac{1}{\omega^2 C^2}\right)}}\sin(\omega t + \phi).$$

L-C Circuit: In the given circuit,



$E_v = (V_L - V_C)$

$V_L \to$ Potential difference across inductance

$V_C \to$ Potential drop across the capacitor

$$Z = (X_L - X_C) = L\omega - \left(\frac{1}{\omega C}\right)$$

Equation of current, when emf E_v leads the current I_v by an angle $\dfrac{\pi}{2}$.

$$I = \frac{E_0}{X_L - X_C}\sin\left(\omega t - \frac{\pi}{2}\right)$$

If $V_C < V_L$

Impedence of the circuit $\to (X_C - X_L)$

The equation of circuit

$$I = \frac{E_0}{X_C - X_L}\sin\left(\omega t + \frac{\pi}{2}\right).$$

Reasonance in L-C Circuit: In series L-C circuit, the resonance takes place when the impedence of the circuit is minimum or the current is maximum.

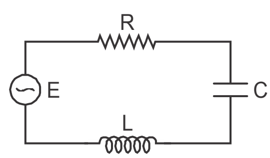
$$X_L = X_C \text{ or } L\omega_0 = \frac{1}{C\omega_0},\ \omega_0^2 = \frac{1}{LC}$$

or $$\omega_0 = \frac{1}{\sqrt{LC}}$$

$$2\pi f_0 = \frac{1}{\sqrt{LC}};\ f_0 = \frac{1}{2\pi\sqrt{LC}}$$

At resonance $I_0 = \frac{E_0}{Z} = \infty$

LCR Series Circuit: The three components L, C and R are connected in series as shown in Fig. An alternating emf E is applied to the circuit. Using Kirchhoff's law, we get



$$I = I_{max} \sin(\omega t - \phi)$$

where $$\phi = \frac{X_L \times X_C}{R}$$

$$I_{max} = \frac{E_{max}}{Z} = \frac{E_{max}}{\sqrt{(X_L - X_C)^2 + R^2}}$$

$$E_{max} = V_R + V_L + V_C$$

$$= \sqrt{V_R^2 + (V_L - V_C)^2}$$

$$= I_{max} \times \sqrt{R^2 + (X_L - X_C)^2}$$

$$= I_{max} Z.$$

For phase angle ϕ, $\tan\phi = \frac{V_L - V_C}{V_R}$

$$\frac{X_L - X_C}{R} = \frac{\omega L - \frac{1}{\omega C}}{R}$$

$$I_v = \frac{E_v}{Z}$$

$$Z = \sqrt{\left[R^2 + (X_L - X_C)^2\right]}$$

$$= \sqrt{\left[R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2\right]}$$

When $\omega L > \frac{1}{\omega C}$ e.m.f. leads the current.

When $\omega L < \frac{1}{\omega C}$ e.m.f. leads behind the current.

When $\omega L = \frac{1}{\omega C}$ current and e.m.f. are in plane with each other.

RESONANCE IN SERIES LCR CIRCUIT

When the frequency of ac supply is such that the inductive reactance and capacitive reactance become equal ($X_L = X_C$), the impedence of the series LCR circuit is merely equal to the ohmic resistance in the circuit. As such, the current in the circuit becomes maximum. Such a series LCR circuit is called resonant series LCR circuit.

We know that $\cos\phi = \frac{R}{Z} = \frac{R}{\sqrt{R^2 + (X_L - X_C)^2}}$

If $X_L = X_C$, $\cos\phi = 1$ and $Z = R$

The average power delivered to the resistor in circuit is a maximum and impedance of LCR circuit is minimum.

$$\omega L = \frac{1}{\omega L}$$

$$\Rightarrow \quad W_{resonance} = \frac{1}{\sqrt{LC}}$$

At resonance, amplitude of current,

$$X_L - X_C = \omega L - \frac{1}{\omega C} = \frac{L}{\omega}(\omega^2 - \omega_{res})^2$$

$$= \frac{E^2 R\omega^2}{R^2\omega^2 + L^2(\omega^2 - \omega_{res}^2)}$$

QUALITY FACTOR OR Q-FACTOR

The quality factor of series resonant circuit is defined as the ratio of the voltage developed across the inductance or capacitance at resonance due to the impressed voltage, which voltage applied across R,

$$Q = \frac{1}{R}\sqrt{\frac{L}{C}}$$

Voltage Magnification: We have

$$i_0 = \frac{E_0}{R}$$

$$V_L = X_L\, i_0 = \omega L \frac{E_0}{R} = \frac{\omega L E_0}{R} = QE_0$$

$Q \rightarrow$ quality factor.

The chief characteristic of the series resonant circuit $\rightarrow$ "voltage magnification".

POWER OF AN AC CIRCUIT

It is defined as the rate at which work is being done in the circuit. In AC circuit, the current and emf are not necessarily in the same phase, hence, we can write,

$$P_{av} = \frac{V_0 I_0}{\sqrt{2}\sqrt{2}} \cos\theta$$

$$P_t = EI = E_0 \sin\omega t . I_0 \sin(\omega \pm \phi)$$

$$P_t = \frac{E_0 I_0}{2}[\cos\phi - \cos(2\omega t \pm \phi)]$$

$$\overline{P} = \frac{1}{T}\int_0^T EI\, dt$$

$$= \frac{E_0 I_0}{2}\cos\phi$$

or $\vec{P} = E_{rms}.I_{rms}\cos\phi$

where $\cos\phi$ is called the power factor and

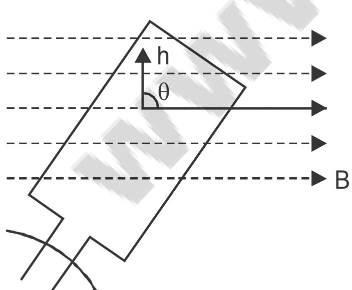
$$\cos\phi = \frac{R}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}}$$

Wattless Current: The current which consumes no power for the maintenance in the circuit is called wattless current.

i.e., $P = E_v I_v \cos\phi$.

AC GENERATOR AND TRANSFORMER

AC Generator: A simple generator of alternating current is a coil rotating in a uniform magnetic field as shown in Fig, where the unit vector $\hat{n}$ normal to the plane of the coil makes an angle θ with a uniform magnetic field B. The magnetic flux through the coil is



$$\phi_B = NBA\cos\theta$$

Let ω be the angular velocity

Then, $\phi = \omega t$

$\therefore$ $\phi_B = NBA\cos\omega t$

$\because$ $e = -\frac{d\phi_B}{dt}$

$= NBA\,\omega\sin\omega t$ $[\sin\omega t = 1]$

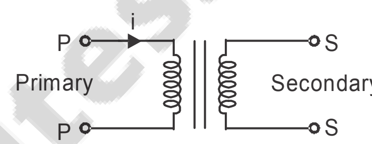
$\therefore$ $e = e_0 \sin\omega t$.

AC generator should be better to call it as convertor.

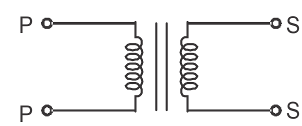
Transformer: Transformer is a device used for converting low alternating voltage at high current into high voltage at low current and vice-versa. There are two types of transformer:

Step up Transformer: The transformer used to change low voltage alternating emf to high voltage alternating emf is called a step-up transformer. The current value in output is less than that in input.

Step Down Transformer: The transformer used to change high voltage alternating emf to low voltage alternating emf is called a step-down transformer. The current in output is more than that in input.



(a) Step up transformer



(b) Step down transformer

If N_p and N_s are number of turns in primary and secondary coils and ϕ_p and ϕ_s are magnetic flux linked with them, then

$$\frac{\phi_s}{\phi_p} = \frac{N_s}{N_p}$$

or $$\phi_s = \frac{N_s}{N_p}\cdot\phi_p$$

If e_p and e_s induced e.m.f. produced in primary and secondary coils at any time, then

$$e_s = \frac{N_s}{N_p}e_p$$

$$\frac{N_s}{N_p} = K \rightarrow \text{transformation ratio.}$$

If there are no energy losses.

Instantaneous output power = Instantaneous input power

$$e_s i_s = e_p i_p$$

$$\frac{e_s}{e_p} = \frac{i_s}{i_p}$$

Efficiency of the transformer

$$\eta = \frac{\text{output power}}{\text{input power}} \times 100.$$

EXERCISE

1. A rectangular coil of 100 turns and size 0.1 m × 0.05 m is placed perpendicular to a magnetic field of 0.1 T. If the field drops to 0.05 T in 0.05 s, the magnitude of the emf induced in the coil is
A. 0.5 V B. 0.75 V
C. 1.0 V D. 1.5 V

2. A coil of area 10 cm^2, 10 turns and resistance 20 Ω is placed in a magnetic field directed perpendicular to the plane of the coil and changing at the rate of 10^8 gauss/second. The induced current in the coil will be
A. 5 A B. 0.5 A
C. 0.05 A D. 50 A

3. A coil of cross-sectional area 400 cm^2 having 30 turns is making 1800 rev/min in a magnetic field of 1T. The peak value of the induced emf is
A. 36 V B. 226 V
C. 339 V D. 452 V

4. A magnetic field of flux density 1.0 Wb m^{-2} acts normal to a 80 turn coil of 0.01 m^2 area. The induced emf in it, if this coil removed from magnetic field in 1 second is
A. 4 V B. 8 V
C. 10 V D. 12 V

5. An ideal transformer is used to step up an alternating emf of 220 V to 4.4 kV to transmit 6.6 kW of power. The current rating of the secondary is
A. 30 A B. 3 A
C. 1.5 A D. 1 A

6. An ideal transformer steps down 220 V to 22 V in order to operate a device with an impedence of 220 Ω. The current in the primary is
A. 0.01 A B. 0.1 A
C. 0.5 A D. 1.0 A

7. A toroidal solenoid with an air core has an average radius of 15 cm, area of cross-section 12 cm^2 and 1200 turns. Ignoring the field variation across the cross-section of the toroid, the self inductance of the toroid is
A. 4.6 mH B. 6.9 mH
C. 2.3 mH D. 9.2 mH

8. A jet plane having a wing span of 25 m is travelling horizontally towards the east with a speed of 1800 km/h. If the earth's magnetic field at the location is 5×10^{-10} T and the angle of dip is 30° then the potential difference between the ends of the wing is
A. 3.1 V B. 0.31 V
C. 6.2 V D. 0.62 V

9. A current of 2A flowing through a coil of 100 turns gives rise to a magnetic flux of 5×10^{-5} Wb per turn. The magnetic energy associated with the coil is
A. 5 J B. 0.5 J
C. 0.05 J D. 0.005 J

10. A coil having 500 square loops, each of side 10 cm is placed normal to a magnetic field which increases at the rate of 1.0 T/s. The induced emf in volts is
A. 0.1 B. 0.5
C. 1.0 D. 5.0

11. A capacitor of 1 μF initially charged to 10 V is connected across an ideal inductor of 0.1 mH. The maximum current in the circuit is
A. 0.5 A B. 1 A
C. 1.5 A D. 2 A

12. A thin circular ring of area A is held perpendicular to a uniform magnetic field of induction B. a small cut is made in the ring and a galvanometer is connected across the ends such that the total resistance of the circuit is R. When the ring is suddenly squeezed to zero area, the charge flowing through the galvanometer is
A. $\frac{BR}{A}$ B. $\frac{AB}{R}$
C. ABR D. $\frac{B^2A}{R^2}$

13. A toroidal solenoid has a mean radius of 0.12 m and a cross sectional area of 2×10^{-3} m^2. When a current of 20A flows through it, the energy stored is 0.1 J. Find the number of turns in the solenoid.
A. 347 B. 218
C. 378 D. 387

14. In a car spark coil, emf of 40,000 V is induced in the secondary when the primary current changes from 4 A to zero in 10 μs. The mutual inductance between the primary and secondary windings of this spark coil is
A. 0.01 H B. 0.1 H
C. 0.001 H D. 0.0001 H

15. The current in a coil of self inductance 2.0 henry is increasing according to $I = 2 \sin t^2$ ampere. Find the amount of energy spent during the peiod when the current changes from 0 to 2 ampere.
A. 3 J B. 8 J
C. 4 J D. 10 J

16. A steady p.d. of 10 V produces heat at a rate x in a resistor. The peak value of the alternating voltage which will produce heat at a rate $\frac{x}{2}$ in the same resistor is

A. 5 V B. $5\sqrt{2}$ V
C. 10 V D. $10\sqrt{2}$ V

17. An inductive coil has a resistance of 100 Ω. When an AC signal of frequency 1000 Hz is applied to the coil, the voltage leads the current by 45°. The inductance of the coil is

A. $\frac{1}{10\pi}$ B. $\frac{1}{20\pi}$
C. $\frac{1}{40\pi}$ D. $\frac{1}{60\pi}$

18. An inductor of 1 henry is connected across a 220 V, 50 Hz supply. The peak value of the current is approx

A. 0.5 A B. 0.7 A
C. 1 A D. 1.4 A

19. An LCR series circuit consist of a resistance of 10 Ω, a capacitance of reactance 60 Ω and an inductor coil, The circuit is found to resonate when put across a 300 V, 100 Hz supply. The inductance of the coil is (take $\pi = 3$)

A. 0.1 H B. 0.01 H
C. 0.2 H D. 0.02 H

20. When 100 V DC is applied across a coil, a current of 1 A flows through it. When 100 V AC of 50 Hz is applied across the same coil, only 0.5 A flows. The resistance and inductance of the coil are (take $\pi^2 = 10$)

A. 50 Ω, 0.3 H B. 50 Ω, $\sqrt{0.3}$ H
C. 100 Ω, 0.3 H D. 100 Ω, $\sqrt{0.3}$ H

21. In an AC circuit V = 100 sin (100 t) volt and I = 100 sin (100 t + π/3) mA. The power dissipated in the circuit is

A. 10^4 W B. 10 W
C. 2.5 W D. 5 W

22. An electric bulb which runs at 80 V DC and consume 10 A current is connected across a 100 V, 50Hz AC supply. The inductance of the choke required is [takes $\pi = 3$]

A. 0.01 H B. 0.02 H
C. 0.04 H D. 0.08 H

23. The tuning circuit of a radio receiver has a resistance of 50 Ω, an inductor of 10 mH and a variable capacitor. A 1 MHz radio wave produces a potential difference of 0.1 mV. The value of the capacitor to produce resonance is (take $\pi^2 = 10$)

A. 2.5 pF B. 5.0 pF
C. 25 pF D. 50 pF

24. The impedance of a circuit consist of 3 Ω resistance and 4 Ω reactance. The power factor of the circuit is

A. 0.4 B. 0.6
C. 0.8 D. 1.0

25. An LCR series circuit containing a resistance of 120 Ω has angular resonance frequency 4×10^5 rad s^{-1}. At resonance the voltage across resistance and inductance are 60 V and 40 V. The values of L & C are

A. 0.2 mH, $\frac{1}{32}$ μF B. 0.4 mH, $\frac{1}{16}$ μF
C. 0.2 mH, $\frac{1}{16}$ μF D. 0.4 mH, $\frac{1}{32}$ μF

26. An LCR series circuit with 100 Ω resistance is connected to an AC source of 200 V and angular frequency 300 rad/s. When only the capacitance is removed the current lags behind the voltage by 60°. When only the inductance is removed, the current leads the voltage by 60°. The power dissipated in LCR circuit is

A. 300 W B. 800 W
C. 400 W D. 100 W

27. An alternating emf given by V = V_0 sin ωt has peak value of 10 V and frequency 50 Hz. The instantaneous emf at $t = \frac{1}{600}$ s is

A. 10 V B. $5\sqrt{3}$ V
C. 5 V D. 1 V

28. A 100 V AC source of frequency 500 Hz is connected to an LCR circuit with L = 8.1 millihenry, C = 12.5 microfarad and R = 10 Ω, all connected in series. The potential difference across the resistance is

A. 100 V B. 120 V
C. 300 V D. 200 V

29. The average emf during the positive half cycle of an AC supply of peak value E_0 is

A. $\frac{E_0}{\pi}$ B. $\frac{E_0}{\sqrt{2}\pi}$
C. $\frac{E_0}{2\pi}$ D. $\frac{2E_0}{2\pi}$

30. An ac generator consists of a coil of 2000 turns each of the area 80 cm^2 and rotating at an angular speed of 200 rpm in a uniform magnetic field of 4.8×10^{-2} T. Find the peak value of emf induced in the coil.

A. 16.085 V B. 21.025 V
C. 25.075 V D. 30.058 V

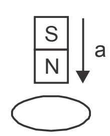
31. How much current is drawn by the primary of a transformer connected to 220 V supply, when it delivers power to a 110 V and 550 W refrigerator?
A. 1.5 A
B. 2.5 A
C. 3.5 A
D. 4.0 A

32. A 20 volt A.C. is applied to a circuit consisting of a resistance and a coil with a negligible resistance (in series). It the voltage across the resistance is 12 volt, the voltage across the coil is
A. 16 volt
B. 10 volt
C. 8 volt
D. 6 volt

33. In an AC circuit, the instantaneous values of emf and current are E = 200 sin 314 t volt and $i = \sin\left(314t + \frac{\pi}{3}\right)$ ampere. The average power consumed in watt is
A. 200
B. 100
C. 50
D. 25

34. An AC source is 120 V – 60 Hz. The value of voltage after $\frac{1}{720}$ sec from start will be
A. 20.2 V
B. 42.4 V
C. 84.8 V
D. 106.8 V

35. A metallic ring is attached with the wall of the room. When the north pole of magnet is brought near to it, the induced current in the ring will be



A. In anticlockwise direction
B. In clockwise direction
C. First clockwise then anticlockwise
D. First anticlockwise then clockwise

36. A coil having an area A_0 is placed in a magnetic coil field, which changes from B_0 to 4 B_0 in a time interval t. The emf induced in the coil will be
A. $\frac{4B_0}{A_0 t}$
B. $\frac{3B_0}{A_0 t}$
C. $\frac{3A_0B_0}{t}$
D. $\frac{4A_0B_0}{t}$

37. A square coil of 10^{-2} m^2 area is placed perpendicular to the uniform magnetic field of intensity 10^3 Wb m^{-2}. The magnetic flux through the coil is
A. 10^5 Wb
B. 100 Wb
C. 10^6 Wb
D. 10 Wb

38. A coil having 500 sq. loops each of side 10 cm is placed normal to magnetic flux which increases at the rate of 1 tesla/sec. The induced emf in volts is
A. 1 V
B. 5 V
C. 0.5 V
D. 0.1 V

39. A coil of area 100 cm^2 has 500 turns. Magnetic field of 0.1 Wb/m^2 is perpendicular to the coil. The field is reduced to zero in 0.1 s. The induced emf in the coil is
A. 0
B. 1 V
C. 5 V
D. 50 V

40. A coil having an area 2 m^2 is placed in magnetic field which changes from 1 Wb m^{-2} to 4 W m^{-2} in an interval of 2 second. The emf induced in the coil will be
A. 3 V
B. 2 V
C. 1.5 V
D. 4 V

41. The magnetic field in the coil of 100 turns and 40 sq cm area is increased from 1T to 6T in 2 second. The magnetic field is perpendicular to the coil. The emf generated in it is
A. 1 V
B. 10^{-2} V
C. 10^4 V
D. 1.2 V

42. A wire of length 50 cm moves with a velocity of 300 m/min perpendicular to magnetic field. If the emf induced in the wire is 2V, the magnitude of the field in tesla is
A. 2.5
B. 0.8
C. 5
D. 2

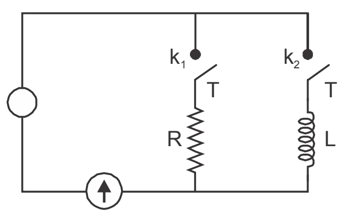
43. In a circuit with a coil of resistance 2 Ω, the magnetic flux change from 2.0 Wb to 10 Wb in 0.2 s. The charge that flow in the coil during that time is
A. 4 C
B. 5 C
C. 8 C
D. 7 C

44. The magnetic flux threading a coil changes from 12×10^{-3} Wb to 6×10^{-3} Wb in 0.1 s. The induced emf is
A. 0.6 V
B. 0.5 V
C. 0.3 V
D. 0.4 V

45. The armature of an eight polar dynamo rotates making 750 revolutions per minute. The frequency of alternating current produced is
A. 8 Hz
B. 4 Hz
C. 12.5 Hz
D. 50 Hz

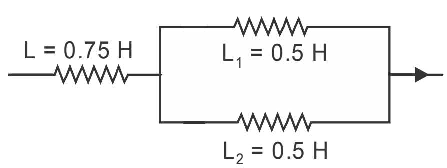
46. The magnetic flux through a stationary loop with resistance R varies during interval of time T as $\phi = at(T - t)$. The heat generated during this time neglecting the inductance of loop will be
A. $\frac{a^2T^3}{3R}$
B. $\frac{a^2T^2}{3R}$
C. $\frac{a^2T}{3R}$
D. $\frac{a^3T^2}{3R}$

47. In the circuit shown here, R is pure resistance, L is an inductor of negligible resistance (as compared to R), S is a 100 V, 50 Hz AC source of negligible resistance. With either key k_1, alone or k_2 alone closed, the current is I_0. If the source is changed to 100 V, 100 Hz, the current with k_1 alone closed and with k_2 alone closed will be respectively



A. $I_0, \frac{I_0}{2}$ B. $I_0, 2I_0$
C. $2I_0, I_0$ D. $2I_0, \frac{I_0}{2}$

48. Three pure inductances are connected as shown in fig. The equivalent inductance of the coil will be



A. 1.00 H B. 1.50 H
C. 1.49 H D. 1.75 H

49. A coil of inductance 0.525 H is connected to a DC source of 120 V. A current of 0.5 A flows through the coil. If the coil be connected to an AC source of frequency 60 cycles/sec and 120 V, the current in the coil will be
A. 0.386 A B. 0.437 A
C. 0.479 A D. 0.443 A

50. An AC ammeter is used to measure current and circuit. When a given direct current passes through the circuit, the AC ammeter reads 3A. When alternating current passes through the circuit, the AC ammeter reads 4 A. Then the reading of this ammeter, if DC and AC through the circuit is
A. 7 A B. 5 A
C. 4 A D. 3 A

51. In an alternating circuit, connected to an emf of 100 V and frequency 50 Hz, a resistance of 10 Ω and an inductance of $\left(\frac{1}{10\pi}\right)$H are connected in series. The power dissipated in the circuit will be
A. 500 W B. 534 W
C. 584 W D. 589 W

52. Two pure inductanes, each of value L are connected in parallel but are well separated from each other. The inductance of the parallel combination is
A. L B. 2 L
C. 4 L D. $\frac{L}{2}$

53. An aeroplane with wing span of 50 m flies at 540 km/h. The component of earth's magnetic field perpendicular to velocity of plane is 0.2 gauss. The potential difference between the wing tips is (Wb m^{-2} = 10 gauss)
A. 0.15 V B. 15 V
C. 1500 V D. 0

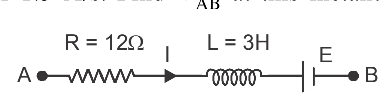
54. The time taken by sinusoidal AC of frequency 50 Hz to rise from zero to its maximum value is
A. 1×10^{-3} s
B. 2×10^{-3} s
C. 4×10^{-3} s
D. 5×10^{-3} s

55. Two conducting circular loops of radii R_1 and R_2 are placed in the same plane with their centres coinciding. If $R_1 >> R_2$, the mutual inductance M between them will be directly proportional to
A. $\frac{R_2}{R_1}$ B. $\frac{R_1}{R_2}$
C. $\frac{R_2^2}{R_1}$ D. $\frac{R_2^2}{R_1^2}$

56. Two identical circular loops of metal wire are lying on a table without touching each other. Loop A carries a current which increases with time. In response, the metal loop B
A. rotates about its CM with CM fired
B. is repelled by the loop A
C. is attracted by the loop A
D. remains stationary

57. An inductor of 2 H and a resistance of 10 Ω are connected in series with a battery of 5 V. The initial rate of change of current is
A. 0.25 As^{-1} B. 2 As^{-1}
C. 2.5 As^{-1} D. 0.5 As^{-1}

58. In the circuit shown in fig. R = 12 Ω, L = 3 H, E = 14 V, I = 2.2 A. The current is decreasing at the rate of 1.5 A/s. Find V_{AB} at this instant.



A. 31.7 V B. 35.9 V
C. 41.5 V D. 43.7 V

59. An electric lamp, which runs at 100 V DC and 10 A, is connected to 200 V and 50 cycle/s AC main. Then, the inductance of the choke needed to be used in series with the lamp is

A. 0.022 H B. 0.044 H
C. 0.055 H D. 0.083 H

60. A power transformer is used to step up an alternating emf of 220 V to 4.4 kV to transmit 0.6 kW of power. If the primary coil has 1000 turns, the current rating a secondary will be (assuming a 100% efficient transformer)

A. 1.20 A B. 2.40 A
C. 1.50 A D. 1.80 A

ANSWERS

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
A	A	B	B	C	A	C	A	D	D
11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
B	B	D	B	C	C	B	C	A	D
21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
C	B	A	B	A	C	C	A	D	A
31	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
B	A	C	C	A	C	D	B	C	A
41	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**
A	B	A	A	D	A	A	A	A	B
51	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**
A	D	A	D	C	B	C	B	C	C

EXPLANATORY ANSWERS

1. As, $\varepsilon = -\dfrac{NA(B_f - B_t)}{t}$

$= -\dfrac{100 \times 0.1 \times 0.05 \times (0.05 - 0.1)}{0.05}$

$= -0.5$ V

2. As, $I = \dfrac{NA\left(\dfrac{dB}{dt}\right)}{R} = \dfrac{10 \times 10 \times 10^{-4} \times 10^{4}}{20}$

$= 5$ A

3. As, $\varepsilon_{peak} = NBA\omega$

$= 30 \times 1 \times 0.04 \times 30 \times 2\pi$

$= 226$ V

4. As, $d\phi = nA\ (B_2 - B_1) = 80 \times 0.01\ (0 - 1.0)$

$= 0.8$ Wb

Now, $|e| = -\dfrac{d\phi}{dt} = \dfrac{0.8}{0.1} = 8V$

5. As, $N_s = \dfrac{\varepsilon_s}{\varepsilon_p} N_p = \dfrac{4.4 \times 1000 \times 1000}{220} = 20{,}000$

$I_p = \dfrac{P}{\varepsilon_p} = \dfrac{6.6 \times 10^3}{220} = 30$ A

$\therefore$ $I_s = \dfrac{N_p}{N_s} \cdot I_p = \dfrac{1000}{20{,}000} \times 30 = 1.5$ A

6. As, $I_s = \dfrac{\varepsilon_s}{Z} = \dfrac{22}{220} = 0.1$ A

$\therefore$ $I_p = \dfrac{\varepsilon_s I_s}{\varepsilon_p} = \dfrac{22 \times 0.1}{220} = 0.01A$

7. As, $B = \dfrac{\mu_0 NI}{2\pi r}\ \phi = NBA = N\left(\dfrac{\mu_0 NI}{2\pi r}\right) A$

$\therefore$ $L = \dfrac{\phi}{I} = \dfrac{\mu_0 N^2 A}{2\pi r}$

$= \dfrac{4\pi \times 10^{-7} \times (1200)^2 \times 12 \times 10^{-4}}{2\pi \times 0.15}$

$= 2.3 \times 10^{-3}$ H

8. We have, $V = 5.0 \times 10^{-4} \times \sin 30° \times 1800 \times \dfrac{5}{18} \times 25$

$= 3.1$ V.

9. As, $L = \dfrac{N\phi}{I} = \dfrac{100 \times 5 \times 10^{-5}}{2} = 2.5 \times 10^{-3}$ H

$U = \dfrac{1}{2} LI^2 = \dfrac{1}{2} \times 2.5 \times 10^{-3} \times 4$

$= 5 \times 10^{-3}$ J

10. As, $\varepsilon = \dfrac{-d\phi}{dt}$

$\phi = BA\cos\theta;\quad \theta = 0°;\quad \cos\theta = 1$

$\varepsilon = -\dfrac{d(BA)}{dt} = -A\dfrac{dB}{dt}$ for one turn

$\therefore$ ε for n turns $= n\left(-A\cdot\dfrac{dB}{dt}\right)$

$= -nA\cdot\dfrac{dB}{dt}$

$= -500 \times (.1 \times .1) \times 1$

$= -5$ volts.

11. The current is max. when the capacitor is fully discharged because then the whole of the electrical energy stored in the capacitor is converted into the magnetic energy in the inductor.

$\therefore \quad \frac{1}{2}LI^2 = \frac{1}{2}CV^2$

$I^2 = \dfrac{CV^2}{L} \Rightarrow I = V\sqrt{\dfrac{C}{L}}$

$= 10 \times \sqrt{\dfrac{10^{-6}}{0.1\times10^{-3}}} = \dfrac{10\times10^{-3}}{1\times10^{-2}}$

$\Rightarrow \quad I = 1A$

12. Induced emf $\varepsilon = \dfrac{AB}{\Delta t}$

$\therefore$ Induced current $I = \dfrac{AB}{\Delta t\cdot R}$

Charge flowing through the galvanometer

$q = I\Delta t = \dfrac{AB}{R}$

13. Inductance, $L = \mu_0 N^2\dfrac{A}{l}$

$= \dfrac{\mu_0 N^2 A}{2\pi r}$

Energy stored, $\mu = \dfrac{1}{2}LI^2 = \dfrac{\mu_0 N^2 AI^2}{4\pi r}$

or $N = \sqrt{\dfrac{4\pi rV}{\mu_0 AI^2}}$

$= \sqrt{\dfrac{0.12\times0.1}{10^{-7}\times2\times10^{-3}\times400}} = 387$

14. As, $M = -\dfrac{\varepsilon}{dI/dt} = -\dfrac{40000}{(0-4)/10\times10^{-6}} = 0.1$ H

15. As, $U = \dfrac{1}{2}LI^2 = \dfrac{1}{2}\times2.0\times(2)^2 = 4J$

16. For d.c.: $x = \dfrac{V^2}{R} = \dfrac{10^2}{R};\quad \therefore R = \dfrac{100}{x};$

For a.c.: $\dfrac{x}{2} = \dfrac{\left(\dfrac{V_0}{\sqrt{2}}\right)^2}{R} = \dfrac{V_0^2}{2R};$

or, $V_0^2 = x.R = x.\dfrac{100}{x} = 100$

$\therefore \quad V_0 = 10$ V.

17. As, $\dfrac{\omega L}{R} = \tan 45° = 1 \Rightarrow L = \dfrac{R}{\omega} = \dfrac{100}{2000\pi}$

$= \dfrac{1}{20\pi}$

18. As, $X_L = \omega L = 2\times3.14\times50\times1 = 314\ \Omega$

$\therefore \quad I_0 = \dfrac{220\sqrt{2}}{314} \simeq 1A \quad \left[\because I_0 = \dfrac{\varepsilon_0}{\omega L} = \dfrac{\varepsilon_0\sqrt{2}}{\omega L}\right]$

19. As, $X_L = X_C \Rightarrow 2\pi fL = X_C \Rightarrow L = \dfrac{X_C}{2\pi f}$

$= \dfrac{60}{2\times3\times100} = 0.1$ H

20. We have, $R = \dfrac{100}{1} = 100\ \Omega,\ Z = \dfrac{100}{0.5} = 200\ \Omega$

Since, $R^2 + \omega^2L^2 = Z^2 \Rightarrow L^2 = \dfrac{Z^2 - R^2}{\omega^2}$

$= 0.3 \quad \therefore L = \sqrt{0.3}$H

21. We have, $P = V_{rms} I_{rms} \cos\phi$

$= \dfrac{100}{\sqrt{2}}\times\dfrac{100\times10^{-3}}{\sqrt{2}}\times\cos\dfrac{\pi}{3} = 2.5$ W

22. Choke reduces the a.c. current without power loss.

$R = \dfrac{80}{10} = 8\ \Omega$

$I = \dfrac{V}{Z}$ or $Z = \dfrac{V}{I} \Rightarrow R^2 + \omega^2L^2 = \left(\dfrac{V}{I}\right)^2$

$\Rightarrow \quad \omega L = \sqrt{100-64} = 6 \therefore L = 0.02$ H

23. For resonance $\dfrac{1}{\omega C} = \omega L$ or $C = \dfrac{1}{L\omega^2}$

$= \dfrac{1}{10^{-2}\times4\pi^2\times10^{12}} = 2.5$ pF

24. We have, $\tan\phi = \frac{4}{3}$, Power factor = $\cos\phi = \frac{3}{5} = 0.6$

25. As, $\omega = \frac{1}{\sqrt{LC}} \Rightarrow C = \frac{1}{\omega^2 L} = \frac{1}{16\times10^{10} L}$

$$I_{eff} = \frac{V_R}{R} = \frac{60}{120} = 0.5\text{ A};\ I_{eff} = \frac{V_L}{\omega L}$$

$$\therefore \quad L = \frac{40}{4\times10^5\times0.5} = 20\times10^{-5} = 0.2\text{ mH}$$

and $C = \frac{1}{16\times10^{10}\times20\times10^{-5}} = \frac{1}{32}\mu F$

26. When capacitance is removed, it is an LR circuit

$$\tan\phi = \frac{X_L}{R} = \sqrt{3} = \frac{X_L}{100}$$

or $X_L = 100\sqrt{3}\ \Omega$

When the inductance is removed it is an RC circuit

$$\therefore \quad \tan\phi = \frac{X_C}{R} \Rightarrow X_C = 100\sqrt{3}\ \Omega$$

$$\therefore \quad Z = \sqrt{R^2 + (X_L - X_C)^2}$$

$$= R = 100\ \Omega$$

$$\therefore \quad I_{eff} = \frac{200}{100} = 2A$$

$$P = I_{eff}^2 Z = 400\text{ W}$$

27. We have, $V = 100\sin(100\pi t)$

at $t = \frac{1}{600}$s, $\therefore V = 100\sin\frac{\pi}{6} = 5V$

28. We have, $X_L = 2\pi\times500\times8.1\times10^{-3}$

$= 25.434\ \Omega$

$$X_C = \frac{10^6}{2\pi\times500\times12.5} = 25.478\ \Omega$$

$$X_L \approx X_C \quad \therefore \quad V_L \approx V_C$$

Now $V_{eff} = \sqrt{V_R^2 + (V_L - V_C)^2} = V_R$

$V_R = 100\text{ V}$

29. As, E_{av} (half cycle) $= \frac{2E_0}{T}\int_0^{T/2} \sin\omega t\, dt$

$$= \frac{2E_0}{\pi} \qquad \left(\because \omega = \frac{2\pi}{T}\right)$$

30. Given as, $n = 2000$, $A = 80\text{ cm}^2 = 80\times10^{-4}\text{ m}^2$

$B = 4.8\times10^{-2}$ T and $\omega = 200$ rpm

$$= \frac{2\pi\times200}{60}$$

$$= \frac{20\pi}{3}\text{ rad s}^{-1}$$

As, $e_0 = n\,BA\,\omega$

$$= 2000\times4.8\times10^{-2}\times80\times10^{-4}\times\frac{20}{3}\pi$$

$$= 16.085\text{ V}$$

31. As, $e_p I_p = e_s I_s$

$$\therefore \quad I_p = \frac{e_s I_s}{e_p}$$

$$= \frac{550}{220} = 2.5A$$

32. As, $V = \sqrt{V_R^2 + (V_L)^2}$

$20^2 = (12)^2 + V_L^2$

$V_L = \sqrt{256} = 16\text{ V}$

33. As, $P_{av} = E_v I_v \cos\theta$

$$= \frac{200}{\sqrt{2}}\times\frac{1}{\sqrt{2}}\times\cos\frac{\pi}{3} = 50\text{ watt}$$

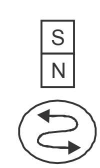
34. As, $V = V_0\sin\omega t = \sqrt{2}V_{rms}.\sin\omega t$

$$= \sqrt{2}\times120\times\sin\left(2\pi\times60\frac{1}{720}\right)$$

$$= \sqrt{2}\times120\times\sin\frac{\pi}{6}$$

$$= \sqrt{2}\times120\times\frac{1}{2} = 84.8\text{ V}$$

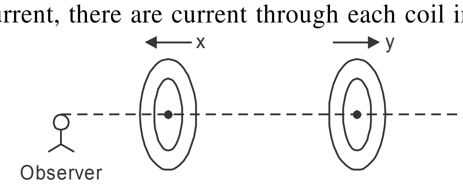
35. In fig. it is clear from the magnet side, induced emf current will be anticlockwise,



36. As, $e = \frac{-d\theta}{dt} = \frac{-3B_0A_0}{t}$

$$|e| = \frac{3B_0A_0}{t}$$

37. Induced current in both the coils assist the main current, there are current through each coil increases.



38. As, $|e| = N\left(\frac{\Delta B}{\Delta t}\right) A\cos\theta$

$= 500 \times 1 \times (10 \times 10^{-2})^2 \cos 0°$

$= 500 \times 100 \times 10^{-4} \times 1$

$= 5$ V

39. As, $e = \frac{-N(B_2 - B_1)A\cos\theta}{\Delta t}$

$= \frac{-500(0 - 0.1) \times 100 \times 10^{-4} \times \cos 0°}{0.1}$

$= 500 \times 100 \times 10^{-4} = 5$V

40. As, $e = A \cdot \frac{\Delta B}{\Delta t} = 2 \times \frac{(4-1)}{2} = 3$V

41. As, $e = \frac{-N(B_2 - B_1)}{t} A \cos\theta$

$= \frac{-100 \times (6-1)}{2} \times (40 \times 10^{-4}) \cos 0°$

$\therefore$ $|e| = -50 \times 5 \times 40 \times 10^{-4}$

$= -10^4 \times 10^{-4} = |-1| = 1$V

42. If a wire of length l moves with velocity v, perpendicular to magnetic field B, the induced emf is produced. The induced magnitude is

As, $|\in| = Blv$

Given, $l = 50$ cm $= 5 \times 10^{-1}$ m,

$v = 30$ m/min $= 5$ m/sec

$|\in| = 2$V

$\therefore$ $B = \frac{|\in|}{lV} = \frac{2}{0.5 \times 5} = 0.8$T

43. Given, $\phi_1 = 2$Wb; $\phi_2 = 10$ Wb, R = 2 Ω

As, $\Delta Q = \frac{\phi_2 - \phi_1}{R} = \left(\frac{10-2}{2}\right) = \frac{8}{2} = 4$ C

44. Given, $\phi_1 = 12 \times 10^{-3}$ Wb, $\phi_2 = 6 \times 10^{-3}$ Wb

$dt = 0.01$s $= 10^{-2}$ s

As, $e = \frac{-d\phi}{dt} = \frac{-\phi_2 - \phi_1}{dt}$

$= \frac{-(6 \times 10^{-3} - 12 \times 10^{-3})}{10^{-2}}$

$= 0.6$ V

45. As, $f = \frac{750}{60} = \frac{75}{6}$

Eight polar dynamo has 4 coils

$\therefore$ Effective value is $\frac{75}{6} \times 4$ Hz $= 50$ Hz

46. We have, $|E| = \frac{d}{dt}[atT - at^2] = aT - 2at$

Now, $dQ = \frac{E^2}{R} dt$

$\Rightarrow$ $Q = \frac{a^2}{R}\int_0^T (T - 2t)^2$

$\Rightarrow$ $Q = \frac{a^2}{R}\int_0^T (T^2 + 4t^2 - 4Tt)dt$

$= \frac{a^2}{R}\left[T^2\int_0^T dt + 4\int_0^T t^2 dt - 4T\int_0^T t\, dt\right]$

$= \frac{a^2}{R}\left[T^3 + \frac{4T^3}{3} - 4T\left(\frac{T^2}{2}\right)\right]$

$= \frac{a^2}{R}\left[\frac{4T^3}{3} - T^3\right] = \frac{a^2}{R} \cdot \frac{T^3}{3} = \frac{a^2T^3}{3R}$

47. At 50 Hz, Lω = R; at 100 Hz, Lω = 2R

Current remains unchanged in R. However, it becomes half in I_0.

48. As, $L' = \frac{L_1L_2}{L_1 + L_2} = \frac{0.5 \times 0.5}{0.5 + 0.5} = 2.5$ H

Equivalent Inductance

$\therefore$ $= L + L' = 0.75 + 0.25 = 1.00$ H

49. We have, $R = \frac{120}{0.5} = 240$

$Z = \sqrt{R^2 + \omega^2L^2} = \sqrt{R^2 + (2\pi f)^2 L^2}$

$= \sqrt{(240)^2 + (2 \times 3.14 \times 60)^2 (0.525)^2}$

$= 311$ Ω

$\therefore$ $I = \frac{V}{Z} = \frac{120}{311} = 0.386$ A

50. We have, $I^2R = 3^2R + 4^2R$ or $I^2 = 9 + 16$

$I^2 = 25$A

$\therefore$ I = 5A

51. As, $P = V_{rms} \times I_{rms} \times \cos\phi$

$= V_{rms} \times \frac{V_{rms}}{Z} \times \frac{R}{Z}$

$= \frac{V_{rms}^2 R}{Z^2} = \frac{V_{rms}^2 R}{R^2 + (\omega L)^2}$

$= \frac{(100)^2 \times (10)^2}{(10)^2 + \left(50 \times \frac{1}{10\pi}\right)^2} = 500$ W

52. We have, $I = I_1 + I_2$

$$\frac{dI}{dt} = \frac{dI_1}{dt} + \frac{dI_2}{dt}$$

$$\Rightarrow \quad E_1 = -L_1\frac{dI_1}{dt},\ E_2 = -L_2\frac{dI_2}{dt}$$

$$E = -L'\frac{dI}{dt}$$

$$E_1 = E_2 = E$$

$$\therefore \quad \frac{dI_1}{dt} = \frac{-E}{L_1'} \Rightarrow \frac{-E}{L'} = \frac{-E}{L_1} - \frac{E}{L_2}$$

$$\therefore \quad \frac{1}{L'} = \frac{1}{L_1} + \frac{1}{L_2}$$

But $L_1 = L_2 = L$

$$\therefore \quad \frac{1}{L'} = \frac{2}{L} \Rightarrow L' = \frac{L}{2}$$

53. We have, $E = 0.2 \times 10^{-4} \times 50 \times 540 \times \frac{5}{18} = 0.15$ V

54. $t = \frac{1}{4}T = \frac{1}{4} \times \frac{1}{n} = \frac{1}{200}\text{s} = 5 \times 10^{-3}\text{s}$

55. The mutual inductance between two coils in the same plane with their centres coinciding is given by

$$M = \frac{\mu_0}{4\pi}\left(\frac{2\pi^2 R_2^2 N_1 N_2}{R_1}\right)H$$

$$= \frac{\mu_0}{4\pi}2\pi^2 \cdot N_1 N_2 \frac{R_2^2}{R_1}$$

$$= \frac{\mu_0}{2}\pi N_1 N_2 \frac{R_2^2}{R_1} \quad \therefore M \propto \frac{R_2^2}{R_1}$$

56. When current increases with time in loop A, then magnetic flux in B will increase. According to Lenz's law loop B is repelled by loop A.

57. As, $i = i_0\left(1 - e^{-\frac{R}{L}t}\right)$

$$\frac{di}{dt} = \frac{d}{dt}L_0 - \frac{d}{dt}L_0 e^{-\frac{R}{L}t}$$

$$\frac{di}{dt} = 0 - L_0\left(-\frac{R}{L}\right)e^{-\frac{R}{L}t}$$

$$= L_0\frac{R}{L}e^{-\frac{Rt}{L}}$$

Initially, $t = 0$

$$\therefore \quad \frac{di}{dt} = \frac{i_0 \times R}{L} = \frac{E}{L} = \frac{5}{2} = 2.5\ \text{As}^{-1}$$

58. As, $V_L = L\frac{dI}{dt}$

$= (3)(-1.5) = -4.5$ V

Now, $V_A - IR - V_L - E = V_B$

$$V_{AB} = V_A - V_B$$
$$= E + IR + V_L$$
$$= 14 + (2.2)(12) - 4.5$$
$$= 14 + 26.4 - 4.5$$
$$= 35.9 \text{ V}$$

59. Resistance of the bulb $= \frac{100}{10} = 10\ \Omega$

The rms current is given by

$$I_{rms} = \frac{E_{rms}}{\sqrt{R^2 + \omega^2 L^2}}$$

or

$$10 = \frac{200}{\sqrt{10^2 + (2\pi \times 50 \times L)^2}}$$

$$\therefore \quad L = \frac{\sqrt{300}}{100\pi} = 0.055 \text{ H}$$

60. As, $N_S = \left(\frac{e_s}{e_P}\right)N_P = \left(\frac{4.4 \times 1000}{220}\right) \times 1000$

$$I_P e_P = 6.6 \times 10^3 \text{ W}$$

$$\therefore \quad I_P = \frac{6.6 \times 10^3}{220} = 30 \text{ A}$$

$$\therefore \quad \frac{I_S}{I_P} = \frac{N_P}{N_S} = \left(\frac{1000}{20000}\right) = \frac{1}{20}$$

$$\therefore \quad I_S = \frac{1}{20} \times I_P = \frac{1}{20} \times 30 = 1.5 \text{ A.}$$

CHAPTER

5

ELECTROMAGNETIC WAVES

ELECTROMAGNETIC WAVES AND THEIR CHARACTERISTICS

Electromagnetic waves: An electromagnetic wave is characterised by two vectors, the electric field E and the magnetic field B, which oscillate at right angles to each other and also to the propagations of wave.

Electromagnetic fields are represented by the following equations:

$$E = E_y = E_0 \sin \omega\left(t - \frac{x}{c}\right)$$

$$B = B_z = B_0 \sin \omega\left(t - \frac{x}{c}\right)$$

The combination of mutually perpendicular electric and magnetic fields, yields a light wave disturbance is called electromagnetic wave.

Conduction current: It is the current which arises due to flow of electrons through the connecting wires in an electric current.

Displacement current: It is the current which comes into play in the region, wherever the electric field and hence the electric flux in changing with time.

The displacement current is given by

$$I_D = \epsilon_0 \frac{d\phi_E}{dt}$$

Where $\epsilon_0 \rightarrow$ Absolute permittivity of free space and

$\frac{d\phi_E}{dt} \rightarrow$ Rate of change of electric flux.

Characteristics of Electromagnetic Waves

1. The planes of oscillation of electric and magnetic fields are perpendicular to each other.
2. Direction of propagation of the EM wave is perpendicular to the directions of oscillations of electric and magnetic fields.
3. They propagate with the speed of light (c), in vacuum, given by

   $$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 3 \times 10^8 \text{ m/s.}$$
4. They follow the principle of superposition.
5. The ratio of electric to magnetic field is equal to their velocity (c) is $\frac{E}{B} = c$
6. Electric and magnetic fields oscillate with the same phase or with a constant phase difference.
7. They travel without the aid of any material medium.

Maxwell's Equations

Gauss's Law of Electrostatics: It states that the total normal electric flux through a closed surface is equal to $\frac{1}{\epsilon_0}$ times the total charge enclosed within the surface.

$$\boxed{\phi_E = \oint \vec{E} \cdot \vec{ds} = \frac{q}{\varepsilon_0}}$$

Gauss's Law of Magnetism: It states that the total magnetic flux through a closed surface is always zero.

$$\boxed{\phi_B = \oint \vec{B} \cdot \vec{ds} = 0}$$

Ampere's Law: It states that the line integral of magnetic field along a closed path is equal to μ_0 times the total current threading the surface bounded by that closed path.

Mathematically,

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 (I_C + I_D)$$

or $$\boxed{\oint \vec{B}\cdot\overrightarrow{dl} = \mu_0\left(I_C + \varepsilon_0 \frac{d\phi_E}{dt}\right)}$$

Faraday's Law: It states that the rate of change of magnetic flux with time is equal to induced emf and that the direction of induced emf is always such as oppose the change that produces it.

Mathematically,

$$\varepsilon = -\frac{d\phi}{dt}$$

$$e = \boxed{\oint \vec{E}\cdot\overrightarrow{dl} = -\frac{d\phi}{dt}}$$

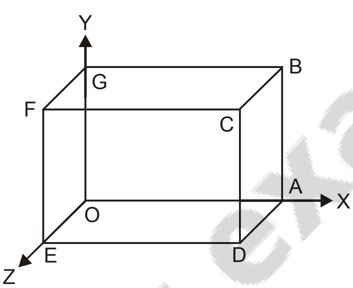
TRANSVERSE NATURE OF ELECTROMAGNETIC WAVES

According to Gauss's law, the total electric flux across, must be zero, when the rectangular parallelopiped does not enclosed any charge *i.e.*,

$$\oint_S \vec{E}\cdot\overrightarrow{ds} = 0$$

In the Fig.,

When E_x and E_x' are the values of x-component of electric field on face ABCD and OGFE respectively and S be the area of each of these faces, then



$$\int_{ABCD} \vec{E}\cdot\overrightarrow{ds} = E_s S \quad \text{and} \quad \int_{OGFE} \vec{E}\cdot\overrightarrow{ds} = -E_x' S$$

So, $\quad E_x S - E_x' S = 0$

$\Rightarrow \quad (E_x - E_x')S = 0$

When, $\quad E_x - E_x' = 0 \quad \Rightarrow \quad E_x = E_x' = 0$ (static)

The electric field is perpendicular to the direction of propagation of em wave. Thus, the electric and magnetic fields are transverse *i.e.*, perpendicular to the direction of propagation of wave. That's why the electromagnetic waves are transverse in nature.

Energy in EM Waves (U): E.M. waves consist of two fields – electric and magnetic.

Energy density in the Electric field $= \frac{1}{2}\varepsilon_0 E^2$

Energy density in the magnetic field $= \frac{1}{2\mu_0}B^2$

where B = magnetic field or induction.

Total Energy Density, $U = \varepsilon_0 E^2$

Momentum Carried by EM Waves (p):

$$p = \frac{EH}{C^2} \text{ or } \frac{S}{C^2}$$

This is momentum density of the EM wave. This is the property of the field alone and is not associated with any moving mass.

Standing EM Wave: By the law of superposition, if a progressive wave is reflected back in the opposite direction, then the resulting wave is a standing wave.

$$E = 2E_0 \cos \omega t \sin kx$$

ELECTROMAGNETIC SPECTRUM

The orderly distribution of electromagnetic radiations according to their wavelength or frequency is called electromagnetic spectrum. All electromagnetic waves in vacuum have the same speed ($c = n\lambda = 3 \times 10^8$ ms^{-1}).

Radiowaves: Radiowaves are produced by oscillating electronic circuit. The frequency of radiowaves varies from a few Hz to 10^{19} Hz. The radiowaves are used as carrier waves in radio broadcasting and TV transmission.

Microwaves: Microwaves produced by oscillating electric circuit. The frequency of microwaves lies between $10^{19} - 3 \times 10^{11}$ Hz. The microwaves are used in RADAR and other communication system.

Infrared Rays: Infrared rays are heat radiation and all hot bodies are sources of infrared rays. The frequency range of infrared rays is 10^{13} to 4×10^{14} Hz. About 60% of solar radiation is infrared in nature.

Visible light: The visible light emitted due to atomic excitation. Human eye is sensitive to only visible part of the electromagnetic spectrum. The frequency ranges from 4×10^{14} Hz to 8×10^{14} Hz.

Ultraviolet Rays: The ultraviolet rays are the part of solar spectrum. They can produced by arcs of mercury and iron. The frequency of ultraviolet rays lies between in the range of 8×10^{14} to 10^{16} Hz.

X-rays: When a target of an element having high atomic number is bombarded by fast moving electrons, X-rays are produced. The frequency range of X-rays is 10^{16} Hz to 3×10^{19} Hz. These rays passes a high penetrating power.

Gamma rays (γ): γ-rays are nuclear origin and range from 3×10^{19} Hz to 5×10^{20} Hz. These rays are highly energetic radiation and are mainly emitted by radioactive substances.

APPLICATIONS OF ELECTROMAGNETIC WAVES

EM waves are used to transmit short or long or FM wavelength radio waves. They are used to transmit TV or telephone or wireless signals and energies.

- They are responsible for the transmission of energy in the forms of microwaves, visible light, infrared radiation, UV light, gamma rays and also X-rays.
- EM waves accomplish the transmission of energy through a vacuum or using no medium. Since EM waves transmit energy, it plays an important role in our daily lives including the communication technology.
- Electromagnetic radiation is the foundation for working of radar which in turn is used for guiding and remote sensing the study of our planet earth.
- X-rays detect the bone breaks by passing through the flesh and capturing the image.
- Gamma rays can couse and also treat cancers.
- Infrared radiation is visible at all times, thus is used by officials to capture enemy.

Spectrum of EM Waves

S.No.	*Name*	*Frequency Range (Hz)*	*Wavelength Range (m)*	*How Produced*
1.	γ-rays	$3 \times 10^{19} - 5 \times 10^{20}$	$6 \times 10^{-13} - 1 \times 10^{-10}$	Nuclei of atom
2.	X-rays	$1 \times 10^{16} - 3 \times 10^{19}$	$1 \times 10^{-10} - 3 \times 10^{-8}$	Bombardment of high Z target by electrons
3.	Ultra-violet	$8 \times 10^{14} - 1 \times 10^{16}$	$3 \times 10^{-8} - 4 \times 10^{-7}$	Excitation of atoms and vacuum sparks.
4.	Visible Light	$4 \times 10^{14} - 8 \times 10^{14}$	$4 \times 10^{-7} - 8 \times 10^{-7}$	Excitation of atoms, spark and arc flames
	VIOLET		$4 - 4.5 \times 10^{-7}$	
	BLUE		$4.5 - 5 \times 10^{-7}$	
	GREEN		$5 - 5.7 \times 10^{-7}$	
	YELLOW		$5.7 - 5.9 \times 10^{-7}$	
	ORANGE		$5.9 - 6.2 \times 10^{-7}$	
	RED		$6.2 - 7.5 \times 10^{-7}$	
5.	Infrared	$1 \times 10^{13} - 4 \times 10^{14}$	$8 \times 10^{-7} - 3 \times 10^{-5}$	Excitation of atoms and molecules
6.	Heat radiation	$3 \times 10^{11} - 3 \times 10^{13}$	$1 \times 10^{-5} - 1 \times 10^{-1}$	Heating
7.	Micro wave	$1 \times 10^{9} - 3 \times 10^{11}$	$1 \times 10^{-3} - 3 \times 10^{-1}$	Oscillating currents in special vacuum tubes
8.	Ultra-high radio frequencies	$3 \times 10^{8} - 3 \times 10^{9}$	$1 \times 10^{-1} - 1$	Oscillating circuits
9.	Very high radio frequencies	$3 \times 10^{-7} - 3 \times 10^{8}$	$1 - 10$	Oscillating circuits
	TV, FM	$1 \times 10^{8} - 2 \times 10^{8}$		Oscillating circuits
10.	Radio frequencies	$3 \times 10^{4} - 3 \times 10^{7}$	$10 - 10^{4}$	Oscillating circuits
11.	Power frequencies	$60 - 50$	$5 \times 10^{6} - 6 \times 10^{6}$	Weak radiation from AC circuits.

EXERCISE

1. The transmitting antenna of a radio station is mounted vertically. At a point 10 km due north of the transmitter the peak electric field is 10^{-3} volt/m. The magnitude of the radiated field in gauss is

A. 3.33
B. 3.33×10^{-3}
C. 3.33×10^{-8}
D. 10^{-3}

2. If the electric amplitude of the wave is $5\frac{V}{m}$, magnetic amplitude of this wave is

A. $1.67 \times 10^{-10} \frac{wb}{m^2}$ B. $5\frac{A}{m}$

C. $1.67 \times 10^{-8} \frac{wb}{m^2}$ D. $5 \times 10^{-10} \frac{wb}{m^2}$

3. A brilliant arc lamp delivers a luminous flux of 100 watt to a 1 cm^2 absorber. The force due to radiation pressure is

A. 3.3×10^{-4} N   B. 16.5×10^{-7} N
C. 3.3×10^{-6} N   D. 3.3×10^{-7} N

4. An L.C. resonant circuit contains a 400 PF capacitor and a 100 μ H inductor. It is set into oscillation coupled to an antenna. The wavelength of the radiate electromagnetic wave is

A. 377 mm   B. 377 m
C. 377 cm   D. 3.77 cm

5. In a plane electromagnetic wave, the electric field oscillates sinusoidally at a frequency of 2.0×10^{10} Hz and amplitude 48 V m^{-1}. The wavelength of the wave is

A. 1.5 m   B. 1.5×10^{-1} m
C. 1.5×10^{-2} m   D. 1.5×10^{-3} m

6. What an intantaneous displacement current of 1A current in the space between the parallel plates of 1 μF capacitor?

A. 10^4 Vs^{-1} B. 10^5 Vs^{-1}
C. 10^7 Vs^{-1} D. 10^6 Vs^{-1}

7. In an electric circuit, a capacitor of reactance 50 Ω is connected across the source of 220 V. The displacement current is

A. 3.5 A   B. 6.9 A
C. 4.4 A   D. 4.5 A

8. An electromagnetic wave in vacuum has the electric and magnetic fields E and B, which are always perpendicular to each other. The direction of polarization is given by X and that of wave propagation by k. Then

A. X ∥ B and k ∥ B × E
B. X ∥ B and k ∥ E × B
C. X ∥ E and k ∥ E × B
D. X ∥ E and k ∥ B × E

9. In a plane electromagnetic wave propagating in space has an electric field of amplitude 9×10^3 Vm^{-1}, then the amplitude of the magnetic field is

A. 3×10^{-5} J   B. 2×10^{-4} J
C. 3×10^{-6} J   D. 5×10^{-5} J

10. The continuous X-rays spectrum produced by an X-ray machine at constant voltage has a

A. single wavelength
B. minimum wavelength
C. maximum wavelength
D. minimum frequency

11. A circular ring of radius r is placed in a homogeneous magnetic field perpendicular to the place of the ring. The field B changes with time according to the equation B = kt, where k is a constant and t is the time. The electric field in the ring is

A. $\frac{kr}{2}$ B. $2\ kr$

C. $\frac{3}{2}kr$ D. $\frac{5}{3}kr$

12. In a plane EM wave electric field varies with time having an amplitude 1 Vm^{-1}. The frequency of wave is 0.5×10^{15} Hz. The wave propagation along x-axis. The average density of magnetic field is:

A. 2.2×10^{-12} Jm^{-3} B. 3.5×10^{-11} Jm^{-3}
C. 4.5×10^{-12} Jm^{-3} D. 1.2×10^{-10} Jm^{-3}

13. The radiation of 200 W is incident on a surface which is 60% reflecting and 40% absorbing. The total force on the surface is

A. 2.04×10^{-5} N   B. 1.07×10^{-6} N
C. 3.05×10^{-7} N   D. 4.5×10^{-5} N

14. The sun delivers 10^4 Wm^{-2} of electromagnetic flux to the surface of the earth. The total power that in incident on a root of dimension 10 m square will be

A. 10^6 W   B. 10^5 W
C. 10^7 W   D. 10^4 W

15. A point source of electromagnetic radiation has an average power output of 800 W. The maximum value of electric field at a distance 4.0 m from the source is

A. 53.21 Vm^{-1} B. 58.56 Vm^{-1}
C. 54.8 Vm^{-1} D. 50.2 Vm^{-1}

16. The amplitude of oscillating magnetic field in an EM wave is 2×10^{-6} T. What will be the amplitude of the oscillating electric field?

A. 500 Vm^{-1} B. 600 Vm^{-1}
C. 700 Vm^{-1} D. 400 Vm^{-1}

17. A laser emits a beam of light of 2 mm diameter. If the power of beam is 10 mW, find the intensity of the beam of light.

A. 3.18×10^3 Wm^{-2} B. 4.15×10^3 Wm^{-2}
C. 6.13×10^4 Wm^{-2} D. 9.26×10^3 Wm^{-2}

18. A 100 PF capacitor is connected to a 230 V, 50 H_2 ac source. What is the rms value of the conduction current?

A. 7.2 μA   B. 3.5 μA
C. 9.5 μA   D. 4.6 μA

19. The angle made by direction of travel of an em wave with y-axis, when the wave point travelling in free space is given by $\vec{a} = \hat{k} + \hat{j} + \hat{i}$ is

A. $\theta = \sin^{-1}\left(\frac{1}{\sqrt{2}}\right)$ B. $\theta = \cos^{-1}\left(\frac{3}{5}\right)$

C. $\theta = \cos^{-1}\left(\frac{1}{\sqrt{3}}\right)$ D. $\theta = \sin^{-1}\left(\frac{3}{5}\right)$

20. What is the force exerted by a photon of intensity 1.4 kW/m^2, if it falls on a perfect absorber on radius 2 m?

A. 1.35×10^{-4} N B. 2.35×10^{-4} N
C. 4.51×10^{-5} N D. 3.5×10^{-3} N

21. The photon energy in units of eV for electromagnetic waves of wavelength 40 m is
(Given, $h = 6.6 \times 10^{-34}$ Js.)

A. 3.1×10^{-8} eV B. 5.8×10^{-7} eV
C. 4.2×10^{-9} eV D. 2.1×10^{-5} eV

22. A plane EM wave of frequency 25 MHz travels in free space along the x-direction. At a particular point in space and time the electric vector is $\vec{E} = 6.3\ \text{V}/m\hat{j}$. Find the $\vec{B}$ at this point.

A. $3.5 \times 10^{-5}\hat{k}$T B. $2.1 \times 10^{-8}\hat{k}$T
C. $4.5 \times 10^{-7}\hat{k}$T D. $6.9 \times 10^{-7}\hat{k}$T

23. An electromagnetic wave with Poyinting vector 6 Wm^{-2} is absorbed by a surface of area 12 m^2. The force on the surface is

A. 2.4×10^{-8} N B. 3.5×10^{-7} N
C. 6.2×10^{-8} N D. 1.2×10^{-6} N

24. A plane of EM wave of wave intensity 5 Wm^{-2} strikes a small mirror of area 20 cm^2, used perpendicular to the approaching wave. The momentum transferred by the wave to mirror each second is

A. 3.25×10^{-11} kgms^{-1}
B. 6.67×10^{-11} kgms^{-1}
C. 1.12×10^{-12} kgms^{-1}
D. 4.91×10^{-11} kgms^{-1}

25. Electromagnetic waves travel in a medium at a speed of 2×10^8 ms^{-1}. The relative permeability of the medium is 1.0. The relative permittivity is

A. 2.25 B. 3.25
C. 1.25 D. 1.00

26. A radio transmitter operates at a frequency of 800 kHz and a power of 10 kW. The number of photons per second emitted is

A. 2.171×10^{31} B. 1.171×10^{31}
C. 0.171×10^{30} D. 1.125×10^{32}

27. An EM wave passing through vacuum is described by the equations

$E = E_0 \sin(kx - \omega t)$ and $B = B_0 \sin(kx - \omega t)$. Then,

A. $E_0\omega = B_0k$ B. $E_0k = B_0\omega$
C. $E_0B_0 = \omega k$ D. $E_0 = B_0$

28. The rms value of the electric field of the light comming from the sum is 720 N/C. The average total energy density of the electromagnetic wave is

A. 8.35×10^{-12} J/m^3 B. 4.58×10^{-6} J/m^3
C. 6.31×10^{-9} J/m^3 D. 3.4×10^{-3} J/m^3

29. The electric field in an EM wave is given by $E = 50\ \text{N/C}\ \sin\omega\left(t - \frac{x}{c}\right)$. Find the energy contained in a cylinder of cross section 10 cm^2 and length 50 cm along x-axis.

A. 5.5×10^{-12} J B. 8.5×10^{-11} J
C. 3.5×10^{-10} J D. 2.5×10^{-12} J

30. The sun radiates EM energy at the rate of 3.9×10^{26} W. Its radius is 6.96×10^8 m. The intensity of sun light in (Wm^{-2}) at the solar surface will be

A. 3.8×10^6 B. 3.5×10^6
C. 4.1×10^7 D. 5.6×10^7

31. An electromagnetic radiation has an energy 11 keV. To which region of electromagnetic spectrum does it belong?

A. x-ray region B. UV region
C. γ-ray region D. Visible region

32. The magnetic of magnetic field part of harmonic EM wave in vacuum is $B_0 = 510\ n$T. The magnitude of the electric field part of the wave is

A. 123 NC^{-1} B. 153 NC^{-1}
C. 167 NC^{-1} D. 183 NC^{-1}

33. In plane EM wave, the electric field oscillates sinusoidally at a frequency of 2.5×10^{10} Hz and amplitude 480 Vm^{-1}. The amplitude of oscillating magnetic field will be

A. 1.6×10^8 Wbm^{-2}
B. 1.6×10^{-6} Wbm^{-2}
C. 1.52×10^7 Wbm^{-2}
D. 2.25×10^{-6} Wbm^{-2}

34. If a source is transmitting EM wave of frequency 8.2×10^6 Hz, then wavelength of the EM wave transmitted from the source will be

A. 42.5 m B. 45.3 m
C. 48.5 m D. 36.6 m

35. The phase and orientation of the magnetic velocity associated with electromagnetic oscillation differ respectively from those of the corresponding electric vector by

A. 0 and $\frac{\pi}{2}$ B. 0 and ∞

C. $-\frac{\pi}{2}$ and $\frac{\pi}{2}$ D. $-\frac{\pi}{2}$ and 0

ANSWERS

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
C	C	D	B	C	D	C	C	A	B
11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
A	A	B	A	C	B	A	A	C	B
21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
A	B	A	B	A	B	B	B	A	D
31	**32**	**33**	**34**	**35**					
A	B	B	D	A					

EXPLANATORY ANSWERS

1. As, $B_0 = \frac{E_0}{C} = \frac{10^{-3}}{3 \times 10^8}$

$= 3.33 \times 10^{12}$ Tesla $= 3.33 \times 10^{-8}$ Gauss.

2. Here, $E_0 = 5$ V/m

$B_0 = \frac{E_0}{C} = \frac{5}{3 \times 10^9} = 1.67 \times 10^{-8}$ wb/m^2.

3. Energy/sec = 100 watt

or $\frac{hv}{t} = 100$ J/s

$hv = 100$ J

Force = momentum/sec.

$\frac{hv}{C} = \frac{100}{3 \times 10^8} = 3.3 \times 10^{-7}$ N.

4. As, $v = \frac{1}{2\pi\sqrt{LC}}$

$= \frac{1}{2\pi\sqrt{100 \times 10^{-6} \times 400 \times 10^{-12}}}$

$= \frac{10^7}{4\pi}$ Hz.

$\lambda = \frac{c}{v} = \frac{3 \times 10^8}{10^4} \times 4\pi = 377$ m.

5. Given, $v = 2 \times 10^{10}$ Hz

$E_0 = 48$ V/m

$\lambda = \frac{C}{V} = \frac{3 \times 10^8}{2 \times 10^{10}} = 1.5 \times 10^{-2}$ m.

6. As, $i_d = \epsilon_0 \frac{d\phi_E}{dt} = \epsilon_0 A \cdot \frac{d}{dt}\left(\frac{V}{d}\right)$

or $i_d = \frac{\epsilon_0 A}{d} \times \frac{dV}{dt} = c\frac{dV}{dt}$

or $\frac{dV}{dt} = \frac{i_d}{C} = \frac{1}{10^{-6}} = 10^6 \text{Vs}^{-1}$

Hence, an intantaneous displacement current of 1 A can be set up by changing the *p-d.* across the parallel plates of capacitor at the rate of 10^6 Vm^{-1}.

7. Displacement current = conduction current

$\therefore \quad i_d = \frac{V}{\pi_c} = \frac{220}{50}$

$= 4.4$ A.

8. In electromagnetic wave, electric and magnetic fields are mutually perpendicular i.e., wave propagates perpendicular to $\vec{E}$ and $\vec{B}$ or along $\vec{E} \times \vec{B}$. While polarization of wave takes place parallel to electric field vector.

9. As, $B_0 = \frac{E_0}{c} = \frac{9 \times 10^3}{3 \times 10^8} = 3 \times 10^{-5}$ J.

10. The continous spectrum of X-rays consists of radiations of all possible wavelength range having a definite minimum (short) wavelength.

11. As, $\oint \vec{E}d\vec{l} = -B\frac{d\phi}{dt}$

or $E \times 2\pi r = \frac{d}{dt}(kt \times \pi r^2) = k\pi r^2$

$\Rightarrow \quad E = \frac{kr}{2}$.

12. As, $C = \frac{\epsilon_0 KA}{d} = \frac{8.85 \times 10^{-12} \times 10 \times 1}{10^{-3}}$

$= 8.85 \times 10^{-8}$ F

$i = \frac{d}{dr}(CV) = \frac{CdV}{dr}$

$= 8.85 \times 10^{-8} \times 25$

$= 2.2 \times 10^{-6}$ Jm^{-3}.

13. We have, $F_{total} = F_{reflecting} + F_{absorbing}$

$$= \frac{1.2}{c}P + \frac{0.4P}{c} = \frac{1.6P}{c}$$

$$= \frac{1.6 \times 200}{3 \times 10^8} = 1.07 \times 10^{-6} \text{ N.}$$

14. We have, total power = Solar constant × area

$$= 10^4 \times (10 \times 10)\text{W} = 10^6\text{W.}$$

15. The intensity of EM wave

$$I = \frac{P_{av}}{4\pi \times r^2} = \frac{E_0^2}{2\mu_0 c}$$

or $$E_0 = \sqrt{\frac{\mu_0 P_{av} c}{2\pi r}}$$

$$= \sqrt{\frac{4\pi \times 10^{-7} \times 800 \times 3 \times 10^8}{2\pi \times (4)^2}}$$

$$= 54.8 \text{ Vm}^{-1}.$$

16. As, $E_0 = cB_0$

Given $c = 3 \times 10^8$ m/s, $B_0 = 2 \times 10^{-6}$ T

$\therefore$ $E_0 = 3 \times 10^8 \times 2 \times 10^{-6} = 600 \text{ Vm}^{-1}$.

17. Given, diameter of beam = 2 mm = 2×10^{-3} m

$\therefore$ Area of the beam $= \pi r^2 = \pi\left(\frac{D}{2}\right)^2$

$= 3.14 \times 1 \times 10^{-6}$

$= 3.14 \times 10^{-6} \text{ m}^2$

Power, P = 10 mW = 10×10^{-3} W

$= 10^{-2}$ W

$$\text{Intensity, } I = \left(\frac{P}{A}\right) = \frac{10^{-2}\text{ W}}{3.14 \times 10^{-6}\text{ m}^2}$$

$= 3.18 \times 10^3 \text{ Wm}^{-2}$.

18. As, $$I_{rms} = \frac{V_{rms}}{X_C}$$

Given, $V_{rms} = 230$ V

As, $$X_C = \frac{1}{C\omega} = \frac{1}{C \times 2\pi\nu}$$

$\therefore$ $$I = \frac{V_{rms}}{C \times 2\pi r}$$

$$= \frac{1}{100 \times 10^{-12} \times 2\pi \times 50}\Omega$$

$\therefore$ $I_{rms} = 7.2 \times 10^{-6}$ A = 7.2 μA

19. Let θ be the desired angle,

$$\vec{a} \cdot \hat{j} = a \cos\theta \quad i.e., \cos\theta = \frac{\vec{a}\,\hat{j}}{a}$$

$$= \frac{\hat{k} + \hat{j} + \hat{i}}{\sqrt{1+1+1}} = \frac{1}{\sqrt{3}}$$

i.e., $$\theta = \cos^{-1}\left(\frac{1}{\sqrt{3}}\right).$$

20. Pressure, $$P = \frac{I}{c} = \frac{1.4 \times 10^3}{3 \times 10^8}$$

$= 0.47 \times 10^{-5} \text{ Nm}^{-2}$

Forced exterted = P × area

$= P \times 4\pi r^2$

$= 0.47 \times 10^{-5} \times 4 \times 3.142 \times 4$

$= 2.35 \times 10^{-4}$ N.

21. Given, λ = 40 m,

$G = 6.6 \times 10^{-34}$ Js

As, $$E = h\nu = \frac{hc}{\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{40}\text{J}$$

$$= \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{40 \times 1.6 \times 10^{-19}}\text{eV}$$

$= 3.1 \times 10^{-8}$ eV.

22. As, $$B = \frac{E}{c} = \frac{6.3 \text{ V/m}}{3 \times 10^8 \text{ m/s}} = 2.1 \times 10^{-8} \text{ J}$$

As, $\vec{E}$ is along *y*-direction and wave is travelling along *x*-direction, hence $\vec{B}$ is along the *z*-direction.

i.e., $\vec{B} = 2.1 \times 10^{-8}\hat{k}\text{J}$.

23. As, P = FA but $P = \frac{I}{c}$

Therefore, $$F = \frac{IA}{c} = \frac{6 \times 12}{3 \times 10^8} = 24 \times 10^{-8} \text{ N.}$$

24. Momentum transferred by one second by EM wave to the mirror is

$$P = \frac{2S_{av}A}{c} = \frac{2 \times 5 \times 20 \times 10^{-4}}{3 \times 10^8}$$

$= 6.67 \times 10^{-11} \text{ kgms}^{-1}$.

25. Given, $v = 2 \times 10^8 \text{ ms}^{-1}$, $\mu_r = 1$, $c = 3 \times 10^8 \text{ ms}^{-1}$

Speed of EM wave in a medium is given by

$$v = \frac{1}{\sqrt{\mu \in}} = \frac{1}{\sqrt{\mu_0 \mu_r (\in_0 \in_r)}}$$

$$= \frac{1}{\sqrt{\mu_0 \in_0}} \times \frac{1}{\sqrt{\mu_r \in_r}}$$

or, $$\in_r = \frac{c^2}{v^2 \mu_r} = \frac{(3 \times 10^8)^2}{(2 \times 10^8)^2 \times 1} = 2.25.$$

26. No. of photons, $$n = \frac{p}{h\nu} = \frac{10 \times 10^3}{6.6 \times 10^{-34} \times 880 \times 10^3}$$

$= 1.171 \times 10^{31}$.

27. In case of EM wave described by the equations of electric field and magnetic field,

$$E_0 = CB_0 \quad ...(1)$$

Velocity of EM wave,

$$c = v\lambda = \frac{\omega}{2\pi}\cdot\lambda = \frac{\omega}{k} \quad [\because k = 2\pi/\lambda]$$

From (1), we have

$$E_0 = \frac{\omega}{k}B_0$$

or $\quad E_0 k = B_0\omega.$

28. Total energy density,

$$\langle U\rangle = \langle U_e\rangle + \langle U_m\rangle$$
$$= \frac{1}{2}\epsilon_0 E_0^2$$
$$= \epsilon_0 E_{rms}^{\ 2} \quad \left[\because E = \frac{E_0}{\sqrt{2}}\right]$$
$$= (8.85 \times 10^{-12}) \times (720)^2$$
$$= 4.58 \times 10^{-6}\ Jm^{-3}.$$

29. The energy density, $U_{av} = \frac{1}{2}\epsilon_0 E_0^2$

$$= \frac{1}{2}\times 8.85\times 10^{-12} C^2/Nm^2 \times (50\ N/C)^2$$
$$= 1.1 \times 10^{-8}\ J/m^3$$

The volume of the cylinder

$$V = 10 \times 50 = 500\ cm^3$$
$$= 5 \times 10^{-4} m^3$$

$\therefore$ The energy contained in volume,

$$U = 1.1 \times 10^{-8} \times 5 \times 10^{-4} = 5.5 \times 10^{-12}\ J.$$

30. As, intensity $= \frac{P}{A} = \frac{3.9\times 10^{26}}{4\pi r^2}$

$$= \frac{3.9\times 10^{26}}{4\times\frac{22}{7}\times(6.96\times 10^8)^2}$$
$$= 5.6 \times 10^7\ Wm^{-2}.$$

31. Given, $\quad E = 11\ keV$

$$= 11 \times 10^3 \times 1.6 \times 10^{-19} J$$

As, $\quad E = \frac{hc}{\lambda}$

or $\quad \lambda = \frac{hc}{E} = \frac{6.6\times 10^{-34}\times 3\times 10^8}{11\times 10^3\times 1.6\times 10^{-19}}$

$$= 1.125 \times 10^{-10}\ m$$
$$= 1.125\ Å.$$

32. Given, $B_0 = 510\ nT = 510 \times 10^{-9}\ T$

As, $E_0 = cB_0 = 3 \times 10^8 \times 510 \times 10^{-9} = 153\ NC^{-1}$.

33. Amplitude of oscillating magnetic field

$$B_0 = \frac{E_0}{c} = \frac{480}{3\times 10^8}$$
$$= 1.6 \times 10^{-6}\ Wbm^{-2}.$$

34. As, $\lambda = \frac{c}{\nu} = \frac{3\times 10^8}{8.2\times 10^6} = 36.6\ m.$

35. The electric and magnetic field vectors are in the same phase in EM wave, but their orientation is perpendicular to each other as well as perpendicular to the direction of propagation of EM wave.

CHAPTER

6

OPTICS

INTRODUCTION

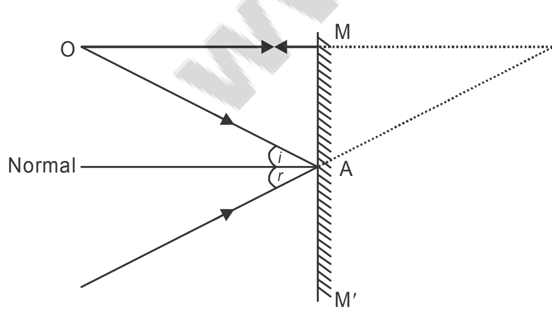
Optics is the branch of Physics that studies the behaviour and properties of light, including its interactions with matter and the construction of instruments that use or detect it. It usually describes the behaviour of visible, ultraviolet and infrared light.

Ray optics were based on the concept that light consists of rays. A ray of light is the straight line path followed by light in going from one point to another.

Wave optics is the branch of optics that studies interference, diffraction, polarization and other phenomena for which the ray approximation of geomateric optics is not valid.

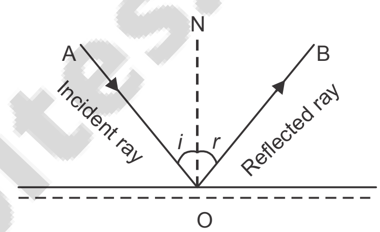
REFLECTION AND REFRACTION OF LIGHT AT PLANE AND SPHERICAL SURFACES

Reflection of Light at Plane Surface: When a ray of light, after being incident on a surface, returns in the same medium along a single well-defined direction, the phenomenon is called reflection.



(i) Laws of Reflection

(*a*) The incident ray, the reflected ray and the normal to the surface all lie in the same plane.



(*b*) The angle of incidence (i) is equal to the angle of reflection (r) *i.e.*, $\angle i = \angle r$.

Reflection at a Plane Surface: The image formed by a plane mirror is always virtual in nature, inverted, erect of the same size and same distance from the object.

(*a*) The size of the image is equal to the size of the object.

(*b*) The image formed by a plane mirror is virtual, erect and laterally inverted.

(*c*) If the mirror is turned through an angle θ, the reflected ray turn through 2θ.

(*d*) The deviation of a ray produced by a plane mirror is $\pi - 2i$, where i is the angle of incidence.

(*e*) When two plane mirrors are held at an angle θ with their reflecting surfaces facing each other and an object is placed between them, images formed by successive reflections. The number of images n is given by

$$n = \left(\frac{360°}{\theta} - 1\right).$$

Reflection at Spherical Surfaces

Spherical mirrors are two types: Concave and convex mirrors. In concave mirror, reflection of light takes place in the bent in concave surface. In convex mirror, reflection of light takes place at bulging out convex surface.

1. **Radius of curvature:** The radius of curvature (R) of a spherical surface is the radius of that sphere, of which it is a part.
2. The parallel rays after reflecting from the concave surface meet at a point called focus. If the rays start from this point, then after reflection, the rays becomes parallel.
3. The distance between the pole of the spherical surface to the focus is called the focal length, which is half the radius of curvature *i.e.*,

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

4. Parallel rays in the concave mirror converse at the focus and produce real image Fig. (*i*), whereas in convex mirror, they appear to diverge and produce virtual image Fig. (*ii*)

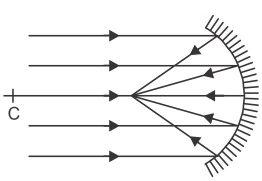


Fig. (*i*)

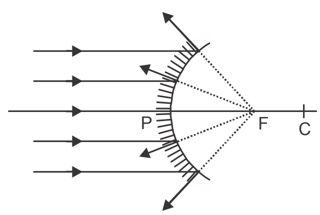


Fig. (*ii*)

Refraction of Light at Plane Surface

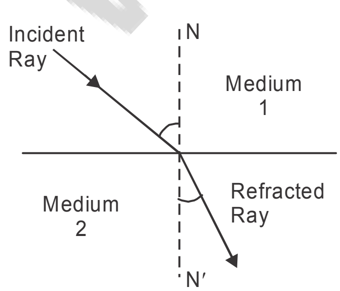
Laws of Refraction

(*a*) The incident ray, the refracted ray and the normal all lie in the same plane.

(*b*) The ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant for any two given media. This is called Snell's law.

The constant is called the refractive index of medium 2 with respect to medium 1.

$${}_1\mu_2 = \frac{\sin i}{\sin r}$$



When a ray of light enters a denser medium it is refracted towards the normal in such a manner than the ratio of sine angle of incidence to the sine of the angle of refraction is constant, is called refractive index (μ).

Refraction occurs because the speed of light is different in different media.

It is maximum in vacuum and has smaller values in other media.

It can be shown that

$${}_1\mu_2 = \frac{c_1}{c_2}$$

c_1 and c_2 are the speeds of light in media 1 and 2.

(***ii***) Absolute refractive index of a medium can be defined as

$$\mu = \frac{c}{c_m}$$

c = speed of light in vacuum

c_m = speed of light in the medium

(***iii***) Medium with larger value of μ is said to be optically denser than another medium with smaller value of μ which is optically rarer.

$$\mu_1 = \frac{c}{c_1} \text{ and } \mu_2 = \frac{c}{c_2}$$

$$\mu_1 c_1 = \mu_2 c_2 \text{ and } {}_1\mu_2 = \frac{\mu_2}{\mu_1}$$

$$\mu_1 \sin i = \mu_2 \sin r$$

(***iv***) Since frequency remains the same as light goes from one medium to another it is obvious that the wavelength must change

$$\frac{c_2}{c_1} = \frac{\lambda_2}{\lambda_1}$$

$$\boxed{\begin{gathered}\mu = \frac{\lambda}{\lambda_m},\ {}_1\mu_2 = \frac{\lambda_1}{\lambda_2}\\ \mu_1\lambda_1 = \mu_2\lambda_2\end{gathered}}$$

(***v***) ***Reversibility of Rays***

$${}_2\mu_1 = \frac{\sin r}{\sin i} = \frac{1}{{}_1\mu_2}$$

$$\boxed{{}_2\mu_1 \times {}_1\mu_2 = 1}$$

(***vi***) ***Apparent Depth***

$$\mu = \frac{\text{Real Depth } (t)}{\text{Apparent Depth}}$$

$$\boxed{\text{Apparent Depth} = \frac{t}{\mu}}$$

$$\boxed{\text{Apparent shift} = t - \frac{t}{\mu} = t\left(1 - \frac{1}{\mu}\right)}$$

MIRROR FORMULA

The relation between focal length of the mirror and distances of the object and image from the mirror is called mirror formula.

Mirror Formula for Concave Mirror: The image formed by concave mirror are:

(*i*) For real image: $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$

(*ii*) For virtual image are: $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$

Mirror Formula for Convex Mirror: The image formed by a convex mirror is always virtual and erect, whatever be the position of the object. *i.e.*, $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$.

TOTAL INTERNAL REFLECTION AND ITS APPLICATIONS

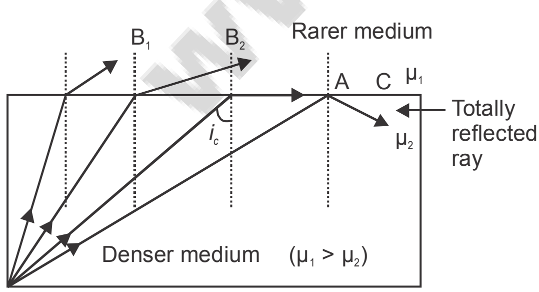
Critical Angle: The angle of incidence (i_C or C) for which the angle of refraction is 90°, is called the critical angle for the pair of media under consideration

$$ {}_1\mu_2 = \frac{\mu_2}{\mu_1} = \frac{\sin C}{\sin 90^\circ} = \sin C. $$

If the second medium is air, first medium has refractive index μ, then

$$ \boxed{\mu = \frac{1}{\sin C}} $$

Total Internal Reflection: If the angle of incidence is more than the critical angle, no refraction takes place and ray is reflected completely into first medium. This phenomenon is called total internal reflection.



Applications of Total Internal Reflection

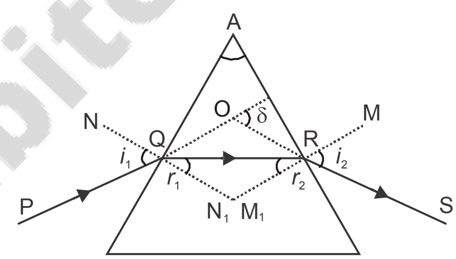
(*i*) Mirage: It is an optical illusion observed due to total internal reflection in deserts and metalled roads on a hot day when the air near the ground is hotter and hence rarer than air above.

(*ii*) The Brillance of Diamonds: The refractive index of diamond is 2.47 and the critical angle for diamond air interfere is 24°. Due to low value of critical angle, a diamond can be cut so as to have a large number of faces. A ray of light entering the diamond from the face undergoes a series of total internal reflection from the other faces, where $i > i_c$. Hence, it shines very brilliantly.

DEVIATION AND DISPERSION OF LIGHT OF A PRISM

Deviation of Light by a Prism

When a ray of light travels through a prism, it bends towards the thicker part of the prism. The deviation produced by the prism is measured by the angle between the incident and emergent rays. The angle, $\delta = i_1 + i_2 - A$ and $A = r_1 + r_2$, where A is refracting angle of prism.

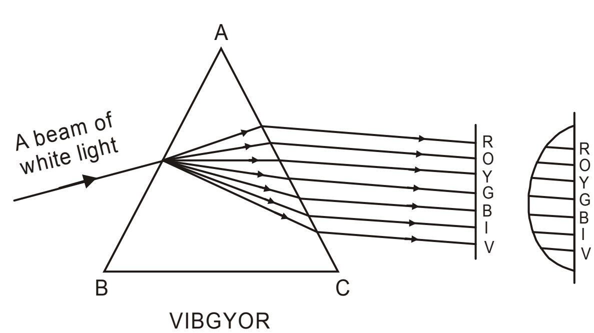


Refractive index of the material of the prism is

$$ \boxed{\mu = \frac{\sin \frac{A+\delta_m}{2}}{\sin \frac{A}{2}}} $$

δ = angle of deviation,
A = refracting angle of prism,
and δ_m = angle of minimum deviation.

Dispersion of Light: The splitting up of white light into seven colours on passing through a transparent medium like a glass prism is called dispersion of light.



Dispersion of composite light takes place because the refractive index of a medium depends on the wavelength of light.

Relation between the two is $\mu = A + \frac{B}{\lambda_2} + \frac{C}{\lambda_4}$

A and B are called Cauchy's constants. Smaller the value of λ, larger is the value of μ. It is maximum for violet colour and minimum for red.

Deviation without Dispersion Achromatic Prism Combination: To combine two prisms of different materials in a way that each cancels the dispersion due to the other. Net dispersion is zero but a net deviation is produced.

$$(\mu_b - \mu_r)A = (\mu_b' - \mu_r')A'$$

b = blue, r = red,

μ = for crown, μ' = for flint glass

$$\boxed{\omega\delta = \omega'\delta'}$$

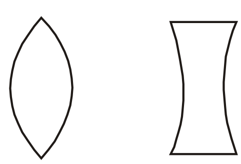
δ = deviation for mean ray

ω = dispersive power

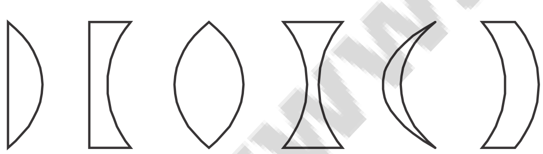
LENS FORMULA

Lens: It is defined as the portion of a transparent medium bounded by two curved surfaces or by one curved surface and the other plane surface.

Spherical Lenses can be



Convex lens Concave lens



(a) (b) (c) (d) (e) (f)

(*a*) Plano Convex; (*b*) Plano Concave;

(*c*) Double Convex; (*d*) Double Concave;

(*e*) Convexo Concave; (*f*) Concavo Convex

Lens Maker's Formulae for Thin Lenses: The relation connecting the focal length of the lens with the radii of curvature of its two surfaces and the refractive index of the lens is called lens maker's formula.

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right),$$

The focal length of convex lens is taken as positive, while that of concave lens is taken as negative.

Lens Formula: The relation between focal length of a lens and distances of object and image from optical centre of the lens.

Convex lens: The image formed may be real or virtual

(*i*) For real image, the required lens formula,

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

(*ii*) For virtual image, the required lens formula,

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

Concave Lens: In concave lens, the image formed is always virtual, the required lens formula,

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

MAGNIFICATION OF LENS

The ratio of the image formed by the lens to the size of image is called magnification produced by lens.

If u and v are the distances of object and image from the optical centre of the lens, and O and I are their sizes, the lateral magnification

$$m = \frac{I}{O} = \frac{v}{u} \quad \text{or} \quad m = \frac{f - v}{f} \quad \text{or} \quad m = \frac{f}{f + u}$$

Linear magnification, $m = \frac{h_2}{h_1}$

For real image of convex lens, $m = \frac{-h_2}{h_1} = \frac{v}{u}$

When image formed is virtual, $m = \frac{h_2}{h_1} = \frac{v}{u}$

In concave lens, image formed is always virtual,

$$m = \frac{h_2}{h_1} = \frac{v}{u}$$

POWER OF A LENS

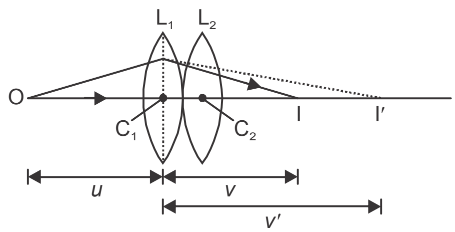
Power of lens is defined as the ability of the lens to converge a beam of light falling on the lens, $P = \frac{1}{f}$.

If f is taken in m, then P is expressed in dioptre (D).

$$\therefore \quad P\ (\text{dioptre}) = \frac{1}{f(\text{m})}$$

COMBINATION OF THIN LENSES IN CONTACT

A single lens which forms the image of the given object at the same point as it is formed by the combination of two more lenses, is called an equivalent lens. Equivalent power, $P = P_1 + P_2$.



MICROSCOPE AND ASTRONOMICAL TELESCOPE

Simple Microscope: A convex lens of small focal length is called a simple microscope or a magnifying glass.

Magnifying power of microscope, $M = \left(1+\frac{D}{f}\right) = \frac{\beta}{\alpha}$

If image formed at infinity $m = \frac{D}{f}$

β = angle subtended by final image (as seen through microscope).

α = angle subtended by the object, when both are at least distance of distinct vision.

D = least distance of distinct vision.

Compound Microscope: A compound microscope is a two lenses system f_0 (object) and f_e (eye piece) of focal lengths. Its magnifying power is very large as compared to the simple microscope,

$$\text{Magnifying power} = M = \frac{\beta}{\alpha} = m_0 \times m_e$$

$$= \frac{v_0}{u_0}\left(1+\frac{D}{f_e}\right)$$

where $\left(1+\frac{D}{f_e}\right) = \frac{v_e}{v_e}$ and $\frac{v_0}{u_0} = m_0$

If the final image is formed at infinity,

then $$m = \frac{v_0}{u_0}\cdot\frac{D}{f_e}$$

Astronomical Telescope: A telescope used to see heavenly bodies is called astronomical telescope. It produces a virtual and inverted image. As such bodies are round, the inverted image does not affect the observation.

Magnifying Power is also called angular magnification. It is defined as the ratio of the angle (β) subtended by the final image at the eye to the angle (α) subtended by the object at the eye.

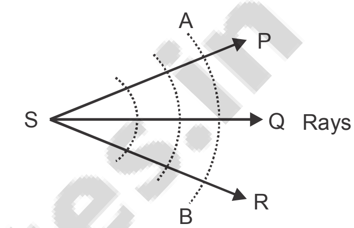
$$\boxed{m \approx -\frac{f_0}{f_e}}$$

If final image is formed at the least distance of distinct vision

$$\boxed{m = -\frac{f_0}{f_e}\left(1+\frac{f_e}{D}\right)}$$

WAVE OPTICS: WAVEFRONT AND HUYGEN'S PRINCIPLE

A surface drawn at any instant in the medium affected by the waves originated from a source on which each particle vibrates in the same phase is called wavefront.



Spherical Wavefront: A spherical wavefront is produced by a point source of light. It is because, the laws of all such points, which are equidistant from the point source, is a sphere.

Cylindrical Wavefront: When the source of light is linear in shape a cylindrical wavefront is produced. It is because all the points, which are equidistant from the linear source, lie on the surface of a cylinder.

Plane Wavefront: A small part of a spherical or cylindrical wavefront originating from a distant source will appear plane and hence it is called a plane wavefront.

Huygen's Principle

It states that

(*a*) Each point on a wavefront acts as a fresh source of secondary wavelets, which spread out with the speed of light in that medium.

(*b*) The new wavefront at any later time is given by the forward envelope of the secondary wavelets at that time.

LAWS OF REFLECTION AND REFRACTION USING HUYGEN'S PRINCIPLE

Hugen's proposed the wave theory of light. These secondary wavelets transmits with the velocity of light in the same medium. A wavefront is a real or imaginary surface where the phase of oscillation is the same. Huygen's principle of wave theory of light is used to prove the laws of reflection and laws of refraction.

INTERFERENCE

The phenomenon of non-uniform distribution of energy in the medium due to superposition of two light waves is called interference.

Interference in Thin Films: For films to appear bright

$$2\mu t \cos r = \frac{2n+1}{2}\cdot\lambda, \text{ where } n = 0, 1, 2, 3, \ldots$$

For films to appear dark

$$2\mu t \cos r = n\lambda, \text{ where } n = 0, 1, 2, 3, \ldots$$

In case the film is of negligible thickness, *i.e.,* $t << \lambda$, then the net path = $\frac{\lambda}{2}$, hence the film will appear dark.

t = thin film thickness; μ = refractive index

r = angle of reflection

Superposition of Waves: If two waves of the same frequency having intensities I_1 and I_2 arrive at a point with phase difference ϕ, then the resultant intensity at that point is

$$I_R = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$$

If $\quad I_1 = I_2$, then $\boxed{I_R = 4I\cos^2(\phi/2)}$

$$I_{max} = 4I I_{min} = 0$$

YOUNG'S DOUBLE SLIT EXPERIMENT AND EXPRESSION FOR FRINGE WIDTH

Alternate dark and bright bands are obtained on a screen placed in front of the slits. These are called interference fringes.

Phase difference = $\frac{2\pi}{\lambda}$ times path difference

Let 'd' be the distance between two slits and 'D' the distance of the screen from the two slits. 'x' be the distance of a point P on the screen from the centre O.

For Maxima

$$\frac{xd}{D} = m\lambda, \ m = 0, 1, 2, \ldots$$

$$x = \frac{m\lambda D}{d}$$

For Minima

$$\frac{xd}{D} = \left(m + \frac{1}{2}\right)\lambda, \ m = 0, 1, 2, \ldots$$

$$x = \left(m + \frac{1}{2}\right)\frac{\lambda D}{d}$$

Fringe Width (β): Distance between two successive bright (or dark) fringes

$$\beta = \frac{\lambda D}{d}$$

Position of the nth bright fringes

$$\theta_n = \frac{y_n}{D} = \frac{n\lambda}{d}$$

Displacement of Fringe: If a thin transparent plate of refractive index μ and thickness t is introduced in front of one of the two slits, then fringe width remains same, but the whole fringe pattern shifts by a distance = $(\mu - 1)t\cdot\frac{D}{d}$.

COHERENT SOURCES ON SUSTAINED INTERFERENCE OF LIGHT

Coherent Sources: Two sources which emit light with respect to space and time with zero or a constant phase difference are called coherent sources.

Sustained Interference of Light: Interference pattern in which the positions of maxima and minima remain fixed is called a sustained interference.

The fundamental condition for the sustained interference is that the two sources should be coherent. Since two independent sources cannot be coherent, a sustained interference pattern can be obtained only if two sources are obtained from a single parent source.

DIFFRACTION DUE TO A SINGLE SLIT

The phenomenon of bending of light around corners, or spreading of light into the geometrical shadow of an obstacle is called diffraction.

A narrow slit of width a is placed at a distance D from the screen. When the slit is illuminated with monochromatic light of wavelength λ, then alternate bright and dark bands of light are formed on both sides of the central maximum.

Condition for dark fringe

$$a\sin\theta = m\lambda, \ m = 1, 2, 3, \ldots$$

$$\sin\theta = \frac{m\lambda}{a}$$

Condition for bright fringe

$$\text{Further } a\sin\theta = \left(m + \frac{1}{2}\right)\lambda, \ m = 1, 2, 3, \ldots$$

$$\sin\theta = \left(m + \frac{1}{2}\right)\frac{\lambda}{a}$$

Angular width of central maximum = $\frac{2\lambda}{a}$

Width of central maximum = $\frac{2\lambda D}{a}$

D = Distance of the screen from the slit.

a = Width of the slit

WIDTH OF CENTRAL MAXIMUM

The central maximum extends upto distance y_1 (the distance of first secondary minimum) on both sides of the centre of the screen.

Thus, width of the central maximum

$$\beta_0 = 2y_1$$

$$\therefore \qquad y_1 = \frac{D\lambda}{a}$$

$$\therefore \qquad \beta_0 = \frac{2D\lambda}{a}$$

Since $\qquad \beta_0 = 2\beta$

Hence, the central maximum is twice as wide as any other secondary maximum or minimum.

Fresnel's Distance (D_F): It is the distance of the screen from the slit at which the spreading of light due to diffraction becomes equal to the size of the slit.

$$\frac{D_F\lambda}{a} = a \quad \text{or} \quad D_F = \frac{a^2}{\lambda}$$

RESOLVING POWER OF A MICROSCOPE AND ASTRONOMICAL TELESCOPES

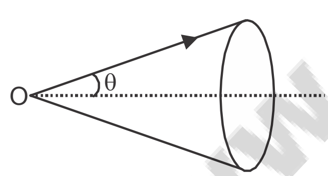
Resolving Power of a Microscope: It is defined as the reciprocal of the least separation between two close objects, so that they appear just separated, when seen through microscope.

The least separation between two objects,

$$d = \frac{\lambda}{2\mu \sin\theta} \quad \text{where, } \mu \rightarrow \text{refractive index}$$

$$\text{Resolving power of a microscope} = \frac{1}{d} = \frac{2\mu\sin\theta}{\lambda}$$

where, $\theta \rightarrow$ half angle and $\mu \sin \theta \rightarrow$ numerical aperture.



Resolving Power of Astronomical Telescope: It is defined as the reciprocal of the smallest angular separation between two distinct *objects*, so that they appear just separated, when seen through the telescope.

The smallest angular separation between two objects, so that they appear just separated is found to be

$$d\theta = \frac{1.22\lambda}{D}$$

where D $\rightarrow$ diameter of objective

$$\therefore \text{ Resolving of an astronomical telescope} = \frac{D}{1.22\lambda}.$$

POLARISATION

If the vibrations take place equally in all directions in a plane perpendicular to the direction of propagation the wave is called an unpolarized wave. If the vibrations are limited to just one direction in a plane perpendicular to the direction of propagation, the wave is said to be polarised or plane polarised. The phenomenon of the restriction of the vibrations to a particular direction is called polarisation.

PLANE OF POLARISED LIGHT

It is the light in which the vibration of the light (vibrations of the electric vector) are restricted in a particular plane.

Plane of Polarisation: The plane perpendicular to the plane containing the vibrations of plane polarised light is called plane of polarisation.

BREWSTER'S LAW

According to this law, when unpolarized light is incident at an angle called polarising angle, i_p on an interface separating air from a medium of refractive index μ, then the reflected light is fully polarized, provided

$$\mu = \tan\, i_p$$

Malus Law: It states that when a completely plane polarised light beam is incident on an analyser, the intensity of the emergent light veries as the square of the cosine of the angle between the planes of transmission of analyser and polariser. When plane polarised light passes through a polariser, then

$$I = I_0 \cos^2\theta$$

I_0 = maximum intensity of the plane polarised light

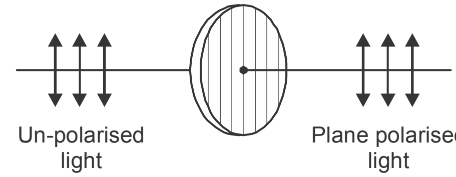
I = intensity when the angle between the axes of the two crystals is θ, after it comes out of the second polariser.

USES OF PLANE POLARISED AND POLAROIDS

1. Polaroids are used in sunglasses, they protect the eyes from glare.
2. The polaroids are used in window panes of train and an aeroplane.
3. These are used as filters in photography to produce and detect the plane polarised light in the laboratory.

Polaroids: Polaroids are thin and large sheets of crystalline polarising material capable of producing plane polarised beams of light.

A polaroid has a charactertistic plane called transmission plane. When unpolarised light falls on a polaroid, only the vibrations parallel to the transmission plane get transmitted.



EXERCISE

1. A fish looking up through the water sees the outside world contained in a circular horizon. If the refractive index of water is $\frac{4}{3}$ and the fish is 12 cm below the surface of water, the radius of the circle in cm is

A. $12 \times 3 \times \sqrt{5}$ B. $12 \times 3 \times \sqrt{7}$

C. $\frac{12 \times 3}{\sqrt{7}}$ D. $4 \times \sqrt{5}$

2. A ray of light passes from vacuum into a medium of refractive index *n*. If the angle of incidence is twice the angle of refraction then the angle of incidence is

A. $\cos^{-1}\left(\frac{n}{2}\right)$ B. $\sin^{-1}\left(\frac{n}{2}\right)$

C. $2\cos^{-1}\left(\frac{n}{2}\right)$ D. $2\sin^{-1}\left(\frac{n}{2}\right)$

3. A ray of light entering from air to glass (refractive index 1.5) is partly reflected and partly refracted. If the incident and the reflected rays are at right angles to each other, the angle of refraction is

A. $\sin^{-1}\left(\sqrt{\frac{2}{3}}\right)$ B. $\sin^{-1}\left(\frac{\sqrt{2}}{3}\right)$

C. $\sin^{-1}\left(\frac{2}{\sqrt{3}}\right)$ D. $\sin^{-1}\left(\frac{1}{\sqrt{3}}\right)$

4. An air bubble inside a glass slab appears to be 6 cm deep when viewed from one side & 4 cm deep when viewed from the opposite side. The thickness of the slab is

A. 10 cm B. 6.67 cm

C. 15 cm D. 2.35 cm

5. A thin prism P_1 with angle 4° and made from glass of refractive index 1.54 is combined with another thin prism P_2 made from glass of refractive index 1.72 to produce disperssion without deviation. The angle of the prism P_2 is

A. 5.33° B. 4°

C. 3° D. 2.6°

6. How much water should be filled in a container, 21 cm in height, so that it appears half filled when viewed from the top of the container. Given refractive index of water = $\frac{4}{3}$

A. 8.0 cm B. 10.5 cm

C. 12.0 cm D. 14.0 cm

7. A real image formed by a convace mirror is 4.5 times the size of the object. If the mirror is 20 cm from the object, its focal length is

A. $\frac{90}{11}$ cm B. $\frac{120}{11}$ cm

C. $\frac{150}{11}$ cm D. $\frac{180}{11}$ cm

8. Two mirrors at an angle θ produce, 5 images of a point. The number of images produced, when θ is decreased to 30° is

A. 8 B. 11

C. 15 D. 20

9. The image formed by a convex mirror of focal length 20 cm is half the size of the object. The distance of the object from the mirror is

A. 10 cm B. 20 cm

C. 30 cm D. 40 cm

10. An object is placed at 20 cm from a convex mirror of focal length 20 cm. The distance of the image from the pole of the mirror is

A. infinity B. 10 cm

C. 15 cm D. 40 cm

11. The refractive index of water for a light going from air to water be 1.33, what will be the refractive index of light going from water to air?

A. 0.25 B. 0.75

C. 0.55 D. 0.95

12. For a concave mirror the magnification of a real image was found to be twice as great when the object was 15 cm from the mirror as it was 15 cm from the mirror as it was when the object was 20 cm from the mirror. The focal length of the mirror is

A. 5.0 cm B. 7.5 cm

C. 10 cm D. 12.5 cm

13. The focal length of a glass lens in air is 10 cm. Its focal length in water will be (refractive of glass = 1.5 refractive index of water = 4/3)

A. 2.5 cm

B. 5 cm

C. 20 cm

D. 40 cm

14. A thin coverging lens of refractive index 1.5 has a power of +0.5 D. When this lens is immersed in a liquid, it acts as diverging lens of focal length 100 cm. The refractive index of the liquid is

A. $\frac{4}{3}$ B. $\frac{3}{2}$

C. $\frac{5}{3}$ D. 2

15. The distance between an object and its real image formed by a lens is D. If the magnification is m, the focal length of the lens is

A. $\frac{(m-1)D}{m}$ B. $\frac{mD}{m+1}$

C. $\frac{(m-1)D}{m^2}$ D. $\frac{mD}{(m+1)^2}$

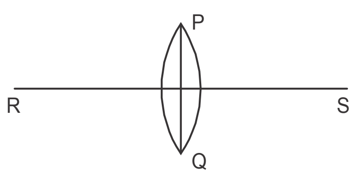
16. A convex lens of focal length 40 cm is in contact with a concave lens of focal length 25 cm. The power of the combination is dioptres is

A. −1.5 B. −6.5
C. +6.5 D. +6.67

17. Two lenses of power + 12 D and –2D are in contact. The focal length of the combination is

A. 10 cm B. 12.5 cm
C. 16.6 cm D. 8.33 cm

18. The figure shows an equiconvex lens of focal length f. If the lens is cut along PQ, the focal length of each half will be



A. $\frac{f}{2}$ B. f
C. $2f$ D. $4f$

19. A short linear object of length b lies along the axis of a concave mirror of focal length f at a distance μ from pole of the mirror. The size of the image is approximately equal to

A. $b\left(\frac{u-f}{f}\right)^{1/2}$ B. $b\left(\frac{u-f}{f}\right)$

C. $b\left(\frac{f}{u-f}\right)^{1/2}$ D. $b\left(\frac{f}{u-f}\right)^2$

20. The image of an object placed in front of a concave mirror of focal length 12 cm is formed at a point which is 10 cm more distant from the mirror than the object. The magnification of the image is

A. 1.5 B. 2
C. 2.5 D. 3

21. An object is moving towards a concave mirror of focal length 24 cm. When it is at a distance of 60 cm from the mirror its speed is 9 cm/s. The speed of its image at the instant is

A. 4 cm/s towards the mirror
B. 9 cm/s towards the mirror
C. 4 cm/s away from the mirror
D. 9 cm/s away from the mirror

22. An object is placed first at infinity and then at 20 cm from the object side focal plane of a convex lens. The two images thus formed are 5 cm apart. The focal length of the lens is

A. 5 cm B. 10 cm
C. 15 cm D. 20 cm

23. A ray of light suffers minimum deviation, when incident on a 60° prism of refractive index $\sqrt{2}$. The angle of incidence is:

A. 15° B. 30°
C. 60° D. 45°

24. A beaker is filled with water to a height of 10.0 cm. A microscope is focussed on a mark at the bottom of the beaker. Water is now replaced by a liquid of refractive index of 1.60 upto the same height. By what distance would the microscope have to be moved to focus on the mark again. Refractive index of water is 1.33

A. 1.25 cm upwards B. 1.25 cm downwards
C. 1.27 cm upwards D. 1.27 cm downwards

25. A ray of light is incident at angle i on one surface of a prism of small angle A and emerges normally from the opposite surface. If the refractive index of the material of the prism is μ, the angle of incidence i is nearly equal to

A. $\frac{A}{\mu}$ B. $\frac{A}{2\mu}$

C. μA D. $\frac{\mu A}{2}$

26. A needle of length 5 cm, placed 45 cm from a lens, forms an image on a screen placed 90 cm on the other side of the lens. Identify the type of lens and find its focal length what is the size of the image?

A. 30 cm, 20 cm B. 40 cm, 20 cm
C. 20 cm, 10 cm D. 30 cm, 10 cm

27. A concave mirror of focal length f in air is placed in a medium of refractive index 2. Its focal length of mirror in the medium is

A. $\frac{f}{2}$ B. f
C. $2f$ D. $4f$

28. For a prism the refractive index (μ) is related to wavelength (λ) as $\mu = A + B/\lambda^2$. The dispersive power is large if

A. A is large B. B is large
C. μ is large D. A and μ are large

29. A dentist has a small mirror of focal length 16 mm. He views the cavity in the tooth of a patient by holding the mirror at a distance of 8 mm from the cavity. The magnification is

A. 2 B. 3.2
C. 1.5 D. 1.8

30. An object is placed asymmetrically between two plane mirrors inclined at an angle of 72°. The number of images formed is
A. 2 B. 0
C. 4 D. 5

31. A car is fitted with a convex mirror of focal length 20 cm. A second car 2 m broad and 1.6 m height is 6 cm away from the first car. The position of the second car as seen in the mirror of the first car is
A. 20.48 cm B. 18.49 cm
C. 17.45 cm D. 19.35 cm

32. A point object is placed at a distance of 30 cm from a convex mirror of a focal length 30 cm. The image will format
A. pole B. 15 cm behind the mirror
C. infinity D. no image will be found

33. A convex mirror forms an image one-fourth the size of the object. If object is at a distance of 0.5 m from the mirror, the focal length of mirror is:
A. 0.14 m B. –2.4 m
C. –1.5 m D. 0.17 m

34. An object is placed a distance of 10 cm from a concave mirror of radius of curvature 0.6 m. Which of the following statements is in correct?
A. The image formed is real
B. The image is 0.5 times the size of the object
C. The image is 1.5 times the size of the object
D. The image is formed at a distance for 15 cm from the mirror

35. An astronomical telescope of ten fold angular magnification has a length of 44 cm. The focal length of the objective is:
A. 20 cm B. 10 cm
C. 30 cm D. 40 cm

36. A lamp is hanging at 40 cm from the centre of table. If its height is increase by 10 cm, the illuminance of the lamp will decreases by
A. 27% B. 36%
C. 20% D. 10%

37. In a photometer, two sources of light when placed at 30 cm and 50 cm respectively produce shadows of equal intensities. Their candle powers are in the ratio of
A. $\frac{13}{15}$ B. $\frac{15}{13}$
C. $\frac{16}{25}$ D. $\frac{9}{25}$

38. A book can be read, if it is placed at a distance of 50 cm from a source of 1 Cd. At what distance should the book be placed, if the source is of 16 Cd?
A. 2 m B. 4 m
C. 3 m D. 6 m

39. A point source of light moves in a straight line parallel to a plane table. Consider a small portion of table directly below the line of movement of the source. The illuminace at this portion varies with this distance r from the source as
A. $E \propto \frac{1}{r^3}$ B. $E \propto \frac{1}{r^4}$
C. $E \propto \frac{1}{r^2}$ D. $E \propto \frac{1}{r}$

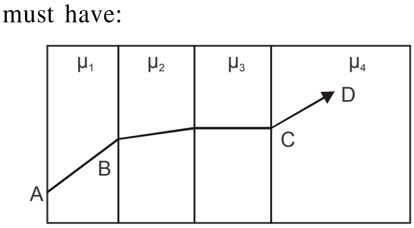
40. A man has a concave shaving mirror of focal length 0.2 m. How for should the mirror be held from his face in order to give an image of two magnification?
A. 0.3 m B. 0.4 m
C. 0.2 m D. 0.1 m

41. A beam of light is incident at 60° to a plane surface. The reflected and refracted rays are perpendicular to each other, then refractive index of the surface is
A. $\sqrt{3}$ B. $\frac{1}{\sqrt{3}}$
C. $2\sqrt{3}$ D. $\frac{1}{2\sqrt{3}}$

42. The focal length of a concave mirror is 20 cm. Where an object must be placed to form an image magnified two times, when the image is real?
A. 10 cm from the mirror
B. 20 cm from the mirror
C. 30 cm from the mirror
D. 15 cm from the mirror

43. A double convex lens of focal length 20 cm is made of glass of refractive index $\frac{3}{2}$. When placed completely in water $(a_{\mu_w}) = \frac{4}{3}$, its focal length will be:
A. 17.7 cm B. 22.5 cm
C. 80 cm D. 15 cm

44. A ray of light passes through four transparent media with refractive indices μ_1, μ_2, μ_3 and μ_4 as shown in fig. The surfaces of all media are parallel. If the emergent ray CD is parallel to the incident ray AB, we must have:



A. $\mu_3 = \mu_4$ B. $\mu_4 = \mu_1$
C. $\mu_1 = \mu_2$ D. $\mu_2 = \mu_3$

45. A short object of length L is placed along the principal axis of concave mirror away from focus. The object distance is u. If the mirror has focal length f, what will be the length of the image (Take $L << |u - f|$)

A. $\left(\frac{f}{u-f}\right)L$ B. $\frac{2fL}{(u-f)^2}$

C. $\frac{f^2}{(u-f)^2}L$ D. $\frac{2f^2L}{(u-f)}$

46. Critical angle is 30° when light travels from a denser medium to rarer medium. Then, the velocity of light in the medium will be

A. $\frac{c}{2}$ B. $\frac{c}{3}$

C. c D. $2c$

47. In a two slit experiment with monochromatic light, fringes are obtained on a screen placed at some distance from the 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 the slits is 10^{-3} m. Calculate wavelength of light used

A. 4000 Å B. 6000 Å

C. 8000 Å D. 2000 Å

48. In a Young's double slit experiment, the distance between the slits is 1 mm and the distance of the screen from the slits is 1 m. If light of wavelength 6000 Å is used then find the distance between the second dark fringe and fourth bright fringe.

A. 1.4 mm B. 1.5 mm

C. 1.3 mm D. 5.1 mm

49. For light of wavelength 6×10^{-7} m, it is found that for near normal incidence in a thin film of air, 9 fringes are observed between two points. Calculate the difference of film thickness between these points:

A. 27×10^{-8} m B. 27×10^{-4} m

C. 27×10^{-7} m D. 27×10^{-10} m

50. A 25 Cd lamp and A 100 Cd lamp are placed at the ends of a photometer bench 200 m long. At what point on the bench will the screen of the photometer be equally illuminated by both lamps.

A. $\frac{3}{2}$ m B. $\frac{1}{2}$ m

C. $\frac{7}{2}$ m D. $\frac{2}{3}$ m

51. An equilateral prism is placed on the prism table of a spectrometer in the position of minimum deviation. If the angle of incidence is 60°, the angle of deviation of the rays is

A. 60° B. 45°

C. 90° D. 30°

52. The near point of a short-sighted person is 10 cm and he desires to read a book 30 cm away from him. The person of the lens to be used by him is

A. –6.66 D B. –7.33 D

C. –5.33 D D. –10.2 D

53. Aperture of the human eye is 2 mm. Assuming the mean wavelength of light to be 5000 Å, the angular resolution limit of the eye is

A. 2 min B. 1 min

C. 0.5 min D. 1.5 min

54. In Young's double slit experiment the intensity of light at a point on the screen where the path difference is λ is I, λ being the wavelength of light used. The intensity at a point where the point difference is $\frac{\lambda}{4}$ will be

A. $\frac{I}{4}$ B. $\frac{I}{2}$

C. I D. zero

55. In the double-slit experiment, the distance of the second dark fringe from the central line is 3 mm. The distance of the fourth bright fringe from the central line is

A. 6 mm B. 8 mm

C. 12 mm D. 16 mm

56. Air has refractive index 1.003. The thickness of an air column, which will have one more wavelength of Yellow light (6000 Å) than in the same thickness of vacuum is

A. 2 mm B. 2 cm

C. 2 m D. 2 km

57. A person sets up Young's experiment using a sodium lamp and placing two slits 1 metre from a screen. The person is not sure of slit separation and he varies the separation and finds that the interference fringes disappear if the slits are too far apart. The angular resolution of his eye is $\frac{1}{60}$. How far apart are the slits when he just cannot see the interference pattern [λ = 5890 Å]?

A. 5 mm B. 4.01 mm

C. 2.025 mm D. 3.025 mm

58. In Young's double slit experiment we get 60 fringes in the field of view if we use light of wavelength 4000 Å. The number of fringes we will get in the same field of view if we use light of wavelength 6000 Å is

A. 40 B. 90

C. 60 D. 50

59. With a monochromatic light, the fringe width obtained is a double slit experiment is 1.33 mm. If the whole set up is immersed in water of refractive index 1.33, the new fringe with will be

A. 1.33 mm B. 1 mm
C. 1.33 × 1.33 mm D. $\frac{1.33}{2}$ mm

60. Light of wavelength 6328 Å is incident normally on a slit having a width of 0.2 mm. The distance of the screen from the slit is 0.9 m. The angular width of the central maximum is
A. 0.09 degrees B. 0.72 degrees
C. 0.18 degrees D. 0.36 degrees

61. In an experiment λ = 480 nm, distance between two coherent source is 0.4 mm, distance between the sources and the screen is 100 cm. Distance between 3rd and 7th bright bands on same side of central bright band is:
A. 4.8 mm B. 5.2 mm
C. 6.8 mm D. 9.4 mm

62. A slit is illuminated by red light of wavelength 6500 Å. The first minimum is obtained at $\theta = 30°$. The width of the slit is
A. 3200 Å B. 1.24 micron
C. 6.5×10^{-4} mm D. 2.6×10^{-4} cm

63. Light of wavelength 540 mm is falling on a wedge of glass (refractive index 1.5) Interference takes place between the rays reflected from top and bottom faces of the wedge. The wedge increases in thickness from one dark fringe to the next by
A. 90 nm B. 180 nm
C. 280 nm D. 360 nm

64. The luminous efficiency of a lamp is 5 lm/ω and its luminous intensity is 35 cd. The power of the lamp is
A. 80 W B. 176 W
C. 88 W D. 36 W

65. If a lamp hanging 2 m directly above a table is lowered by 0.5 m, the intensity of illumination on the table increases by about
A. 22% B. 78%
C. 44% D. 56%

66. Light of wavelength 5000 Å is made to pass through a slit of width 2 mm. Up to what distance is ray optics a good approximation?
A. 5 m B. 7 m
C. 8 m D. 4 m

67. The focal length of the objective lens of a telescope is 30 cm and that of its eye lens is 3 cm. It is focussed on a scale 2 m distant from it. The distance of the objective lens from the eye lens to see with relaxed eye is
A. 38.3 cm B. 42.7 cm
C. 63.5 cm D. 72.3 cm

68. Light wave from two coherent sources of intensity ratio 81 : 1 produces interference. The ratio of the maxima and minima is the interference pattern will be
A. 25 : 16 B. 20 : 18
C. 16 : 25 D. 36 : 25

69. A Galileo telescope has on objective of focal length 100 cm and magnifying power 50. The distance between the two lenges in normal adjustment is
A. 42 cm B. 98 cm
C. 102 cm D. 36 cm

70. A ray of light is incident on the surface of a glass plate of refractive index 1.536 at the polarizing angle. The angle of refraction is
A. 33°4′ B. 31°5′
C. 29°2′ D. 21°1′

71. Width of two slits in Young's experiment are in the ratio 4 : 1. What is the ratio of amplitudes of light waves from them?
A. 2 : 1 B. 3 : 1
C. 1 : 2 D. 2 : 3

72. Light of wavelength 600 nm is incident on the aperture of size 2 mm. Calculate the distance up to which the ray of light can travel, such that its spread is less than the size of the aperture.
A. 6.67 cm B. 6.67 m
C. 8.87 m D. 2.35 cm

73. In a medium, polarising angle is 60°. The critical angle for this medium will be
A. 35°16′ B. 36°15′
C. 29°18′ D. 31°15′

74. Two slits are 1 mm apart and same slits are 1 m apart on a screen. Find out fringe separation, when light of wavelength 500 nm is used.
A. 0.5 mm B. 0.7 mm
C. 0.1 mm D. 0.2 mm

75. Two slits in Young's experiment are 0.02 cm apart. The interference fringes for light a wavelength 6000 $\times 10^{-8}$ cm are formed on a screen 80 cm away. The distance of the fifth bright fringe is
A. 2.5 cm B. 1.2 cm
C. 2.4 cm D. 3.1 cm

76. In a certain region A to B in a thin film. How we get 10 fringes with light of wavelength 4125 Å. How many fringes will be observed in the same region with wavelength 5893 Å?
A. 4 B. 5
C. 6 D. 7

77. A star is moving towards the earth with a speed of 9.0×10^6 m/sec. If the wavelength of a particular spectral line emitted by it is 6000 Å, then the value of apparent wavelength is
A. 5000 Å B. 3250 Å
C. 5820 Å D. 4315 Å

78. The velocity of moving galaxy is 300 kms^{-1} and apparent change in wavelength of spectral line emitted from the galaxy is observed as 0.5 nm. Then, the actual wavelength of the spectral line is

A. 6000 Å B. 4500 Å
C. 5000 Å D. 3000 Å

79. How fast a person should drive his car so that the red signal of light appears green? (wavelength for red colour = 6200 Å and wavelength of green colour = 5400 Å)

A. 3.9×10^7 m/sec B. 2×10^8 m/sec
C. 7×10^7 m/sec D. 1.5×10^8 m/sec

80. A plane wavefront ($\lambda = 6 \times 10^{-7}$ m) falls on a slit 0.4 mm wide. A convex lens of focal length 0.8 m placed behind the slit focusses the light on a screen. What is the linear diameter of secondary maxima?

A. 3 mm B. 9 mm
C. 12 mm D. 6 mm

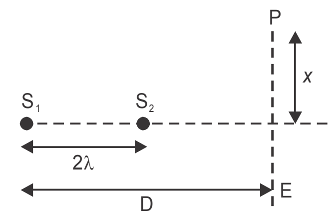
81. A zone plate of focal length 60 cm behaves as a convex lens. If wavelength of incident light is 6000 Å, then radius of first half period zone plate will be

A. $\sqrt{6} \times 10^{-8}$ m B. 6×10^{-8} m
C. 6×10^{-4} m D. 36×10^{-8} m

82. Light of wavelength 6×10^{-5} cm falls on a screen at a distance of 100 cm from a narrow slit. The width of the slit, if the first minima lies 1 mm on either side of the central maxima is

A. 0.06 cm B. 0.09 cm
C. 0.13 cm D. 0.18 cm

83. Two coherent point sources S_1 and S_2 vibrating in phase emit light of wavelength λ. The separation between them is 2λ. The light is well collected on a screen placed at a distance D >> λ from the slit S_1. The minimum distance so that intensity at P is equal to intensity at O is



A. $\sqrt{2}$ D B. $\sqrt{3}$ D
C. $\sqrt{5}$ D D. D

84. In Young's double slit experiment interference fringes 1° part are produced on the screen the slit separation is

A. 0.546 mm
B. 0.0337 mm
C. 0.246 mm
D. 0.0927 mm

85. The diameter of the lens of a telescope is 0.61 m. Wavelength of light is 5000Å. The resolution power of telescope is

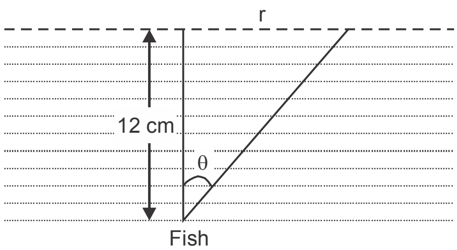
A. 2×10^3 B. 2×10^4
C. 1×10^6 D. 2×10^5

ANSWERS

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
C	C	B	C	C	C	D	B	B	B
11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
B	C	D	C	D	A	A	C	D	A
21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
C	B	D	C	C	D	B	B	A	D
31	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
D	B	D	C	B	B	D	A	C	D
41	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**
A	C	C	B	C	A	B	B	C	D
51	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**
A	A	B	B	B	A	C	A	B	D
61	**62**	**63**	**64**	**65**	**66**	**67**	**68**	**69**	**70**
A	B	B	C	B	C	A	A	B	A
71	**72**	**73**	**74**	**75**	**76**	**77**	**78**	**79**	**80**
A	A	A	A	B	D	C	C	A	D
81	**82**	**83**	**84**	**85**					
C	A	B	B	C					

EXPLANATORY ANSWERS

1. Since θ is the crticial angle, we have $\sin\theta = \frac{3}{4}$



$$\therefore \quad \cos\theta = \sqrt{1-\frac{9}{16}} = \frac{\sqrt{7}}{4}$$

$$\tan\theta = \frac{3}{\sqrt{7}}$$

$$\text{But } \tan\theta = \frac{r}{12} \Rightarrow \frac{r}{12} = \frac{3}{\sqrt{7}} \Rightarrow r = \frac{12\times 3}{\sqrt{7}}.$$

2. $$n = \frac{\sin i}{\sin(i/2)} = \frac{2\sin(i/2)\cos(i/2)}{\sin(i/2)}$$
$$= 2\cos(i/2) \quad \text{or} \quad i = 2\cos^{-1}(n/2).$$

3. Clearly $i = 45°$

$$\frac{\sin 45°}{\sin r} = \frac{3}{2} \Rightarrow r = \sin^{-1}\left(\frac{\sqrt{2}}{3}\right).$$

4. Let the thickness of the slab be t and the real depth of the bubble from the first side be x

Then, $\frac{x}{6} = \frac{t-x}{4} = 1.5 \Rightarrow x = 9$ cm

$t - x = 6$ cm

$\therefore \quad t = 15$ cm.

5. $$A' = \left(\frac{n-1}{n'-1}\right)A = \frac{0.54}{0.72}\times 4° = 3°.$$

6. $$\frac{x}{21-x} = \frac{4}{3} \Rightarrow x = 12 \text{ cm}.$$

7. $$f = \frac{uv}{u+v} = \frac{(20)(20\times 4.5)}{20+(20\times 4.5)} = \frac{180}{11}\text{cm}.$$

8. Number of images $= \frac{360°}{\theta} - 1$

$$\therefore \quad 5 = \frac{360}{\theta} - 1$$

$$\therefore \quad \theta = \frac{360}{6} = 60°$$

New angle, $\theta' = \theta - 30° = 60° - 30° = 30°$

$\therefore$ Number of images $= \frac{360}{30°} - 1 = 11.$

9. $$\frac{I}{O} = \frac{v}{u};\ \frac{1}{2} = \frac{v}{u};\ v = \frac{u}{2}$$

or $v = -\frac{u}{2}$ ($\because$ u is negative)

$$\frac{1}{u}+\frac{1}{v} = \frac{1}{f}$$

$$\Rightarrow \quad \frac{1}{u}-\frac{2}{u} = \frac{1}{-20} \Rightarrow u = 20 \text{ cm}.$$

10. $$\frac{1}{u}+\frac{1}{v} = \frac{1}{f}$$

$$\Rightarrow \quad \frac{1}{v} = \frac{1}{f}-\frac{1}{u}$$

$$= \frac{1}{-20}-\frac{1}{20} = -\frac{1}{10}$$

$\therefore \quad v = -10$ cm

$= 10$ cm

11. Here, $a_{\mu_w} = 1.33$

Now, $$w_{\mu_a} = \frac{1}{a_{\mu_w}} = \frac{1}{1.33} - 0.75$$

12. $$2m = \frac{f}{15-f},\ m = \frac{f}{20-f}$$

$$\Rightarrow \quad 2 = \frac{20-f}{15-f} \Rightarrow f = 10 \text{ cm}.$$

13. $$P = \frac{1}{f} = \left(\frac{n_2}{n_1}-1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

In air $$P_{air} = \frac{1}{f_{air}} = (1.5-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

In water, $$P_{water} = \frac{1}{f_{water}} = \left(\frac{1.5}{4/3}-1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

$$\Rightarrow \quad \frac{P_{water}}{P_{air}} = \frac{f_{air}}{f_{water}} = \frac{1}{4}$$

$\Rightarrow \quad f_{water} = 4f_{air} = 40$ cm

Thus, $P_{water} < P_{air}$.

14. $$P = \frac{1}{f} = \left(\frac{n_2}{n_1}-1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

$$5 = 0.5\left(\frac{1}{R_1}-\frac{1}{R_2}\right) \quad \text{and}$$

$$-1 = \left(\frac{1.5}{n_1}-1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

$$\Rightarrow \quad n_1 = \frac{5}{3}.$$

15. $m = \frac{v}{u}, \quad v + u = D$

$\Rightarrow \quad u = \frac{D}{m+1}, \; v = \frac{mD}{m+1}$

$f = \frac{uv}{u+v} \quad \Rightarrow f = \frac{mD}{(m+1)^2}.$

16. $P = \frac{1}{f_1} + \frac{1}{f_2} = \frac{1}{0.4} - \frac{1}{0.25} = -1.5$ dioptre.

17. $P = P_1 + P_2 = 12 - 2 = 10$ D

$\therefore \; f = \frac{1}{10} = 0.1$ m = 10 cm.

18. Let the focal length of each half be f' on combining the two halves, we get back the original lens

$\therefore \quad \frac{1}{f} = \frac{1}{f} + \frac{1}{f'} = \frac{2}{f'} \Rightarrow f' = 2f$

19. We have, $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

Differenting: $\quad 0 = -\frac{du}{u^2} - \frac{dv}{v^2}$

or $\quad dv = -\frac{v^2}{u^2} du$

But $\quad \frac{v}{u} = \frac{f}{u-f}$ and $du = b$

$\therefore \quad dv = -\left(\frac{f}{u-f}\right)^2 \cdot b.$

Hence, $\quad |dv| = b\left(\frac{f}{u-f}\right)^2.$

20. $\frac{1}{u} + \frac{1}{u+10} = \frac{1}{12} \Rightarrow u = 20$ cm

$v = 30$ cm

$\therefore \quad m = \frac{v}{u} = \frac{30}{20} = 1.5.$

21. $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$

$\Rightarrow \quad v = \frac{uf}{u-f} = \frac{60 \times 24}{36} = 40$ cm

Further differentiation gives

$\frac{1}{u^2}\frac{du}{dt} + \frac{1}{v^2}\frac{dv}{dt} = 0 \Rightarrow \frac{dv}{dt} = -\frac{v^2}{u^2}\frac{du}{dt}$

$= -\left(\frac{40}{60}\right)^2 \times 9 = -4$ cm/s

$= 4$ cm/s

The speed of object is 4 cm/s away from the mirror.

22. As, $\quad f = \frac{uv}{u+v} = \frac{(f+20)(f+5)}{f+20+f+5}$

or $\quad 2f^2 + 25f = f^2 + 25f + 100$

$\Rightarrow \quad f = 10$ cm.

23. We have, $\quad \mu = \frac{\sin\left[\left(A + \frac{\delta_m}{2}\right)\right]}{\sin\frac{A}{2}}$

$\therefore \quad \sqrt{2} = \frac{\sin\left[\frac{(A+\delta_m)}{2}\right]}{\sin\left(\frac{60°}{2}\right)}$

$\therefore \quad \sin\left[\frac{(A+\delta_m)}{2}\right] = \sqrt{2} \times \frac{1}{2} = \frac{1}{\sqrt{2}}$

$\Rightarrow \quad \left[\frac{(A+\delta_m)}{2}\right] = 45°$

$\frac{2i}{2} = 45°$

$\therefore \quad i = 45°$

24. Apparent depth in water $= \frac{10.0}{1.33} = 7.52$ cm

Apparent depth in liquid $= \frac{10.0}{1.60} = 6.25$ cm

$\therefore$ Distance through which the microscope would have to be shifted.

$= 7.52 - 6.25 = 1.27$ cm upwards.

25. Here the angle of emergency $i = 0$

$\therefore \quad A + \delta = i$, Also $\delta = (\mu - 1)A$

$\Rightarrow \quad i - A = (\mu - 1)A$ or $i = \mu A$.

26. $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

$\frac{1}{f} = \frac{1}{45} + \frac{1}{90}$ or $f = 30$ cm

magnification $m = \frac{v}{u} = \frac{90}{45} = 2$

$\therefore \quad$ size of image $= 2 \times 5 = 10$ cm.

27. Focal length of a mirror does not depend on the medium in which light is incident, the mirror is placed. Hence, it remains equal to f.

28. $u = A + \frac{B}{\lambda^2}$

$\therefore \quad \frac{du}{d\lambda} = \frac{-2B}{\lambda^3}$

$\therefore$ Dispersive power is large if B is large.

29. As, $m = \dfrac{f}{f-u} = \dfrac{-16}{-16-(-8)} = \dfrac{-16}{-8} = 2$.

30. We have, $n = \dfrac{360°}{\theta} \Rightarrow n = \dfrac{360°}{72°} = 5$

Here, $\dfrac{360°}{\theta}$ is odd one object is line asymmetrically.

31. We have, $\dfrac{1}{v} + \dfrac{1}{-600} = \dfrac{1}{20}$ or $\dfrac{1}{v} = \dfrac{31}{600}$

$\Rightarrow$ $v = \dfrac{600}{31}$ cm = 19.35 cm.

32. We $-\dfrac{1}{30} + \dfrac{1}{v} = \dfrac{1}{30}$ or $\dfrac{1}{v} = \dfrac{2}{30} = \dfrac{1}{15}$

$\therefore$ v = 15 cm

Hence, image 15 cm behind the mirror.

33. As, $\dfrac{f}{f-4} = \dfrac{1}{4} = \dfrac{f}{f-(0.5)}$

$\Rightarrow$ $4f = f + 0.5$

We have,

$\therefore$ $f = \dfrac{0.5}{3}$ = 0.17 m.

34. We have, $f = -\dfrac{0.6}{2}$ = 0.3 m = –30 cm

Now, $\dfrac{1}{v} + \dfrac{1}{-10} = -\dfrac{1}{30}$

or $\dfrac{1}{v} = \dfrac{1}{10} - \dfrac{1}{30} = \dfrac{3-1}{30}$

or $v = \dfrac{30}{2}$ = 15 cm

As, $m = -\dfrac{v}{u} = \dfrac{-15}{-10}$ = 1.5

Since the object lies between principal focus and pole

Hence, the image is 1.5 times the size of the object.

35. We have, $f_0 + f_e$ = 44 cm and f_o/f_e = 10

$\Rightarrow$ $f_e = \dfrac{f_0}{10}$, $\therefore f_0 + \dfrac{f_0}{10} = 44$

$= 40\, f_0 + f_0 = \dfrac{440}{41} = 10$

f_0 = 10 cm

36. We have, $\dfrac{I'}{I} = \left(\dfrac{r_1}{r_2}\right)^2$

$\Rightarrow$ $\dfrac{I'}{I} = \dfrac{40 \times 40}{50 \times 50} = \dfrac{16}{25}$

$\Rightarrow$ $I - \dfrac{I'}{I} = 1 - \dfrac{16}{25} = \dfrac{9}{25}$

$\Rightarrow$ $I - \dfrac{I'}{I} \times 100 = \dfrac{9}{25} \times 100$ = 36%.

37. If the screen is equally illuminated, *i.e.*, $E_1 = E_2$

$\dfrac{I_1}{r_1^2} = \dfrac{I_2}{r_2^2} = \dfrac{I_1}{I_2} = \dfrac{r_1^2}{r_2^2} = \dfrac{(30)^2}{(50)^2} = \left(\dfrac{3}{5}\right)^2 = \dfrac{9}{25}$.

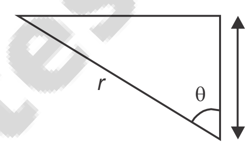
38. Given, I_1 = 1 cd, I_2 = 16 cd and r_1 = 50 cm

We have, $\dfrac{1}{(50)^2} = \dfrac{16}{d^2}$

$d^2 = (50)^2 \times 16$

$\Rightarrow$ d = 50 × 4 cm = 200 cm = 2 m.

39.



As, $E = \dfrac{I\cos\theta}{r^2}$

$\Rightarrow$ $E = \dfrac{Ih}{r^2}$ or $E \propto \dfrac{1}{r^2}$

40. As, $m = \dfrac{f}{f-u} \Rightarrow 2 = \dfrac{-0.2}{-0.2-u}$

or $2 = \dfrac{0.2}{0.2+u}$ or $0.4 + 2u = 0.2$

or $2u = 0.2 - 0.4 = -0.2$

$\therefore$ u = –0.1 m *i.e.*, 0.1 m

41. From the Brewster's law

$\mu = \tan ip = \tan 60° = \sqrt{3}$

42. As, $m = \dfrac{f}{f-u} \Rightarrow -2 = \dfrac{-20}{-20-u}$

$\Rightarrow$ $-2 = \dfrac{20}{20+u} \Rightarrow 20 + u = -10$

$\therefore$ u = 30 cm.

43. As, $\dfrac{f_w}{f_a} = \dfrac{(\mu_g - 1)}{\left(\dfrac{\mu_g}{\mu_w} - 1\right)}$

$\Rightarrow$ $\dfrac{f_w}{f_a} =$

$\Rightarrow$ $f_w = 4 \times f_a$

$\Rightarrow$ 4 × 20 = 80 cm.

44. From given fig. we see CD ∥ AB.

Therefore, refractive indies μ_1 and μ_2 are equal, $\mu_4 = \mu_1$

45. Let the two ends of the object be at distance $u_1 = u - \frac{L}{2}$ and $u_2 = u + \frac{L}{2}$ respectivly. So that $|u_1 - u_2|$ = L. Let the image of the two ends to formed at u_1 and u_2. So that the image would be $L' = |u_1 - u_2|$

Since, $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$

or, $v = \frac{fu}{u-f}$, The image of the two

$$v_1 = \frac{f\left(u - \frac{L}{2}\right)}{(u-f) - \frac{L}{2}}$$

and $$v_2 = \frac{f\left(u + \frac{L}{2}\right)}{u - f + \frac{L}{2}}$$

$\therefore$ $$L' = |v_1 - v_2| = \frac{f^2 L}{(u-f)^2 \times \frac{L^2}{4}}$$

Since, the object is short and kept away from the focus

We have, $\frac{L^2}{4} << (u-f)^2$

$\therefore$ Finally $L' = \frac{f^2}{(u-f)^2} L.$

46. As, $\mu = \frac{1}{\sin c} = \frac{1}{\sin 30°} = \frac{1}{1/2} = 2$

$\therefore$ $\mu = \frac{c}{\mu} = \frac{3 \times 10^8}{2}$ m/s $= \frac{c}{2}$.

47. Fringe width, $\beta = \frac{\lambda D}{d}$

$$\Delta\beta = \frac{\lambda}{d}\Delta D$$

$$\lambda = \frac{d\Delta B}{\Delta D} = \frac{10^{-3} \times 3 \times 10^{-3}}{5 \times 10^{-2}}$$

$= 6 \times 10^{-7} = 6000$ Å

48. Portion of 2nd dark fringe

$$x_2(\text{dark}) = \left(1 + \frac{1}{2}\right)\frac{\lambda D}{d} = \frac{3}{2} = \frac{\lambda D}{d}$$

Position of fourth bright fringe

$$x_4 \text{ (bright)} = \frac{4\lambda D}{d}$$

Distance $= \left(4 - \frac{3}{2}\right)\frac{\lambda D}{d} = \frac{5}{2} \times \frac{6 \times 10^{-7} \times 1}{10^{-3}}$ m

$= 1.5$ mm.

49. Let the thickness at the two points be t_1 and t_2

$$2t_1 = \left(m_1 + \frac{1}{2}\right)\lambda \text{ and } 2t_2 = \left(m_2 + \frac{1}{2}\right)\lambda$$

$\therefore$ $2(t_2 - t_1) = (m_2 - m_1)\lambda$

or $t_2 - t_1 = (m_2 - m_1)\frac{\lambda}{2}$

$= \frac{9 \times 6 \times 10^{-7}}{2} = 27 \times 10^{-7}$ m.

50. Let the screen be placed at a distance x from the 25 cd lamp. According to the principle of photometry

$$\frac{I_1}{r_1^2} = \frac{I_2}{r_2^2}$$

$$\frac{25}{x^2} = \frac{100}{(2-x)^2} \text{ or } x = \frac{2}{3} \text{m.}$$

51. In the position, of minimum deviation

$i_1 = i_2$

But $i_1 = 60°$, hence, $i_2 = 60°$

Now, $A + \delta_m = i_1 + i_2$ or $60° + \delta_m = 60° + 60°$

$\therefore$ $\delta_m = 60°$

52. Given, $u = 30$ cm, $v = -10$ cm and $f = ?$

As, $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$ or $-\frac{1}{10} - \frac{1}{-30} = \frac{1}{f}$

Solving, we get

$f = -15$ cm (concave lens)

$\therefore$ $p = \frac{100}{f} = \frac{100}{-15} = -6.66$ D

53. Angular resolution limit of eye $= \frac{1.22\lambda}{a}$

$= \frac{1.22 \times 5 \times 10^{-7}}{2 \times 10^{-3}}$ rad

$= \frac{1.22 \times 5 \times 10^{-7}}{2 \times 10^{-3}} \times \frac{180}{\pi} \times 60$ minutes

$\simeq 1$ minute.

54. Phase difference $\phi = \frac{2\pi}{\lambda}\frac{\lambda}{4} = \frac{\pi}{2}$

$$I_R = I^2 \cos\left(\frac{\pi}{4}\right) = \frac{I}{2}.$$

55. Distance of 2nd dark fringe

$$= \left(1+\frac{1}{2}\right)\beta = 3 \text{ mm} \Rightarrow \beta = 2 \text{ mm}$$

Distance of 4th bright fringe

$$= 4\beta = 8 \text{ mm.}$$

56. Let the required thickness be t Å

Number of wavelengths in vacuum $= \dfrac{t}{6000}$

Number of wavelengths in air $= \dfrac{1.0003}{6000}t$

$$\therefore \quad \frac{1.0003t}{6000} = \frac{t}{6000}+1$$

or $\quad 0.003\ t = 6000$ or $t = \dfrac{6000}{0.0003}$ Å

$$= 2 \times 10^7 \text{ Å} = 2 \text{ mm.}$$

57. As, $\quad \theta = \dfrac{1^\circ}{60} = \dfrac{1}{60}\times\dfrac{1}{180}\times\pi$ (rad)

$$= \frac{\beta}{D} = \frac{D}{d}\frac{\lambda}{D} = \frac{\lambda}{d}$$

$$\therefore \quad \frac{1}{60}\times\frac{\pi}{180} = \frac{\lambda}{d} = \frac{5890}{d}\times 10^{-8}$$

$$d = \frac{5890\times10^{-8}\times60\times180}{\pi} \text{ cm}$$

$$= 0.2025 \text{ cm} = 2.025 \text{ mm.}$$

58. As, $\quad x = \dfrac{m_1\lambda_1 D}{d}$

$\Rightarrow 60 \times 4000 = m_2 \times 6000 \Rightarrow m_2 = 40.$

59. Wavelength in water $\lambda' = \dfrac{\lambda}{n}$

$$\text{Now } \beta = \frac{\lambda D}{d}$$

$$\beta' = \frac{\lambda' D}{d}$$

$$\Rightarrow \quad \beta' = \frac{\lambda'}{n}\beta = \frac{\beta}{n} = \frac{1.33}{4/3} = 1 \text{ mm.}$$

60. Angular width

$$= \frac{2\lambda}{a} = \frac{2\times6328\times10^{-10}}{2\times10^{-4}}\times\frac{180}{\pi} = 0.36 \text{ degrees.}$$

61. We have, $x_n = \dfrac{n\lambda D}{d}$

$$\therefore \quad x_7 = \frac{7\lambda D}{d} \text{ and } x_3 = \frac{3\lambda D}{d}$$

$$\Rightarrow x_7 - x_3 = \frac{4\lambda D}{d} = \frac{4\times480\times10^{-9}\text{ m}\times1\text{ m}}{0.4\times10^{-3}}$$

$$= 4.8 \text{ mm.}$$

62. We have, $\quad a = \dfrac{\lambda}{d} = \dfrac{6500\times10^{-10}}{(\pi/6)} = 1.24 \times 10^{-6}$ m

$= 1.24$ micron.

63. $\quad 2nt = 1\cdot\lambda \Rightarrow t = \dfrac{\lambda}{2n}$

$$= \frac{540}{2\times1.5} = 180 \text{ nm.}$$

64. We have, $\dfrac{4\pi\times35}{P} = 5 \Rightarrow P = 28\pi = 88$ W.

65. As, $\quad E_1 = \dfrac{1}{r_1^2};\ E_2 = \dfrac{1}{r_2^2}$

$$\Rightarrow \quad \frac{E_2}{E_1} = \left(\frac{r_1}{r_2}\right)^2 = \left(\frac{2}{1.5}\right)^2 = \frac{4}{2.25}$$

$\therefore$ Percentage increase in intensity

$$= \frac{E_2 - E_1}{E_1}\times100 = \left(\frac{E_2}{E_1}-1\right)\times100$$

$$= \frac{1.75}{2.25}\times100 = 77.8\%.$$

66. As, $\quad D_F = \dfrac{a^2}{\lambda} = \dfrac{(2\times10^{-3})^2}{5\times10^{-7}}$

(D_F = Fresnel Distance) = 8 m.

67. Given, $u_0 = -200$ cm, $f = 30$ cm

$$\frac{1}{v_0}+\frac{1}{200} = \frac{1}{30}$$

or $\quad \dfrac{1}{v_0} = \dfrac{1}{30}-\dfrac{1}{200}$

$$v = \frac{600}{17} = 35.3$$

$\therefore \quad L = v_0 + f_e = 35.3 + 3 = 38.3$ cm

68. As, $\quad \dfrac{I_1}{I_2} = \dfrac{a^2}{b^2} = \dfrac{81}{1}$

$\therefore \quad \dfrac{a}{b} = \dfrac{9}{1} \Rightarrow a = 9b$

In the interference pattern,

$$\frac{I_{max}}{I_{min}} = \frac{(a+b)^2}{(a-b)^2} = \frac{(9b+b)^2}{(9b-b)^2}$$

$$= \frac{100b^2}{64b^2} = \frac{25}{16}.$$

69. Given, $f_0 = 100$ cm, $m = 50$

$$f_e = \frac{f_0}{m} = \frac{100}{50} = 2 \text{ cm}$$

$\therefore$ The distance between two lenges in normal adjustment $= f_o - f_e = 100 - 2 = 98$ cm.

70. Given, $\mu = 1.536$

It P is the polarization angle, then

$$\tan P = \mu\ 1.536$$

or, $P = 56°56'$

If r is the angle of refraction, then

$$r = 90° - P$$
$$= 90° - 56°56' = 33°4'.$$

71. Given, $\dfrac{\omega_1}{\omega_2} = \dfrac{4}{1}$

Now, $\dfrac{a_1^2}{a_2^2} = \dfrac{\omega_1}{\omega_2} = \dfrac{4}{1}$

$\therefore$ $\dfrac{a_1}{a_2} = \dfrac{2}{1}.$

72. Given, $d = 600\text{ nm} = 600 \times 10^{-9}\text{m}$,

$a = 2\text{ mm} = 2 \times 10^{-3}\text{ m}$

$\therefore$ Required distance $Z_f = \dfrac{a^2}{\lambda} = \dfrac{(2\times10^{-3})^2}{600\times10^{-9}}$

$$Z_f = 6.67\text{ m}.$$

73. Given, $P = 60°$

As, $\mu = \tan P = \tan 60° = \sqrt{3}$

If C is the critical angle, then

$$\mu = \frac{1}{\sin C}$$

or $\sin C = \dfrac{1}{\mu} = \dfrac{1}{\sqrt{2}} = 0.5774$

$\therefore$ $C = 35°16'.$

74. Given, $d = 1\text{ mm} = 10^{-3}\text{ m}$, $D = 1\text{ m}$,

$\lambda = 500\text{ nm} = 500 \times 10^{-9}\text{ m}$

As, $\beta = \dfrac{D\lambda}{d}$

$$= \frac{1\times500\times10^{-9}}{10^{-3}}$$
$$= 0.5 \times 10^{-3}\text{ m} = 0.5\text{ mm}.$$

75. Given, $d = 0.02$ cm, $D = 80$ cm,

$\lambda = 6000 \times 10^{-8}\text{ cm} = 6 \times 10^{-5}\text{ cm}$

For n^{th} bright fringe $Y_n = \dfrac{nD\lambda}{d}$

For 5^{th} maximum, $n = 5$,

$$Y_5 = \frac{5\times80\times6\times10^{-5}}{0.02} = 1.2\text{ cm}.$$

76. Let n, and n_2 be no. of fringes observed between A and B. If t is the change in thickness of the film and λ_1 and λ_2 are wavelengths, then the normal incidence,

$$2\mu t = n_1\lambda_1 = n_2\lambda_2$$

or $n_2 = \dfrac{n_1\lambda_1}{\lambda_2}$

Given, $n_1 = 10$, $\lambda_1 = 4125\text{ Å}$

$\lambda_2 = 5893\text{Å}$

$\therefore$ $n_2 = \dfrac{10\times4125}{5893} = 7.$

77. As, $\Delta\lambda = \dfrac{v}{c}\cdot\lambda$

$$= \frac{9\times10^6\times6000\text{Å}}{3\times10^8}\times6000\text{Å}$$
$$= 180\text{ Å}$$

$\therefore$ Apparent wave length,

$$\lambda' = \lambda - \Delta\lambda = 6000 - 180 = 5820\text{ Å}.$$

78. Given, $\Delta\lambda = 0.5\text{ nm} = 0.5 \times 10^{-19}\text{m}$,

$v = 300\text{ kms}^{-1} = 300 \times 10^3\text{ ms}^{-1}$

As, $\dfrac{\Delta\lambda}{\lambda} = \dfrac{v}{c} \Rightarrow \lambda = \dfrac{\Delta\lambda c}{v}$

$\therefore$ $\lambda = \dfrac{(0.5\times10^{-8}\text{m})(3\times10^8\text{ms}^{-1})}{300\times10^3\text{ms}^{-1}}$

$$= 5 \times 10^{-7}\text{ m}$$
$$= 5000 \times 10^{-10}\text{ m} = 5000\text{Å}.$$

79. Doppler shift source moving towards the observer,

$$\lambda' = \lambda\left(1-\frac{v}{c}\right)$$

$\Rightarrow$ $5400 = 6200\left(1-\dfrac{v}{c}\right)$

$$W\left(1-\frac{v}{c}\right) = \frac{5400}{6200}$$

$\Rightarrow$ $v = \left[1-\dfrac{54}{62}\right]c$

$$= 3.9 \times 10^7\text{ m/sec (approx.).}$$

80. For the secondary maxima,

$$d\sin\theta = \frac{5\lambda}{2}$$

$\Rightarrow$ $2n = \dfrac{5\lambda F}{d}$

$$= \frac{5\times0.8\times6\times10^{-7}}{4\times10^{-4}}$$
$$= 6 \times 10^{-3}\text{ m} = 6\text{ mm}.$$

81. As, $f_p = \dfrac{r^2}{(2p-1)\lambda}$

For the first half period zone,

$$r = \sqrt{f_p\lambda} = \sqrt{0.6 \times 6000 \times 10^{-10}}$$

$\therefore$ $r = 6 \times 10^{-4}$ m.

82. Given, $n = 1$, $\lambda = 6 \times 10^{-5}$ cm

Distance of screen from slit = 100 cm

Distance of first minima from central maxima = 0.1 cm

As, $$\sin\theta = \dfrac{\text{Distance of 1st minima from the central maxima}}{\text{Distance of the screen from the slit}}$$

$\therefore$ $$\sin\theta = \dfrac{0.1}{100} = \dfrac{1}{1000}$$

As, $a \sin\theta = n\lambda$ or $a = \dfrac{n\lambda}{\sin\theta} = \dfrac{1 \times 6 \times 10^{-5}}{\dfrac{1}{1000}}$

$\therefore$ $a = 0.06$ cm.

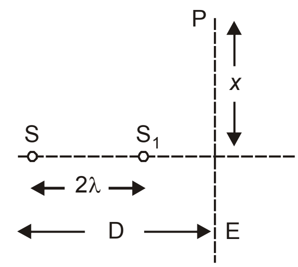
83. Path difference = $2\lambda \cos\theta$

$$2\lambda \cos\theta = h\lambda$$

For x to be minimum $n = 1$

$$\cos\theta = \dfrac{1}{2}$$

$$\theta = 60°$$



$\Rightarrow$ $x = \text{D} \tan 60° = \sqrt{3}\text{D}$.

84. The width fringe width $\beta = \dfrac{\lambda \text{D}}{d}$

The angular seperation of the fringes is given by

$$\theta = \dfrac{\beta}{\text{D}} = \dfrac{\lambda}{d}$$

Given, $\theta = 1° = \dfrac{\pi}{180}$ rad

$$d = \dfrac{589 \times 180 \times 10^{-9}}{\pi}$$

$= 0.0337$ mm.

85. The diameter of telescope (d) = 0.61 m

Wavelength of light (λ) = 5000Å = 5×10^{-7} m

$\therefore$ Resolution power = $\dfrac{d}{1.22\lambda} = \dfrac{0.61}{1.22 \times 5 \times 10^{-7}}$

$= 1 \times 10^6$

CHAPTER

7

DUAL NATURE OF MATTER AND RADIATION

DUAL NATURE OF RADIATION

The phenomena such as interference, diffraction and polarisation in which interaction of radiation takes place with radiation itself. Such phenomenon can be explained on the basis of electromagnetic wave nature of radiation.

The phenomena such as rectilinear propagation reflection, refraction etc. which can be explained on the basis of either of the wave nature of the particle nature of radiation.

PHOTOELECTRIC EFFECT

The phenomenon of ejection of electrons from a metal surface, when light of sufficiently high frequency falls upon it, is called photoelectric effect. The electrons so emitted are called photoelectrons.

Threshold Frequency: The minimum frequency (ν_o) which the incident light must, posses so as to eject photoelectrons from a metal surface, is called threshold frequency of the metal. i.e., work function, W = $h\nu_o$.

Laws of Photoelectric Effect

(*i*) Photoelectric emission takes place from a metal surface, when the frequency of incident light is above its threshold frequency.

(*ii*) The photoelectric emission starts as soon as the light is incident on the metal surface.

(*iii*) The number of photoelectrons emitted is independent of the frequency of the incident light and depends only upon its intensity.

(*iv*) The maximum kinetic energy with which an electron is emitted from a metal surface is independent of the intensity of light and depends upon its frequency.

HERTZ AND LENARD'S OBSERVATIONS

Hertz Observations: Hertz studing experimentally, the production of electromagnetic waves by means of spark discharged, found that the high voltage sparks across the detector loop were enhanced, when emitter plate was illuminated by ultraviolet light from an arc lamp. If the suitable radiation fall on a metal surface, some electrons near the surface absorb enough energy from the incident radiations. So that the attraction of the positive ions in the material of the surface and escape to the surrounding space.

Lenard's Observations: These indicate that when ultraviolet radiations fall on emitter plate electrons are ejected from it which are attracted towards the other metal plate kept at positive potential. The flow of electrons through the evacuated glass tube results in the current flow in the external circuit. Thus, light falling on the surface of emitter causes current in the external circuit.

EINSTEIN'S PHOTOELECTRIC EQUATION

Einstein explained photoelectric equation on the basis of Max Planck's quantum theory of radiation.

A photon striking the metal surface transfer whole of its energy $h\nu$ to any one of the electrons present in the metal and its own existence is vanished. The energy supplied to the electrons is used in two ways—

1. A part of this energy is used in ejecting the electron from the metal surface (W), called work Function.

2. The rest of energy is given to the electron in the form of Kinetic energy, (E_K). Suppose the Kinetic energy of photoelectrons emitted from the metal surface is E_K, and W is the energy required to eject a photo electron from the metal surface, (W is the work function of the metal and is different for different metals), then we have—

$$h\nu = W + E_K$$

$$E_K = h\nu - W \qquad ...(i)$$

where, $h\nu$ is the energy of incident photon.

If $h\nu < W$, then the photoelectrons will not be emitted, so if the light of frequency ν_0 (threshold frequency) is incident on the metal surface, then an amount of energy $h\nu_0$ of the photon of light will be spent in ejecting the electrons out of the metal *i.e.*,

$$W = h\nu_0$$

Putting this value of W in equation (*i*), we get

$$E_K = h(\nu - \nu_0)$$

or, $$\frac{1}{2}mv_{max}^2 = h(\nu - \nu_0) \qquad ...(ii)$$

Where ν_{max} is the maximum velocity of emitted photoelectrons.

Electrons which get emitted may have belonged to the conduction shell or some shell below it. Naturally, conduction shell-electrons will need least energy to come out of the metal slab. Hence, the balance remainig energy for them will be more. Hence, the electrons coming out of the metal slab will have various kinetic energies or speeds. Out of these, we are concentrating on the electrons having the maximum speeds.

or, $$\frac{1}{2}mv_{max}^2 = h\left(\frac{c}{\lambda} - \frac{c}{\lambda_0}\right) \qquad ...(iii)$$

Equations (*i*), (*ii*) and (*iii*) represent Einstein's photoelectric equations.

The (negative) potential V_0 at which the current is just reduced to zero is called the 'Stopping Potential'. Since the energy of the fastest electrons is just balanced, when they fall through the stopping potential, we have,

$$\frac{1}{2}mv_{max}^2 = eV_0 \qquad ...(iv)$$

where e is the electronic charge and V_0 is the stopping potential. Thus, the stopping potential multiplied by electronic charge gives the maximum kinetic energy of the photoelectrons.

Millikan plotted a graph between the stopping potential and the frequency of light over a wide range of frequencies and obtained a straight line. Parallel lines were obtained for other metallic surfaces.

Now, according to Einstein's equation, we have

$$\frac{1}{2}mv_{max}^2 = h(\nu - \nu_0)$$

But $$\frac{1}{2}mv_{max}^2 = eV_0$$

$\therefore$ $$eV_0 = h(\nu - \nu_0)$$

or $$E_K = h(\nu - \nu_0)$$

Since h and e are constants and V_0 is constant for a given surface, this eq indicates that the graph between the kinetic energy, (eV_0) and the frequency of light v must be a straight line. This is actually the case, as found by Millikan. Hence Einstein's equation is verified. The slope of the curves determines Planck's Constant.

PARTICLE NATURE OF LIGHT (PHOTON)

A definite value of energy as well as momentum gives a strong indication that the light quantum is a particle, which was later named as photon. The particle like behaviour of light on the scattering of X-rays from electrons.

Energy of photon, $E = h\nu = \dfrac{hc}{\lambda}$

and $$p = \frac{h\nu}{c} = \frac{h}{\lambda}$$

where h is Planck's constant.

MATTER WAVES-WAVE NATURE OF PARTICLE

Matter waves are associated with a moving particle. These waves are not electromagnetic waves in nature de-Broglie's concept of nature loves symmetry led to the discovery of matter of waves.

DE-BROGLIE WAVES RELATION

According to de-Broglie wave is associated with energy moving particle.

The quantum theory of radiation energy of the photon is given by

$$E = h\nu \qquad ...(i)$$

Further the energy of relativistic particle is given by

$$E = \sqrt{m_0^2c^2 + p^2c^2} \quad [\because \text{Rest mass } m = 0]$$

$\therefore$ $$E = pc \qquad ...(ii)$$

From equation (i) and (ii), we get

$$pc = h\nu \Rightarrow p = \frac{h\nu}{c} = \frac{h\nu}{c\lambda}$$

or $$p = \frac{h}{\lambda} \quad \text{or} \quad \lambda = \frac{h}{p}$$

Hence, de-Broglie wavelength is given by, $\lambda = \dfrac{h}{mv}$.

This relation is called de-Broglie relation.

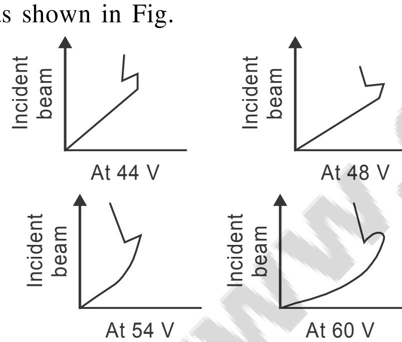
DAVISSON-GERMER EXPERIMENT

The wave nature of slow moving electrons has been established experimentally by Davisson and Germer in 1927. The electrons from hot tungsten cathode (C) are accelerated by the potential difference (V) between cathode (C) and anode (A). The fine beam of electron strike to the Ni crystal. By rotating the electron defector on circular scale at different positions, the intensity of scattered beam is measured for different values of scattering angled, the angle between the incident and the scattered electron beam.

The graph is plotted between angled and the intensity of scattered electron beam. Such graphs are plotted at different accelerating voltages. In each graph, the intensity of electron beam is in given curve point from the point O, direction is proportional to the distance, *i.e.*,

$$I \propto d$$

The experimental curves obtained by Davisson and Germen as shown in Fig.



From the above curve, we have

$$\theta = \frac{1}{2}(180° - \phi), \text{ For } \phi = 50°,$$

$$\theta = \frac{1}{2}(180° - 50°) = \frac{1}{2} \times 130° = 65°$$

From Bragg's law, for first order diffraction, $n = 1$

$$2d \sin\theta = 1 \times \lambda$$

For Ni crystal, distance between atomic planes

$$d = 0.91 \text{ Å}$$

$$\therefore \quad \lambda = 2 \times 0.91 \times \sin 65° = 1.66 \text{ Å}$$

From de-Broglie hypothesis, the wavelength associated with electron,

$$\lambda = \frac{12.27}{\sqrt{V}} = \frac{12.54}{\sqrt{54}} = 1.66 \text{ Å}$$

This verify the experiment at value determined by Davisson and Germer.

Max Planck's Quantum Theory of Radiation

In an attempt to explain the spectral distribution of energy in the spectrum of a black body, Max Planck, gave a revolutionary idea regarding the nature of light. His theory is known as Quantum theory of radiation. According to this theory, radiation consists of tiny packets of energy called photons or light quanta (each photon has a definite amount of energy by $h\nu$, 2 $h\nu$, 3 $h\nu$ ..... where h is plank's constant and ν is the frequency of radiation.

The rest mass of the photon is zero while the mass of moving photon is $\dfrac{h\nu}{c^2}$. The momentum of photon of wavelength λ is $\dfrac{h}{\lambda}$ and the momentum of photon of energy E is E/c).

EXERCISE

1. If a light wave of wavelength 4950 Å is viewed as a continous flow of photons, what is the energy of each photon in eV?

A. 1.2 eV B. 1.5 eV

C. 0.8 eV D. 2.5 eV

2. The radio transmitter operates on a wavelength of 1500 m at a power of 400 kilowatt. Then the frequency corresponding to this wavelength is

A. 500 kHz B. 200 kHz

C. 100 kHz D. 400 kHz

3. The work function of caesium is 2.14 eV. Find the threshold frequency for caesium, if the photocurrent is brought to zero by a stopping potential of 0.60 eV.

A. 1.25×10^{12} Hz B. 5.16×10^{14} Hz

C. 3.14×10^{16} Hz D. 1.0×10^{12} Hz

4. If a light of wavelength 4950 Å is viewed as a continous flow of photons, what is the energy of each photon in eV? (Given $h = 6.6 \times 10^{-34}$ Js, $c = 3 \times 10^8$ ms^{-1})

A. 1.2 eV B. 3.9 eV

C. 0.5 eV D. 2.5 eV

5. Light of two different frequencies whose photons have energies 1 and 2.5 eV respectively, successively illuminate a metal whose work function is 0.5 eV. The ratio of the maximum speeds of the emitted electrons will be

A. 1 : 5 B. 1 : 4
C. 1 : 2 D. 1 : 1

6. If the energy of a photon corresponding to a wave length of 6000 Å is 3.32×10^{-19} joule, the photon energy for a wavelength of 4000 Å will be

A. 1.11×10^{-19} joule B. 2.22×10^{-19} joule
C. 4.44×10^{-19} joule D. 4.98×10^{-19} joule

7. The mass of ${}_3Li^7$ nucleus is 0.042 amu less than the sum of masses of its nucleons. The binding energy per nucleon is

A. 3.358 Mev B. 5.586 MeV
C. 7.586 MeV D. 9.586 MeV

8. The work function of a photoelectric meterial is 3.32 eV. The threshold frequency will be equal to

A. 8×10^{14} Hz B. 8×10^{10} Hz
C. 5×10^{20} Hz D. 4×10^{14} Hz

9. An x-particle moves in a circular path of radius 0.83×10^{-12} m in the presence of magnetic field of 0.25 Wb/m^2. The de-Broglie wavelength associated with the particle will be.

A. 0.1 Å B. 10 Å
C. 0.01 Å D. 1 Å

10. The momentum of each photon in a given radiation is 3.3×10^{-29} kg metre/sec. The frequency of radiation is: Given $h = 6.6 \times 10^{-34}$ joule sec.

A. 3×10 Hz B. 6×10^{10} Hz
C. 7.5×10^{12} Hz D. 1.5×10^{13} Hz

11. The human eye can barely detect a yellow light (6000 Å) that delivers 1.7×10^{-18} watt to the retina. Nearly how many photons per second does the retina receive

A. 50 B. 5
C. 500 D. more than 5 million

12. A radio transmitter operates at a frequency of 880 kHz and a power of 10 kW. The number of photons emitted per second are

A. 1.71×10^{31} B. 1327×10^{34}
C. 13.27×10^{34} D. 0.75×10^{-34}

13. What is the energy of emitted photoelectrons, if light frequency 10^{16} Hz is incident on a Na-target? Work for function of Na = 2.5 eV

A. 38.875 eV B. 42.235 eV
C. 47.123 eV D. 51.234 eV

14. If the speed of photo electrons is 10^4 ms^{-1}, what should be the frequency of incident radiation on the potassium metal? (Work function potassium = 2.3 eV)

A. 5.56×10^{14} Hz B. 3.15×10^{12} Hz
C. 1.12×10^{16} Hz D. 2.14×10^{10} Hz

15. The distance between two plates of a cathode ray oscilloscope is 1 cm and potential difference between them is 1200 volt. If an electron of energy 2000 eV enters at right angles to the field, what will be its deflection if the plate be 1.5 cm long?

A. 0.03×10^{-2} m B. 0.43×10^{-2} m
C. 0.34×10^{-4} cm D. 0.34×10^{-2} m

16. In a Cathode ray tube, a potential difference of 3000 volts is maintained between the deflector plates whose separation is 2 cm. A magnetic field of 2.5×10^{-3} wbm^{-2} at right angles to the electric field gives no deflection of the electron beam which received an initial acceleration by a potential difference of 10,000 V. Calculate (e/M) of an electron

A. 1.5×10^{11} C/kg B. 2.8×10^{11} C/kg
C. 1.8×10^{11} C/kg D. 1.2×10^{11} C/kg

17. A drop of oil of radius 10^{-4} cm and carrying a charge q esu is moved vertically upward through air by an electric field of 1950 v/cm with a constant velocity of 0.035 cm/sec. If the viscosity of air is 180×10^{-6} cgs units. Calculate the charge q on the drop. Neglect density of air. Given the density of oil = 0.96 gm/cm^3 and g = 980 cm/sec^2

A. 23.43×10^{10} esu B. 24.34×10^{-10} esu
C. 34.24×10^{-10} esu D. 24.43×10^{-10} esu

18. How many photon per second does a one watt bulb emit if its efficiency is 10% and the wavelength of light emitted is 500 nm.

A. 2.53×10^{17} B. 2.35×10^{17}
C. 3.25×10^{17} D. 2.30×10^{17}

19. If the wavelength of light falling on a surface in increased from 3000 Å to 3040 Å then what will be the corresponding change in the stopping potential (Given that $hc = 12.4 \times 10^{-7}$ eV Å).

A. -5.5×10^{-12} V B. $+5.5 \times 10^{-12}$ V
C. -6.7×10^{-12} V D. $+6.7 \times 10^{-12}$ V

20. With what velocity must an electron travel so that its momentum is equal to that of a photon with a wavelength of 5200 Å?

A. 1200 m/s B. 1000 m/s
C. 1800 m/s D. 1400 m/s

21. If the wavelength of light incident on a photoelectric cell be reduced from 4000 Å to 3600 Å, then what

will be the change in the cut off potential. (h = 6.6 × 10^{-34} J – s, C = 3.0 × 10^{8} m/s, e = 1.6 × 10^{-19} C)
A. 0.42 volt B. 0.30 volt
C. 0.34 volt D. 0.43 volt

22. The kinetic energy of an electron gets tripled then the de-Broglie wavelength associated with it changes by a factor

A. $\frac{1}{\sqrt{3}}$ B. $\sqrt{3}$

C. $\frac{1}{3}$ D. 3

23. A particle of mass 1 mg has the some wavelength as an electron moving with a velocity of 3 × 10^{6} m/sec. The velocity of the particle is
A. 2.7 × 10^{-18} m/sec B. 2.7 × 10^{-21} m/sec
C. 3 × 10^{-31} m/sec D. 9 × 10^{-2} m/sec

24. de-Broglic wavelength λ associated with an electron having kinetic energy E is given by the expression

A. $2\,mh\,\mathrm{E}$ B. $\frac{2h}{m\mathrm{E}}$

C. $\frac{h}{\sqrt{2m\mathrm{E}}}$ D. $\frac{2\sqrt{2m\mathrm{E}}}{h}$

25. Consider the metal exposed to light of wavelength 600 nm. The maximum energy of electron doubles, when light of wavelength 400 nm is used. Then, the value of work-function is
A. 0.50 eV B. 2.35 eV
C. 1.02 eV D. 2.45 eV

26. If an electron and a photon propagate in the form of waves having the same wavelength, it implies that they have the same
A. Energy
B. Momentum
C. Angular momentum
D. Velocity

27. The de-Broglie wavelength of particle moving with a velocity 2.25 × 10^{8} m/sec is equal to the wavelength of proton. The ratio of kinetic energy of the particle to the energy of the photon is (velocity of light is 3 × 10^{8} m/sec)

A. $\frac{7}{8}$ B. $\frac{1}{8}$

C. $\frac{5}{8}$ D. $\frac{3}{8}$

28. The kinetic energy of electron and proton is 10^{-32} J. Then, find the relation between their de-Broglie wavelengths is
A. $\lambda_p = \lambda_e$ B. $\lambda_p > \lambda_e$
C. $\lambda_p = 2\lambda_e$ D. $\lambda_p < \lambda_e$

29. A proton accelerated through a potential V has de-Broglie wavelength λ. Then, the de-Broglie wavelength of an α-particle, when accelerated through the same potential V is

A. $\frac{\lambda}{2}$ B. $\frac{\lambda}{\sqrt{2}}$

C. $\frac{\lambda}{2\sqrt{2}}$ D. $\frac{\lambda}{8}$

30. λ_e, λ_p and λ_α are the de-Broglie wavelengths of electron, proton and α-particle. If all are accelerated by same potential, then
A. $\lambda_e > \lambda_p < \lambda_\alpha$ B. $\lambda_e < \lambda_p < \lambda_\alpha$
C. $\lambda_e < \lambda_p < \lambda_\alpha$ D. $\lambda_e > \lambda_p > \lambda_\alpha$

31. When the momentum of proton in charged by an amount P_o, the corresponding change in the de-Broglie wavelength is found to be 0.25%. Then, the original momentum of the proton was
A. 400 p_o B. 4 p_o
C. p_o D. 100 p_o

32. The wavelength of photon is 1.4 Å. It collides with an electron at rest. Its wavelength after collision is 2.0 Å. Then, the energy of the scattered electron is:
A. 3.11 × 10^{-15} J B. 1.15 × 10^{-14} J
C. 4.26 × 10^{-16} J D. 0.12 × 10^{-16} J

33. A proton and α-particle are accelerated through a potential difference of 100 V, the ratio of the wavelength associated with the proton to associated with an α-partide is

A. $2\sqrt{2}:1$ B. 2 : 1

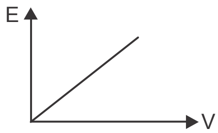
C. $\sqrt{2}:1$ D. $\frac{1}{2\sqrt{2}:1}$

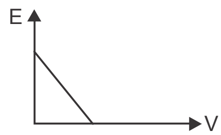
34. The kinetic energy of an electron is 5 eV. Calculated the de-Broglie wavelength associated with it (h = 6.6 × 10^{-34} Js, m_e = 9.1 × 10^{-31} kg)
A. 2.71 Å B. 5.47 Å
C. 12.5 Å D. 9.23 Å

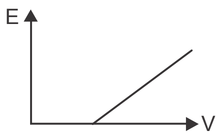
35. The de-Broglie wavelength of a proton (charge = 1.6 × 10^{-19}C mass = 1.6 × 10^{-27} kg) accelerated through a potential difference of 1 kV is
A. 7 Å B. 0.9 × 10^{-12} m
C. 0.9 nm D. 600 Å

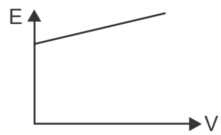
36. If the kinetic energy of the particle is increased by 16 times, the percentage change in the de-Broglie wavelength of the particle is
A. 60% B. 50%
C. 25% D. 75%

37. Maximum kinitic energy of photoelectron varies, with the frequency of the incident radiation of graph.

A. 

B. 

C. 

D. 

38. For a radiation of wavelength 3000 Å incident on a metal surface, maximum kinetic energy of emitted photoelectrons is 0.5 eV. If radiation of wavelength 2000 Å falls on the metal, then maximum kinetic energy of photoelectron will be

A. < 0.5 eV B. = 0.5 eV
C. > 0.5 eV D. Zero

39. In work function of a metal plate is negligible, then find the KE of the photoelectrons emitted, when radiations of 1000 Å are incident on the metal surface

A. 13.6 eV B. 14.4 eV
C. 11.6 eV D. 12.9 eV

40. If efficiency of a one watt bulb is 10% and it emits light of wavelength 500 nm, then number of photons emitted per second are about

A. 4.5×10^{19} B. 5.2×10^{19}
C. 2.5×10^{17} D. 3.1×10^{18}

41. The work function of caesium metal is 214 eV. When light of frequency 6×10^{14} Hz is incident on the metal surface, photoemission of electrons occurs. The maximum KE of the emitted electrons is

A. 0.34 eV B. 0.64 eV
C. 0.11 eV D. 0.26 eV

42. In an experiment of photoelectric effect, the slope of cut off voltage vs frequency of incident light is found to be 4.12×10^{-15} Vs. One value of Planck's constant is

A. 3.5×10^{-34} Js B. 6.6×10^{-34} Js
C. 2.1×10^{-33} Js D. 8.9×10^{-34} Js

43. The work function for a certain metal is 4.2 eV will this metal given photoelectric emission for incident radiation of wavelength 330 nm.

A. 1.246 eV B. 2.567 eV
C. 3.767 eV D. 4.1281 eV

44. The photoelectric cut off voltage in a certain experiment is 1.5 V. The maximum KE of photoelectric emitted is

A. 2.4×10^{-19} J B. 1.5×10^{-19} J
C. 1.6×10^{-19} J D. 0.6×10^{-19} J

45. Use Moseley's law with $b = 1$ to find the frequency of the K_α X-rays of La(X = 57), if the frequency of the K_α X-rays of Cu(z = 29) is known to be 1.88×10^{18} Hz

A. 7.52×10^{18}Hz B. 8.75×10^{16}Hz
C. 12.34×10^{17}Hz D. 4.05×10^{16}Hz

46. The wavelength of light incident on metal A is twice than that of falling on metal B. If maximum kinetic energy of photoelectrons emitted in two cases, is E_{kA} and E_{kB} respectively, then

A. $E_{kA} = E_{kB}/2$ B. $E_{kA} < E_{kB}/2$
C. $E_{kA} = E_{kB}$ D. $E_{ukA} = 2E_{kB}$

47. Light of wavelength 332 mm is incident on the metal surface of work function 1.07 eV. What will be the value of stopping potential required to stop emission of photoelectrons? ($h = 6.6 \times 10^{34}$Js)

A. 1.33 V B. 4.66 V
C. 6.44 V D. 2.66 V

48. A neutron beam of energy E scatters from atoms on a surface with a spacing $d = 0.1$ nm. The first maximum intensity in the reflected beam occurs at $\theta = 30°$. What is the kinetic energy E of the beam in eV?

A. 0.11 eV B. 0.31 eV
C. 0.21 eV D. 0.01 eV

49. Ultraviolet radiations of 6.2 eV fall on an aluminium surface, whose work function is 4.2 eV. KE of the fastest emitted electron will be

A. 3.2×10^{-17} J B. 3.2×10^{-12} J
C. 3.2×10^{-21} J D. 3.2×10^{-19} J

50. If the stopping potential for a photoelectrons is 39.9 V, then maximum velocity of photoelectron is

A. 3.75×10^{6} ms^{-1} B. -3×10^{8} ms^{-1}
C. 2.9×10^{7} ms^{-1} D. 4.8×10^{7} ms^{-1}

ANSWERS

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
D	B	D	B	C	D	B	A	C	D
11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
B	A	C	A	D	C	B	A	A	D
21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
C	C	A	C	C	B	D	D	C	D

31	32	33	34	35	36	37	38	39	40
A	C	A	B	B	D	C	C	D	C
41	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**
A	B	C	A	A	B	D	C	D	A

EXPLANATORY ANSWERS

1. Energy of photon,

$$E = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^{8}}{4950\times10^{-10}}$$

$$= 4.0 \times 10^{-19}\ \text{J}$$

$$= \frac{4.0\times10^{-19}}{1.6\times10^{-19}} = 2.5\ eV$$

2. Given, $\lambda = 1500$ m

As, $v = \frac{c}{\lambda} = \frac{3\times10^{8}}{1500}$

$= 20000$ Hz $= 200$ kHz.

3. For the minimum, cut off or threshold frequency.

Energy $h\nu_0$ of incident photon = work function W_0

$$\therefore\ \nu_0 = \frac{W_0}{h} \Rightarrow \nu_0 = \frac{2.14\ \text{eV}}{6.6\times10^{-34}\ \text{Js}} = 5.16\times10^{14}\ \text{Hz.}$$

4. Given, $\lambda = 4950$ Å $= 4950 \times 10^{-10}$ m

Now, energy of each photon,

$$E = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^{8}}{4950\times10^{-10}}$$

$$= 4.0 \times 10^{-19}\ \text{J}$$

$$= \frac{4.0\times10^{-19}}{1.6\times10^{-19}} eV = 2.5\ \text{eV}$$

5. E = Energy of incident photon

W_0 = Work function

$E - W_0$ = Available energy

$$\therefore\quad E - W_0 = \frac{1}{2}mv^2$$

$$\therefore\quad v = \sqrt{\frac{2(E-W_0)}{m}}$$

$$v \propto \sqrt{\text{available energy}}$$

$$\therefore\quad \frac{v_1}{v_2} = \sqrt{\frac{1-0.5}{2.5-0.5}} = \sqrt{\frac{0.5}{2}} = \sqrt{\frac{1}{4}} = \frac{1}{2}$$

6. As, $E = hv = \frac{hc}{\lambda}$ and $E_1 = \frac{hc}{\lambda_1}$ and $E_2 = \frac{hc}{\lambda_2}$

$$\therefore\ \frac{E_1}{E_2} = \frac{\lambda_2}{\lambda_1} \Rightarrow E_2 = E_1\frac{\lambda_1}{\lambda_2}$$

$$= 3.32 \times 10^{-19} \times \frac{6000}{4000} = 4.98 \times 10^{-19}\ \text{J.}$$

7. We have, $\frac{BE}{A} = \frac{\Delta m\times931}{A}$

$$= \frac{0.042\times931}{7}$$

$= 5.586$ MeV

8. As, $E = hv$

Since $E = 3.3$ eV $= 3.3 \times 1.6 \times 10^{-19}$

$$\therefore\quad v = \frac{3.3\times1.6\times10^{-19}}{6.6\times10^{-34}}\ \text{Hz}$$

$= 8 \times 10^{14}$ Hz.

9. As, $\lambda = \frac{h}{p} \Rightarrow \lambda = \frac{h}{mv}$

$$\because\quad r = \frac{mv}{qB}$$

$$\Rightarrow\quad mv = qrB = 2e \times 0.83 \times 10^{-12} \times \frac{1}{4}$$

$$\therefore\quad \lambda = \frac{6.6\times10^{-34}\times4}{2\times1.6\times10^{-19}\times0.83\times10^{-12}}$$

$= 0.01$ Å

10. Momentum $= p = \frac{hv}{c}$

$$\therefore\quad v = \frac{pc}{h} = \frac{3.3\times10^{-29}\times3\times10^{8}}{6.6\times10^{-34}}$$

$= 1.5 \times 10^{13}$ Hz.

11. n = number of photons falling per second on retina

$nhv = 1.7 \times 10^{-18}$

or $nh\frac{c}{\lambda} = 1.7 \times 10^{-18}$

$$\therefore\quad n = \frac{1.7\times10^{-18}\times\lambda}{hc}$$

$$= \frac{1.7\times10^{-18}\times6000\times10^{-10}}{6.6\times10^{-34}\times3\times10^{8}} = 5.15 \approx 5.$$

12. As, $nhv = P$, n = number of photons/sec

$n \times 6.6 \times 10^{-34} \times 880 \times 10^{3} = 10 \times 10^{3}$

$$n = \frac{10\times10^{3}}{6.6\times10^{-34}\times880\times10^{3}} = 1.71 \times 10^{31}.$$

13. As, $\frac{1}{2}mv\max^2 = h\nu - W = \frac{6.6\times10^{-34}\times10^{16}}{1.6\times10^{-19}} - 2.5$

$= 41.375 - 2.5$

$= 38.875\ eV$

14. As, $h\nu = \frac{1}{2}mu^2 + W_0$

$= \frac{1}{2}\times 9.1\times10^{-31} \times (10^4)^2 + 2.3 \times 1.6 \times 10^{-19}$

$= 4.55 \times 10^{-23} + 3.68 \times 10^{-19}$

$= 3.6795 \times 10^{-19}$ J

$\therefore \quad \nu = \frac{3.6795\times10^{-19}\,J}{h}$

$= \frac{3.6795\times10^{-19}}{6.6\times10^{-34}} = 5.56\times10^{14}\,Hz$

15. As, $E = \frac{V}{d} = \frac{1200\,V}{10^{-2}\,m} = 1.2 \times 10^5$ V/m

Kinetic energy of electron entering the field K = 2000 $eV = 3.2 \times 10^{-16}$

Deflection of electron in the field of length 1.5×10^{-2} is

$y = \frac{eEl^2}{2mv^2} = \frac{eEl^2}{4K}$

$= \frac{1.6\times10^{-19}\times1.2\times10^5\times(1.5\times10^{-2})^2}{4(3.2\times10^{-16})}$

$= 0.34 \times 10^{-2}$ m.

16. $Bev = eE$ or $V = \frac{E}{B} = \frac{V}{dB}$

$= \frac{3000}{2\times10^{-2}\times2.5\times10^{-3}} = 6.7 \times 10^7$ m/s

Now, $\quad eV' = \frac{1}{2}mv^2$

or $\quad v = \sqrt{\frac{2eV'}{m}} = \sqrt{\left(2\times\frac{e}{m}\times10000\right)}$

or $\quad (6 \times 10^7)^2 = 2 \times \left(\frac{e}{m}\right)\times 10{,}000$

$\therefore \quad \frac{e}{m} = 1.8 \times 10^{11}$ coulomb/kg.

17. As, $qE = 6\pi\eta rv + \left(\frac{4}{3}\right)\pi r^3\rho g$

$q = \frac{6\pi\eta rv + (4\pi r^3\rho g/3)}{E}$

$= [6 \times 3.14 \times (180 \times 10^{-6}) \times 10^{-4} \times .035 + (4/3) \times 3.14 \times (10^{-4})^3 \times 0.96 \times 980]/[1950/300]$

$= 24.34 \times 10^{-10}$ esu or stat coulomb

18. $\frac{hc}{\lambda}$ = energy of one photon for the light of wavelength λ.

n = number of photons emitted per sec.

$\frac{nhc}{\lambda}$ = energy emitted by bulb per sec.

Efficiency of the bulb is 10%

$\frac{nhc}{\lambda} = \frac{P}{10}$ or $n = \frac{P_\lambda}{10\,hc}$ or

$n = \frac{1\text{ watt}\times(500\times10^{-9}\,m)}{10\times(6.6\times10^{-34}\,J.s)\times(3\times10^8\,m.s^{-1})}$

$= 2.53 \times 10^{17}$.

19. As, $eV_0 = \frac{hc}{\lambda} - W_0$

W_0 = work function of the metal over which light is incident

W = is a constant for a given metallic surface

$edV_0 = \frac{hc\cdot d\lambda}{\lambda^2} = \frac{(12.4\times10^{-7}\,eV\text{Å})(40\text{Å})}{(3000\text{ Å})^2}$

$\therefore \quad dv_0 = -5.5 \times 10^{12}$ eV

20. As $\quad P = \frac{h}{\lambda} = \frac{6.63\times10^{-34}}{5200\times10^{-10}}$ kgm/sec.

Momentum of the electron = mv

$= 9.1 \times 10^{-31}\,v$

$9.1 \times 10^{-31} \times v = \frac{6.63\times10^{-34}}{5200\times10^{-10}}$

$\therefore \quad v = 1400$ m/s.

21. As, $eV_0 = \frac{hc}{\lambda} - w$ or $V_0 = \frac{hc}{e\lambda} - \frac{W}{e}$

$\Delta V_0 = (V_0)_2 - (V_0)_1$

$= \left(\frac{h_c}{e\lambda_2} - \frac{W}{e}\right) - \left(\frac{hc}{e\lambda_1} - \frac{W}{e}\right)$

$= \frac{hc}{e}\left(\frac{1}{\lambda_2} - \frac{1}{\lambda_1}\right) = \frac{hc}{e}\left(\frac{\lambda_1-\lambda_2}{\lambda_1\lambda_2}\right)$

$= \frac{(6.6\times10^{-34})\times(3\times10^8)}{(1.6\times10^{-19})}\times\left[\frac{0.4\times10^{-7}}{4.0\times10^{-7}\times3.6\times10^{-7}}\right]$

$= 0.34$ volt.

22. For an electron, the de-Broglie wavelength, $\lambda = \frac{h}{\sqrt{2mk}}$

where, h = Planck's constant,

m = mass of an electron
and k = kinetic energy of an electron
Since, h, m remain the same, then $\lambda \propto \frac{1}{\sqrt{k}}$

$$\Rightarrow \quad \frac{\lambda}{\lambda'} = \sqrt{\frac{k'}{k}} = \sqrt{\frac{3k}{k}} = \lambda' = \frac{\lambda}{3}.$$

23. The de-Broglie wavelength, $\lambda = \frac{h}{mv}$

As both particle electron having same wavelength Therefore, momentum will be equal

$$m_p v_p = m_e v_e \Rightarrow U_p = \frac{m_e v_e}{m_p}$$

$$= \frac{9.1 \times 10^{-31} \times 3 \times 10^6}{10^{-6}}$$

$$\Rightarrow \quad v_p = \frac{m_e v_e}{m_p}$$

$$\Rightarrow \quad v_p = 2.7 \times 10^{-18} \text{ m/sec.}$$

24. As, $E = \frac{1}{2}mv^2$ or $E = \frac{1}{2}\frac{(mv)^2}{m}$

$$\Rightarrow \quad mv = \sqrt{2mE}$$

$$\therefore \quad h = \frac{h}{m\nu} = \frac{h}{\sqrt{2mE}}.$$

25. Maximum energy = $h\nu - \phi$

$$\left(\frac{1230}{600} - \phi\right) = \frac{1}{2}\left(\frac{1230}{400} - \phi\right)$$

$$\therefore \quad \phi = \frac{1230}{1200} = 1.02 \text{ eV}.$$

26. When an electron and photon propagate in the form of the waves having the same wavelength, hence, they have same momentum. By de-Broglie equation

$$p \propto \frac{1}{\lambda}.$$

27. We have, $K_{\text{electron}} = \frac{1}{2}mv^2$ and $\lambda = \frac{h}{mu}$ ...(*i*)

$$\Rightarrow \quad K_{\text{electron}} = \frac{1}{2}\left(\frac{h}{\lambda\nu}\right)\nu^2 = \frac{\nu h}{2\lambda} \quad ...(ii)$$

$$K_{\text{photon}} = \frac{hc}{\lambda} \quad ...(iii)$$

Dividing equation from (*i*) & (*ii*), we get

$$\frac{K_{\text{electron}}}{K_{\text{photon}}} = \frac{\nu}{2c} = \frac{2 \times 25 \times 10^8}{2 \times 3 \times 10^8} = \frac{3}{8}.$$

28. As, $\lambda = \frac{h}{\sqrt{2mE}}$, $E = 10^{-32}$ J, which in constant for both particles, hence, $\lambda \propto \frac{1}{\sqrt{m}}$

$$m_p > m_e$$

$$\therefore \quad \lambda_p < \lambda_e.$$

29. As, $\lambda = \frac{h}{\sqrt{2mE}} = \frac{h}{\sqrt{2mqV}} \Rightarrow \lambda \propto \frac{1}{\sqrt{mq}}$

$$\Rightarrow \quad \frac{\lambda_\alpha}{\lambda_p} = \sqrt{\frac{m_p q_p}{m_\alpha q_\alpha}}$$

$$\therefore \quad q_\alpha = 2q_p,\ m_\alpha = 4mp,\ \lambda_p = \lambda$$

$$\lambda_a = \frac{\lambda}{2\sqrt{2}}.$$

30. As, $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mE}} \Rightarrow \lambda \propto \frac{1}{\sqrt{mE}}$

KE, gained by charged particle under potential V

$$E = qE$$

$$E_e = eV, \quad E_p = eV$$

$$E_\alpha = 2eV \quad \Rightarrow \quad E_e = E_p < E_\alpha$$

and $m_e < m_p < m_\alpha$

$$\Rightarrow \quad \lambda = \frac{h}{\sqrt{2m_e E_e}} > \frac{h}{\sqrt{2m_p E_p}} > \frac{h}{\sqrt{2m_\alpha E_\alpha}}$$

$$\lambda_e > \lambda_p > \lambda_\alpha.$$

31. As, $\lambda \propto \frac{1}{p} \Rightarrow \frac{\Delta p}{p} = -\frac{\Delta\lambda}{\lambda}$

$$\Rightarrow \left|\frac{\Delta p}{p}\right| = \left|\frac{\Delta\lambda}{\lambda}\right| \Rightarrow \frac{p_0}{p} = \frac{0.25}{100} = \frac{1}{400}$$

$$\Rightarrow \quad p = 400\ p_0.$$

32. As, $E = hc\left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right)$

$$= 6.63 \times 10^{-34} \times 3 \times 10^8 \left(\frac{1}{1.4 \times 10^{-10}} - \frac{1}{2 \times 10^{10}}\right)$$

$$= 4.26 \times 10^{-16} \text{ J}$$

33. As, $\lambda = \frac{h}{\sqrt{2mQV}} \Rightarrow \lambda \propto \frac{1}{\sqrt{mQ}}$

$$\Rightarrow \quad \frac{\lambda_p}{\lambda_\alpha} = \sqrt{\frac{m_\alpha Q_\alpha}{m_p Q_p}} = \sqrt{\frac{4m_p \times 2Q_p}{m_p \times Q_p}} = 2\sqrt{2}.$$

34. As, $\lambda = \frac{h}{\sqrt{2mE}}$

$$= \frac{6.6 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 5 \times 1.6 \times 10^{-19}}}$$

$$\lambda = 5.47 \text{ Å}.$$

35. As, $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mE}} = \frac{h}{\sqrt{2mqV}}$

$$\Rightarrow \quad \lambda = \frac{6.6\times10^{-34}}{\sqrt{2\times(1.6\times10^{-27})\times(1.6\times10^{-19})\times100}}$$

$\therefore \quad \lambda = 0.9 \times 10^{-12}$ m.

36. As, $\lambda = \dfrac{h}{\sqrt{2mk}} \Rightarrow \dfrac{\lambda_1}{\lambda_2} = \sqrt{\dfrac{k_2}{k_1}} = \sqrt{\dfrac{16k}{k}} = 4$

or $\dfrac{\lambda_1}{\lambda_2} = 4 \Rightarrow \lambda_2 = \dfrac{\lambda_1}{4} = \dfrac{100}{4} = 25$

$\therefore \quad \lambda_1 = 25 \times 4 = 100$

$\therefore$ Increase in percentage = 100 – 25 = 75%.

37. Some minimum frequency is required to eject the photoelectrons.

38. When wavelength of incident radiation is decreased, their frequency increases and hence, electron with more energy come out of the surface of the metal.

39. As $E = h\nu = \dfrac{hc}{\lambda}$

$$E = \frac{6.62\times10^{-34}\times3\times10^{8}}{1000\times10^{-10}\times1.6\times10^{-19}}\,eV$$

$\therefore \quad E = 12.41$ *e*V.

40. Let $\dfrac{hc}{\lambda}$ is energy emitted by bulb in 1 s

$\therefore \quad \dfrac{nhc}{\lambda} = \dfrac{p}{10}$ or $n = \dfrac{p\lambda}{10hc}$

$\therefore \quad n = 2.53 \times 10^{17}$.

41. Given, $W_0 = 2.14$ eV, $\nu = 6 \times 10^{14}$ Hz

As, $K_{max} = h\nu - W_0$

$= 6.63 \times 10^{-34} \times 6 \times 10^{14}$ J – 2.14 eV

$= \dfrac{6.63\times6\times10^{-20}}{1.6\times10^{-19}}$ eV – 2.14 eV

= 2.48 – 2.14 = 0.34 eV.

42. We have, $\dfrac{\Delta V}{\Delta\nu} = 4.12 \times 10^{-15}$ Vs

$e = 1.6 \times 10^{-19}$

$\therefore$ Planck's constant, $h = \dfrac{\Delta V}{\Delta\nu}\cdot e$

$= 4.12 \times 10^{-15} \times 1.6 \times 10^{-19}$

$= 6.592 \times 10^{-34}$ Js

$= 6.6 \times 10^{-34}$ Js.

43. Given, $W_0 = 4.2$ eV, $\lambda = 230$ nm $= 330 \times 10^{-9}$ m

Energy of incident photon, $E = \dfrac{hc}{\lambda}$

$$= \frac{6.63\times10^{-34}\times3\times10^{8}}{330\times10^{-9}}\,J$$

= 3.767 eV.

44. Given, $V_0 = 1.5$ V

As, $K_{max} = eV_0 = 1.5$ eV

$= 1.5 \times 1.6 \times 10^{-19}$ J

$= 2.4 \times 10^{-19}$ J

45. As, $\sqrt{f} = a(z - b)$

$$\frac{f_{La}}{f_{Cu}} = \left(\frac{z_{La}-1}{z_{Cu}-1}\right)^2$$

$$f_{La} = f_{Cu}\left(\frac{z_{La}-1}{z_{Cu}-1}\right)^2$$

$$= 1.88 \times 10^{18}\left(\frac{57-1}{29-1}\right)^2$$

$= 7.52 \times 10^{18}$ Hz.

46. As, $E_{kA} = \dfrac{hc}{\lambda} - W \Rightarrow \dfrac{hc}{\lambda} = E_{kA} + W$

$$E_{kB} = \frac{hc}{\lambda/2} - W$$

or $\quad E_{kB} = \dfrac{2hc}{\lambda} - W = 2(E_{kA} + W) - W$

or $\quad E_{kB} = \dfrac{E_{uB}}{2} - \dfrac{W}{2}$

or $\quad E_{kB} < E_{uB}$.

47. As, $V_0 = \dfrac{hc}{e\lambda} - \dfrac{\phi_o}{e}$

$$= \frac{6.6\times10^{-34}\times10^{8}}{1.6\times10^{-19}\times332\times10^{9}} - \frac{1.07\times1.6\times10^{-19}}{1.6\times10^{-19}}$$

= 3.73 – 7.07 = 2.66 V.

48. As, $2d \sin\theta = \lambda = d = 10^{-10}$ m

$$p = \frac{h}{10^{-10}} = \frac{6.6\times10^{-34}}{10^{-10}} = 6.6 \times 10^{-21}\ \text{kg ms}^{-1}$$

$$\therefore \quad E = \frac{(6.6\times10^{-24})^2}{2\times(1.7\times10^{-27})}\times1.6\times10^{-19}$$

$$= \frac{6.6^2}{2\times1.7}\times1.6\times10^{-2}\,eV$$

$= 2.05 \times 10^{-2}$ eV = 0.21 eV.

49. As, $E_k = h_\nu - W = (6.2 - 4.2)$ eV = 2.0 eV

$= 2 \times 1.6 \times 10^{-19}$ J $= 3.2 \times 10^{-19}$ J

50. As, $eV_0 = \dfrac{1}{2}mv^2$

$\therefore \quad v^2 = \dfrac{2eV_0}{m}$ or $v = \sqrt{\dfrac{2eV}{m}}$

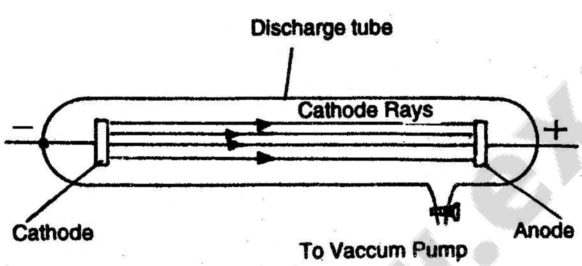
$\therefore \quad v = 3.75 \times 10^6$ ms^{-1}.

CHAPTER

8

ATOMS & NUCLEI

In the early 19th century, John Dalton developed his atomic theory that matter is made up of extremely small and indivisible particles of matter called atoms. In 1859, Plucker and others discovered that when a high potential of the order of 10,000 volts is applied to a discharge tube at low pressure of about 10^{-6} atmosphere, rays are liberated at the cathode. These rays are known as cathode rays consisting of negative charged particles.



These negatively charged particles are known as electron.

Properties of Cathode Rays

(*a*) Cathode rays always travel in a straightline.

(*b*) Cathode rays cast shadows of any solid object placed in their path.

(*c*) Cathode rays consist of negatively charged particles and therefore, they get deflected towards the positive place in an electric field.

(*d*) Cathode rays travel with high speed equivalent to that of velocity of light and penetrate through thin metallic sheets.

(*e*) The nature of these rays is independent of the gas and the cathode material used in the discharge tube.

(*f*) These rays ionize the gas through which they pass.

(*g*) These rays cause fluorescence and heat the object on which they fall due to the transfer of kinetic energy.

(*h*) Cathode rays consists of material particle and possess energy.

ELECTRON

Later in the 19th century, J.J. Thomson demonstrated that atoms are electromagnetically constituted and from them fundamental material units bearing electric charge that are now called electron can be extracted. Electrons are the universal constituents of all atoms as the electrons emitted in a cathode ray tube all possess the same mass and a unit electron-charge. The same is true of electron emitted, in the photoelectric cell or the thermionic value or by a radioactive source. Therefore, it may be said that electrons are prevalent in all forms of matter.

J.J. Thomson (1900-1906) studied the effect of magnetic field on cathode rays and found the ratio of change to mass (e/m) of an electron and calculated the mass of electron from it.

Charcteristics of the Electron

Mass and Charge: The mass of an electron is about 1/1840 time that of a hydrogen atom or proton.

$m_e = 9.109 \times 10^{-31}$ kg

An electron possesses a unit negative charge

$e = 1.602 \times 10^{-19}$ coulombs

PROTONS

Goldstein (1886) in an experiment with discharge tube containing perforated cathode showed the presence of another type of radiation, that passed through hole in the cathode and carried positive charge. These rays consisting of positive charged particles were called positive rays or anode rays or canal rays and these positive charged particle are called proton.

Properties of Anode Rays

(*a*) Positive rays consist of positively charged particles.

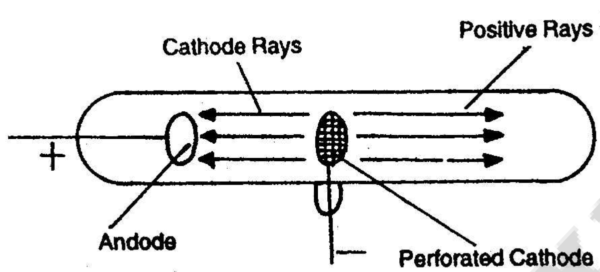
(*b*) These rays travel in straight lines.

(*c*) These rays get deflected by an electrical field and bend towards the negative plate.

(*d*) The nature of these rays depend on the gas used in the discharge tube.

(*e*) These rays can produce mechanical as well as chemical change.

(*f*) Particle of these rays are heavier than the cathode ray particle.

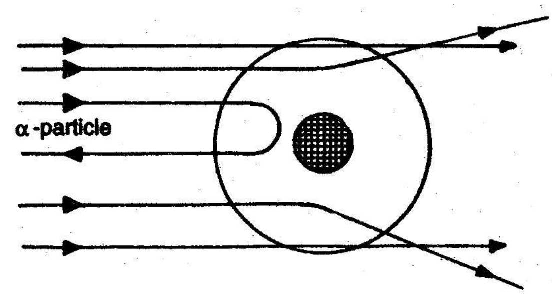


NEUTRONS

Rutherford (1920) suggested that in an atom, there must be present at least a third type of fundamental particles which should be electrically neutral and possess mass nearly equal to that of proton. He proposed the name for such fundamental particle as neutron. In 1932, **Chadwick** bombarded beryllium with a stream of α-particles. He observed that the penetrating radiations were produced which were not affected by electric and magnetic fields. These radiations consisted of neutral particles, which were called neutrons.

THE NUCLEUS

In the twentieth century, 1911, Rutherford performed a scattering experiment and in this experiment a thin gold of thickness 4×10^{-7} m was bombarded with α-particle. It was observed that most of the particles passed through the metallic foil without any deflection. But a few waves deflected from their most original path, some of them deflected backwards. From this observation, he arrived at the following conclusions:



(*a*) T α-particle pass through the Gold foil without suffering any change in their path shows that the atom consists largely of empty space.

(*b*) A few α-particle get deflected through wide angle or backwards shows that these must be present in each atom a heavy positively charged body at its centre and called its nucleus.

(*c*) The number of α-particles which undergoes such strong deflection is very small shows that the volume occupied by this heavy positively charged body is only a minute fraction of the total volume of the atom.

RUTHERFORD MODEL OF AN ATOM

On the basis of α-particle scattering experiment, Rutherfored put the nuclear model of the atom in 1912:

(*a*) The atom consists of positively charged nucleus on which entire mass of the atom resides.

(*b*) Electrons and the nucleus are held together by electrostatic forces of attraction.

BOHR'S ATOMIC MODEL

(*a*) The electrons keep on revolving in one or more of the infinite number of circular orbits about the nucleus without losing or gaining any energy.

(*b*) The electrons can move in only those circular orbits where the angular momentum (mvr) is a whole number multiple of $h/2\pi$.

(*c*) The absorption or emission of energy can occur only by transition of electron from lower to higher energy level or vice versa, respectively.

MODERN STRUCTURE OF ATOM

The modern structure of atom was developed in light of de Broglie and Heisenberg's uncertainty principle.

De Broglie Principle: All the moving material objects possess wave like characteristic. The de Broglie wavelength of material particle is given by

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

h = Planck's constant (J-sec)
m = Mass of particle (kg)
v = Velocity (ms^{-1})

SHAPES OF ATOMIC ORBITALS

The wave function for an electron is termed as atomic orbital, which is the region of finding an electron.

The diffuse electron cloud in an orbital has its greatest density near the nucleus which becomes thinner as the distance from the nucleus increases.

(*a*) **s-Orbital:** They are spherical in shape and have symmetrical orientation.

(*b*) **p-Orbital:** They are dumb bell in shape with two lobes.

(*c*) **d-Orbitals:** They are five in number (double dump-bell shaped)

(*d*) **f-Orbitals:** There are seven f-orbital, f-orbitals have 8 lobes and 3 nodes.

FILLING OF ORBITALS

(*a*) **Aufbau Principle:** It states that electrons are feeded in the orbitals in order of increasing energy and energy of the orbitals is governed by (n + 1) rule.

Therefore, orbitals of lower energy are filled first followed by orbitals of higher energy.

(*b*) **Pauli's Exclusion Principle:** It states that no two electrons can have the same value of the four quantum numbers.

(*c*) **Hund's Rule:** This rule states that pairing of electrons in degenerate orbitals belonging to a particular sub shell does not take place till each orbital is occupied by a single electron with a parallel spin.

QUANTUM NUMBERS

The set of four integers required to define the state of electron in an atom are called quantum numbers.

(*a*) **Principal Quantum Number (n):** It has integral values 1, 2, 3, 4..... and denoted as K, L, M, N.....

(*b*) **Azimuthal Quantum Number (l):** For each value of n, l have values from 0, 1, 2, 3..... (n – 1).

(*c*) **Magnetic Quantum Number (m):** For each sub-energy shell, there can be ($2l$ + 1) number of orbitals.

(*d*) **Spin Quantum Number (s):** Each spinning electron can have two values $+\frac{1}{2}$ (clockwise spin), $-\frac{1}{2}$ (anticlockwise spin).

VALENCE

Valence, also known as valency or valence number, is a measure of the number of bonds formed by an atom of a given element. "Valence" can be defined as the number of valence bonds a given atom has formed, or can form, with one or more other atoms. For most elements the number of bonds can vary. The IUPAC definition limits valence to *the maximum number of univalent atoms that may combine with the atom,* that is the maximum number of valence bonds that is possible for the given element.

The valence of an element depends on the number of valence electrons that may be involved in the forming of valence bonds. A univalent (monovalent) atom, ion or group has a valence of one and thus can form one covalent bond. A divalent *molecular entity* has a valence of two and can form two sigma bonds to two different atoms or one sigma bond plus one pi bond to a single atom. Alkyl groups and hydroxyl ions are univalent examples; oxo ligands are divalent.

Covalence

The concept of covalence was developed in the middle of the nineteenth century in an attempt to rationalize the formulae of different chemical compounds. In 1919, Irving Langmuir, borrowed the term to explain Gilbert N. Lewis's cubical atom model by stating that "the number of pairs of electrons which any given atom shares with the adjacent atoms is called the *covalence* of that atom." The prefix co-means "together", so that a co-valent bond means that the atoms share valence. Hence, if an atom, for example, had a + 1 valence, meaning it has one valence electron beyond the complete shell, and another a – 1 valence, meaning it requires one electron to complete its outer shell (missing an electron), then a bond between these two atoms would result because they would be complementing or sharing their out of balance valence tendencies. Subsequent to this, it is now more common to speak of covalent bonds rather than "valence", which has fallen out of use in higher level work with the advances in the theory of chemical bonding, but is still widely used in elementary studies where it provides a heuristic introduction to the subject.

Common Valences

For elements in the main groups of the periodic table, the valence can vary between one to seven, but usually these elements form a number of valence bonds between one and four. The number of bonds formed by a given element was originally thought to be a fixed chemical property. In fact, in most cases this is not true. For example, phosphorus often has a valence of three, but can also have other valences.

Nevertheless, many elements have a common valence related to their position in the periodic table, following the octet rule. Elements in the main groups 1 (alkali metals) and 17 (halogens) commonly have a valence of 1; elements in groups 2 (alkaline earth metals) and 16 (chalcogens) valence 2; elements in groups 13 (boron group) and 15 (nitrogen group) valence 3; elements in group 14 (carbon group) valence 4.

Valence Vs Oxidation State

The "oxidation state" of an atom in a molecule gives the number of valence electrons it has gained or lost. In contrast to the *valency number,* the *oxidation state* can be positive (for an electropositive atom) or negative (for an electronegative atom).

Elements in a high oxidation state can have a valence larger than four. For example, in perchlorates, chlorine has seven valence bonds and ruthenium, in the +8 oxidation state in ruthenium (VIII) tetroxide, has even eight valence bonds.

Examples : (Valencies according to the *number of valence bonds* definition and conform oxidation state)

Compound	Formula	Valence		Oxidation State	
Hydrogen chloride	HCl	H = 1	Cl = 1	H = +1	Cl = –1
Chlorine	Cl_2	Cl = 1	Cl = 1	Cl = +1	Cl = –1
Perchlorate*	$HClO_4$	H = 1	Cl = 7	O = 2 H = +1	Cl = +7 O = –2
Sodium hydride	NaH	Na = 1	H = 1	Na = +1	H = –1
Ferrous oxide**	FeO	Fe = 2	O = 2	Fe = +2	O = –2
Ferric oxide**	Fe_2O_3	Fe = 3	O = 2	Fe = +3	O = –2

* The univalent perclhorate ion (ClO_4^-) has valence 1.

** Iron oxide appears in a crystal structure, so on typical molecule can be identified.

In ferrous oxide, Fe has oxidation number II, in ferric oxide, oxidation number III.

NUCLEAR REACTION

When nucleon comes into contact with a target, a new nucleus results and it is called a nuclear reaction. During nuclear reactions, the total mass number of reactants should be equal to total mass of products. The nuclear reaction in which energy is released is exogeric and in which energy are of two categories :

A. Reactions that depend on nature of bombarding particles.

B. Reactions which depend on transformation of target nucleus.

Nuclear Fission

In this process U-235 is hit by slow moving neutrons, it splits up into a number of fragments with the release of large amount of energy. The fission of an atom of U-235 releases 211.5 MeV of energy. Nuclear Reactor is a device in which nuclear fission is carried in a controlled manner.

Nuclear Fusion

It is the process in which lighter nuclei of atoms fuse together to form a heavier nucleus. The heavier nucleus has less mass. Fusion reaction occur at high temperature so these are called thermonuclear reactions.

Hydrogen bomb is based on nuclear fusion.

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n + 17.6\text{MeV}$$

Radio-Carbon Dating and Carbon Dating

Radiocarbon Dating: It is the technique to find out the age of archaeological objects like plants and animals fossils.

Carbon Dating: C_{14} isotope produced in upper atmosphere is incorporated in CO_2 which is inhaled by plants and in turn consumed by human beings.

$$^{14}_{7}H + ^{1}_{0}n \rightarrow ^{14}_{6}C + ^{1}_{1}H$$

A plant animal carbon cycle exists in nature as long as it is alive the C-14 content remains same. When a plant or animal dies, the process of incorporation of $^{14}_{6}C$ stops and it starts decaying.

Age can be calculated by $t = \dfrac{2.303}{\lambda}\log\dfrac{N_0}{N_t}$

$$\lambda = \frac{.693}{5770} Y_r^{-1}$$

Half-Life Period

Is the time in which half of the original amount of the substance disintegrates.

Half life period $t_{1/2} = \dfrac{.693}{\lambda}$

Average life period

Average life $= \dfrac{1}{\lambda} = \dfrac{t_{1/2}}{.693} = 1.44 t_{1/2}$

Artificial Radioactivity

Discovered by Madam Curie and her husband E. Joliot by artificial disintegration a stable nucleus is made radioactive isotope.

$$^{4}_{2}He + ^{27}_{13}\underset{\text{Stable}}{Al} \longrightarrow \underset{\text{Radioactive}}{^{30}_{15}P} + ^{1}_{0}n$$

$$^{30}_{15}P \xrightarrow{t_{1/2}=2.55\,min} ^{30}_{14}Si + _{-1}e^{0} \text{ positive}$$

Phenomenon in which non-radioactive element is formed is called artificial radioactivity.

Artificial Transmutation of Elements

Transformation of an element into another by bombarding it with high energy particle is termed as artificial transmutation of elements. It was discovered by Rutherford.

EXERCISE

1. Which of the following has the same atomic number and atomic weight?
A. Hydrogen B. Helium
C. Oxygen D. Nitrogen

2. Nuclides having the same atomic and mass numbers are known as
A. Isotones B. Isomers
C. Isobars D. Isotopes

3. Which of the following are α-emitters?
A. Polonium-212 B. Radium-226
C. Helium-5 D. Tritium

4. Which of the following is true for Thomson Model of the atom?
A. The radius of an electron can be calculated using Thomson Model.
B. In an undisturbed atom, the electrons will be at their equilibrium positions, where the attraction between the cloud of positive charge and the electrons balances their mutual repulsion.
C. When the electrons are disturbed by collision, they will vibrate around their equilibrium positions and emit electromagnetic radiation whose frequency is of the order of magnitude of the frequency of electromagnetic radiation of a vibrating electron.
D. Both (B) and (C)

5. Tritium is a radioactive isotope of hydrogen. It emits
A. β-particles B. α-particles
C. γ-rays D. neutrons

6. The SI unit of Radioactivity is:
A. Becquerel B. Curie
C. Weber D. Gauss

7. What are nucleons?
A. the sum of protons and neutrons present in the nucleus
B. the number of protons in the nucleus
C. the number of neutrons in the nucleus
D. the sum of protons, neutrons and electrons present in the nucleus

8. Isobars have:
A. same mass number but different atomic number
B. same number of neutrons but different mass number
C. same difference between number of protons and neutrons
D. same mass number and atomic number

9. Charge on fundamental particle neutrino is
A. 0 B. +1
C. −1 D. None of these

10. The fundamental particle that has least mass is
A. meson B. α-particle
C. electron D. neutron

11. Which of the following has highest mass?
A. Neutron B. Alpha particle
C. Electron D. Deuterium

12. The wavelength of an electron
A. is equal to that of light
B. remains constant with velocity
C. decreases with an increasing velocity
D. increases with an decreasing velocity

13. No two electrons in an atom can have the same values of all four quantum numbers according to
A. Hund's rule
B. Flemming rule
C. Pauli's exclusion principle
D. Bohr theory

14. The velocity of a photon is
A. dependent on its wavelength
B. dependent on its source
C. equal to cube of its amplitude
D. independent of its wavelength

15. Isotopes have different
A. arrangement of electrons
B. no. of P and e^-
C. no. of neutrons
D. no. of electrons

16. The electrons configuration of a dispositive ion M^{2+} is 2, 8, 14 and its mass number is 56. The number of neutrons present is
A. 32 B. 42
C. 30 D. 34

17. How many unpaired electrons are there in Ni^{2+}?
A. 0 B. 2
C. 4 D. 8

18. In two H atoms A and B the electrons move around the nucleus in circular orbits of radius r and $4r$ respectively. The ratio of the times taken by them to complete one revolution is
A. 1 : 4 B. 1 : 2
C. 1 : 8 D. 2 : 1

19. How many unpaired electrons are there in Ni^{2+}?
A. 0 B. 2
C. 4 D. 8

20. The number of electrons in the M shell of the element with atomic number 24 is
A. 24 B. 12
C. 13 D. 8

21. The atomic radius is of the order of
A. 10^{-8} cm B. 10^{8} cm
C. 10^{-12} cm D. 10^{-10} cm

22. Mass number of an element represents number of
A. Protons and neutrons
B. Protons and electrons
C. Electrons and neutrons
D. None of these

23. The symbol of a metal element which is used in making thermometers is:
A. Ag B. Hg
C. Mg D. Sg

24. If the value of principal quantum number is 3, the total possible values for magnetic quantum number will be
A. 1 B. 4
C. 9 D. 12

25. Which one of the following elements has an atomicity of 'one'?
A. helium B. hydrogen
C. sulphur D. ozone

26. The law of conservation of mass was given by
A. Dalton B. Proust
C. Lavoisier D. Berzelius

27. The atoms of which of the following pair of elements are most likely to exist in free state?
A. hydrogen and helium
B. argon and carbon
C. neon and nitrogen
D. helium and neon

28. Which of the following elements has the same molecular mass as its atomic mass?
A. nitrogen B. neon
C. oxygen D. chlorine

29. Charge on a positron is equal to that of
A. proton B. electron
C. nucleon D. neutron

30. The atomic theory of matter was proposed by
A. John Kennedy B. Lavoisier
C. Proust D. John Dalton

31. Gamma radiation from a radioactive nucleus results in change in the number of
A. neutrons B. protons
C. Both (A) and (B) D. None of these

32. Smallest particle of an element or a compound which is capable of independent existence is called
A. Atom B. Molecule
C. Element D. Compound

33. The particles that display dual nature of both waves and particles are
A. Protons B. Electrons
C. Mesons D. Neutrons

34. Avogadro's number represents the number of atoms in
A. 12 g of C^{12} B. 320 g of sulphur
C. 32 g of oxygen D. 14.3 of sulphur

35. The total number of ions present in 111 g of $CaCl_2$ is
A. One mole B. Two mole
C. Four mole D. Three mole

36. The nuclides $^{40}_{18}Ar$ and $^{41}_{19}K$ are
A. isotopes B. isobars
C. isotones D. None of these

37. The law of the multiple proportion was proposed by
A. Dalton B. Dulong
C. Petit D. Lavoisier

38. Match the following:

Term introduced	**Name of the Scientist**
(*a*) Atom	(*i*) Avogadro
(*b*) Molecule	(*ii*) Einstein
(*c*) Element	(*iii*) Robert Boyle
(*d*) Mass energy relationship	(*iv*) Dalton

	(*a*)	(*b*)	(*c*)	(*d*)
A.	(*iv*)	(*i*)	(*ii*)	(*iii*)
B.	(*iv*)	(*i*)	(*iii*)	(*ii*)
C.	(*iv*)	(*iii*)	(*i*)	(*ii*)
D.	(*iv*)	(*iii*)	(*ii*)	(*i*)

39. Give reason why atomic mass has no units
A. It is well defined physical quantity.
B. Properties of atoms are not measurable.
C. It is a ratio of masses.
D. It is the average mass.

40. Which of the following statement is true?
A. A photon is a waveform of light energy.
B. A photon is a positively charged nuclear particle.
C. A photon is a quantum of light.
D. A photon is a bundle of energy of definite magnitudes but not necessarily light energy.

41. The positron is as heavy as
A. electron B. neutron
C. alpha particle D. proton

42. An atom which doesn't have any neutron is
A. deutrium B. tritium
C. helium D. hydrogen

43. When $3p$ orbitals are completely filled, then the newly entering electron goes into
A. $4p$ B. $3d$
C. $4s$ D. $4d$

44. Bohr's model of atom is not in agreement with
A. Line spectra of hydrogen atom
B. Pauli's principle
C. Planck's theory
D. Heisenberg's principle

45. The total number of subshells in the nth main energy level are
A. n^2 B. $2n^2$
C. $(n - 1)$ D. n

46. How many electrons in $_{19}K$ have $n = 3$; $l = 0$
A. 1 B. 2
C. 4 D. 3

47. The maximum number of $3d$ electrons having spin quantum number $s = +\frac{1}{2}$ are
A. 10
B. 14
C. 5
D. any number from 1 to 10

48. In the Schrodinger's wave equation ψ represents
A. Orbit B. Wave function
C. Wave D. Radial probability

49. The valence electrons of $_{29}Cu$ lie in the
A. K-shell
B. M-shell
C. N-shell
D. both M and N shell

50. In the atomic spectrum of hydrogen, the spectral lines pertaining to electronic transition of $n = 4$ to $n = 2$ refers to
A. Lyman lines B. Balmer lines
C. Paschen lines D. Brackett lines

ANSWERS

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
A	B	B	D	A	A	A	B	A	D
11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
B	C	C	D	C	C	B	C	B	C
21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
A	A	B	C	A	C	D	B	A	D
31	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
D	B	B	A	D	C	A	B	C	C
41	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**
A	D	C	D	D	B	C	B	C	B

CHAPTER

9

ELECTRONIC DEVICE

SEMICONDUCTORS

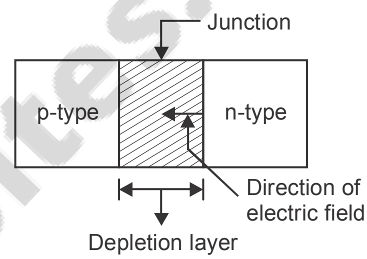
Semiconductors are certain elements (e.g., Ge, Si, Ga, As and Se) which behave like good conductors under certain conditions (generally at shightly elevated temperatures) and as bad conductors when those conditions do not exist. Their resistivities lie between 10^{-5} and 10^{7} ohm m at room temperature.

Intrinsic and Extrinsic Semiconductors: Pure semiconductors are called intrinsic semi-conductors to enhance the desirable characteristics of pure semiconductors, certain impurities are added to them. This is called doping. Suppose we take the case of Germanium (Ge) crystal. It's atom has 4 electrons in its valence band. Thus, it needs 4 more electrons to complete its octet. Let we dope it with phosphorus (P) which has 5 electrons in its valence band. This doping will complete octets for both Ge and P, but one electron will become extra in the lattice. Such doped semiconductors are called ***n*-type** (*i.e.*, negative-type) semiconductors. Similarly, doping Ge with Boron (B) will make it a ***p*-type** (*i.e.*, positive-type) semiconductor.

SEMICONDUCTOR DIODE

A diode made of semiconductor components, usually silicon. The cathode, which is negatively charged and has an excess of electrons, is placed adjacent to the anode, which has an inherently positive charge, carrying an excess of holes.

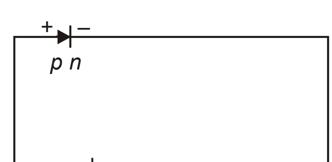
Junction Diode: It is a device in which *p*-type semi-conductor is joined with an *n*-type semiconductor, back to back. At their junction, within a limited width, holes of *p*-type are neutralised by extra eletrons of *n*-type semiconductor. This is called depletion layer.



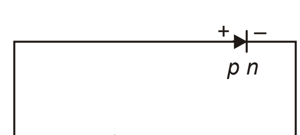
Circuit Symbol of pn-junction

Forward and reverse biasing on a junction diode.

Forward Bias: When a battery is connected across the junction diode with its positive terminal connected to the *p*-side and the negative terminal connected to the *n*-side of the diode it is said to be forward biased. If the bias voltage is greater than the barrier potential across the depletion layer, the majority carriers move towards the junction and cross it, causing a flow of current.



Reverse Bias: When a battery is connected across the junction diode with its negative terminal connected to *p*-side and positive terminal connected to *n*-side, the diode is said to be reverse biased.



Zener Breakdown

If the reverse bias is continuously increased, then at a certain value, the covalent structure breaks down and large number of electrons are released causing an abrupt increase in current. This voltage is called *Zener voltage*.

Dynamic Resistance (R): We have,

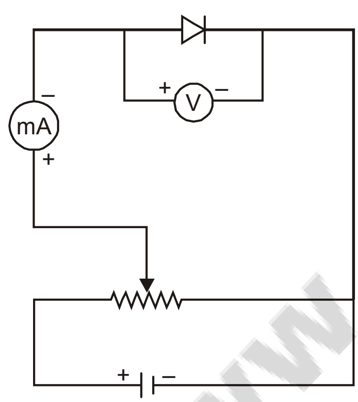
$$R = \frac{\Delta V}{\Delta I}$$

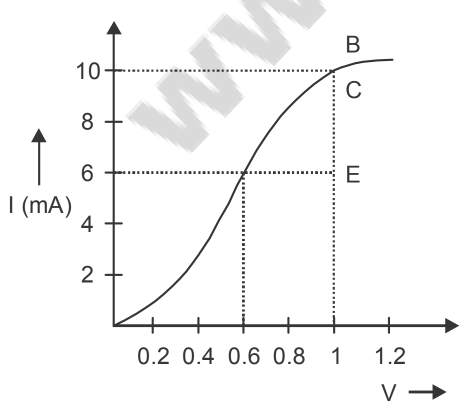
ΔV = small change in applied voltage

ΔI = corresponding change in current

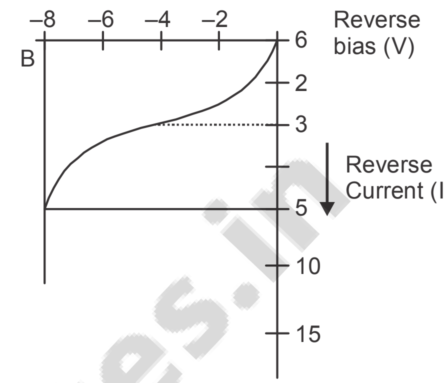
I-V CHARACTERISTICS IN FORWARD AND REVERSE BIAS

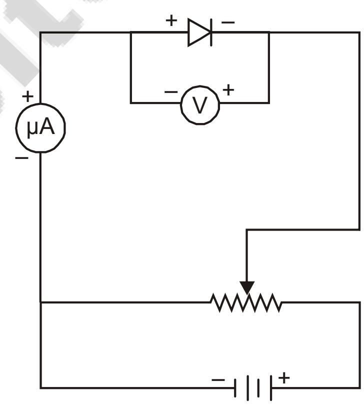
Forward Characteristics: For a given low forward bias voltage (V) note the forward current (ImA) which due to migration of majority carriers across the *pn* junction. On plotting, the graph between forward bias and forward current, we get the curve OPQ. This is called forward characteristics.





Reverse characteristics: For a reverse bias voltage (V) applied to the *pn* junction not the reverse current (μA) which is due to magnetic of majority charge carrier across the *pn* junction so on increasing the reverse biased voltage and note the corresponding reverse current. On plotting the graph between reverse bias and reverse current, we note the reverse biasing of *pn* junction diode, the reverse current is very small and voltage independent upto certain reversed bias voltage known as breakdown voltage. It is called reverse saturation current.





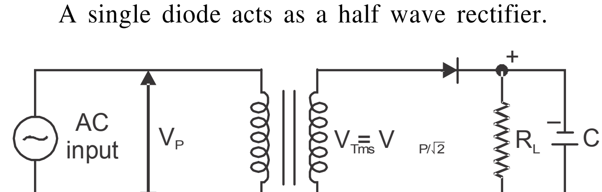
Knee voltage: It is forward bias voltage beyond which the current through the junction starts increasing rapidly with voltage, showing the linear variation but below the knee voltage the variation is non-linear.

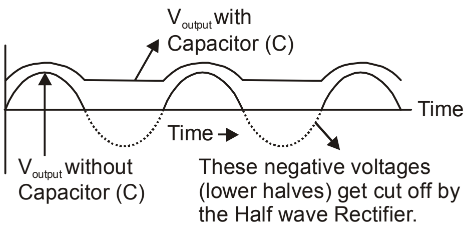
DIODE AS A RECTIFIER

Rectifier: It is a device which used for converting alternating current/voltage in direct current (DC). A *pn* junction can be used as a rectifier in two types.

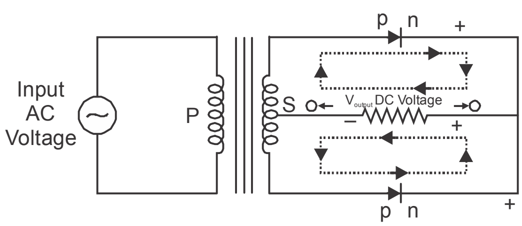
(*a*) ***Half Wave Rectifier:*** It is based on the fact that the resistance *pn* junction becomes low, when forward biased and becomes high when reversed biased.

A single diode acts as a half wave rectifier.

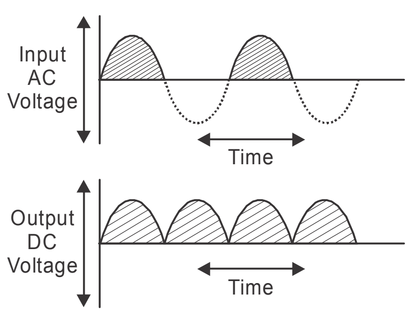




(*b*) ***Full Wave Rectifier:*** A rectifire which rectifies both halves of the A.C. input is called a Full Wave Rectifier. To make use of both the halves of the input cycle, two junction diodes are used.

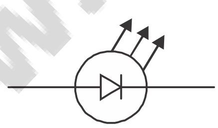


Step down transformer

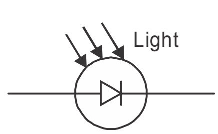


I-V CHARACTERISTICS

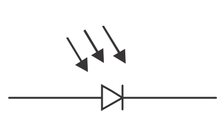
LED (Light Emitting Diode): It is photoelectric device which converts electrical energy into light energy. It is heavily doped *pn* junction diode. LED is made of GaAsP, GaP etc.



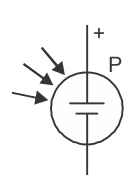
Photodiode: It is an opto-electronic device in which current carriers are generated by photons through photo excitation *i.e.*, photo conduction of light.

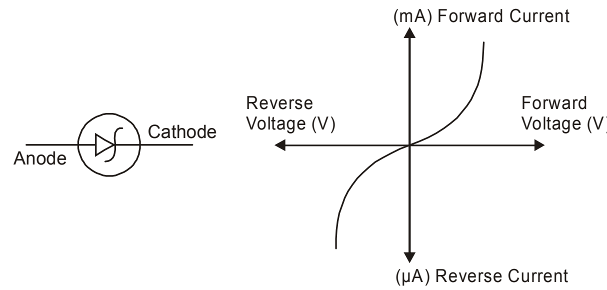


Solar Cell: It is basically a solar energy converter. It is a *pn* junction device, which converts solar energy into electrical energy.



Zener Diode: It is highly doped *pn* junction which is not damaged by high reverse current. It can operated continuously, without damage in the region of reverse breakdown voltage. In the forward biased, the zener diode acts as ordinary diode. It can be used as voltage regulator.





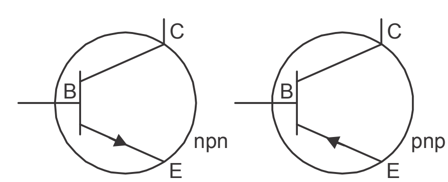
ZENER DIODE AS A VOLTAGE REGULATOR

Zener diode is connected to the positive terminal of the d.c. It is more heavily doped than ordinary diodes, due to which it has narrow region. While regular diode gets damaged when the voltage across them exceeds the reverse breakdown voltage, zener diode works exclusively in depletion region. The depletion region in zener diode goes back to its normal state when the reverse voltage gets removed. This particular property of zener diode makes it useful as a voltage regulator.

JUNCTION TRANSISTOR

If a single crystal continuous crystal of a semiconductor is grown in such a way that it is equivalent to two diodes (either *p-n* and *n-p*, or *n-p* and *p-n*) fused together back to back, such that the middle sandwitched layer is thin, it is called a Junction Transistor.

Junction transistors are two types *npn* and *pnp*. In a *npn* transistor, a thin *p* layer is sandwiched between two thick *n* type layers; and in a *pnp* transistor a thin *n* type layer is sandwiched between two thick *p* type layers.



Emitter (E): It is that electrode which supplies majority carriers (*i.e.*, positive holes in case of *p*-type and electrons in case of *n*-type semiconductors) to the base for current flow within the transistor.

Base (B): This is the electrode which is attached to the middle sandwitched layer. Through it, current passes from emitter to collector.

Collector (C): It is the other end of the transistor, which collects the current which comes to it from the emitter via the base.

Note: In the symbol of a transistor, arrow is put on the emitter. The direction of this arrow indicates the direction of current within a transistor.

Whether the transistor is a *pnp* or an *npn*, base-emitter junction is Always forward-biased; and base-collector junction is always reverse biased.

α-value

The portion of I_E in the collector is called α-value.

$$\alpha = \frac{I_C}{I_E}$$

where,

I_C = Collector current

I_E = Emitter current

β-value

The portion of base-current (IE) in the collector is called β-value.

$$\beta = \frac{I_C}{I_B}$$

Relationship between α and β

We known $I_E = I_C + I_B$

From this we can derived easily

$$\beta = \frac{\alpha}{1-\alpha}$$

and $$\alpha + \frac{\beta}{1+\beta}$$

dc current gains

α and β are called

dc current gains.

α is generally ≃ 0.9 and

β is generally ≃ 1.

Transistor is used in a circuit: It is used in any one of the following three ways:

(*i*) Common Base

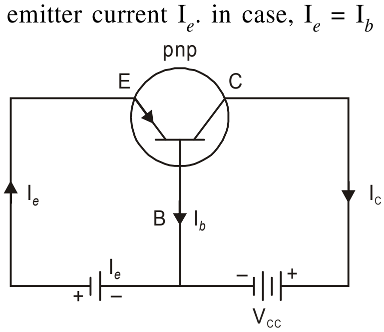
(*ii*) Common Emitter

(*iii*) Common Collector

'Common' mean 'grounded', *i.e.*, 'earthed'.

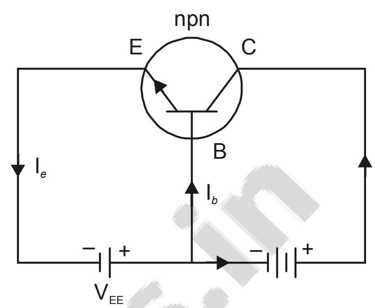
TRANSISTOR ACTION

pnp transistor: The EB junction is forward biased. It means the positive pole of emitter-base battery V_{EE} is connected to emitter and its negative pole the base. Holes are majority carriers in emitter *p*-type semiconductor are repelled towards the base by positive potential an emitter due to bettery V_{EE}, resulting in emitter current I_e. in case, $I_e = I_b + I_c$.



npn transistor: The EB junction is forward biased, the positive pole of the emitter-base battery V_{EE} is connected to base and its negative pole to emitter.

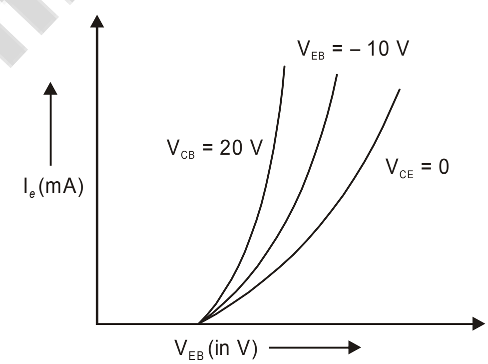
The resistance of emitter base junction is very low. So the voltage of V_{EE} (*i.e.*, V_{EB}) is quite small is 1.5 V, then in this case, $I_e = I_b + I_c$.



CHARACTERISTICS OF TRANSISTOR

CB configuration: Base in common to both emitter and collector.

Input characteristics: When V_{CE} is constant, curve between I_e and V_{EB} is known as input characteristics. It is also known as emitter characteristics.



Input characteristics of *npn* transistor are also similar to the figure but I_e and V_{EB} both are negative and V_{CB} is positive. Dynamic input resistance of a transistor is given by

$$R_i = \left(\frac{\Delta V_{EB}}{\Delta I_e}\right)_{V_{CB} = \text{constant}}$$

[R_i is order of 100 Ω]

Output characteristics: Taking the emitter current I_e constant, the curve drawn between I_C and V_{CB} are known as output characteristics of CB configuration.

Dynamic output resistance,

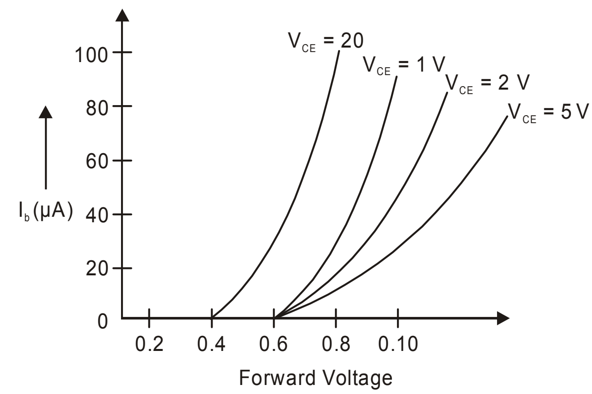
$$R_o = \left(\frac{\Delta V_{CB}}{\Delta I_C}\right)_{I_e = \text{constant}}$$

CE configuration: Emitter is common to both base and collector.

Input characteristics: Input characteristics curve is drawn between base current I_b and emitter base voltage V_{EB} at constant emitter voltage V_{CE}.

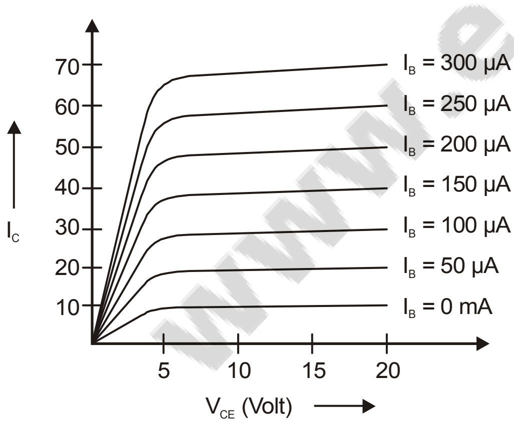
Dynamic input resistance,

$$R_i = \left(\frac{\Delta V_{BE}}{\Delta I_B}\right)_{V_{CE} = \text{constant}}$$



Output characteristics: Variation of collector current I_C with V_{CE} can be noticed for V_{CE}, between O and V. The value of V_{CE} upto which the I_C charges with V_{CE} is called Knee voltage. The transistors are operated in the region above Knee voltage.

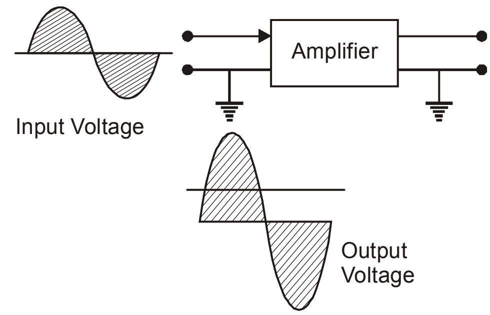
Dynamic out resistance, $R_o = \left(\frac{\Delta V_{CB}}{\Delta I_C}\right)_{I_B = \text{constant}}$



TRANSITOR AS AN AMPLIFIER

An amplifier is a device, which is used for increasing the amplitude of variation of alternating voltage/current or power. The amplifier thus produces an enlarged version of input signal.

To amplify means to increase the amplitude of the input signal without changing its frequency or wavelength. The general concept is represented below:



ac Volatge Gain (A_V)

$$A_v = \frac{\delta V_0}{\delta V_i} = \frac{v_0}{v_i}, \text{ where}$$

δV_0 = small change in output voltage corresponding to δV_i (small) change in input voltage.

ac Current gains (β_{ac}) and (α_{ac})

$$\beta_{ac} = \frac{\delta I_C}{\delta I_B} = \frac{i_C}{i_B}$$

$$\alpha_{ac} = \frac{\delta I_C}{\delta I_e} \text{ at constant } V_C$$

Transconductance (g_m) of the transistor: It is also called mutual conductance.

$$g_m = \frac{\beta_{ac}}{R_i}, \text{ where } R_i = \text{input resistance}$$

$$= \frac{\delta I_C}{\delta I_B} + \frac{\delta V_{BE}}{\delta I_B}, \text{ at constant } V_{CE}$$

$$= \frac{\delta I_C}{\Delta V_{BE}}, \text{ at constant } V_{CE}$$

= Rate of change of output current w.r.t. input voltage keeping output voltage constant.

Power Gain (A_p)

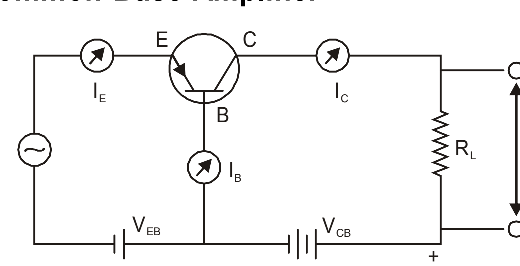
A_p = Current gain × Voltage gain

$$A_p = \beta_{ac}^2 \frac{R_L}{R_i}$$

Resistance Gain

$$\text{Resistance gain} = \frac{R_{out} \text{ or } R_L}{R_{input} \text{ or } R_i}$$

Common Base Amplifier



(*a*) ***Voltage Gain***

δ_{IE} = increment change in I_E

δ_{IC} = incremental change in I_C

E_i = Input voltage

R_i = Input Resistance

E_0 = Output voltage

R_L = Load Resistance

$$\therefore \quad E_i = R_i \times \delta I_E$$

$$E_0 = R_L \times \delta I_C$$

$$\text{Voltage gain} = \frac{E_0}{E_i} = \frac{R_L\ \delta I_C}{R_i\ \delta I_E}$$

$$= \alpha_{ac} \times \frac{R_L}{R_i} \qquad \left[\therefore \frac{\delta I_C}{\delta I_E} = \alpha\right]$$

$$= \alpha_{ac} \times \text{Resistance gain}$$

(***b***) ***Power Gain***

$$\text{Power Output} = E_0 \times \delta I_C$$

$$\text{Power Input} = E_i \times \delta I_E$$

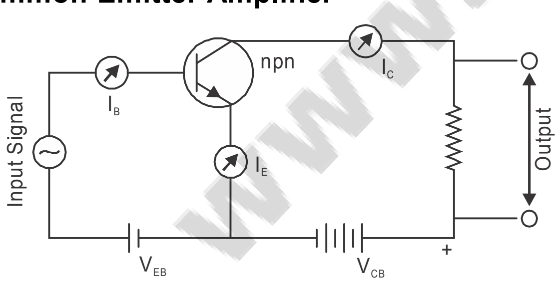
$$\therefore \quad \text{Power Gain} = \frac{E_0 \times \delta I_C}{E_i \times \delta I_E}$$

$$= \frac{(R_L \times \delta I_C) \times \delta I_C}{(R_i \times \delta I_E) \times \delta I_E}$$

$$= \left(\frac{\delta I_C}{\delta I_E}\right)^2 \times \frac{R_L}{R_i}$$

$$= \alpha_{ac}^2 \times \text{Resistance gain}$$

Common Emitter Amplifier



(*a*) ***Voltage Gain***

$$\text{Voltage input} = \delta I_B \times R_i$$

$$\text{Voltage output} = \delta I_C \times R_L$$

$$\therefore \quad \text{Voltage Gain} = \frac{\delta I_C \times R_L}{\delta I_B \times R_i}$$

$$= \beta_{ac} = \text{Resistance Gain}$$

(***b***) ***Power Gain***

$$\text{Power Output} = E_0 \times \delta I_C$$

$$\text{Power Input} = E_i \times \delta I_B$$

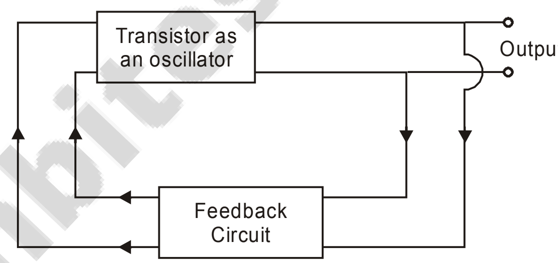
$$\therefore \quad \text{Power Gain} = \frac{E_0 \times \delta I_C}{E_i \times \delta I_B} = \frac{(R_L \times \delta I_C) \times \delta I_C}{(R_i \times \delta I_B) \times \delta I_B}$$

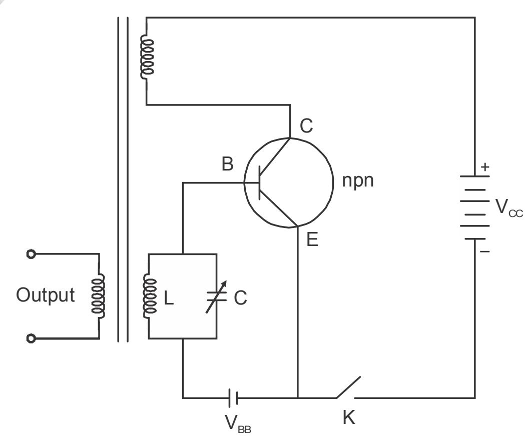
$$= \left(\frac{\delta I_C}{\delta I_B}\right)^2 \times \frac{R_L}{R_i}$$

$$= \beta_{ac^2} \times \text{Resistance gain}$$

Transistor as an Oscillator

The radio waves which are used as carrier waves in radio communication are produced by the circuits called oscillators. The damped em wave suitable for the transmission of code messages on telegraphic messages but to transmit speech or music, we require undamped em waves or carrier waves. The block diagram of feedback oscillator.





LOGIC GATES COR, AND, NOT, NAND AND NOR

Logic gates are the building blocks of a digital system. A gate is a electronic circuit which follows a logical relationship between input and output voltages and for this reason, it is called a logic gate.

There are three basic logic gates.

1. OR gate
2. AND gate and
3. NOT gate.

Each logic gate has its characterisitics symbol its function is defined either by a truth table or by a Boolean expression.

In digital circuit, low and high voltage are often represented by 0 and 1 respectively.

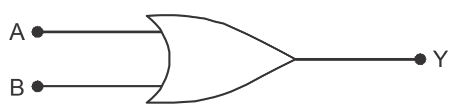
Truth Table: It is a table that shows all input/output possibilities for a logic gate. It is also called a table of combinations.

Boolean Expression: George Boolean invented a different kind of algebra based on binary nature (two valued) of logic. It was first applied to switching circuits, as a switch is a binary device (on or off).

Logic gates are applied in digital circuits.

'OR' GATE

In Boolean algebra, addition symbol (+) is referred to as OR gate.



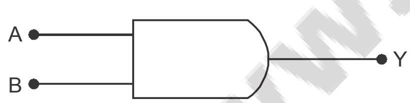
y = A + B ⇒ Y = equals A or B.

Truth table of the 'OR' gate

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

'AND' GATE

The multiplication sign [either × or] is referred to an AND gate.



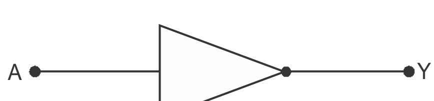
Y = A.B implies Y equals A and B

Truth table of 'AND' gate.

A	B	Y
0	0	0
1	0	0
0	1	0
1	1	1

'NOT' GATE

The bar symbol (¯) is referred to NOT gate. Y = $\overline{A}$ implies Y equals NOT A.



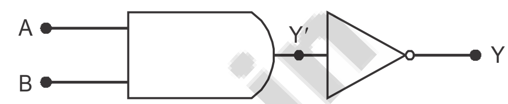
$\overline{0} = 1$ and $\overline{1} = 0$

The NOT operation is also called negation or inversion.

A	Y
1	0
0	1

The NAND gate

If the output of AND gate is connected to the input of NOT gate, the gate so obtained is called NAND gate.



Boolean expression for the NAND gate is

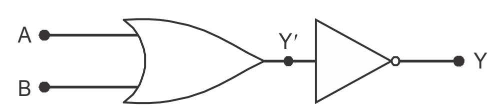
$$y = \overline{A\,.\,B}$$

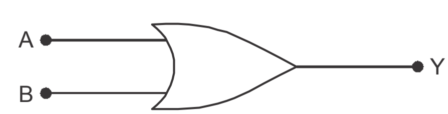
Truth Table

A	B	y	y'
0	0	0	1
1	0	0	1
0	1	0	1
1	1	1	0

The NOR gate

If the output (y') of OR gate is connected to the input of a NOT gate, the gate so obtained is called the NOR gate.





Boolean expression for the NOR gate is

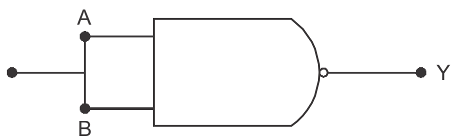
$$y = \left(\overline{A + B}\right)$$

Truth Table

A	B	y'	y
0	0	0	1
1	0	1	0
0	1	1	0
1	1	1	0

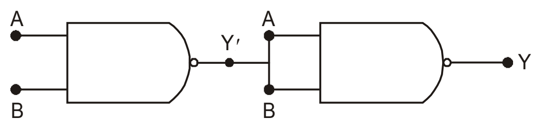
NAND or NOR gate is building block in digital circuit

(*i*) To create Not gate by NAND gate

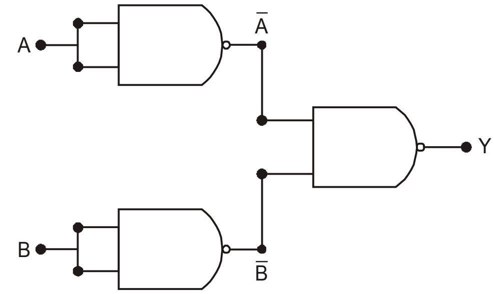


If the two input terminals are joined together, you get a NOT gate

(*ii*) To create AND gate by NAND gates



(*iii*) To create OR gate by NAND gates



TRANSISTOR AS A SWITCH

The transistors that are full 'OFF' are said to be in their cut off region. When using the transistor as a switch, a small base current controls a much larger collector load current, when using transistors to switch inductive loads such as relays and solonoids, a fly wheel diode is used.

EXERCISE

1. A piece of semiconductor is connected in series in an electric circuit on increasing the temperature, the current in the circuit will

A. stop flowing B. decrease
C. increase D. remain unchanged

2. A common emitter transistor amplifier has a current gain of 50. If the load resistance is 4 kΩ and the input resistance is 500 Ω, find the voltage gain of the amplifier.

A. 700 B. 400
C. 500 D. 900

3. In a pn-junction photo cell, the value of photo electro motive force produced by monochromatic light proportional to the

A. frequency of light falling on the cell
B. voltage applied at pn-junction
C. intensity of light falling on the cell
D. barrier voltage at pn-junction

4. A transistor is connected in common emitter (CE) configuration. The collector supply is 8 V and the voltage drop across a resistor of 800 Ω in the collector circuit is 0.5 V. If the current gain factor (α) is 0.96, find the base current.

A. 40 μA B. 35 μA
C. 26 μA D. 15 μA

5. The input resistance of a common emitter amplifier is 665 Ω and the load resistance is 5 kΩ. A change of base current by 15 μA results in the change of collector current by 2 mA. Find the voltage gain of the amplifier.

A. 1002 B. 4300
C. 2100 D. 6103

6. A triode has a mutual conductance of 2.5 m A/V and a plate resistance of 20 kΩ. Calculate the load resistance required for a voltage gain of 30.

A. 10 kΩ B. 20 kΩ
C. 30 kΩ D. 40 kΩ

7. In a triode, the plate current changes by 0.5 mA when the plate potential is changed by 12 V. Find the plate resistance. If the amplification factor is 16, find the change in the grid voltage necessary to produce a change of 4 mA in the plate current.

A. 4 V B. 2 V
C. 7 V D. 6 V

8. A *p*-type semiconductor has acceptor level 57 MeV above the valence band. The maximum wavelength of light required to create a hole is

A. 57 Å B. 57×10^{-3} Å
C. 217100 Å° D. 11.61×10^{-33} Å

9. A triode value has amplification factor 33 and anode resistance of 16 kilo ohm. It is required to amplify a sinusodial signal of 0.5 V to give on output of 12.5 volt. Determine the load resistance required.

A. 70×10^3 Ω B. 40×10^3 Ω
C. 50×10^3 Ω D. 80×10^3 Ω

10. The slope of anode and mutual characteristics of a triode value are 0.02 mA/volt and 1 mA/volt. Then the amplification factor of the value is

A. 5 B. 50
C. 500 D. 0.5

11. 14×10^{15} electrons reach the anode per second. If the power consumed is 448 milli-watts, the anode voltage is

A. 150 V B. 200 V
C. 14 × 448 V D. 448/14 V

12. A change of 0.5 mA in the plate current of a triode occurs when the plate potential is changed by 12 V. Find the plate resistance. If the amplification factor is 16, find the change in grid voltage required to produce a change of 4 mA in the anode current.
A. 600 V B. 0.006 V
C. 6 V D. 60 V

13. The voltage amplification of a triode is 20 with 50 kΩ and 25 with 75 kΩ load resistance. Determine the value constant.
A. 6.66×10^{-4} mho B. 5.55×10^{-4} mho
C. 2.22×10^{-4} mho D. 8.88×10^{-4} mho

14. A diode operating in sapce charge limited region has an anode voltage of 80 V when the current is 100 mA. What is the anode voltage and anode dissipation if the current is 60 mA?
A. 50.2 V, 4.20 W B. 54.6 V, 3.38 W
C. 60.3 V, 8.29 W D. 30.1 V, 6.53 W

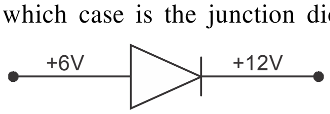
15. A transistor, connected in common emitter configuration, has input resistance R_{in} = 2 kΩ and load resistance of 5 kΩ. If β = 60 and an input signal 12 mV is applied. Calculate the resistance gain, voltage gain, the power gain and the value of output signal.
A. 2.5, 1.8 V, 9000 B. 5.2, 8.1 V, 7000
C. 6.2, 9.8 V, 6000 D. 7.6, 4.3 V, 2000

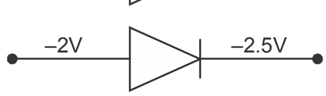
16. The current gain of a common base circuit is 0.97. Calculate the current gain of common emitter circuit.
A. 4.41 B. 8.13
C. 5.62 D. 32.3

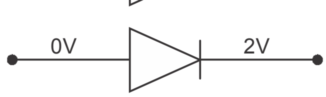
17. In a common base circuit of a transistor, current amplification factor is 0.95. Calculate the base current when emitter current is 2 mA.
A. 0.1 mA B. 100 mA
C. 10 mA D. 1 mA

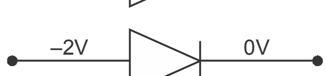
18. In a common-base circuit of a transistor, current amplification factor is 0.95. Calculate the emitter current when base current is 0.2 mA.
A. 6 mA B. 2 mA
C. 9 mA D. 4 mA

19. In which case is the junction diode forward biased

A.


B.


C.


D.


20. The probability of electrons to be found in the conduction band of an intrinsic semiconductor at a finite temperature.
A. decreases exponentially with increasing band gap.
B. decreases with increasing temperature
C. increasing exponentially with increasing band gap
D. is independent of the temperature and the band gap

21. The electrical conductivity of a semiconductor increases when electromagnetic radiation of wavelength shorter than 2480 nm is incident on it. The band gap (in eV) for the semiconductor is
A. 0.8 B. 0.5
C. 0.7 D. 0.9

22. A Light Emitting Diode (LED) has a voltage drop 2 V across it and passed a current of 10 mA, when it operates with a V battery through a limit resistor R. The value of R is
A. 5 Ω B. 250 Ω
C. 400 Ω D. 300 Ω

23. The part of transistor, which is heavily doped to produce a large number of majority carriers is called
A. emitter B. base
C. collector D. diode

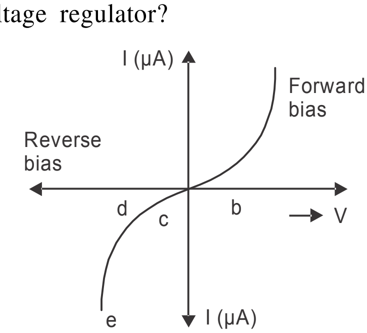
24. In a transistor amplifier, the two ac current gains α and β are defined as $\alpha = \frac{\Delta I_C}{\Delta I_E}$ and $\beta = \frac{\Delta I_C}{\Delta I_B}$. The relation between α and β is

A. $\beta = \frac{\alpha}{1-\alpha}$ B. $\beta = \frac{\alpha}{\alpha+1}$

C. $\beta = \frac{1+\alpha}{\alpha}$ D. $\beta = \frac{1-\alpha}{\alpha}$

25. In an *npn* transistor, 108 electrons enter the emitter in 10^{-8} s. If 1% electrons are lost in the base, the fraction of current that enters the collector and current amplification factor are respectively.
A. 0.9 and 90 B. 0.8 and 49
C. 0.99 and 99 D. 0.7 and 50

26. The graph given below represents the I-V characteristics of zener diode, which part of the characteristics curve is most relevant for its operation as voltage regulator?



A. ab B. bc
C. cd D. de

27. The saturation current of a *pn* junction germanium at 27°C, is 10^{-5}. What will be the required potential to be applied in order to obtained a current of 250 mA in forward bias?
A. 0.26 V B. 0.34 V
C. 0.41 V D. 0.54 V

28. A transistor is connected in common emitter configuration. The collector supply is 8 V and the voltage drop across a resistor of 800 Ω in the collector circuit is 0.5 V. If the current gain factor (α) is 0.96, then the base current will be
A. 0.125 mA B. 0.0256 mA
C. 0.041 mA D. 0.098 mA

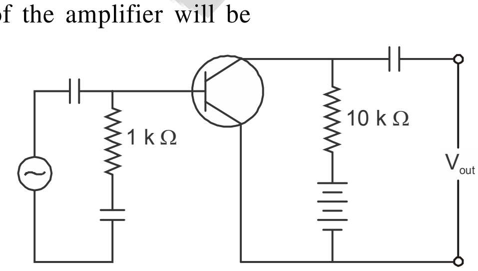
29. A *pn* photodiode is fabricated from a semiconductor with band gap of 2.8 eV. Which of the following wavelengths it can detect?
A. 442 nm B. 580 nm
C. 820 nm D. 950 nm

30. A Ge specimen is dopped with Al. The concentration of accepter atoms is $\simeq 10^2$ atom m^{-3}. Given the intrinsic concentration of electron hole pair is $\simeq 10^{19}$ m^{-3}. The concentration of electrons in the specimen is
A. $10^2\ m^{-3}$ B. $10^4\ m^{-3}$
C. $10^{17}\ m^{-3}$ D. $10^{15}\ m^{-3}$

31. In a semiconducting material, the mobilities of electrons and holes are μ_e and μ_h respectively. Which of the following is true?
A. $\mu_e < \mu_h$ B. $\mu_0 < 0,\ \mu_h > 0$
C. $\mu_e = \mu_h$ D. $\mu_e > \mu_h$

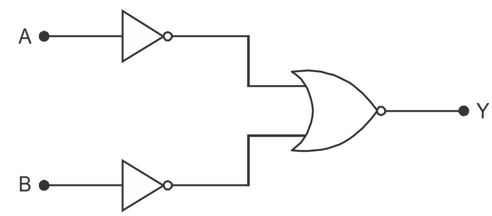
32. A small impurity is added to germanium to get *p*-type semiconductor. This impurity is a
A. pentavalent substance B. bivalent substance
C. monovalent substance D. trivalent substance

33. In the following CE configuration, an *npn* transistor with current gain = 100 is used. The output voltage of the amplifier will be



A. 10 V B. 1 V
C. 0.1 V D. 10 mV

34. Which logic gate is represented by the following combination of logic gates?



A. NOR B. OR
C. AND D. NAND

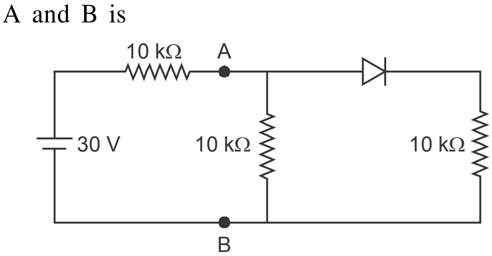
35. A certain logic circuit has A and B as the two inputs and *y* as the output. What is the logic gate in the circuit, if the truth table of circuit is shown?

A	B	Y
0	0	0
1	0	1
0	1	1
1	1	0

A. NAND B. XOR
C. NOR D. OR

36. When the inputs of two input logic gate are 0 and 0, the output is 1. When the inputs are 1 and 0, the output is zero. The type of logic gate is
A. XOR B. NAND
C. NOR D. OR

37. In the given circuit, the potential difference between A and B is



A. 15 V B. 10 V
C. 18 V D. 20 V

38. The common emitter amplifier has a voltage gain 50, an input impedance of 100 Ω and an output impedance of 200 Ω. The power gain of the amplifier is
A. 1000 B. 1250
C. 100 D. 500

39. A transistor is operated in CE configuration at constant collector voltage V_C = 1.5 V, such that a change in the base current from 100 μA to 150 μA produces. A change in the collector current from 5 mA to 10 mA. The current gain β is
A. 50 B. 67
C. 100 D. 75

40. The number of density of electrons and holes in pure silicon at 27°C are equal and its value is 2.0×10^{16}

m^{-3} on doping within, the hole density increases to 4.5×10^{22} m^{-3}, the electron density dopes silicon is

A. 3.57×10^8 m^{-3} B. 8.89×10^9 m^{-3}
C. 3.25×10^9 m^{-3} D. 0.89×10^9 m^{-3}

41. In *pn* junction diode, the reverse saturation current is 10^{-5} A at 27°C. Find the forward current for a voltage 0.2 V. Given exp 7.62 = 2038, K = 1.4×10^{-23} JK^{-1}

A. 2.04×10^{-3} A B. 2.04×10^{-2} A
C. 1.04×10^{-2} A D. 0.34×10^{-2} A

42. A transistor has a current amplification factor (current gain) of 50. In a CE amplifier circuit, the collector resistance is chosen as 5 Ω and the input resistance is 1 Ω. Calculate the outvolt, if input voltage is 0.01 V.

A. 1.5 V B. 0.5 V
C. 2.5 V D. 3.5 V

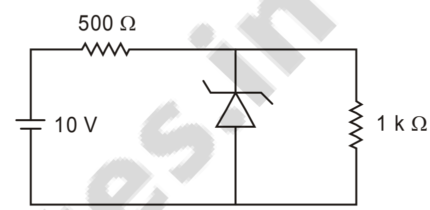
43. Three photodiodes D_1, D_2 and D_3 are made of semiconductors having band gaps of 2.5 eV, 2 eV and 3 eV respectively. Which ones will be able to detect light of wavelength 6000 Å?

A. D_1 B. D_2
C. D_3 D. D_1 and D_3

44. A zener diode has a contact potential of 0.8 V in the absence of biasing. It undergoes zener breakdown for an electric field of 10^6 V/m at the depletion region of *pn* junction. If the width of the depletion region is 2.4 μm, what should be the reverse biased potential for the zener breakdown to occur?

A. 2.4 V B. 3.4 V
C. 4.1 V D. 5.6 V

45. In the following circuit, the current flowing through 1 kΩ resistor is



A. 5 mA B. 1 mA
C. 3 mA D. 0 mA

ANSWERS

1	2	3	4	5	6	7	8	9	10
C	B	C	C	A	C	D	C	C	B
11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
B	C	A	B	A	D	A	D	B	A
21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
B	C	A	A	C	D	A	B	A	C
31	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
D	D	B	D	B	C	B	B	C	B
41	**42**	**43**	**44**	**45**					
B	C	B	A	A					

EXPLANATORY ANSWERS

1. It is because with rise in temperature, the resistance of semiconductor decreases, therefore, overall resistance of circuit decreases. Which in turn increases the current in the circuit.

2. Voltage gain $A_v = \dfrac{\beta_{ac} R_L}{R_i}$

$$= \frac{50 \times 4000}{500} = 400.$$

3. If a light wavelength sufficient to break the covalent bond falls on the junction, new hole electron pairs are created. Number of produced electron hole pairs depend upon number of photons. Hence, current is proportional to intensity of light.

4. Collector current $I_e = \dfrac{0.5}{800}$ A

Current gain $\beta = \dfrac{I_c}{I_b} = \dfrac{\alpha}{1-\alpha} = \dfrac{0.96}{1-0.96} = 24$

$\therefore$ $I_b = \dfrac{I_c}{24} = \dfrac{0.5}{800 \times 24} = 26$ μA

5. $\beta_{ac} = \dfrac{\delta I_c}{\delta I_b} = \dfrac{2 \times 10^{-3}}{15 \times 10^{-6}} = \dfrac{2}{15} \times 10^3$

Voltage gain

$$A_V = \frac{\beta_{ac} R_L}{R_i} = \frac{2}{15} \times \frac{10^3 \times 5000}{665}$$
$$= 1002$$

6. We have, Voltage gain $A = \dfrac{\mu R_L}{R_P + R_L} = \dfrac{R_P\, g_m\, P_L}{R_P + R_L}$

$$30 = \frac{20\times10^3\times2.5\times10^{-3}\times R_L}{20\times10^3 + R_L}$$

$\therefore \quad R_L = 30\ \text{k}\Omega$

7. Plate Resistance $R_P = \dfrac{\Delta V_P}{\Delta I_P} = \dfrac{12}{0.5\times10^{-3}}$

$= 24\ \text{k}\Omega$

Mutual Conductance

$$g_m = \frac{\mu}{R_P} = \frac{16}{24000}\Omega^{-1}$$

But $\quad g_m = \dfrac{\Delta I_P}{\Delta V_g}$

$\therefore \quad \Delta V_g = \dfrac{\Delta I_P}{\Delta V_g} = \dfrac{4\times10^{-3}}{16}\times2400 = 6\ \text{V}$

8. As, $\quad \dfrac{hc}{\lambda} = E \Rightarrow \lambda = \dfrac{hc}{E}$

$$= \frac{6.6\times10^{-34}\times3\times10^8}{57\times10^{-3}\times1.6\times10^{-19}}$$

$= 0.2171 \times 10^{-4}$ m

$= 217100$ Å

9. We have, $\quad A$ = Voltage gain

$$= \frac{\text{Output voltage}}{\text{Input voltage}}$$

$$= \frac{12.5}{0.5} = 25$$

As, $\quad A = \dfrac{\mu r_L}{r_P + r_L}$ or 25

$$= \frac{33 r_L}{16\times10^3 + r_L}$$

$33 r_L = 25 \times 16 \times 10^3 + 25\ r_L$

or $\quad r_L = (25 \times 16 \times 10^3)/8$

$= 50 \times 10^3\ \Omega$

10. As, $\quad (\Delta i_p/\Delta V_p) = 02$ mA/Volt $(\Delta i_p/\Delta V_g)$

$= 1$ mA/volt

$\therefore \quad \mu = (\Delta V_p/\Delta V_g)$

$= 1/0.2 = 50$

11. As, $V = \dfrac{P}{i} = \dfrac{P}{ne} = \dfrac{448\times10^{-3}}{14\times10^{15}\times1.6\times10^{-19}}$

$= 200$ V

12. As, $\quad r_p = \left(\dfrac{\Delta V_P}{\Delta i_P}\right)V_g = \dfrac{12\ \text{V}}{0.5\ m\text{A}} = 24000\ \Omega$

$$g_m = \frac{\mu}{r_p} = \frac{16}{24}\times10^{-3}\ \text{mho}$$

$g_m = (\Delta i_p/\Delta V_g)\ V_P$ or $\Delta V_g = \dfrac{\Delta i_p}{g_m}$

$$= \frac{4\ m\text{A}}{(16/24)\times10^{-3}} = 6\ \text{volt}$$

13. As, $\quad A = \dfrac{\mu RL}{r_p + R_L}; 20 = \dfrac{\mu\times(50\times10^3)}{r_p + (50\times10^3)}$

$$25 = \frac{\mu\times(75\times10^3)}{r_p + (75\times10^3)}$$

$\therefore \quad r_p = 75\ \text{k}\Omega$ and $\mu = 50$

$$g_m = \frac{\mu}{r_p} = \frac{50}{75\times10^3} = 6.66\times10^{-4}\ \text{mho}$$

14. As, $I_p = KV_p^{3/2}$ or $100 = K\ (80)^{3/2}$

$60 = K\ (V_p)^{3/2}$

$\therefore \quad \left(\dfrac{V_P}{80}\right)^{3/2} = \dfrac{60}{100}$

or $\quad V_P = 54.6$ volt

Anode dissipation

$= I_P\ V_P = 54.6 \times 60 \times 10^{-3} = 3.38$ W

15. The resistance gain $= \dfrac{R_c}{R_{in}} = \dfrac{5}{2} = 2.5$

Voltage gain $= \dfrac{\text{Output voltage}}{\text{Input voltage}} = \beta\dfrac{R_c}{R_{in}}$

$A = 60 \times 2.5 = 150$

$\therefore$ Output voltage $= 150 \times$ Input voltage

$= 150 \times 12 \times 10^{-3}$

$= 1.8$ V

As, $\quad$ Power gain $= \dfrac{\beta^2 R_c}{R_{in}} = 60\times60\times2.5 = 9000$

16. As, $\beta = \dfrac{\alpha}{1-\alpha} = \dfrac{0.97}{1-0.97} = \dfrac{0.97}{0.03} = 32.3$

17. As, $\quad \alpha = \dfrac{I_C}{I_E}$ or $0.95 = \dfrac{I_C}{2\times10^{-3}}$

$\therefore \quad I_C = 1.90 \times 10^{-3} = 1.9$ mA

$I_B = I_E - I_C = 2$ mA $- 1.9$ mA $= 0.1$ mA

18. As, $\alpha = \dfrac{I_C}{I_e}$

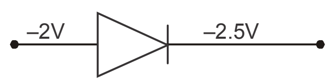
or $I_C = 0.95\ I_e$

$\therefore$ $I_c = I_b + I_c$

$= 0.2\ \text{mA} + 0.95\ I_e$

$\therefore$ $I_e = 4\ \text{mA}$

19. We have,



20. At finite temperature, the probability of jumping an electron from valence band to conduction band decreases exponentially with the increasing band gap.

$$(E_g)n = n_0 e^{-E_g/K_BT}$$

21. As, $E_g = \dfrac{hc}{\lambda_{max}} = \dfrac{1237.5\ eV}{2480\ nm} = 0.5\ eV$

22. A LED is connected to a battery through resistance in series, hence the current flowing is 10 mA.

The voltage drop across LED = 2 V

As the battery has 6 V, the potential difference across,

$R = 4\ V$

$\therefore$ $IR = 4\ V$

or $R = \dfrac{4\ V}{10 \times 10^{-3}\ A} = 400\ \Omega$

23. The emitter of transistor is heavily dopped so to act as source of majority charge carriers.

24. Clearly, the relation between

α and β is, $\beta = \dfrac{\alpha}{1-\alpha}$

25. 108 electrons enter the emitter is 10^{-8} s

$$I_E = \frac{108 \times 106 \times 10^{-19}}{10^{-8}}\ A = 5\ mA$$

$\therefore$ 1% of I_E is lost in base *i.e.*, $I_B = \dfrac{I_E}{100}$

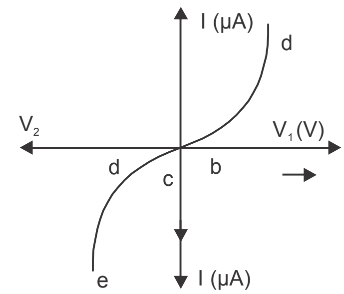
$\Rightarrow$ 90% I_E *i.e.*, $\dfrac{99}{100}$ I_E enters the collector,

$I_C = 0.99\ I_E$

So, the amplification factory, $\beta = \dfrac{I_C}{I_B} = \dfrac{0.99\ I_E}{0.01\ I_E} = 99$

26. When reverse bias is greater than the V_i, there is breakdown condition

For the breakdown region,



Thus, the characteristics curve *de* is most relevant for its operation as voltage regulator.

27. $I = I_0[e^{ev/kT} - 1]$ or $e^{eV/kT}$

$= \dfrac{1}{I_0} + 1$

$= \dfrac{250 \times 10^{-3}}{10^{-5}} + 1 = 25001$

or $\dfrac{eV}{kT} = 10.126$

or $V = \dfrac{10.126 \times kT}{e}$

$= \dfrac{10.126 \times 1.38 \times 10^{-23} \times 300}{1.6 \times 10^{-19}}$

$\therefore$ $V = 0.26\ V$

28. As, $I_C = \dfrac{V_L}{R_L} = \dfrac{0.5}{800} = \dfrac{5}{8}\ mA$

$I_b = I_e - I_c = \dfrac{I_c}{\alpha} - I_c = I_c\left(\dfrac{1}{\alpha} - 1\right)$

$= \dfrac{5}{8}\left(\dfrac{1}{0.96} - 1\right) = 0.0256\ mA$

29. As, $\lambda = \dfrac{1240}{2.8}\ \text{nm} = 442\ \text{nm}$

30. Given, As $n_i = 10^{19}\ m^{-3}$ and $n_h = 10^{21}\ m^{-3}$

$n_i^2 = n_e n_h$

$\therefore$ $n_e = \dfrac{n_i^2}{n_h} = \dfrac{10^{19} \times 10^{19}}{10^{21}} = 10^{17}\ m^{-3}$

31. The mobility of an electron in the conduction band is more than the mobility of a hole in valence band, i.e., $\mu_e > \mu_h$.

32. A trivalent impurity added to germaniam produces a *p*-type semiconductor.

33. As, $A_V = \frac{V_o}{V_i} = \beta \frac{R_o}{R_i}$

or $V_a = V_i \beta \frac{R_o}{R_i} = 10^{-3} \times 100 \times \frac{10}{1} = 1\text{ V}$

34. NAND gate is a universal gate because it repeated, it can give all basic gate like OR, AND and NOT gates.

35. XOR gate gives high output for two difference values of inputs.

36. The logic gate must be a NOR gate, whose output is high, if both the inputs are low.

37. The forward biased *p-n* junction does not offer any resistance,

$\therefore$ $R_{AB} = \frac{10 \times 10}{10 + 10} = 5\,k\Omega$

Total resistance, R = 10 + 5 = 15 kΩ

Current in the circuit, $I = \frac{V}{R} = \frac{30}{15 \times 10^3}\text{A}$

$\therefore$ $I = 2 \times 10^{-3}$ A

Current through each arm $= \frac{I}{2} = 10^{-3}\text{A}$

$\therefore$ $V_{AB} = 10 \times 10^3 \times 10^{-3}$

$= 10$ V

38. $A_p = A_v, A_i = \frac{A_v^2}{A_r} = \frac{(50)^2}{200/100} = 1250$

39. Current gain, $\beta = \frac{\Delta I_C}{\Delta I_B} = \frac{(10-5)\,mA}{(150-100)\,\mu A}$

$= \frac{5 \times 10^{-3}}{50 \times 10^{-6}} = 100$

40. Given, $n_i = 2 \times 10^6\text{ m}^{-3}$,

$n_h = 4.5 \times 10^{22}\text{ m}^{-3}$

As, $n_e = \frac{n_i^3}{n_h} = \frac{(2 \times 10^6)^3}{4.5 \times 10^{22}}$

$= 8.89 \times 10^9\,\text{m}^{-3}$

41. As, $I = I_0\left[\exp\left(\frac{eV}{kT}\right) - 1\right]$ since, $I_0 = 10^{-5}\text{A}$

$I = 10^{-5}\left[e^{\frac{1.6 \times 10^{-19} \times 0.2}{1.4 \times 10^{-23} \times 300}} - 1\right] = 10^{-5}[e^{7.62} - 1]$

$= 10^{-5}\ (2038.6 - 1) = 2037.6 \times 10^{-5}$

$= 2.04 \times 10^{-2}$ A

42. Given, $\beta = 50,\ R_c = 54\ \Omega = 5 \times 10^3\ \Omega$

$R_B = 14\ \Omega = 1 \times 10^3\ \Omega$,

$V_2 = 0.01$ V, $V_0 = ?$

The voltage given of CE amplifier,

$A_V = \beta \frac{R_o}{R_i}$ or $\frac{V_o}{V_i} = \beta \frac{R_C}{R_B}$

$\therefore$ $V_o = \beta \frac{R_C V_i}{R_B}$

$= \frac{50 \times 5 \times 10^3 \times 0.01}{1 \times 10^3} = 2.5\text{ V}$

43. As, $E = hv = hc$

$= \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{6 \times 10^{-7} \times 1.6 \times 10^{-19}}$

$= 2.06$ eV

For the incident radiation to be detected by the photodiode, energy incident radiation photon should be greater than that the band gap. This is true only for D_2.

44. Given, the breakdown field $E = 10^6\ \text{Vm}^{-1}$

The width of the depleton region,

$d = 2.4 \times 10^{-6}$ m

$\therefore$ $V_{breakdown} = E \times d = 10^6 \times 2.4 \times 10^{-6}$

$= 2.4$ V

45. From fig, we see that, the zener diode is used as a voltage regulator device.

So, the voltage across 1 kΩ is 5 V

$\therefore$ Current flowing through 1 kΩ resistor,

$I = \frac{5\text{ V}}{1 \times 10^3\,\Omega}$

$= 5 \times 10^{-3}\,\text{A} = 5\,m\text{A}$

CHAPTER

10

COMMUNICATION SYSTEMS

PROPAGATION OF ELECTROMAGNETIC WAVES IN ATMOSPHERE

The earth plays an important role in the propagation of electromagnetic waves from one place to another place on the surface of the earth. The sun is the main source of electromagnetic radiation and it sends out EM waves of different wavelengths towards the earth. As the EM waves propagate through the earth's atmosphere, a major part of it is absorbed by the atmosphere. Most of the infra-red radiation is absorbed by the atmosphere and the atmosphere gets heated.

Radio waves are a member of the electromagnetic family of waves. They are energy-carriers which travel at the speed of light c, their frequency f and wavelength λ being related, as for any wave motion, by the equation

$$v = f\lambda$$

where,

$v = c = 3.0 \times 10^8$ ms^{-1} in a vacuum (or air). If $\lambda = 300$ m, then $f = v\lambda = 3.0 \times 10^8$ ms^{-1}/(3.0×10^2 m) $= 10^6$ Hz = 1 MHz. The smaller λ is, the larger f.

Radio waves can be described either by their frequency or their wavelength, but the former is more fundamental since, unlike λ (and v), f does not change when the waves travel from one medium to another. They have frequencies extending from about 30 kHz upwards and are grouped into bands, as shown in the table

Frequency band	Some uses
Low (I.f) 30 kHz – 300 kHz	Long-wave radio and communication over large distances
Medium (m.f.) 300 kHz – 3 MHz	Medium-wave, local and distant radio
High (h.f) 3 MHz – 30 MHz	short-wave radio and communication amateur and CB radio
Very High (v.h.f.) 30 MHz – 300 MHz	FM radio, police, meteorology device
Ultra high (u.h.f) 300 MHz – 3 GHz	TV (bands 4 and 5), aircraft landing system
Microwave Above 3 GHz	Radar, communication satellities, mobile telephones and TV links

(1 GHz = 10^9 Hz)

The Earth's Atmosphere: The envelop of gaseous surrounding the earth is called atmosphere. It is divided into various regions as given below.

Troposphere: It extends upto a height of 10 km. The temperature decreases with height from 290 K to 220 K.

Stratosphere: It extends from 10 km to 50 km from the surface of the earth. There is ozone layer in this region in between 30 km to 50 km which absorbs a large portion of UV radiations. The temperature of this region varies from 220 K to 280 K.

Mesosphere: It extends from 50 km to 65 km from the surface of the earth. The temperature of this region falls from 280 K to 180 K with height.

Ionosphere: It extends from 65 km to 400 km from the surface of earth. The temperature of this region increases with height from 180 K to 700 K that is why it is called thermosphere.

SKY AND SPACE WAVE PROPAGATION

Sky Wave Propagation

When the radio waves from the transmitting antenna reah the receiving antenna after reflection in ionosphere, the wave propagation is called sky wave propagation.

This travels skywards and, if it is below a certain *critical frequency* (typically 30 MHz) is returned to earth by the *ionosphere.* This consists of layers of air molecules (the D, E and F layers), stretching from about 80 km above the earth to 500 km, which have becomes positively charged through the removal of electrons by the sun's ultraviolet radiation. On striking the earth, the sky wave bounces back to the ionosphere where it is again gradually refracted and returned earthwards as if by 'reflection'. This continues until it is completely attenuated.

The critical frequency varies with the time of day and the seasons. Sky waves of low, medium and high frequencies can travel thousands of kilometres but at very high frquency and above they usually pass through the ionosphere into outer space.

If both the surface wave and the sky wave from a transmitter are received at the same place, interference can occur if the two waves are out of phase. When the phase difference varies the signal 'fades', i.e., goes weaker and stronger. If the range of the surface wave for the signal is less than the distance to the point where the sky wave first reaches the earth, there is a zone which receives no signal.

Space Wave Propagation

When the radio waves from transmitting antenna reach the receiving antenna either directly or after reflection from the ground or in troposphere, the wave propagation is called space wave propagation.

If a wave comes directly from a transmitting antenna and is received by a receiving antenna, it is called a line-of-sight wave of a space wave. For very high frequency, ultra high frequency and microwave signals, only the space wave, giving line-of-sight transmission is effective. A range of up to 150 km is possible on the earth if the transmitting antenna is on high ground and there are no intervening obstacles such as hills, building or trees. Transmission via communication satellites is considered later.

NEED FOR MODULATION

The sound waves (20 Hz to 20 kHz) cannot be transmitted directly from one place to another for the following reasons.

Height of Antenna: For efficient radiation and reception, the height of transmitting and receiving antennas should be comparable to a quarter of wavelengths of the frequency used for 15 kHz it is 5000 m.

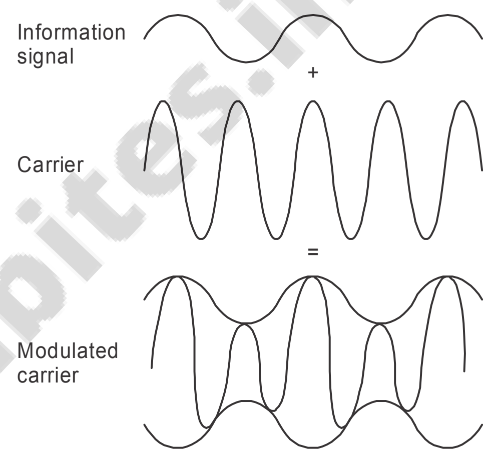
Detecting Signals: Modulation is necessary for a low frequency signal, when it is to be sent to a distant place, so that information may not out in the way itself as well as for proper. Identification of a signal and to keep the height of antenna small.

AMPLITUDE AND FREQUENCY MODULATION

Amplitude Modulation (AM)

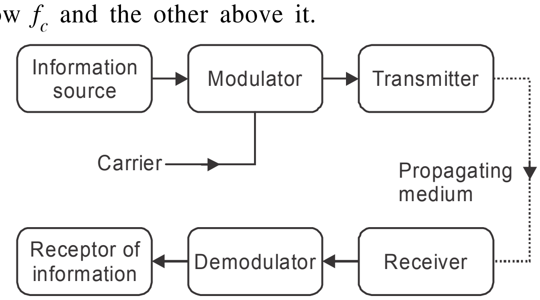
When the modulating wave is super imposed on a high frequency carrier wave in a manner that frequency of the modulated wave is same as that of the carrier wave but its amplitude is modified in accordance with that of the modulating wave, the process is called amplitude modulation.

The information signal is used to vary the amplitude of the carrier so that it follows the wave shape of the information signal.

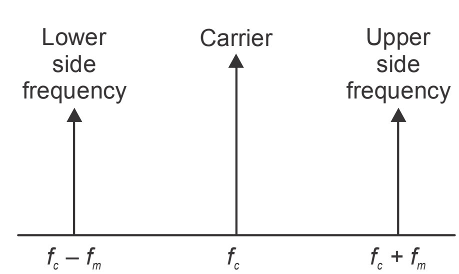


Amplitude modulation

The modulated signal contains other frequencies called side frequencies, which are created on either side of the carrier (a single frequency) in the process of modulation. If the carrier frequency is f_c and the modulating signal is f_m, two new frequencies of $f_c - f_m$ and $f_c + f_m$ are produced, one below f_c and the other above it.

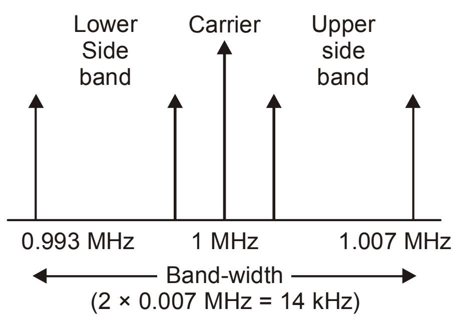


Communication System



If, as usually occurs in practice, the carrier is modulated by a range of audio frequencies a.f., each a.f. gives rise to a pair of side frequencies. The result is a band of frequencies, called the lower and upper sidebands, stretching below and above the carrier by the value of the highest modulating frequency.

For example, If f_c = 1 MHz and the highest f_m = 7 kHz = 0.007 MHz, then $f_c - f_m$ = 0.993 MHz and $f_c + f_m$ = 1.007 MHz.



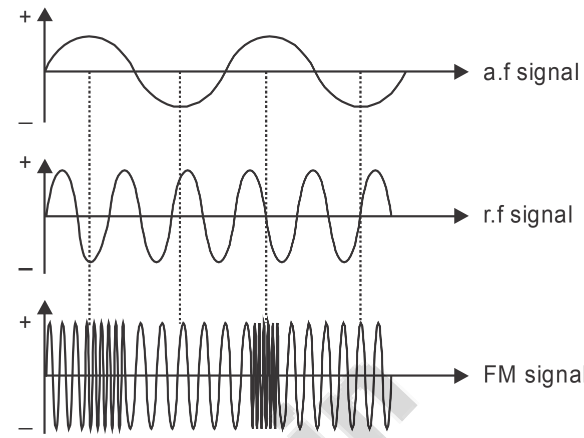
The bandwidth of a signal is the range of frequencies the signal occupies. For intelligible speech it is about 3 kHz (e.g. 300 Hz to 3400 Hz as in the telephone system), for high-quality music it is 16 kHz approx. and for television signals around 8 MHz. The bandwidth of the carrier and sidebands in the figure is 14 kHz.

Frequency Modulation (FM)

When the modulating wave is super imposed on a high frequency carrier wave in a manner that the amplitude of modulated wave is same as that of the carrier wave, but its frequency is modified in accordance with the amplitude of the modulating wave, the process is called frequency modulation.

In this case the frequency of the r.f. (radio frequency carrier, not the amplitude, is changed by the a.f. signal. The change or 'deviation' is proportional to the amplitude of the a.f. at the any instant.

For example, if a 100 MHz carrier is modulated by a 1V 1 kHz sine wave, the carrier frequency might swing 15 kHz either side, if 100 MHz, i.e., from 100.015 to 99.985 MHz, and this would happen 1000 times a second. A 2V 1 kHz signal would cause a swing of ±30 kHz at the same rate; for a 2V, 2 kHz signal the swing remains at ±30 kHz but it occurs 2000 times a second. By international agreement, the maximum deviation allowed is ±75 kHz.

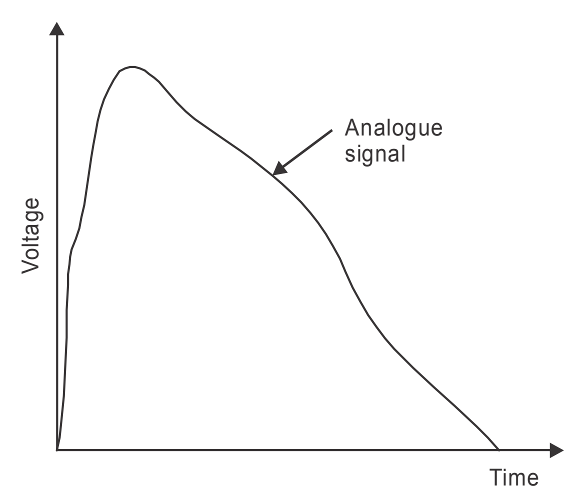


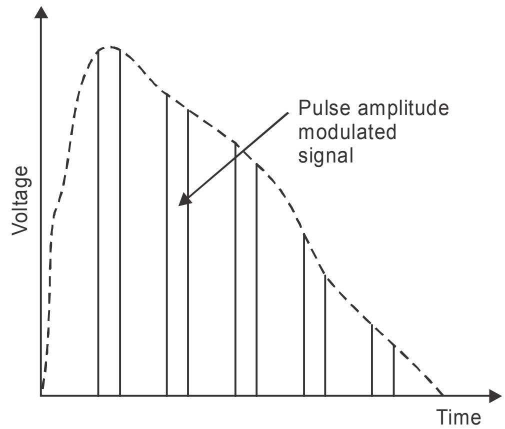
Frequency modulation

The sketch shows frequency modulation; not that when the a.f. signal is positive, the carrier frequency increases but it decreases when the a.f. signal is negative.

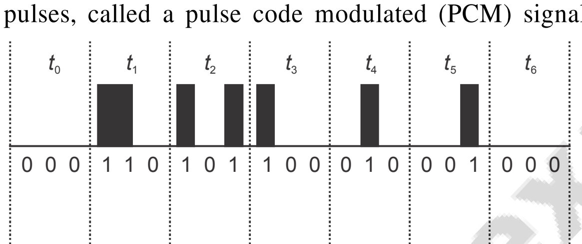
In FM, each a.f. modulating frequency produces a large number of side frequency (not two as in AM) but the more they differ from the carrier the more is the decrease in their amplitudes. In theory, therefore, the band width of an FM system should be extremely wide but in practice the 'out-side' side frequency can be omitted without noticeable distortion. The bandwidth may be taken as roughly $\pm(\Delta f_c + f_m)$ where Δf_c is the deviation and fm is the highest modulation frequency. The BBC uses a 250 kHz bandwidth which is readily accommodated in the v.h.f. (very high frequency) radio broadcasting band and also allows fm to have the full range of audio frequencies. This accounts of the batter sound quality of FM radio.

Pulse Code Modulation (PCM): This is the process by which an analog signal is changed into a digital one before it is transmittd by cable or radio wave.

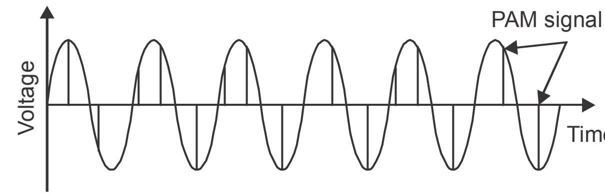




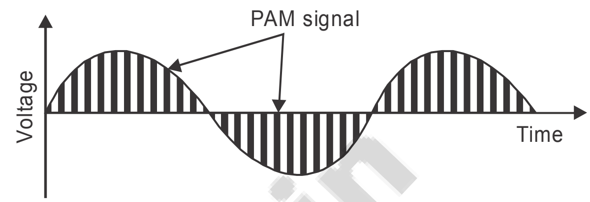
The amplitude of the analog signal is ‘sampled’ at regular time intervals to find its value and a pulse amplitude modulated (PAM) signal is obtained. The values are measured on a scale of equally spaced voltage levels. Each level is represented in binary code by the appropriate pattern of electrical pulses, i.e., by a certain bit-pattern of electrical pulses, i.e., by a certain bit pattern. A 3-bit code, can represent up to eight levels (0 to 7); four bits would allow sixteen levels to be coded. The bit-pattern is sent as a series of pulses, called a pulse code modulated (PCM) signal.



The accuracy of the representation increases with the number of voltage levels and the sampling frequency. The latter should be at least twice as great as the highest frequency of the analog signal since it is sampled least often.



High frequency analog signal



Low frequency analog signal

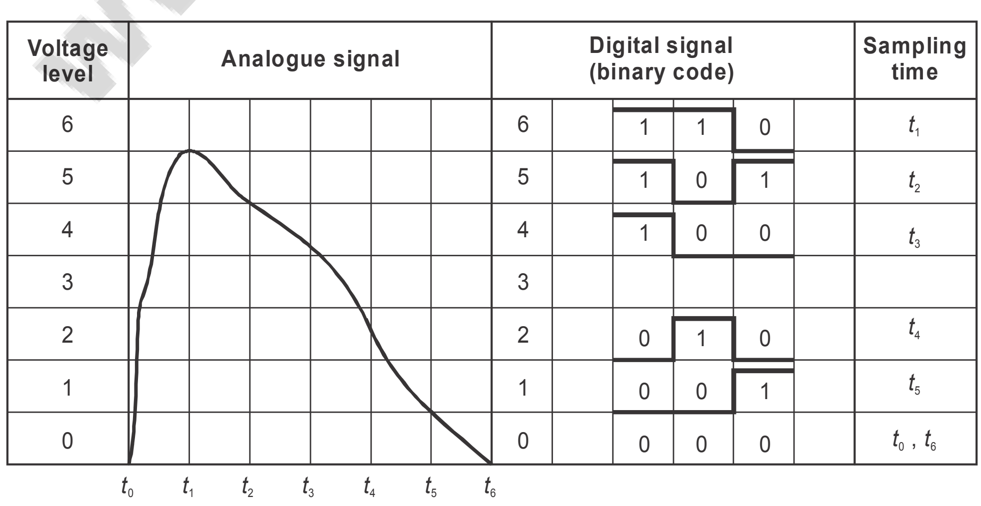
The highest frequency of intelligible speech in the telephone system in 3400 Hz and a sampling system frequency of 8000 Hz is chosen, i.e., samples are choosen at 125 μs intervals, each sample lasting for 2 to 3 μs. An 8-bite code (giving 28 = 256 levels, represented by 00000000 to 11111111) is used and so the number of bits that have to be transmitted per second, called the bit-rate, is 8 × 8000 = 64000 = 64 kilobits/s.

In general, we can write

bit rate = no. of bits × sampling frequency

For good quality, music where frequencies up to about 16 kHz must be transmitted, the sampling frequency is 32 kHz and a 16-bit code (216 = 65236 levels) is used. The bit-rate is therfore 16 × 32 = 512 kbits/s. For television signal which carry much more information, a bit-rate of 70,000,000 = 70 Mbit/s is required.

Modulation Factor (m) for AM: It is the ratio of half the difference between the maximum and minimum amplitudes to the average amplitude. When multiplied by 100, this gives percentage of modulation.

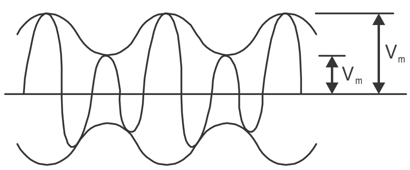


$$\therefore \quad m = \frac{(V_M - V_m)/2}{(V_M + V_m)/2} = \frac{V_M - V_m}{V_M + V_m}$$

m = modulation factor

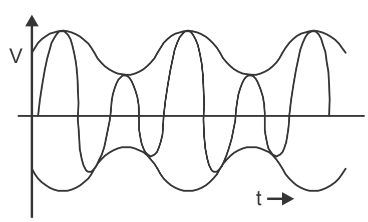
V_M = maximum amplitude of the voltage of the modulated wave

V_m = minimum amplitude of the voltage of the modulated wave

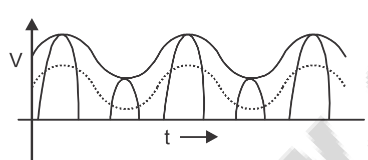


Demodulation or Detection: As stated already, demodulation means to recover the input signals from the modulated wave. These input signals can be audio or visual or of some other type. A demodulator or detector circuit performs two essential function.

(*i*) It rectifies the modulated wave. Half-wave rectifier is used as shown in the sketch.



Modulated wave



Rectified modulated wave

Thus, the average of voltage fluctuation is zero in the modulated wave, it is not zero in the rectified modulated wave. Dotted line shows this average voltage fluctuations. If fed to the diaphragn of a speaker, while the modulated wave will not cause vibrations, the rectified modulated wave will not cause vibrations, the rectified modulated wave will obviously cause vibrations in the diaphragm.

(*ii*) It separates out the signal from the carrier. This recovering is done by a filter circuit. A filter is a selective network of resistors, inductors, or capacitors which offers comparatively little opposition to certain frequencies or to direct current, while blocking or attenuating other frequencies. Thus it is a device or program that separates data, signals, or materials in accordance with specified criteria. it is called an extractor or mask also.

BANDWIDTH OF SIGNALS

The message signal in any communication system may be voice, music, picture etc. Difference signals have different ranges of frequencies. The range over which the frequencies in an information signal vary is call bandwidth.

Bandwidth is equal to the difference between the highest and lowest frequencies present in the signal.

The type of the communication channel needed for a given signal depends on the band of frequencies to be transmitted.

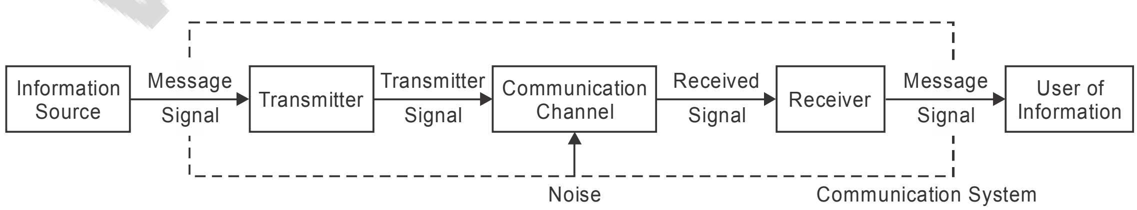
BANDWIDHT OF TRANSMISSION MEDIUM

The bandwidth of transmission medium is defined as the difference the heightest and lowest frequencies that system allows to pass through it *i.e.*, it pass band.

The bandwidth of a transmission system must be sufficiently large to pass all the significant information frequencies. When a television cable transmission has a pass band from 50 kHz to 5000 kHz, so that it has a bandwidth of 4500 kHz or 4.5 MHz.

BASIC ELEMENTS OF A COMMUNICATION SYSTEM

(Block Diagram Only)



EXERCISE

1. Choose the correct options regarding frequency modulation

A. The amplitude of modulated wave varies as amplitude of carrier wave

B. The frequency is modulated wave varies as amplitude of modulating wave

C. The frequency of modulated wave varies as frequency of modulating wave

D. The frequency of modulated wave varies as of modulating wave frequency

2. An audio signal 15 sin 2π (1500 t) amplitude modulates 60 sin 2π (10^5) t. The depth of modulation percentage is
A. 25% B. 20%
C. 50% D. 40%

3. An AM wave is given by V = 150 [1 + 0.5 sin 12860 t] sin (5.26×10^5 t). What will be modulating frequency?
A. 2.04 kHz B. 5.4 kHz
C. 12.5 kHz D. 50 kHz

4. A carrier wave of peak voltage 12 V is used to transmit a message signal. What should be the peak voltage of the modulating signal in order to have a modulation index of 75%
A. 4 V B. 6 V
C. 9 V D. 12 V

5. In a FM system, a 7 kHz signal modulates 107.6 MHz so that the frequency deviation is 50 kHz. The carrier swing will be
A. 7.143 B. 8
C. 10 D. None of these

6. The sky wave propogates a 10 MHz signal, what should be the minimum electron density in ionosphere?
A. 2.3×10^6 m^{-3} B. 1.2×10^{12} m^{-3}
C. 1.0×10^{22} m^{-3} D. 1.2×10^{14} m^{-3}

7. A radar has a power of 1 kw and is operating at a frequency of 10 GHz. It is located on a mountain top of height 500 m. The maximum distance up to which it can detect object located on the surface of the earth (Radius of earth = 6.4×10^6 m) is
A. 50 km B. 63 km
C. 80 km D. 40 km

8. A modulated wave has maximum amplitude of 750 mV and minimum amplitude of 250 mV. Then percentage modulation is
A. 33% B. 50%
C. 75% D. 100%

9. A bandwidth of 15 MHz is available for transmission. If maximum signal frequency used for modulating the carrier is 15 kHz. Then the number of stations which can broadcast without any inference with each other in this band is
A. 300 B. 400
C. 457 D. 500

10. A FM wave is given by V = 20 sin (6×10^8 t + 4 sin 860 t). The modulating frequency will be
A. 136.9 Hz B. 500 Hz
C. 150 Hz D. None of these

11. How many AM broadcast stations can be accommdated in a 100 kHz bandwidth, if the highest frequency modulating a carrier is 5 kHz?
A. 5 B. 10
C. 15 D. 18

12. Through which mode of propagation, the radio waves can be sent from one place to another?
A. Sky wave propagation
B. Space wave propagation
C. Ground wave propagation
D. All of the above

13. In AM wave the modulation index is 100%. If the carrier is suppressed the percentage saving in power will be
A. 66.6% B. 50%
C. 75% D. None of these

14. A 1000 kHz carrier wave is modulated by an audio signal of frequency range 100-5000 Hz. Then, bandwidth of channel is
A. 5 kHz B. 10 kHz
C. 15 kHz D. 20 kHz

15. The velocity of all radio waves in free space is 3×10^8 m/s. The frequency of a radio wave of wavelength 150 m is
A. 1 MHz B. 2 MHz
C. 2 kHz D. 20 kHz

16. If total power content of an A.M. wave is 2.64 kW at 80% modulation, then power content of each side band are
A. 1.32 kW B. 2.64 kW
C. 660 watt D. 320 watt

17. The maximum usable frequency in F-layer with original frequency of 50 MHz will be
A. 181 MHz B. 150 MHz
C. 250 MHz D. 300 MHz

18. The number of AM broadcast stations that can be accommodated in a 300 kHz bandwidth for the highest modulating frequency 15 kHz will be
A. 10 B. 5
C. 7 D. 12

19. An amplitude modulated wave in modulated to 5%. What is the saving power, if carrier as well as one of the side bands are suppressed?
A. 23.5% B. 43.4%
C. 94.4% D. 65.4%

20. A transmitting antenna at the top of tower has a height 32 m and that of the receiving antenna is 50 m. The maximum distance between them for satisfactory communication the of sight mode is [Radius of the earth = 6.4×10^6 m]
A. 32.5 km B. 45.5 km
C. 54.6 km D. 11.2 km

21. The wave propagation is suitable for radiowaves of frequency
A. up to 2 MHz

B. from 2 MHz to 20 MHz
C. from 2 MHz to 30 MHz
D. from 2 MHz to 40 MHz

22. A TV tower has height of 200 m. How much population is covered by TV broadcast, if the average population density around the tower is 100 km^{-2} (Radius of the earth = 6.4×10^6 m)
A. 2.74×10^6 B. 4.5×10^6
C. 1.25×10^6 D. 5.72×10^6

23. A signal wave of frequency 12 kHz is modulated with a carrier wave of frequency 2.51 MHz, the upper and lower side band frequencies are respectively
A. 2512 kHz and 2488 kHz
B. 2522 kHz and 2510 kHz
C. 2512 kHz and 2508 kHz
D. 2502 kHz and 2478 kHz

24. The TV transmission tower in the Lucknow has height of 240 m. The distance upto which the broadcast can be received (Radius of the earth = 6.4×10^6 m) is
A. 50 km B. 55 km
C. 75 km D. 105 km

25. The frequency of EM waves employed in space communication vary over a range of
A. 10^4 Hz to 10^{11} Hz
B. 10^5 Hz to 10^{12} Hz
C. 10^6 Hz to 10^{12} Hz
D. 10^7 Hz to 10^{10} Hz

26. The sound waves after being converted into electrical waves are not transmitted as such become
A. they are heavily absorbed by the atmosphere
B. they travel with the speed of sound
C. the frequency is not constant
D. the height of antenna has to be increased several times.

27. The sky wave with the frequency 55 MHz is incident on D-region of the earth's atmosphere at 45°. The angle of reflection is (electron density for D-region is 400 electron/cc)
A. 30° B. 60°
C. 45° D. 15°

28. Maximum usable frequency (MUF) is F-region layer is x, when the critical frequency is 60 MHz and the angle of incidence is 70°. Then x is
A. 175 MHz B. 140 MHz
C. 190 MHz D. 225 MHz

29. If the heighest modulating frequency of the wave is 5 kHz the number of stations that cen be accommodated in a 150 kHz bandwidth is
A. 12 B. 15
C. 18 D. 20

30. A TV tower has a height of 100 m. What is the maximum distance upto which the TV transmission can be received? (R = 8×10^6 m)
A. 50 km B. 60 km
C. 40 km D. 6 km

31. A microwave telephone link operating at the central frequency of 10 GHz has been established. If 2% of this is available for microwave communication channel, then how many television channels can be simultaneously granted if each telephone is alloted a bandwidht of 8 kHz?
A. 1.2×10^5 B. 3.2×10^6
C. 1.5×10^3 D. 2.5×10^4

32. The maximum distance upto which TV transmission from a TV tower of height h can be received is proportional to
A. h^2 B. $h^{3/2}$
C. h D. $h^{1/2}$

33. The EM wave is transmitted to the height equal to 150 km with maximum frequency 300 kHz and critical frequency 100 kHz. What is the skip distance?
A. 848.4 km B. 372.5 km
C. 422.6 km D. 721.3 km

34. A modulated carrier wave has maximum and minimum amplitudes of 800 mV and 200 mV. Find the percentage modulation.
A. 50% B. 60%
C. 40% D. 70%

35. A 100 kHz bandwidth is to accommodation broadcast's simultaneously. What is the maximum modulating frequency permissible for each station?
A. 9 kHz B. 3 kHz
C. 5 kHz D. 8 kHz

36. A sinusoidal voltage amplitude modulates another sinusoidal voltage of amplitude 2 kV to result in two side bands, each of the amplitude 20 V. The modulation index is
A. 0.02 B. 0.03
C. 0.04 D. 0.01

37. A message signal of 12 kHz and peak voltage 20 V is used to modulated a carrier wave of frequency 12 MHz and peak voltage 30 V. The modulation index and lower side band frequency are
A. 0.67, 11.988 kHz B. 0.35, 12.350 kHz
C. 4.9, 9.875 kHz D. 2.8, 13.819 kHz

38. The maximum peak to peak voltage of an AM wave in 16 mV and the minimum peak to peak voltage is 8 mV. Then modulation factor is
A. 0.22 B. 0.33
C. 0.44 D. 0.11

39. The critical frequency for the sky wave propagation on a day when the electric density per cubic metre of ionosphere is 5.4×10^{11} per/m^3.

A. 3.5 MHz
B. 4.7 MHz
C. 6.6 MHz
D. 0.89 MHz

40. The maximum amplitude of an AM wave is found to be 15 V while its minimum amplitude is found to be 3 V. The modulation index is

A. $\frac{2}{3}$ B. $\frac{1}{3}$
C. $\frac{3}{5}$ D. $\frac{4}{5}$

ANSWERS

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
B	A	A	C	A	B	C	B	D	A
11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
A	D	A	B	B	D	A	A	C	B
21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
A	A	B	B	B	A	A	A	B	C
31	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
D	D	A	B	C	A	A	B	C	A

EXPLANATORY ANSWERS

1. The frequency modulation is define as the process of changing the frequency of carrier wave (modulated wave) in accordance with audio frequency signal.

2. As, $m = \frac{E_m}{E_c} = \frac{15}{60} = \frac{1}{4} = 0.25$

$\therefore$ Depth of modulation % = 25

3. We know, in general

$$V = E[1 + m \sin \omega_m t] \sin \omega_c t$$

$\therefore$ Modulating frequency

$$f_m = \frac{\omega_m}{2\pi} = \frac{12860}{2 \times 3.14} = 2.04 \text{ kHz}$$

4. Amplitude of the carrier wave, A_c = 12 V
Modulation index, m = 75% = 0.75
Amplitude of the modulating wave = A_m

As, $m = \frac{A_m}{A_c}$

$\therefore$ $A_m = mA_c = 0.75 \times 12 = 9$ V

5. Carrier swing = $\frac{\text{Frequency deviation}}{\text{Modulating frequency}}$

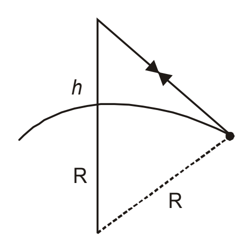
$= \frac{50}{7} = 7.143$

6. The critical frequency of a sky wave for reflection from the layer of atomsphere is $f_C = 9\,(N_{max})^{1/2}$

$= 10 \times 10^6 = 9\,(N_{max})^{1/2}$

$$\Rightarrow \quad N_{max} = \left(\frac{10 \times 10^6}{9}\right)^2 \simeq 1.2 \times 10^{12} \text{ m}^{-3}.$$

7. The range of radar on the surface of the earth



$$\text{Range} = \sqrt{(R+h)^2 - R^2} = \sqrt{2Rh + h^2}$$

$$\simeq \sqrt{2Rh} = \sqrt{2 \times 6400 \times \frac{1}{2}} \text{ km}$$

$= 80$ km

8. As, $m = \frac{E_{C(max)} - E_{C(min)}}{E_{C(max)} + E_{C(min)}} \times 100$

$= \frac{750 - 250}{750 + 250} \times 100 = 50\%$

9. BW required per station

$= 2f_{m(max)} = 2 \times 15$ kHz

$= 30$ kHz

$\therefore$ No. of stations $= \frac{15 \text{ MHz}}{30 \text{ kHz}} = 500$

10. Modulating frequency,

$$f_m = \frac{\omega_m}{2\pi} = \frac{860}{2\times 3.14} = 136.9\ \text{Hz}$$

11. Given, total BW = 100 kHz

f_{max} = 5 kHz

Any station being modulated by a 5 kHz signal will produce an upper side frequency 5 kHz above its carrier and a lower-side frequency 5 kHz below its carrier, there by requiring a bandwith of 10 kHz.

Thus, no. of stations $= \dfrac{\text{Total BW}}{\text{BW per station}}$

$$= \frac{100\times 10^3}{10\times 10^3} = 10 \text{ stations}$$

12. Radio waves can be transmitted from one place to another as sky wave, or space wave or ground wave propagation.

13. When carrier is suppressed the percentage saving is

$$P_{saving} = \frac{1}{1+\dfrac{m^2}{2}} = \frac{1}{1+\dfrac{(1)^2}{2}} = 0.666 = 66.6\%$$

14. Bandwidth = 2 × frequency of modulation

= 2 × 5000 Hz = 10,000 Hz

= 10 kHz.

15. Velocity of EM waves in free space and wavelength $v = 3\times 10^8$ m/s and $\lambda = 150$ m

$\therefore$ Frequency of radio waves $= \dfrac{v}{\lambda} = \dfrac{3\times 10^8}{150}$

$= 2\times 10^6$ Hz = 2 MHz

16. As, $P_{USB} = P_{LSB} = \dfrac{m^2}{4}P_C = \dfrac{(0.8)^2}{4}\times P_C$

where, $P_C - P_T\left(\dfrac{2}{2+m^2}\right) = P_T\left(\dfrac{2}{2+(0.8)^2}\right)$

$$= 2.64\times 10^3\left(\frac{2}{2+(0.8)^2}\right) = 2000\ \text{W}$$

$\therefore$ $P_{USB} = P_{LSB} = \dfrac{(0.8)^2}{4}\times 2000$ W

= 320 watt.

17. As, MUF = f_c sec i, $i = 74°$ for F-layer

$= 50\times 10^6 \times 3.62 = 181$ MHz.

18. No. of stations $= \dfrac{\text{B.W.}}{2\times \text{Highest modulating frequency}}$

$\Rightarrow \dfrac{300{,}000}{2\times 15000} = 10$

19. $P_{sb} = P_C\left(\dfrac{m_a}{2}\right)^2 = P_C\dfrac{(0.5)^2}{2^4} = 0.0625\ P_C$

Also, $P = P_C\left(1+\dfrac{m_a^2}{2}\right) = P_C\left(1+\dfrac{(0.5)^2}{2}\right)$

$= 1.125\ P_C$

$\therefore$ % saving $= \dfrac{(1.125\ P_C - 0.0625\ P_C)}{1.125\ P_C}\times 100$

= 94.4%

20. As, $d_{max} = \sqrt{2Rh_T} + \sqrt{2Rh_g}$

$= \sqrt{2\times 6.4\times 10^6\times 32} + \sqrt{2\times 6.4\times 10^6\times 50}$

$= 45.5\times 10^3$ m = 45.5 km

21. The radioactive of frequency 2 MHz to 30 MHz are used in sky wave propagation as they are reflected by the ionosphere of earth's atmosphere.

22. Given, h = 200 m, $R_e = 6.4\times 10^6$ m

Average population density = 1000 km^{-2}

$= 1000\times (1000\ m)^{-2}$

$= 10^{-3}\ m^{-2}$

The TV transmission range, $d = \sqrt{2hR_e}$

$A = \pi d^2 = \pi\, 2\, hR_e = 2\pi\, hR_e$

$= 2\times 3.14\times 200\times 6.4\times 10^6\ m^2$

$\therefore$ Population covered by TV broadcast

$= 2.74\times 10^9\ m^2$

$= 2.74\times 10^9\times 10^{-3}$

$= 2.74\times 10^6$

23. Given, ν_C = 12 kHz

and ν_S = 2.51 MHz = 2510 kHz

The USB frequency = $\nu_S + \nu_C$ = 2510 + 12

= 2522 kHz

The LSB frequency = $\nu_S - \nu_C$ = 2522 − 12

= 2510 kHz

24. As, $d = \sqrt{2hR} = \sqrt{2\times 240\times 6.4\times 10^6}$

$= 55\times 10^3$ m = 55 km

25. The frequency employed in space communication vary over a range of 10^4 Hz to 10^{11} Hz.

26. The sound waves after being converted into electrical waves are not transmitted as such become they are of short frequency and heavily absorbed by the atmosphere.

27. For D-region, $v = 55\times 10^6$ Hz, $\angle i = 45°$

and $N = 400\times 10^6\ m^{-3}$

As, $\mu = \sqrt{1-\frac{81.45\text{ N}}{v^2}} = \sqrt{1-\frac{81.45\times400\times10^6}{(55\times10^6)^2}} = 1$

Also, $\mu = \frac{\sin i}{\sin r}$ or $\sin i = \mu \sin r = \sin r$

or $\angle i = \angle r = 45°$

28. We have, MUF = $\nu_C \sec i = 6 \times 10^6 \times \sec 70°$

$$= 60\times10^6\times\frac{1}{0.342} = 175.43\times10^6\text{ Hz}$$

$= 175$ MHz

29. No. of stations = $\frac{\text{Total bandwidth}}{\text{Bandwidth/station}}$

$$= \frac{150\text{ kHz}}{2\times5\text{ kHZ}} = 15$$

30. As, $d = \sqrt{2h\text{R}} = \sqrt{2\times100\times8\times10^6}$

$= 4000$ m $= 40$ km

31. Microwave frequency used in television link

$= 10$ GHz $= 10 \times 10^9$ Hz $= 10^{10}$ Hz

Frequency available for microwave communication

$= 2\%$ of 10 GHz

$$= \frac{2}{100}\times10^{10} = 0.2\times10^9\text{ Hz}$$

$\therefore$ No. of microwave telephone channels

$$= \frac{0.2\times10^9}{8\times10^3} = 2.5\times10^4$$

32. As, $d = \sqrt{2\text{R}h}$

So, $d \propto h^{1/2}$

33. Given, $h = 150$ km, $v = 300$ kHz, $\nu_C = 100$ kHz

As, $\text{D}_{\text{skip}} = 2h\sqrt{\left(\frac{v}{\nu_c}\right)^2 - 1} = 2\times150\sqrt{\left(\frac{300}{100}\right)^2 - 1}$

$= 848.5$ km

34. Here, $\text{A}_{\text{max}} = 800$ mV, $\text{A}_{\text{min}} = 200$ mV

As, $\mu = \frac{\text{A}_{\text{max}} - \text{A}_{\text{min}}}{\text{A}_{\text{max}} + \text{A}_{\text{min}}}\times100 = \frac{800-200}{800+200}\times100 = 60\%$

35. If f is the maximum permissible modulation frequency.

Then, $\frac{100\text{ kHz}}{2f} = 10 \quad \therefore f = 5$ kHz

36. Amplitude of each sideband

$$= \frac{\mu\,\text{A}_c}{2}$$

$\Rightarrow \quad 20\text{ V} = \frac{\mu\times2\,k\text{V}}{2}$

$$\mu = \frac{2\times20}{2\,k\text{V}} = \frac{2\times20}{2\times100} = \frac{2}{100} = 0.02$$

37. Given $\text{A}_m = 20$ V, A = 30 V, $f_m = 12$ kHz

and $f_c = 12$ MHz $= 1200$ kHz

(*i*) Modulation index, $\mu = \frac{\text{A}_m}{\text{A}_c} = \frac{20}{30} = 0.67$

(*ii*) USB $= f_c + f_m = 12000 + 12 = 12012$ kHz

$= 12.012$ MHz

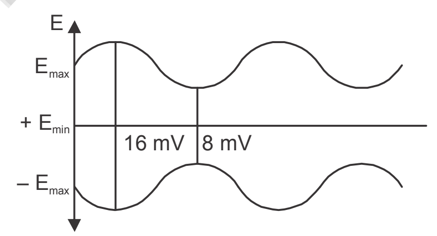
(*iii*) LSB $= f_c - f_m = 12000 - 12 = 11988$ kHz

$= 11.988$ kHz

38. The situation is shown in Fig.

Clearly, $\text{E}_{\text{max}} = 16/2 = 8$ mV

and $\text{E}_{\text{min}} = 8/2 = 4$ mV



$$\therefore m = \frac{\text{E}_{\text{max}} - \text{E}_{\text{min}}}{\text{E}_{\text{max}} + \text{E}_{\text{min}}} = \frac{8-4}{8+4} = \frac{1}{3} = 0.33$$

39. We have, $f_c = 9(\text{N}_{\text{max}})^{1/2}$

where $f_c \rightarrow$ critical frequency electron density/m^3

$= 5.4 \times 10^{11}$/m^3

$\Rightarrow \quad f_c = 9(5.4 \times 1011)^{1/2}$ Hz

$= 9 \times 7.34 \times 10^5$ Hz

$\therefore \quad f_c = 6.6$ MHz

40. As, $\text{A}_\text{C} + \text{A}_m = 15$

and $\text{A}_\text{C} - \text{A}_m = 3$

$\therefore \quad 2\text{A}_\text{C} = 18,\ 2\text{A}_m = 12$

$\therefore \quad \text{A}_\text{C} = 9$ and $\text{A}_m = 6$

As, $m = \frac{\text{A}_m}{\text{A}_\text{C}} = \frac{6}{9} = \frac{2}{3}$.

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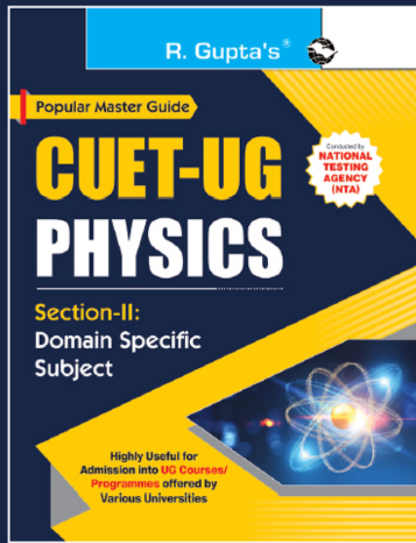

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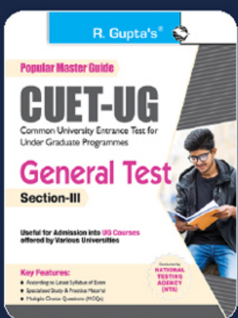

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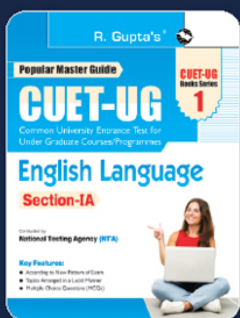

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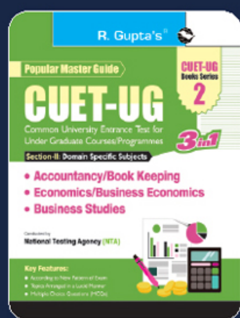

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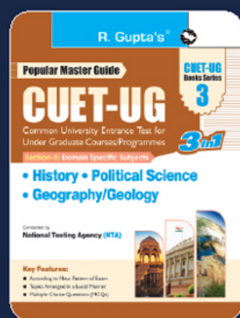

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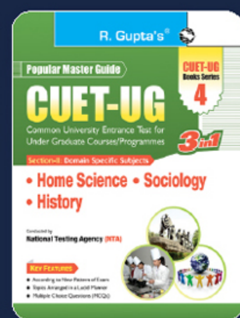

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