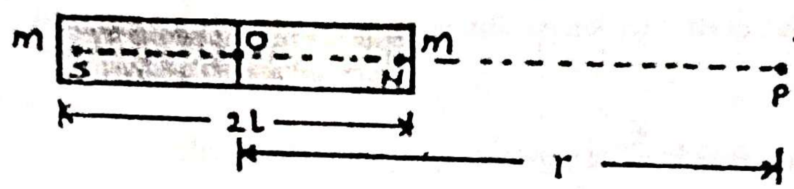
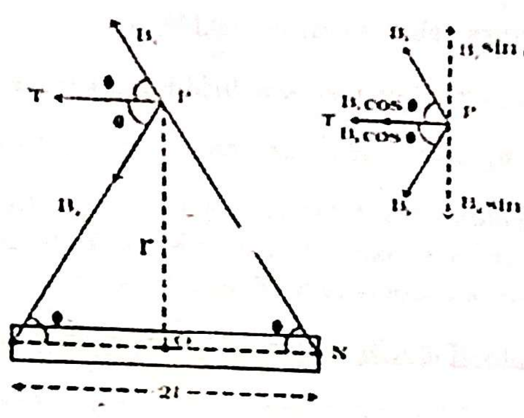
**Key Points:**

- B it is magnetic induction or magnetic flux density
- H = magnetizing force or intensity of magnetizing field
- $B = \mu H$ for a material medium for vacuum $B_0 = \mu_0 H$
- $B/B_0 = \mu/\mu_0 = \mu_r$ is called relative magnetic permeability
- 'I' is called intensity of magnetization it is equal to magnetic moment developed per unit volume in the sample. $I = M/V$ SI unit of I is A/m
- Magnetic susceptibility ($\chi_m$) – Ratio of intensity of magnetization (I) and intensity of magnetizing field (H) is called magnetic susceptibility. It has no units
- $\mu = \mu_0 (1 + \chi_m)$
- Magnetic field lines emerge from the North pole and enter the South pole. But they completes their loop inside the magnet.
- Magnetic dipole moment (M): $M = m \times 2l$ (direction is from S pole to N pole)
- Magnetic field on axial line:




$B = (\mu_0 / 4\pi) \times (2M / r^3)$

B and M are parallel



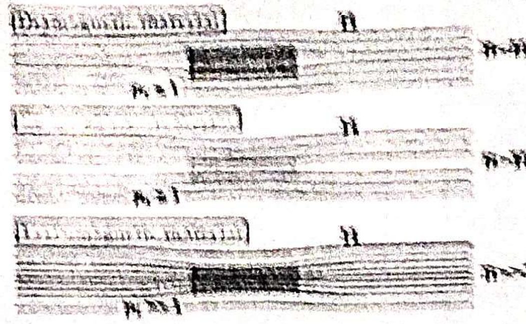

- Magnetic field on equatorial line:
  $B = (\mu_0 / 4\pi) \times (M / r^3)$
  B and M are anti-parallel

Torque on a Magnetic Dipole: $\tau = M \times B$ such that $\tau = MB \sin\theta$

- Potential Energy: $U = -M \cdot B$ or $U = -MB\cos\theta$
- Work done to rotate a magnet in magnetic field
  $W = -MB(\cos\theta_2 - \cos\theta_1)$
- Gauss Law of Magnetism essentially states that the magnetic flux through a closed surface/loopis zero. i.e. $\oint \vec{B} . \vec{ds} = 0$ It means magnetic monopoles do not exist in nature
- A bar magnet of magnetic moment M is equivalent to a coil of magnetic moment NIA
- Magnetic moment of charge moving in a circle is $M = qvr/2$

## Magnetic Properties of Materials

Substances can be divided into three groups based on their magnetic properties i.e. diamagnetic, paramagnetic, and ferromagnetic. They can be classified based on their magnetic susceptibility.



### Diamagnetic Materials

The materials that develop temporary magnetization such that the magnetic moment is in the opposite direction to that of the magnetic field in which they are placed are known as Diamagneticmaterials. In simple words, they are repelled by magnets.

Their magnetic susceptibility is small and negative. They have no unpaired electrons in them so magnetic moment of each atom in them is zero individually. Examples of diamagnetic materials are Bismuth, Copper, Zinc, Lead, etc

### Paramagnetic Materials

The materials that develop temporary magnetization such that the magnetic moment is in the same direction as that ofthe magnetic field in which they are placed are known as

*Paramagnetic materials*. They are slightly attracted by magnets. They have positive but very low susceptibility.They have unpaired electrons in them so each atom has magnetic moment of its own. In an external magnetic field torque acts on tiny atomic magnetic dipoles and align them along applied field. They can be called as poor ferromagnets.

Examples of Paramagnetic materials are Aluminium, Sodium, Calcium, etc

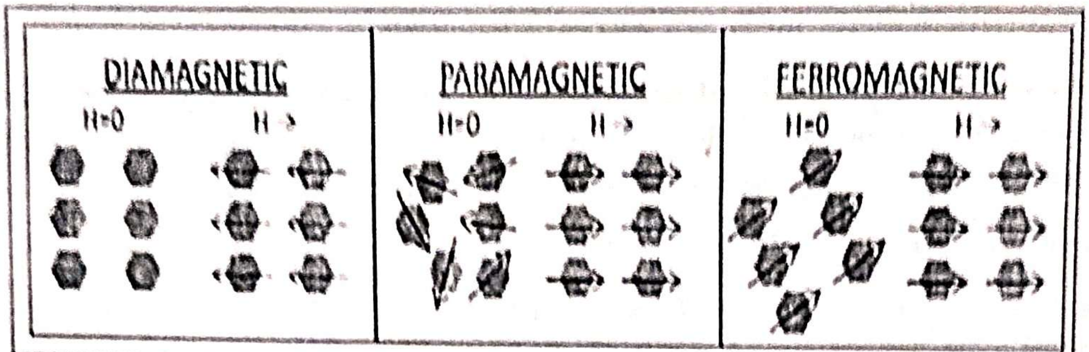
### Ferromagnetic Materials

The materials that develop temporary but strong magnetization such that the magnetic moment is in the same direction to that of the magnetic field in which they are placed are known as *ferromagnetic materials*. They are strongly attracted by magnets.

They have positive and high susceptibility. They have unpaired electrons in them. The atoms interact with neighbouring atoms to form 'domains' in them.In a domain all atoms align their magnetic moment in same direction. So a domain has large magnetic moment compared to an atom.in external field these domains get aligned parallel to the field so they get strongly magnetized.

Examples of Ferromagnetic materials are Iron, Nickel, Cobalt, Haematite, etc

| | Property | Dia | Para | Ferro |
|---|---|---|---|---|
| 1. | Effect of magnet | They are feebly repelled by magnets. | They are feebly attracted by magnets. | They are strongly attracted by magnets. |
| 2. | Relative magnetic permeability ($\mu_r$). | $0 \le \mu_r < 1$ | $1 < \mu_r$ | $\mu_r >> 1$ |
| 3. | Susceptibility value ($\chi$) | $\chi$ is small and negative $-1 \le \chi \le 0$ | $\chi$ is small and positive. $0 < \chi$ | $\chi$ is large and positive. $\chi >> 1$ |




**Effect of temperature on magnetic properties**

According to Curie's Law, the magnetization in a paramagnetic material is directlyproportional to the applied magnetic field. If the object is heated, the magnetization isviewed to be inversely proportional to the temperature

$$\chi = \frac{I}{H} = \frac{C}{T}$$ I = magnetic moment per unit volume

H= intensity of magnetizing field = $B/\mu_0$

The Curie temperature ($T_C$) of a ferro-magnetic material is the temperature above which it behaves like a para-magnetic material.

$$\chi = \frac{I}{H} = \frac{C}{(T-T_c}$$

## MULTIPLE CHOICE QUESTIONS

1 A ball of a diamagnetic material is heated. The magnetic susceptibility of its material will

(a) increase (b) Decrease (c)Not change

(d) Increases than attains a saturation value

2 A diamagnetic bar is suspended freely between parallel magnetic poles. It will tend to align its length

(a) Perpendicular to the poles (c) Parallel to the poles

(b) At 45$^0$ to the poles (d) In any random direction

3 The magnetic nature of atomic hydrogen is

(a) Diamagnetic (b) Paramagnetic (c) Ferromagnetic (d) Non - magnetic

4 In a bar magnet the distance between its magnetic poles is n times the length of bar magnet where 'n' is nearly

(a) 1 (b) 0.64 (c) 0.74 (d)0.84

5 Magnetic susceptibility and relative permeability of a material are

(a) directly proportional
(b) inversely proportional (c) differs by unity
(d) equal

6 Natural bar magnets are not very useful for practical purposes because their

(a) size is small (b) mass is large
(c) magnetic moment is low (d) magnetic moment is high

7 Superconductors are perfect dia-magnets. A superconductor is kept in an external magnetizing field having intensity 'H' the intensity of magnetization (I) due to its own magnetization will be

(a) Zero (b) –H (c) H (d) -1

8 If B denotes magnetic flux density and H denotes intensity of magnetizing field which of the following is correct

(a) $B = \mu H$ (b) $B = H/\mu$ (c) $H.B = \mu$ (d) $\mu BH$ = constant

9 If a bar of volume 'V' is kept in a magnetic field it gets magnetized. If its intensity of magnetization is 'I' and its magnetic moment developed in it is 'M'

(a) I= M (b) I α 1/M (c) I = M/V (d) M= I/V

10 The force between two poles of small sized magnets 'X' and 'Y' is F if their separation is increased to double the force between them will be

(a) F/2 (b) F/4 (c) F/8 (d) F/16

**SOLUTIONS-**

1- c diamagnetism is independent of temperature
2- c $U = -MB\cos\theta$ is minimum in that orientation
3- b Paramagnetic, it has unpaired electrons
4- d
5- c $\mu_r = 1 + \chi_m$
6- c
7- b $\chi_m = -1$ , $I/H = -1$ so $I = -H$
8- a
9- c
10- b F is inversely proportional to $r^2$

**ASSERTION REASON QUESTIONS**

1 ASSERTION- Each atom of a paramagnetic material has a non-zero magnetic moment of its own.

REASON- Paramagnetism is shown by materials having unpaired electrons in them

2 ASSERTION- The magnetic moment of electron in outer orbit of Hydrogen atom is higher

REASON- The kinetic energy of electrons in outer orbit Hydrogen atom is higher

3 ASSERTION- A diamagnetic bar in magnetic field aligns itself along the field.

REASON- Susceptibility of a diamagnet is slightly more than zero

4 ASSERTION- A bar magnet is equivalent to a solenoid as both generate magnetic field

REASON- Magnetic field at the center of bar magnet is weaker as compared to its poles

5 ASSERTION- Two poles of a magnet can never be separated
REASON – Magnetic field lines always form closed loops.

6 ASSERTION- A magnetic dipole tries to align itself at right angle to the applied external magnetic field.
REASON – When a magnet is perpendicular to a magnetic field its potential energy is maximum

7 ASSERTION – The magnetic permeability of a material doesn't depend on its temperature.
REASON – The magnetic induction (B) doesn't depend on temperature.

8 ASSERTION – The magnetic moment of a magnet is equal to the product of magnetic pole strength and least distance between the poles of the magnet.
REASON – Magnetic moment is a vector quantity.

9 ASSERTION – A ferromagnetic material has high magnetic susceptibility.
REASON- Ferromagnetic materials have domains and each domain has high magnetic moment

10 ASSERTION – Two identical charges moving in circular orbits of different radii can have same magnetic moment
REASON- The magnetic moment of a circulating charge is ZERO.

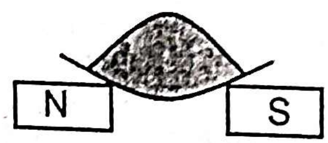
**ANSWERS**

1- a 2- c 3- d 4-d 5-a 6- d 7-d 8-b 9-a 10-c

**2 MARKS QUESTIONS**

1 Can a magnetic monopole exist in nature? Give reason

2 A paramagnetic sample is placed on a watch glass as shown below. Draw diagram to show how the distribution of sample is affected in due course of time. In which case it attains new arrangement quicker (i) a hotter sample (ii) a colder sample




3 A long solenoid has a magnetic field of 0.25T inside it. If a bar of magnetic susceptibility 5 is inserted into it what will be the magnetic flux density inside it?

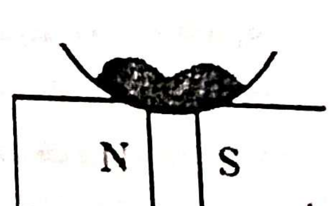
4 A Diamagnetic bar and a paramagnetic bar are kept in a long solenoid for magnetizing them. Draw diagram to show magnetic field lines with samples placed inside clearly mention the magnetic poles induced in the two bars.

5 Why the susceptibility of a diamagnetic material doesn't depend on the temperature?

6 The susceptibility of a ferromagnet is reduced by 10% when its temperature is raised above 1200K by $50^0$C. Find the temperature below which it will be paramagnetic in nature

**SOLUTIONS-**

1- No, A circulating charge causes magnetic character. From one face it appears to move clockwise while from other face it appears to move anticlockwise. So the two faces are two poles. It same thing viewed from two sides.




2- Refere gist given above. The hump will split into two mounts of smaller size as paramagnetic salt is weakly attracted by magnetic poles.

The new arrangement will be quicker in colder sample as hotter sample is less susceptibile to magnetic field so it will respond slower

3- $\mu = \mu_0 (1+\chi_m)$ so $\mu = 6\mu_0$
$B = \mu H = 6\mu_0 H = 6 B_0$

$B = 6 \times 0.25 = 1.5T$

4- refer Gist of chapter
5- In a diamagnetic material all electrons are paired so the magnetic moment of an electron is nullified in pair. Even if we change temperature the magnetic moments get nullified so diamagnetism is independent of temperature.
6- Using formula $\chi_m = C/(T - T_c)$
$1/0.9 = (1250 - T_c) / (1200 - T_c)$

$T_c = 750K$

## 3 MARKS QUESTIONS

1 A bar magnet is bent to make a semi circle. Find the ratio of its initial and final magnetic moment. What will be the magnetic moment of the system if it is broken into three equal parts and make a proper triangle such that at two vertices like poles are held together?

2 The relative permeability of a material is $1.03\mu_0$. Find its susceptibility and identify the magnetic nature of the material. What will be the effect on it's susceptibility if its temperature on heating it.

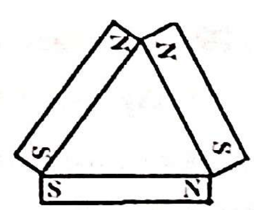
3 For a magnetic material the relative permeability is $1.05\mu_0$. find its susceptibility. Draw a diagram showing the magnetic field lines when such a sample is kept in magnetic field.

4 A square coil of side 20cm and 2000 turns is carrying a current of 10A.Calculate the magnetic field at a point on its axis 8m away from its center.

5 Two identical small bar magnets each of magnetic moment 'M' are placed along X-axis and Y-axis such that their mid point is at origin. (a)Determine the expression for magnetic field at a point 'r' distance away on Z-axis, (b)Find the direction of resultant magnetic field at that point

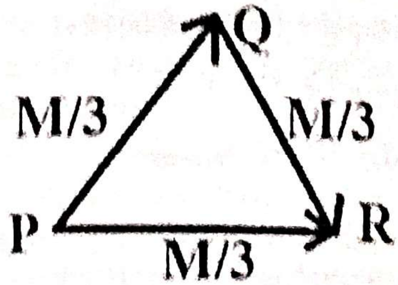
6 A paramagnetic sample shows a saturation magnetization of 12% at 10K in an external magnetic field of 0.5T. what will be the saturation magnetization in a magnetic field of 0.8T at 12K?

7 Three identical bars of magnetic moment M each are arranged as shown to make an equilateral triangle. Find the magnetic moment of the system.



## SOLUTIONS-

1- Let $M = m \times l$
But A.T.Q, $l = \pi r$, so $M' = m \times 2r$, thus $M/M' = m\,l/2mr$, hence $M/M' = \pi/2$




$\overline{PQ} + \overline{QR} = \overline{PR}$ angle between $\overline{PQ}$ & $\overline{QR}$ is $120^0$

so $|\overline{PR}| = \frac{M}{3}$ hence $M_{total} = 2M/3$ along $\overline{PR}$

2- $\mu = \mu_0(1+\chi)$
$1.03\,\mu_0 = \mu_0(1+\chi)$

$\chi = 0.03$, it is paramagnetic.

Susceptibility decreases with temperature inversely as per curie's law

3- do yourself
4- $M = NIA$
$M = 2000 \times 0.2 \times 0.2 \times 10 = 80\ Am^2$.

$B = (\mu_0 / 4\pi) \times (2M / r^3)$

$B = 10^{-7}\,(160/8^3) = 3.125 \times 10^{-8}$ T along the axis of coil

5- Do yourself
6- Do yourself 16%
7- Do as in Q1 2M towards right

## SOURCE BASED QUESTIONS

Q1 In a paramagnetic sample each atom has unpaired electrons so each atom in them has a permanent magnetic moment of its own. Under ordinary conditions the random orientations of these tiny atomic magnets sum up to zero. When the sample is placed in an external magnetic field the tiny magnets get oriented along it due to which sample gets magnetized. If we raise the temperature the thermal agitation disturbs the alignment so system starts losing its magnetic character.

(i) The magnetic moment of each atom is non-zero for

(a) Diamagnets only

(b) Paramagnets and diamagnets both

(c) Paramagnets and ferromagnets both

(d) Ferromagnets and diamagnets both

(ii) When a paramagnet is placed in an external magnetic field B

(a) All the atomic magnets get aligned along B
(b) All the atomic magnets get aligned opposite to B

(c) Few atomic magnets get aligned along B
(d) Most of the atomic magnets get aligned along B

(iii) Two Aluminum bars P and Q have same volume but area of cross-section of P is more than Q they are kept inside a long solenoid. Their saturation magnetic moments are $M_P$ and $M_Q$ respectively and the respective pole strengths are $m_P$ and $m_Q$ respectively then

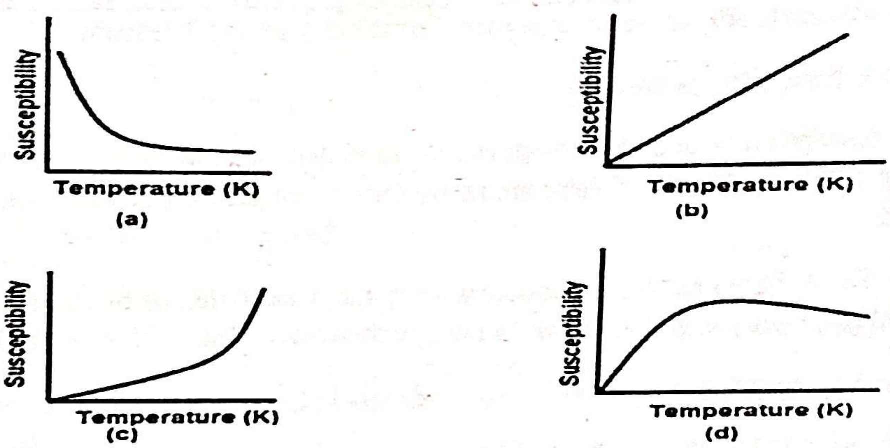
(a) $M_P > M_Q$ and $m_P < m_Q$
(b) $M_P = M_Q$ and $m_P > m_Q$
(c) $M_P < M_Q$ and $m_P = m_Q$
(d) $M_P < M_Q$ and $m_P > m_Q$

**OR**

If a paramagnetic bar is kept in an external magnetic field its

(a) Magnetic moment does not change with magnetizing force (H)
(b) Intensity of magnetization does not change with magnetizing force (H)
(c) Its pole strength rises with magnetizing force (H)
(d) its susceptibility rises with magnetizing force (H)

(iv) The variation of magnetic susceptibility of a paramagnet with temperature is correctly shown by the graph




Q2 P, Q and R are three bars they are kept in magnetic field for some time and their magnetic behavior is observed. The magnetization of P was much higher than that of Q and R. When they are heated after withdrawing from magnetic field Q doesn't show a change in its magnetic strength. The behavior of P is found to be same as R when it is heated to a temperature more than $1100^0$C.

(i) Out of the given bars the diamagnetic behavior is shown by
(a) P (b) Q (c) R (d) None

(ii) The magnetic susceptibility is largest for
(a) P (b) Q (c) R (d) P and R both

(iii) Magnetization or intensity of magnetization is defined as
(a) Magnetic moment developed
(b) Magnetic moment developed per unit area
(c) Magnetic moment developed per unit volume
(d) Pole strength developed

(iv) Which of the following is NOT true ?
(a) P is Ferromagnetic
(b) $1100^0$C is curie's temperature for P
(c) $1100^0$C is curie's temperature for R
(d) Q has negative magnetic susceptibility

**OR**

The difference of relative magnetic permeability and magnetic susceptibility for these bars will be

(a) Zero for all
(b) 1 for all
(c) -1 for all
(d) 1 for P and R only

## SOLUTIONS-

| | | | | |
|---|---|---|---|---|
| 1- | (i) a | (ii) c | (iii) b OR c | (iv) a |
| 2- | (i) b | (ii) a | (iii) c | (iv) b |
| 3- | (i) a | (ii) b | (iii) d OR c | (iv) b |

## LONG ANSWER TYPE (5 MARKS QUESTIONS)

1 "Ferro-magnets are strong paramagnets". Justify by giving 2 reasons.

Define curie's temperature.

The susceptibility of a faerromagnetic material decreases by 20% when its temperature is raised from 1200K to 1250K. if these are above curie's temperature at what temperature will it fall by 50%.

2 Draw diagrams to differentiate among magnetic materials by showing the modified magnetic field lines when a different types of magnetic materials are placed in uniform magnetic field.

(a)Why the magnetization of a paramagnetic bar decreases when it is hammered?

(b) what is the value of susceptibility and relative permeability of a diamagnetic material.

3 A large number of thin identical bar magnets each of magnetic moment M are arranged to make a semicircular disc such that S-pole of each is lying at the center.Find the magnetic moment of the system and its direction if the longest side of disc is taken as X-axis center as origin.

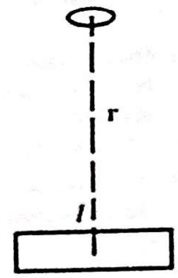
Establish the relation between the magnetic moment and angular momentum of revolving charge. Use your result to show magnetic moment of electron in hydrogen atom is quantized

4 A bar magnet is kept in a uniform magnetic field. Derive the formula for torque acting on it. What will happen if the field is non-uniform?

A bar of diamagnetic nature is left freely in a uniform magnetic field. Draw a diagram to show in which orientation will it rest in finally. Give reason

5 A bar magnet of length $l$ is placed r away from a coil as shown where ($r>>l$ ).

If the magnetic field at the midpoint due to both is same find the area of coil.




Given that coil has N turns and current in it is i.

How shall they be placed so that magnetic field at the mid-point becomes zero.? Draw diagram

Draw diagram.

Give any three properties to differentiate among Dia, Para & Ferromagnetic

Materials

## SOLUTIONS –

1- Refer text book
AS $\chi = C / (T - Tc)$

$\chi = C / (1200 - Tc)$ and $0.8\,\chi = C/(1250 - Tc)$

$0.8 = (1200-Tc)/(1250-Tc)$ so $Tc = 1000K$

2- Refer Text book
(a) On hammering the aligned tiny atomic magnets start to orient them in random directions so component of magnetic moment along intial direction decreases.
(b) For diamagnets susceptibility is negative and low but it lies between zero and -1. For perfectdiamagnets its -1 $-1 \le \chi < 0$
The relative permeability lies between Zero and 1 $0 \le \mu_r < 1$

3- Taking components of **M** along X-axis and Y-axis we see that x-components cancel out in pairs so overall magnetic moment is sum of sine components only along Y-axis so

$M_{total} = \int_0^{\frac{\pi}{2}} M \sin\theta \, d\theta = M$

For an electron in Hydrogen atom $M = -eL/2m$ **L = angular momentum** (prove yourself)

As $|L| = mvr = nh/2\pi$ n= 0,1,2,3.......................

As **L** is quantized so M is quantized also

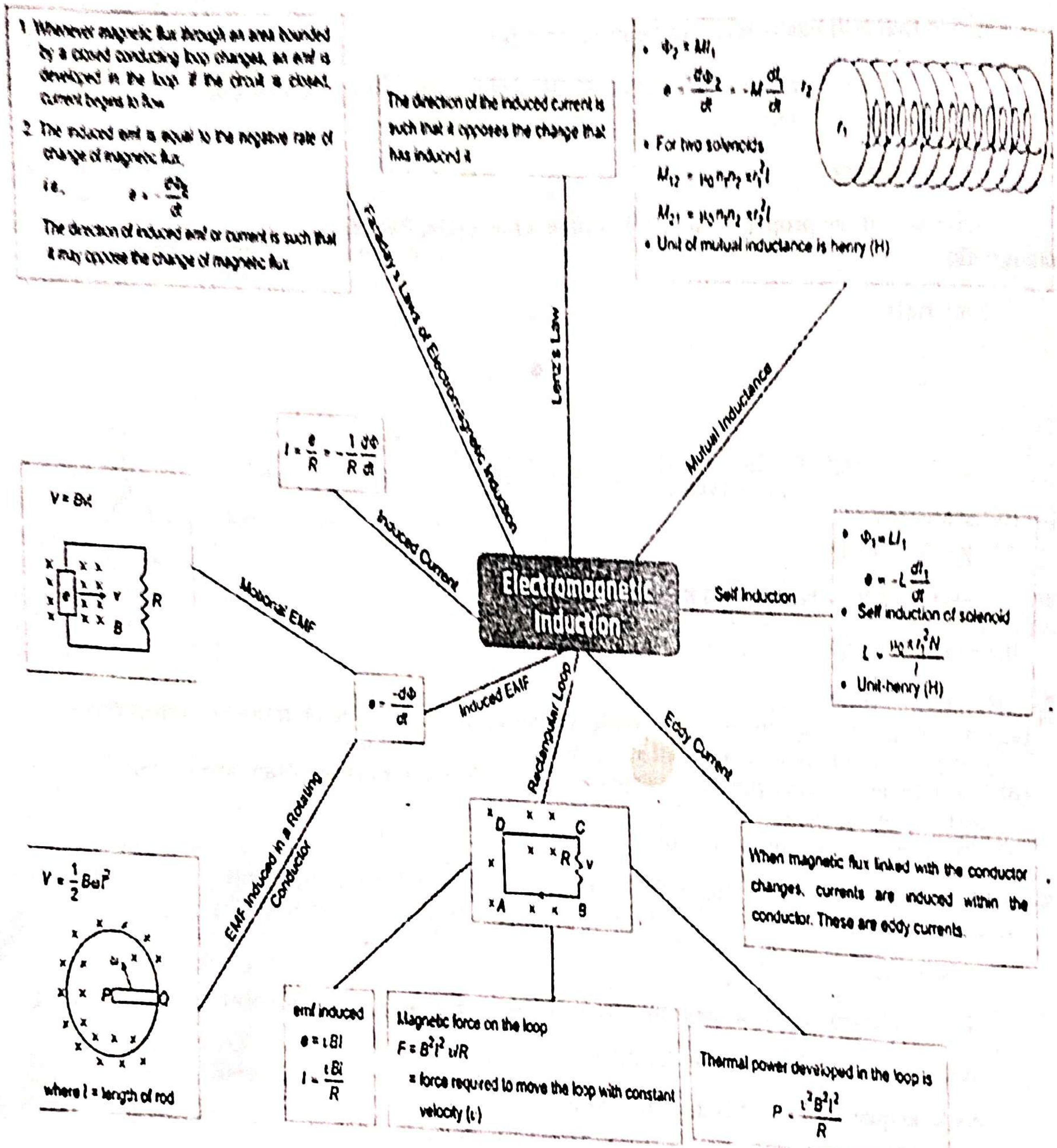
4- Refer gist of chapter and prove yourself
For Non-uniform field it will feel Force and torque both

It will align normal to field to minimize its potential energy.

5- Do yourself
Hint- coil can be replaced by an equivalent magnet.

# CHAPTER 6 – ELECTROMAGNETIC INDUCTION

SYLLABUS: Electromagnetic induction; Faraday's laws, induced EMF and current; Lenz's Law, Self and mutual induction.




## GIST OF THE CHAPTER

**Area Vector($\vec{A}$) :**

An area vector is a vector whose magnitude is equal to the area of a plane and direction is normal to the plane of the area.

**Magnetic Flux $\phi_B$**

**GIST OF THE CHAPTER**

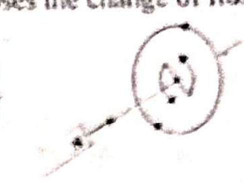
The total number of magnetic lines of force passing normally through an area placed in a magnetic field, is equal to the magnetic flux linked with that area. Net flux through the surface $\phi_B = B.A = BA\cos\theta$ Magnetic flux is a scalar quantity. S.I. unit: weber (Wb), CGS unit : Maxwell or Gauss × $cm^2$ (1 Wb = $10^8$ Maxwell).

**Faraday's laws of EMI**

1. **First law :( Cause of emf)** The induced emf is due to changing magnetic flux linked with the closed loop/coil.
2. **Second law: (magnitude of emf)**

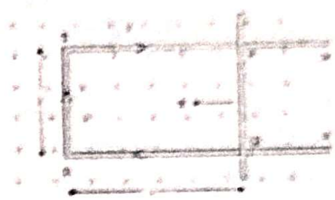
The magnitude of the induced e.m.f. is directly proportional to the rate of change of the magnetic flux. Induced e.m.f.. $\varepsilon = -d\phi/dt = -(\phi_2 - \phi_1)/t$ .Negative sign indicates that induced emf ($\varepsilon$) opposes the change of flux

**Lenz's Law:** - This law gives the direction of induced emf/induced current. According to this law, the direction of induced emf or current in a circuit is such as to oppose the cause that produces it. This law is based upon **law of conservation of energy**



**Motional EMF Due to Translatory Motion:-**

If the length RQ = x (variable) and RS = l, the magnetic flux Φ enclosed by the loop PQRS will be Φ= B l x Since x is changing with time, the rate of change of flux will induce an emf given by: $\varepsilon = -\frac{d\phi}{dt} = -\frac{d(Bl\,x)}{dt} = Bl\,v$



The induced emf $\varepsilon = Blv$ is called **motional emf**

**Motional EMF Due to Rotational Motion:-** Emf induces across the ends of the rod where $\nu$ = frequency (revolution per sec) And T = Time period.

$$\varepsilon = \frac{B\omega R^2}{2}$$

**Inductance** is a property of an electrical conductor (like a coil or solenoid) that describes its ability to **oppose changes in electric current** flowing through it by generating a magnetic field.

**Self Inductance**: Self-inductance (L) of a coil is numerically equal to the magnetic flux ($\phi$) linked with the coil, when a unit current flow through it. $\phi = LI$ $\varepsilon = -L\,dI/dt$ , S.I. unit of self-inductance is Henry (H).

**Self inductance of a long solenoid :** $L = \mu_0\mu_r N^2 A/l = \mu_0\mu_r n^2 Al$

Energy stored in an inductor: $U = \frac{1}{2}LI^2$ and energy density is given by $\frac{B^2}{2\mu_0}$

**Mutual Inductance:** Whenever the current passing through a coil changes, the magnetic flux linked with a neighboring coil will also change. Hence an emf will be induced in the neighboring coil or circuit. This **phenomenon** is called '**mutual induction**'

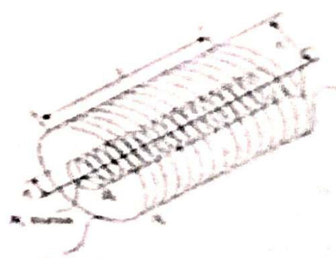
$\phi = MI$ $\varepsilon = -M\,dI/dt$

SI unit is **henry (H).**

**Mutual-Inductance between pairs of long Solenoid:-**

$M_{12} = (\mu_0 n_1 n_2 L\pi r_1^2)$ , $M_{21} = (\mu_0 n_1 n_2 L\pi r_2^2)$

Hence $M_{12} = M_{21}$



**AC generator::** It is a device which converts mechanical energy into an electrical energy and generates alternating current.

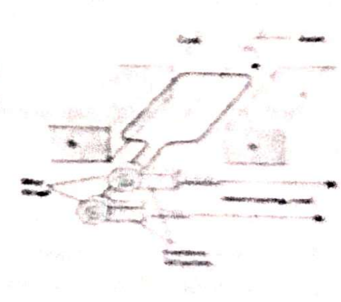
**Principle**: Works on principle of electro-magnetic induction.

**Construction**: 1. Armature coil 2. Filed magnet 3. Slip rings 4. Brushes

**Theory**: When the armature coil rotates between the pole pieces of field magnet, the effective area of the coil is A cos θ, The flux at any time is, $\phi = B.A = NBA\cos\theta = NBA\cos\omega t$

The induced emf is,

$\varepsilon = -d\phi\,dt = -d(NBA\cos\omega t)\,dt$ $V = \varepsilon = -NBA\omega\sin\omega t$



## MULTIPLE CHOICE QUESTIONS

Q1 Lenz's law is a consequence of the law of:
a) conservation of energy
b) conservation of charge
c) conservation of momentum
d) conservation of mass

Q2 The SI unit of inductance is:
a) farad b) coulomb c) weber d) henry

Q3 According to Lenz's law, the direction of induced current is such that it:
a) enhances the cause producing it
b) opposes the cause producing it
c) is in the direction of the cause producing it
d) may be in any direction

Q4 The induced EMF is maximum when the angle between the magnetic field and the normal to the coil is:
a) 0 degrees b) 45 degrees c) 90 degrees d) 180 degrees

Q5 You are required to design an air-filled solenoid of inductance 0.016H having a length 0.81 m and radius 0.02 m. The number of turns in the solenoid should be :
a) 2592 b) 2866 c) 2976 d) 3140

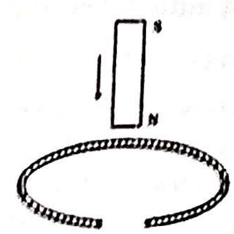
Q6 Current in a circuit falls from 5.0 A to 0.0 A in 0.1 s. If an average EMF of 200V is induced, the self-Inductance of the coil is:
a) 4H b) 5H c) 3H d) 40H

Q7 A coil of area 100 $cm^2$ is kept at an angle of $30^0$ with a magnetic field 0.1 T. The magnetic field is reduced to zero in $10^{-4}$ s. The induced emf in the coil is:
a) $5\sqrt{3}$ V b) $50\sqrt{3}$ V c) 5.0 V d) 50.0 V

Q8 A magnetic flux linked with a coil varies as $\phi = 2t^2 - 6t + 5$ where $\phi$ is in weber and t is in second. The induced current is zero at
a) t = 0 b) t = 1.5s c) t = 3s d) t = 5s

Q9 . A coil is moved quickly out of a magnetic field. While exiting the field ,the direction of the induced current will be such that it will:
a) oppose the increase in magnetic flux
b) support the increase in magnetic flux
c) oppose the motion of the coil
d) support the motion of the coil

Q10 A vertically held bar magnet is dropped along the axis of a copper ring having a cut as shown in the figure acceleration of the falling magnet is:
(a)Zero b) less than g
(c) g (d) more than g




## SOLUTIONS:

1 a) 2 d)
3 b) Lenz's Law states that the direction of the induced current in a conductor is such that it opposes the change in magnetic flux that produced it.
4 a)
5 b)$L=\mu_0 N^2 A/l$
6) a) $e = d\varphi/dt$ = Ldl/dt , L=4H
7) a) $e = d\varphi/dt$ = Ldl/dt
8) b) e=IR = $d\varphi/dt$ , so if I=0 so $\frac{d\varphi}{dt} = 0$ t=1.5s
9) c)
10) c) , due to cut in the ring only emf is induced not the current , so bar magnet falls with acceleration due to gravity.

## ASSERTION AND REASON TYPE QUESTIONS

Q1 **Assertion (A):** A changing magnetic flux induces an emf in a circuit.
**Reason (R):** The induced emf is given by Faraday's law.

Q2 Assertion (A): The induced current always opposes the cause that produces it.

Reason (R): This is due to Lenz's law.

Q3 Assertion (A): When a magnet is moved towards a coil, a current is induced in the coil.

Reason (R): The magnetic flux linked with the coil changes with time.

Q4 Assertion (A): A conductor moving parallel to the magnetic field experiences no induced emf.

Reason (R): The rate of change of magnetic flux is maximum when motion is along the field.

Q5 Assertion (A): The induced emf in a coil depends on the rate of change of current in the Neighbouring coil.

Reason (R): Mutual inductance must exist between two nearby coil.

Q6 Assertion (A): The self-inductance of a coil is a measure of its ability to resist a change in current.

Reason (R): When current changes in a coil, a back emf is induced opposing the change.

Q7 Assertion (A): An ideal transformer has 100% efficiency.

Reason (R): There is no loss of energy in the practical transformer due to heat, eddy currents, or hysteresis.

Q8 Assertion (A): The core of a transformer is made of soft iron and laminated.

Reason (R): This reduces eddy current losses and increases magnetic coupling.

Q9 Assertion (A): No emf is induced in a stationary coil placed in a constant magnetic field.

Reason (R): emf is induced only when there is a change in magnetic flux linked with the coil.

Q10 Assertion (A): The mutual inductance of two coils depends on their relative orientation.

Reason (R): Changing the orientation affects the amount of magnetic flux linking both coils.

**ANSWERS**

1. B Faraday's second law states that emf induced is proportional to the rate of change of magnetic flux — directly explaining the assertion

2. A Lenz's law ensures the direction of induced current opposes the change in magnetic flux, which is the cause.

3.A Motion of the magnet changes the flux through the coil, inducing current.

4.C Motion along the field lines causes no change in flux, so no emf is induced. The rate is maximum when motion is perpendicular to the field.

5.C The emf induced in one coil is due to change of current (and thus flux) in the other, and this effect is quantified by mutual inductance.

6.A Self-inductance resists current changes due to the back emf generated by Lenz's law.

7.A In an ideal transformer, no energy losses occur, hence efficiency is 100%.

8.A Lamination reduces eddy currents and soft iron ensures strong magnetic linkage between coils.

9. A A constant field implies constant flux → no emf. Emf requires changing flux.

10.A

**SHORT ANSWER TYPE QUESTIONS**

Q1 A light metal disc on the top of an electromagnet is thrown up as the current is switched on. Why? Give reason.

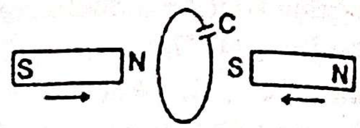
ANS- The induced magnetic field in the disc repels the magnetic field of the electromagnet. This repulsive force between the disc and the electromagnet exerts an upward force on the disc, causing it to be thrown up.

Q2 How does the mutual inductance of a pair of coils change when distance between the coils is increased and number of turns in the coils is increased?

ANS- When the distance between the coils is increased: Mutual inductance decreases.

Mutual inductance M is directly proportional to the product of the number of turns in both coils. M is directly

Q3 Two bar magnets are quickly moved towards a metallic loop connected across a capacitor 'C' as shown in the figure. Predict the polarity of the capacitor.

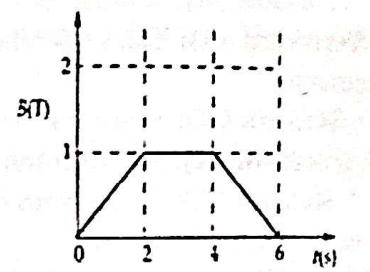



**ANS.** The north poles of both magnets are approaching.The loop will generate a south pole on the side facing the approaching magnets, to oppose their motion.Hence, the induced current in the loop will be clockwise (when viewed from the front). In a clockwise current, the upper plate of the capacitor gets positive and the lower plate gets negative.

Q4 Two identical coils one of copper and the other of aluminium are rotated with the same angular speed in an external magnetic field. In which of the two coils will the induced current be more?

**ANS-** Same emf in both coils,Lower resistance in copper coil,Hence, induced current in the copper coil will be more.

Q5 The magnetic field is perpendicular to the plane of the loop, what is the induced current in the loop during 2 to 4 seconds.




**ANS-** As there is NO change in magnetic field during 2 Sec to 4 Sec , so $\varepsilon = 0$ , $I_{ind} = 0$ However emf will be induced between 0 to 2s and 4 to 6s. (can be calculated with the help of slope of the graph)

Q6 A coil of N turns is placed in a magnetic field $\vec{B}$ such that $\vec{B}$ is perpendicular to the plane of the coil. Magnetic field changes with time as $B=B_0 \cos(\frac{2\pi}{T}t)$ where T is time period. Calculate the time at which emf induced in the coil is maximum.

**Ans:** $e=\frac{d\varphi}{dt}$ , $\frac{d\varphi}{dt} = -B_0 \times A\ \frac{2\pi}{T}\sin(\frac{2\pi}{T}t)$ $e=N\frac{d\varphi}{dt}$,

Magnitude of EMF is max when $\sin(\frac{2\pi}{T}t) = 1$

This occurs when , $\frac{2\pi}{T}t = \frac{\pi}{2}, \frac{3\pi}{2}, \frac{5\pi}{2}, \ldots$ so t= T/4 , 3T/4, 5T/4 .......

Q7 Derive an expression for the self inductance of a section of a long solenoid and hence show that self inductance is proportional to the square of number of turns per unit length.

**Ans:** For a long solenoid, the magnetic field inside is:

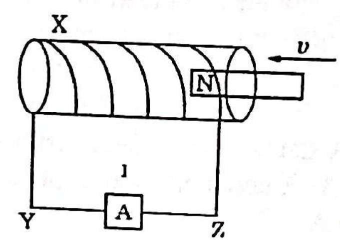
$B=\mu_0 n I$ , $\Phi=B\cdot A=\mu_0 n I A$ Total flux linkage for N turns:

$N\Phi=N(\mu_0 n I\cdot A)$ But $N=n \times L$ , so: Total flux $\Phi = nL\cdot\mu_0 n I A$

$\Phi= L I = \mu_0 n^2 A l I$ ,

Self inductance $L = \mu_0 n^2 A l$ so $L \alpha n^2$

Q8 In the given figure, X is a coil wound over a hollow wooden pipe. A permanent magnet is pushed at a constant speed v from the right into the pipe and it comes out of at the left end of the pipe. During the entry and the exit of the magnet. What will be the current in the wire YZ. (draw it diagrammatically)

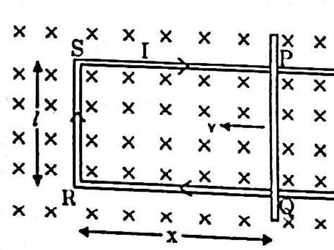



**Ans:** Z to Y and then Y to Z by using Lenz law.

Q9 Define mutual induction and derive the formula of coefficient of mutual inductance between two coils.

Q10 Explain how Lenz's Law applies when a metal ring is dropped into a region where a magnetic field is increasing upwards. What will be the direction of the induced current in the ring as it comes closer to the magnetic field?

Q11 Figure shows a rectangular conductor PSRQ in which movable arm PQ has a resistance 'r' and resistance of PSRQ is negligible. What are factors on which the induced emf will depend magnitude when PQ is moved with velocity v. calculate its magnitude also.




**Ans:**. The induced emf depends on magnetic field, velocity , length of conductor PQ. Its magnitude will be given by e=Bvl.

## SHORT ANSWER TYPE QUESTIONS

Q1 Two concentric circular coils, one of small radius $r_1$ and the other of large radius $r_2$, such that $r_1 << r_2$ are placed co-axially with centers coinciding. Obtain the mutual inductance of the arrangement.

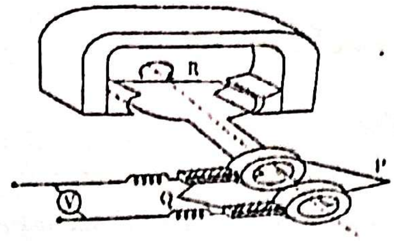
Q2 i) State Lenz law.

ii) Identify the machine in the given figure.

iii) Identify the parts P , Q and R of the machine

iv) Give the polarities of the magnetic poles.

v) Write the two ways of increasing the output voltage.



Ans: i) Lenz's law- The polarity of induced emf is such that it tends to produce a current which opposes the change in magnetic flux that produced it.

ii) AC generator

iii) P – Slip rings   Q – Carbon brushes   R- Armature coil

iv) Left side of the magnet is North & right side is South or vice-versa.

v)write any two :

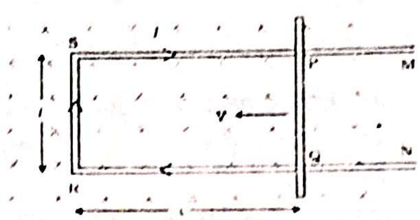
By increasing the number of turns in the armature coil.

By increasing the speed of rotation of the armature coil.

By increasing the strength of the magnetic field B.

Q3 Fig . shows, a rectangular loop PQRS, where PQ is free to move with velocity v. A uniform magnetic field acts ⊥ to loop. Assume PQ has resistance r, obtain expression for

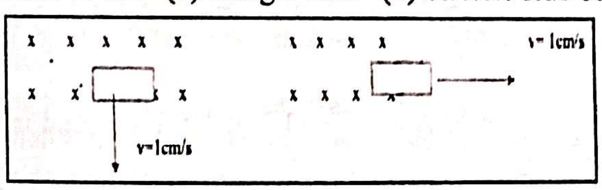
(i) current (ii) force (iii) power to move PQ.



Ans : (i) $I = \frac{Blv}{r}$ (ii) $F = B^2 l^2 \frac{v}{r}$ (iii) $P = B^2 l^2 \frac{v^2}{r}$

Q4 A rectangular wire loop of sides 8 cm and 2 cm with a small cut is moving out of a region of uniform magnetic field of 0.3 T directed normal to the loop.

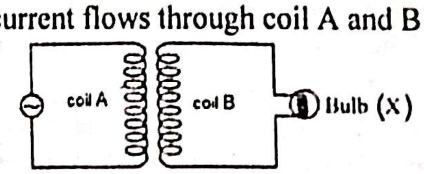
(i)What is the emf developed across the cut if the velocity of the loop is 1 $cms^{-1}$ in a direction normal to the (a) Longer side (b) Shorter side of the loop?




Ans: (a) longer side : $\varepsilon = Blv = 2.4 \times 10^{-4}$ V , T=b/v= 2seconds

(b) shorter side: $\varepsilon = 0.6 \times 10^{-4}$ V , T= l/v = 8seconds

Q5 Figures shows an arrangement by which alternatively current flows through coil A and B is placed near A and connected to a bulb X.




Now explain the observations with reason

(i) When the switch S is closed the bulb lights up. Why?

(ii) What happens to the brightness if an iron rod is inserted in coil A.

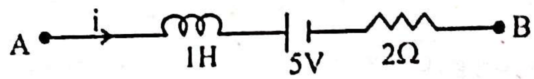
(iii) What happens to the brightness if a copper plate is inserted in the gap between the coils?

Ans: -(i) Due to mutual induction

(ii) Brightness decreases as the induced current decreases

(iii) Brightness decreases due to production of induced current set up in the copper plate which opposes passage of magnetic flux.

Q 6 Show that coefficient of self inductance is independent of flux and current passing through the coil.
Q7 AB is a part of an electrical circuit(see figure) Calculate the potential difference $V_A - V_B$ at the instant when current of i=2A is increasing at a rate of 1A/second and in between points




**Ans:** $V_A - L\frac{dI}{dt} - 5 - 2 \times 2 = V_B$ $\quad V_A - V_B = 10V$

Q8 The magnetic flux linked with a coil in Wb is given by the equation $\varphi = 5t^2 + 3t + 16$ . Calculate the magnitude of induced emf in the coil at the fourth second.
Sol: $e = \frac{d\varphi}{dt} = 10t + 3$ emf in 4th sec is $e_4 - e_3 = 43V - 33V = 10V$

Q9. Calculate the self-inductance of a coil using the following data obtained when an AC source of frequency $\frac{200}{\pi}$ Hz and a DC source is applied across a coil.

| AC Source | | |
|---|---|---|
| S.No. | V (Volts) | I (A) |
| 1 | 3.0 | 0.5 |
| 2 | 6.0 | 1.0 |
| 3 | 9.0 | 1.5 |

| DC Source | | |
|---|---|---|
| S.No. | V (Volts) | I (A) |
| 1 | 4.0 | 1.0 |
| 2 | 6.0 | 1.5 |
| 3 | 8.0 | 2.0 |

Sol: When DC is connected there will be only resistance and when AC is connected then there will be both inductance and resistance(Z).
From the table Z = 6 Ω and R= 4 Ω
So $Z = \sqrt{R^2 + X_L^2}$ so $X_L = \sqrt{20} = 2\sqrt{5} \approx 4.5\Omega$ $X_L = \omega L$ , $L = 4.5/2\pi v$ so L=11 mH

## LONG ANSWER TYPE QUESTIONS

Q1. (a) Define mutual inductance and write its SI units.
(b) Derive an expression for the mutual inductance of two long co-axial solenoids of same length wound one over the other.
Q2. (a) Draw a labelled diagram to explain the principle and working of an A.C. generator. Deduce the expression for emf generated. (b)Why cannot the current produced by an A.C. generator be measured with a moving coil ammeter?
Q3 a) State Lenz's law. Give one example to illustrate this law. "The Lenz's law is a consequence of the principle of conservation of energy." Justify this statement.
b) A long solenoid with 15 turns per cm has a small loop of area 2.0 cm$^2$ placed inside the solenoid normal to its axis. If the current carried by the solenoid changes steadily from 2.0 A to 4.0 A in 0.1 s, what is the induced emf in the loop while the current is changing?
Ans: b) Magnetic field , $B = \mu_o n I$ $\quad \frac{dB}{dt} = \mu_o n \frac{dI}{dt}$ , $\frac{dI}{dt} = 20$ A/s $\quad \frac{dB}{dt} = 3.77 \times 10^{-2}$ T/s and induced emf is e=7.54 μV

## CASE STUDY BASED QUESTIONS

1. EMI is defined as the production of an electromotive force across an electric conductor in the changing magnetic field. The discovery of Induction was done by Michael Faraday in the year 1831. Electromagnetic induction finds many applications such as in electrical components which includes transformers, inductors, and other devices such as electric motors and generators.
Alternating current is defined as an electric current which reverses in direction periodically.
In most of the electric power circuits, the waveform of alternating current is the sine wave.
I. How to increase the energy stored in an inductor by four times?
(a) By doubling the current (b) This is not possible
(c) By doubling the inductance (d) By making current 2 times
II. Consider an inductor whose linear dimensions are tripled and the total number of turns per unit length is kept constant, what happens to the self-inductance?

(a) 9 times (b) 3 times (c) 27 times (d) 13 times

III. Lenz law is based on which of the following conservation

(a) Charge (b) Mass (c) Momentum (d) Energy

IV. What will be the acceleration of the falling bar magnet which passes through the ring such that the ring is held horizontally and the bar magnet is dropped along the axis of the ring?

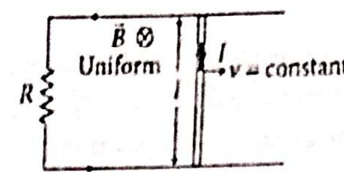
(a) It depends on the diameter of the ring and the length of the magnet

(b) equal due to gravity

(c) It is less than due to gravity

(d) It is more than due to gravity

2. The emf induced across the ends of a conductor due to its motion in a magnetic field is called motional emf. It is produced due to the magnetic Lorentz force acting on the free electrons of the conductor. For a circuit shown in figure, if a conductor of length l moves with velocity v in a magnetic field B perpendicular to both its length and the direction of the magnetic field, then all the induced parameters are possible in the circuit




I. Direction of current induced in a wire moving in a magnetic field is found using

(A) Fleming's L Hand rule (B) Fleming's Right hand

(C) Ampere's rule (D) Maxewell's Thumb rule

II.A bicycle generator creates 1.5 V at 15 km/hr. The EMF generated at 10 km/hr is

(A) 1.5 volts (B) 2volts (C) 0.5volts (D) 1 volt

III. A 0.1 m long conductor carrying a current of 50 A is held perpendicular to magnetic field of 1.25 mT. The mechanical power required to move the conductor with a speed of 1 m $s^{-1}$ is

(A) 62.5 mW (B) 625 mW (C) 6.25 mW (D) 12.5 Mw

IV. A conducting rod of length is moving in a transverse magnetic field of strength B with velocity V. The resistance of the rod is R. The current in the rod is.

(A) $BVl$ (B) Zero (C) $\frac{BVl}{R}$ (D) $\frac{B^2V^2L^2}{R}$

3. Faraday's law of electromagnetic induction, also known as Faraday's law is the basic law of electromagnetism which helps us to predict how a magnetic field would interact with an electric circuit to produce an electromotive force (EMF). This phenomenon is known as electromagnetic induction. Faraday's Experiment: Relationship Between Induced EMF and Flux. In the first experiment, he proved that when the strength of the magnetic field is varied, only then-current is induced. An ammeter was connected to a loop of wire; the ammeter deflected when a magnet was moved towards the wire. In the second experiment, he proved that passing a current through an iron rod would make it electromagnetic. He observed that when a relative motion exists between the magnet and the coil, an electromotive force will be induced. When the magnet was rotated about its axis, no electromotive force was observed, but when the magnet was rotated about its own axis then the induced electromotive force was produced. Thus, there was no deflection in the ammeter when the magnet was held stationary. While conducting the third experiment, he recorded that the Galvanometer did not show any deflection and no induced current was produced in the coil when the coil was moved in a stationary magnetic field. The ammeter deflected in the opposite direction when the magnet was moved-away from the loop.

I. According to Faraday's law, EMF stands for

a) Electromagnetic field b) Electromagnetic force

c) Electromagnetic friction d) Electromotive force

II. As per Faraday's laws of electromagnetic induction, an e.m.f. is induced in a conductor whenever it

a) Lies perpendicular to the magnetic flux

b) Lies in a magnetic field

c) Cuts magnetic flux

d) Moves parallel to the direction of the magnetic field

III. For time varying currents, the field or waves will be

a) Electrostatic  b) Magnetostatic  c) Electromagnetic  d) Electrical

IV. Find the displacement current when the flux density is given by $t^3$ at 2 seconds.

a) 3  b) 6  c) 12  d) 27

**OR**

Which of the following statements is true?

a) E is the cross product of v and B  b) B is the cross product of v and E

c) E is the dot product of v and B  d) B is the dot product of v and E

4. The migratory birds' patterns are one of the mysteries in the field of science. For example, every winter birds from Siberia fly unerringly to water spots in the Indian sub- continent. There has been a suggestion that electromagnetic induction may provide a clue to the migratory patterns. The earth's magnetic field has existed throughout evolutionary history. It would be of great benefit to migratory birds to use this field to determine the direction. As far as we know birds contains no ferromagnetic materials. So, electromagnetic induction seems to be the only reasonable mechanism to determine the direction. Consider the optimal case where the magnetic field B, the velocity of the bird v and two relevant points of its anatomy separated by a distance l, all three are mutually perpendicular. From the formula for motional emf i.e., $\mathcal{E}=Blv$ Certain kinds of fishes are able to detect small potential differences. However, in these fishes, special cells have been identified. Thus, the migration patterns of birds continue to remains a mystery.

I. An emf is produced in a coil, which is not connected to an external voltage source. This can be due to

(a) the coil being in a time varying magnetic field

(b) the coil moving in a time varying magnetic field

(c) the coil moving out of constant magnetic field

(d) All of the above

II. A circular coil expands radially in a region of magnetic field and no electromotive force is produced in the coil. This can be because

(a) the magnetic field is in the same plane as the circular coil and it may or may not vary

(b) the magnetic field has a perpendicular (to the plane of the coil) component whose magnitude is decreasing suitably.

(c) there is constant magnetic field in the perpendicular (to the plane of their coil) direction.

(d) Both (a) and (b)

III. A migratory Siberian bird is flying in the sky with a velocity of 10 m/s and the distance between two feathers is 2 cm. The earth's magnetic field B perpendicular to the feather is $4 \times 10^{-5}$ T. Then emf generated between the two feathers is

(a) 4 μV  (b) 6 μV  (c) 8 μV  (d) 10 μV

**OR**

An airplane having a wing span of 35 m flies due north with speed of 90 m/s, given $B = 4 \times 10^{-5}$ T, the potential difference between the tips of the wings will be

(a) 0.126 V  (b) 1.26 V  (c) 12.6 V  (d) 0.013 V

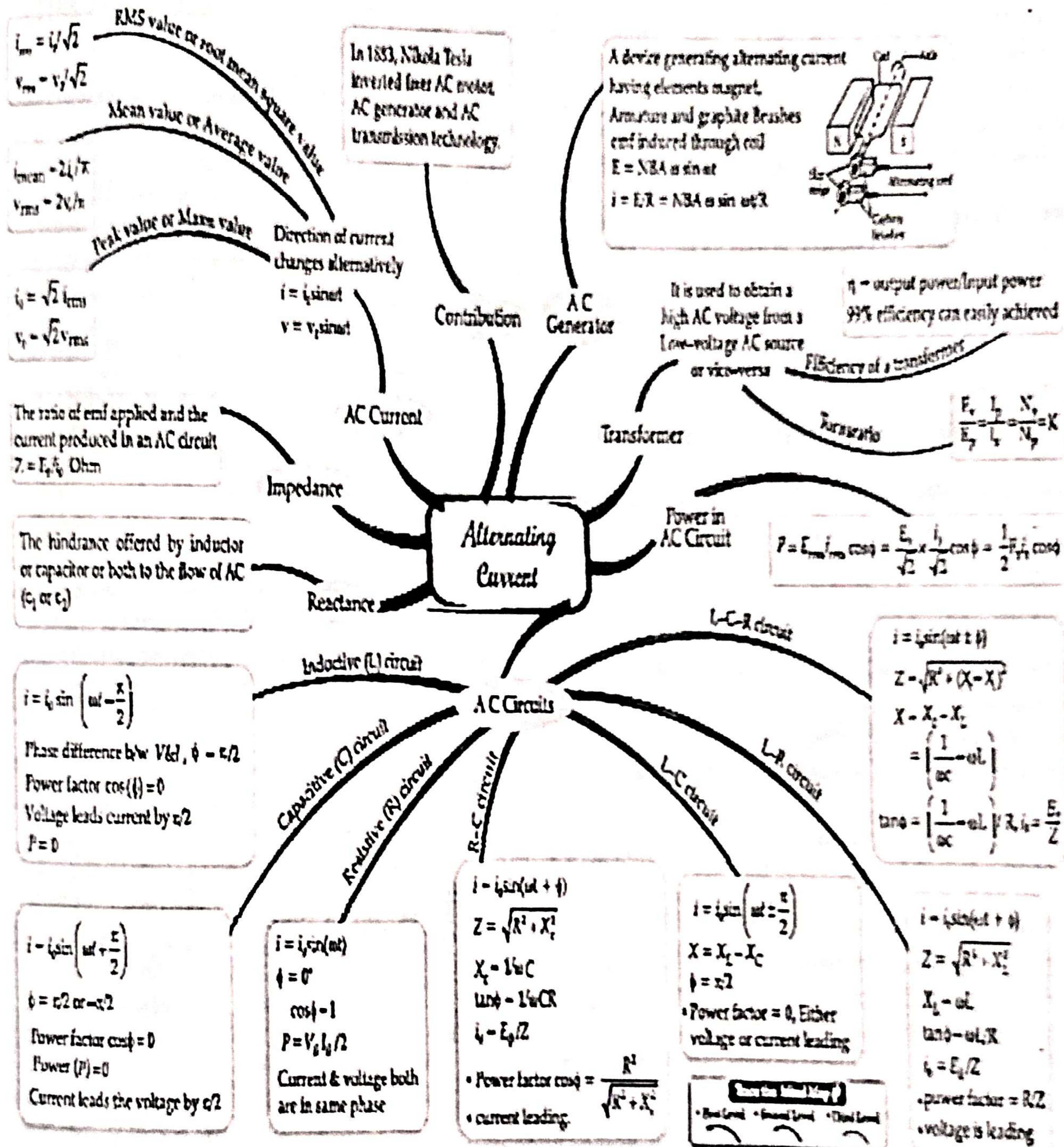
IV. A moving conductor's coil produces an induced emf. This is in accordance with

(a) Lenz's Law  (b) Coulomb's Law  (c) Faraday's Law  (d) Ampere's Law

# CHAPTER–7: ALTERNATING CURRENT

SYLLABUS: Alternating currents, peak and RMS value of alternating current/voltage; reactance and impedance; LCR series circuit (phasors only), resonance, power in AC circuits, power factor, wattless current. AC generator, Transformer.

**Mind map**




**Gist of the chapter**

Alternating current and voltage: A signal changing its values periodically is called an alternating signal. & represented as $I = I_0 \sin \omega t$,

alternating voltage (or emf) is $V = V_0 \sin \omega t$

## MEAN AND RMS VALUE OF ALTERNATING CURRENTS

The mean or average value of alternating current over complete cycle is zero. For half cycle it's value is given by

$(I_{mean})$ half cycle $= \frac{2I_0}{\pi} = 0.636\ I_0$ $\qquad$ $V_{avg}$ for half cycle $= \frac{2V_0}{\pi} = 0.636\ V_0$

An ammeter or a voltmeter read its Root Mean Square value as

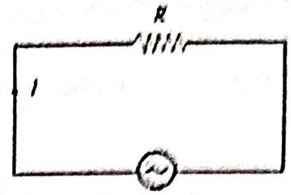
$I_{rms} = \frac{I_0}{\sqrt{2}} = 0.707\ I_0$ $\qquad$ $V_{rms} = \frac{V_0}{\sqrt{2}} = 0.707\ V_0$

V= Vo sin ωt then current is I = Io sin (ωt + Φ) where Φ is the phase difference between voltage and current.

The average power loss over a complete cycle is given by,

$P = E_{rms} I_{rms} \cos \Phi$ where cos Φ is called the power factor

**Purely resistive circuit.**




(1) Current : $i = i_0 \sin \omega t$

(2) Peak current : $i_0 = \frac{V_0}{R}$

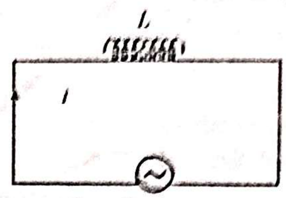
(3) Phase difference between voltage and current : $\phi = 0^o$

(4) Power factor : $\cos \varphi = 1$

(5) Power : $P = V_{rms} I_{rms} = \frac{V_0 I_0}{2}$

(6) Phasor diagram : Both are in same phase

**Purely Inductive Circuit (*L*-Circuit)**




(1) Current : $i = i_0 \sin\left(\omega t - \frac{\pi}{2}\right)$

(2) Peak current :

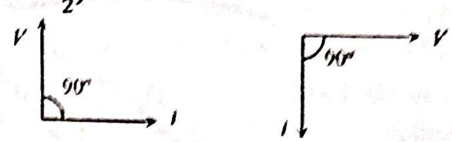
$$i_0 = \frac{V_0}{X_L} = \frac{V_0}{\omega_L} = \frac{V_0}{2\pi\nu L}$$

(3) Phase difference between voltage and current $\varphi = 90^o$ (or $+\frac{\pi}{2}$)

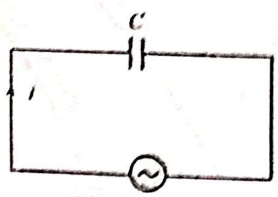
(4) Power factor : $\cos \varphi = 0$

(5) Power dissipated : $P = 0$

(6) Phasor diagram : Voltage leads the current by $\frac{\pi}{2}$




**Purely capacitive circuit**




(1) Current : $i = i_0 \sin\left(\omega t + \frac{\pi}{2}\right)$

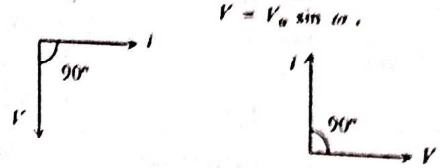
(2) Peak current $i_0 = \frac{V_0}{X_C} = V_0 \omega C = V_0(2\pi\nu C)$

(3) Phase difference between voltage and current :

$\varphi = 90^o$ Power factor : $\cos \varphi = 0$

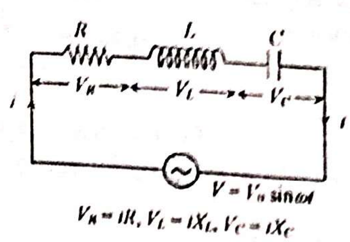
(4) Average Power : $P_{avg} = 0$

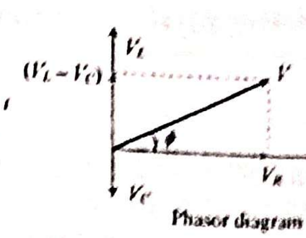
(5) Phasor diagram : Current leads the voltage by $\pi/2$




**Series LCR circuit**

Voltage $V = V_0 \sin\omega t$,



(1) $I = I_0 \sin(\omega t + \Phi)$ , where $I_0 = V_0/Z$, and impedance $Z = \sqrt{R^2 + (X_L - X_C)^2}$

(2) $\tan \Phi = (X_L - X_C)/R$

(3) The average power loss over a complete cycle is given by $P = V_{rms} I_{rms} \cos \Phi$
where, the term $\cos \Phi$ is called the power factor

(4) $\cos \Phi = R/\sqrt{R^2 + (X_L - X_C)^2}$ )

(5) If net reactance is inductive: Circuit behaves as LR circuit

(6) If net reactance is capacitive: Circuit behave as CR circuit

(7) If net reactance is zero: Means $X_L - X_C = 0$ $X_L = X_C$ . This is the condition of electric resonance

(8) At resonance (series resonant circuit)

(i) $X_L = X_C \Rightarrow Z_{min} = R$ i.e. circuit behaves as resistive circuit

(ii) $V_L = V_C \Rightarrow V = V_R$ i.e. whole applied voltage appeared across the resistance

(iii) Phase difference : $\phi = 0^\circ \Rightarrow$ power factor $= \cos \phi = 1$

(iv) Power consumption $P = V_{rms} I_{rms}$

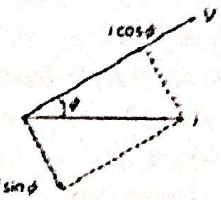
(v) These circuits are used for current amplification and as tuning circuits in wireless telegraphy.

(9) **Resonant frequency** (Natural frequency) : At resonance $X_L = X_C \Rightarrow w_0 L = \frac{1}{C\omega_0}$

$\Rightarrow w_0 L = \sqrt{\frac{1}{LC}}$ OR, $w_0 L = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}$ (Resonant frequency doesn't depend upon the resistance of the circuit)

(10) **Watt less Current**

The component of current which does not contribute to the average power dissipation is called watt less current.




(i) The average of component of watt less component over one cycle is zero

(ii) Amplitude of watt less current = $I_0$ sin and r.m.s. value of watt less current= $I_{rms} \sin\theta = I_0 \sin\theta/\sqrt{2}$

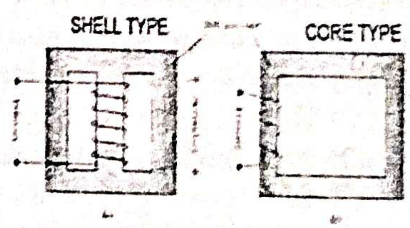
**Transformer:-**

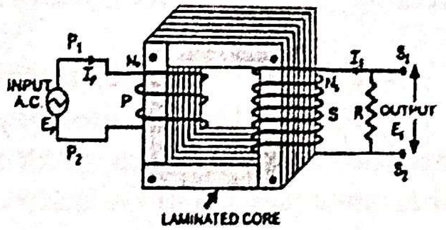
It is a device which Increase or decreases the voltage or current in ac circuits through mutual induction.

It does not work in DC circuit.

Principle: It is based on the principle of mutual induction.

Working: When an alternating voltage is applied to the primary coil , magnetic flux linked with it changes which links to the secondary coil and induces an emf in it due to mutual induction.




$\frac{E_s}{E_p} = \frac{I_p}{I_s} = \frac{N_s}{N_p}$

$\eta = \frac{E_s I_s}{E_p I_p} \times 100\ \%$

Types of **transformer: Step-up** Transformer: Ns> Np. It increases voltage and decreases current. Transformation Ratio must be greater than 1.

**Step-Down** Transformer: – Ns< Np; It increases current and decreases voltage. Transformation Ratio must be less than 1.

From Faraday's laws the emf induced in the primary coil

$\varepsilon_p = -N_P \frac{\Delta\phi}{\Delta t}$ ----(i) also for secondary coil $\varepsilon_s = -N_s \frac{\Delta\phi}{\Delta t}$ ---------(ii)

$\frac{\varepsilon_s}{\varepsilon_p} = \frac{N_S}{N_P}$ = k (transformation ratio) -----------(iii)

For ideal transformer input power = output power $\Rightarrow \varepsilon_P I_P = \varepsilon_s I_s$ ------(iv)

By equation (iii) and (iv)

$$\frac{e_s}{e_p} = \frac{N_S}{N_P} = \frac{I_P}{I_S}$$

Energy losses in a transformer:

(i) Copper loss (ii) Hysteresis loss (iii) Flux leakage (iv) Humming losses (v) Eddy current loss

## MULTIPLE CHOICE QUESTIONS

Q1 A resistance 'R' draws power 'P' when connected to an AC source. If an inductance is now placed in series with the resistance, such that the impedance of the circuit becomes 'Z', the power drawn will be :

(a) $P\sqrt{\frac{R}{Z}}$ (b) $P(\frac{R}{Z})$ (c) P (d) $P(\frac{R}{Z})^2$

Q2 To reduce the resonant frequency in an L-C-R 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

Q3 Average value of A.C voltage for positive half cycle is [If $V_0$ is its peak voltage]

(a) zero (b) $V_0/\sqrt{2}$ (c) $2V_0/\pi$ (d) $V_0$

Q4 An alternating current in a circuit is given by $I = 20\sin(100\pi t + 10.05\pi)$ A . The r.m.s value of current & its frequency respectively are

(A) 10A & 100 Hz (B) 10 A & 50 Hz (C) 10 $\sqrt{2}$A & 50Hz (D) 20 $\sqrt{2}$A & 100Hz

Q5 In an ideal transformer, the no. of turns of primary and secondary coil are 500 and 400 respectively. If 220 V is supplied to the primary coil, then ratio of currents in primary and secondary coils is

(A) 4 : 5 (B) 5 : 4 (C) 5 : 9 (D) 9 : 5

Q6 The power factor of LCR circuit at resonance is

(A) 0.707 (B) 1 (C) Zero (D) 0.5

Q7 At resonance frequency in an A.C circuit containing L, C and R in series

(A) The voltage and current will be in same phase.

(B) The voltage will lead the current

(C) The voltage will lag behind the current.

(D) Phase difference depends on peak voltage of source

Q8 A voltage $v = v_o \sin wt$ applied to a circuit drives a current $i = i_o \sin(wt + \varphi)$ in the circuit. The average power consumed in the circuit over a cycle is

a) Zero b) $i_o v_o \cos\varphi$ c) $i_o v_o /2$ d) $(i_o v_o \cos\varphi)/2$

Q9 In the case of an inductor

(a) voltage lags the current by $\pi/2$ (b) voltage leads the current by $\pi/2$

(c) voltage lags the current by $\pi/3$ (d) voltage lags the current by $\pi/4$

Q10 A power transformer is used to step up an alternating e.m.f. of 220 V to 11 kV to transmit 4.4 kW of power. If the primary coil has 1000 turns, what is the current rating of the secondary? Assume 100% efficiency for the transformer

(a) 4 A (b) 0.4 A (c) 0.04 A (d) 0.2 A

Q11 An inductor, a capacitor and a resistor are connected in series across an ac source of voltage. If the frequency of the source is decreased gradually, the reactance of :

(a) both the inductor and the capacitor decreases.

(b) inductor decreases and the capacitor increases.

(c) both the inductor and the capacitor increases.

(d) inductor increases and the capacitor decreases.

## ANSWERS

1 d 2 b 3 c 4 c 5 a 6 b 7 a 8 d 9 b 10 b 11 b

## ASSERTION AND REASON TYPE QUESTIONS

Q1 **Assertion:** In a pure resistive circuit, voltage and current are in the same phase.
**Reason:** In resistors, energy is alternately stored and released.

Q2. **Assertion:** In an ideal LC circuit, the current oscillates indefinitely.
**Reason:** There is no energy loss in an ideal LC circuit.

Q3. **Assertion:** In an LCR circuit at resonance, the impedance is minimum.
**Reason:** At resonance, the inductive and capacitive reactance cancel each other.

Q4. **Assertion:** The average power consumed in a pure inductive circuit is zero.
**Reason:** In a pure inductive circuit, the current leads the voltage by $90^0$

Q5. **Assertion:** The power factor in a purely capacitive circuit is zero.
**Reason:** In a capacitive circuit, the current leads the voltage by $90^0$

Q6. **Assertion:** In an AC circuit containing only a capacitor, current lags the voltage by $90^0$
**Reason:** Capacitors offer no resistance to A C current.

Q7. **Assertion:** The power consumed in an AC circuit is given by $P=V_{RMS} I_{RMS} \cos\phi$
**Reason:** The product $V_{RMS} I_{RMS}$ gives the apparent power.

Q8. **Assertion:** The voltage across the inductor leads the current by $90^0$.
**Reason:** The induced emf in the inductor opposes the change in current.

Q9. **Assertion:** The quality factor of an LCR series circuit increases with increase in resistance.
**Reason:** Higher resistance causes sharper resonance

Q10. **Assertion:** In a transformer, higher value of alternating voltage can be converted into lower voltage and vice versa.
**Reason:** A transformer works on the principle of electromagnetic induction.

## ANSWERS

1-C 2-A 3-A 4- C 5- A 6-D 7-B 8-B 9-D 10-B

## VERY SHORT ANSWER TYPE QUESTIONS

Q1 Explain why current flows through an ideal capacitor when it is connected to an ac source but not when it is connected to a dc source in a steady state.

Ans: In DC , $X_c$ is infinite.

Q2 Draw the graphs showing variation of inductive reactance and capacitive reactance with frequency of applied ac source.

Ans: General concept and shapes.

Q3 Prove that an ideal capacitor in an ac circuit does not dissipate any average power.

Ans: $P_{avg}$ is propotional to $\cos\varphi$ and $\varphi$ is $90^0$ so average power dissipated is zero.

Q 4 In a series LCR circuit, obtain the condition under which the impedance of circuit is minimum as well as explain its one practical use.

Ans: $X_L= X_c$ , to get maximum current in any circuit.

Q5 Mention any two characteristics properties of the material suitable of making the core of transformer

Ans: Mention any two.

Q6 Define 'quality factor' of resonance in series LCR circuit. What is its SI unit.

Ans: Write definition , no unit and dimensions.

Q7 A bulb B and an inductor are connected in series to the ac mains. The bulb glows with some brightness. How will the glow of the bulb change when a paramagnetic slab is introduced in side the inductor.

Ans: $X_L$ increases so brightness decreases.

Q8 A transformer has 50 tunes in the primary and 100 in the secondary. If primary is connected to 220 V DC supply, what will he the voltage across the secondary?

**Ans:** Transformer does not work on DC.

## SHORT ANSWER TYPE QUESTIONS

Q1A sinusoidal voltage is applied to an electric circuit containing element X in which current leads the voltage by $\frac{\pi}{2}$

(a) Identify the circuit

(b) Write the formula for its reactance.

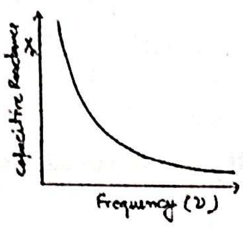
(c) Show graphically the variation of this reactance with frequency of ac voltage.

(d) Explain the behaviour of this element when it is used in (i) an ac circuit, and (ii) a dc circuit

Ans: a) Capacitor

b) $X_c = 1/\omega C$

c)




(d) (i) For ac Xc is finite and therefore allows the ac to pass. For dc Xc is infinite and therefore does not allow the dc to pass.

2. With the help of a suitable phasor diagram, obtain an expression for impedance of a series LCR circuit, connected to a source $v = v_0 \sin\omega t$.

**Ans :** Refer textbook and gist above

3. Find the condition under which a series LCR circuit could draw maximum power from an ac source. Name the factors at which this characteristics frequency depends. Draw the frequency response curve for such a circuit.

**Ans:** refer textbook (Resonance in LCR circuit)

4. A series CR circuit with R=200Ωand C=50/π μF is connected across an ac source of peak voltage V= 100V and frequency ν = 50 Hz. Calculate a) impedance of the circuit(Z) b) phase angle (φ) and c) voltage across the resistor.

**Ans:** $Z^2 = R^2 + (1/2\pi\nu C)^2 = 200\sqrt{2}\Omega$

$\cos\varphi = R/Z = 1/\sqrt{2}$, $\varphi = 45^0$

V across R = RV/Z = $50\sqrt{2}$ V

5. An ac source $v = v_m \sin\omega t$ is connected across an ideal capacitor. Derive the expression for the (i) current flowing in the circuit, and (ii) reactance of the capacitor, Plot a graph of current i versus ωt.

**Ans :** refer textbook

6. A series combination of an inductor L, a capacitor C and a resistor R is connected across an ac source of voltage in a circuit. Obtain an expression for the average power consumed by the circuit. Find power factor for (i) purely inductive circuit, and (ii) purely resistive circuit.

**Ans:** refer textbook

7.A resistor of 30 Ωand a capacitor of 250/π μF are connected in series to a 200 V, 50 Hz ac source. Calculate (i) the current in the circuit, and (ii) voltage drops across the resistor and the capacitor. (iii) Is the algebraic sum of these voltages more than the source voltage ? If yes, solve the paradox.

**Ans:** $X_c = 1/\omega C = 40\Omega$ , $Z^2 = R^2 + X_c^2$ , $Z = 50\ \Omega$ ,

I=200/50 = 4A

$V_c = IX_c = 160V$ , $V_R = IR = 120V$

The algebraic sum of the two voltages $V_R$ and VC is 280V, which is more than the source voltage of 200V. This paradox can be removed by considering impedance triangle because VR and VC are out of phase by 90°, therefore $V^2 = V_R^2 + V_C^2$, V= 200V This is equal to the source voltage

8.A series LCR circuit with $R = 20\Omega$ $L = 2$ H and $C = 50$ F is connected to a 200 volts ac source of variable frequency. What is (i) the amplitude of the current, and (ii) the average power transferred to the circuit in one complete cycle, at resonance?
(iii) Calculate the potential drop across the capacitor.

**Ans:** (i) At resonance Z=R so I=V/R $I_{rms}$=10A and $I_o=I_{rms}\sqrt{2}$=14.14A
Average power transferred to the circuit in one complete cycle at resonance : $P=I^2_{rms}R$=2000W
$\omega_r=\frac{1}{\sqrt{LC}}$= 100 rad/s , $X_c=1/\omega C$ , $V_c=I_{rms}X_c$=2000V

## LONG ANSWER TYPE QUESTIONS

Q1 i) Write the principle of working of an ac generator. Draw its labelled diagram and explain its working.
A resistor of 400Ω , an inductor of $(\frac{5}{\pi})$ H and a capacitor of $(\frac{50}{\pi})$ uF are joined in series across an ac source v=140 sin (100π) t V. Find the rms voltages across these three circuit elements. The algebraic sum of these voltages is more than RMS voltages of source. ExplainAns: from the equation $V_{rms}$=100V so , $I_{rms}=V_{rms}/Z$ , Z=500Ω, so $I_{rms}$=0.2A hence $V_R$=80V, $V_L$=100V and $V_C$=40V
The algebraic sum of voltages is more than the rms voltage of source because voltages across R, L and C are not in phase.

Q2 i) Name the device which can increase alternating current or voltage without increasing electric power. Write the principle of working of this device, Explain why it cannot be used for same purpose when direct current source is used?
ii) An ideal transformer is designed to convert 50 V into 250 V. It draws 200 W power from an ac source whose instantaneous voltage is given by $v_i = 20 \sin (100\pi t)$ V. Find
Rms value of input current
Expression for instantaneous output voltage
Expression for instantaneous output current
Ans: Transformer , EMI , Flux change Zero. $I_{rms}$=7.07A
$P_p=V_pI_p$ , so $Ip=20\sqrt{2}$ A , $Vo=100 \sin(100\pi t)$ V , $I_0= 4\sin(100\pi t)$ A

Q3 Find the condition of resonance in a series LCR circuit connected to a source $V=V_m \sin \omega t$, where ω can be varied. Give the factors on which the resonant frequency of a series LCR circuit depends. Plot a graph showing the variation of electric current with frequency in a series LCR circuit.
Ans: General concept and direct graph

Q4 i)Describe the construction and working of of a transformer and hence obtain the relation for $(\frac{V_s}{V_p})$ in terms of number of turns of primary and secondary.
ii Discuss the main causes of energy loss in a real transformer.
Ans: Direct question , see answer from the gist

Q5 i) you are given three circuit elements X , Y and Z. They are connected one by one across a given ac source. It is found that V and I are in phase of element X. V leads I by $\frac{\pi}{2}$ for element Y where I leads V by $\frac{\pi}{2}$ for element Z. Identify elements X,Y and Z.
ii) Establish the expression for total opposition offered to circuit when elements X , Y and Z are connected in series to an ac source. Show the variation of current in circuit with the frequency of the applied source when only Y & Z are connected in circuit.
iii) In a series LCR circuit obtain, the conditions under which impedance is minimum, justify why circuit becomes purely resistive at resonance?
Ans: i) X-resistor Y-inductor Z-Inductor ii) Deduce expression for Z . Graph for LC combination circuit. iii) Condition of resonance , $X_c=X_L$ so Z=R

# CHAPTER-8: ELECTROMAGNETIC WAVES

***SYLLABUS:*** Basic idea of displacement current, Electromagnetic waves, their characteristics, their transverse nature (qualitative idea only). Electromagnetic spectrum (radio waves, microwaves, infrared, visible, ultraviolet, X-rays, gamma rays) including elementary facts about their uses.

## MIND MAP

**ELECTROMAGNETIC WAVES**

### DISPLACEMENT CURRENT

Produced by changing electric field

$$\varepsilon_0\left(\frac{d\Phi}{dt}\right) = I$$

### Modified Ampere's law:

The source of magnetic field is: conduction current due to flowing charge.

Time rate of change of electric field

$$I = I_c + I_d = I_c + \varepsilon_0\left(\frac{d\Phi_E}{dt}\right)$$

### Maxwell's equations

$$\int \vec{E}.d\vec{A} = \frac{Q}{\varepsilon_0}$$

$$\int \vec{B}.d\vec{A} = 0$$

$$\int \vec{E}.d\vec{l} = -\frac{d\Phi_B}{dt}$$

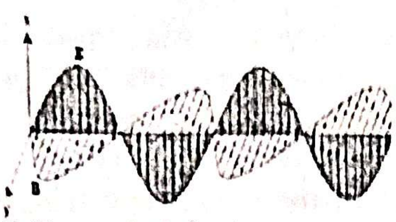
$$\int \vec{B}.d\vec{l} = \mu_0 i_c + \mu_0\varepsilon_0 \frac{d\Phi_E}{dt}$$

### How are EM waves produced?

Produced by accelerating or oscillating charges only.

### Properties of EM waves

1. Does not require a medium for their propagation
2. Does not get deflected by electric or magnetic field
3. E and B has zero phase difference but are mutually perpendicular to each other.
4. Momentum delivered when wave is completely absorbed by the surface : p=U/c ,where U is the total energy transferred to the surface
5. momentum transferred is p=2U/c when wave is completely reflected by the surface.



$E_0/B_0 = c = 3\times10^8$ m/s .

Travels with speed(c) = $\frac{1}{\sqrt{\mu_0\varepsilon_0}}$ in free space.

Both E and B are also perpendicular to the direction of wave propagation

### EM spectrum and its order

The classification of EM waves according to frequency is the electromagnetic spectrum.

EM spectrum in order of increasing frequency and decreasing wavelength.

1. Radio Waves
2. Micro Waves
3. Infrared
4. Visible
5. Ultraviolet
6. X-rays
7. Gamma Rays

# GIST OF THE CHAPTER

**Displacement Current**: -If there exists an electric current as well as changing electric field, results magnetic field & cause displacement current

$$\varepsilon_0\left(\frac{d\varphi_E}{dt}\right) = i$$

So, Ampere-Circuital Law was modified called as Ampere-Maxwell Law.

$$\oint B.dl = \mu_0 i_C + \mu_0\varepsilon_0\left(\frac{d\varphi_E}{dt}\right)$$

**Electromagnetic Waves**: - The electromagnetic waves are those waves in which there are sinusoidal variations of electric and magnetic field vectors to right angles to each other as well as at right angles to the direction of wave propagation. (i.e., electric current and magnetic fields vary with space and time.)

**Transverse nature of electromagnetic waves**: - Electric and magnetic fields oscillate sinusoidally in space and time in an electromagnetic wave. The oscillating electric and magnetic fields, E and B are perpendicular to each other, and to the direction of propagation of the electromagnetic wave.

- Conduction current & displacement current are the same.
- Conduction current arises due to flow of electrons in the conductor.
- Displacement current arises due to electric flux changing with time.

$$I_D = \varepsilon_0\, d\phi_E/dt$$

- **Maxwell's equations**

Gauss's Law in Electrostatics $\oint E.dS = Q/\varepsilon_0$

Gauss's Law in Magnetism $\oint \vec{B}.dS = 0$

• Ampere's – Maxwell law $\int \vec{B}.dl = \mu_0 I + \mu_0\varepsilon_0\, d\phi_E/dt$

- Electromagnetic Wave :- The wave in which there are sinusoidal variation of electric and magnetic fields at right angles to each other as well as right angles to the direction of wave propagation. • Velocity of EM waves in free space: $c = 1/\sqrt{\mu_o\varepsilon_o} = 3\times10^8$ m/s
- The Scientists associated with the study of EM waves are Hertz, Jagdish Chandra Bose & Marconi.
- EM wave is a transverse wave because of which it undergoes polarization effect.
- Electric vectors are only responsible for optical effects of EM waves.
- The amplitude of electric & magnetic fields are related by $E/B = c$
- Oscillating or accelerating charged particle produces EM waves.
- Orderly arrangement of electromagnetic radiation according to its frequency or wavelength i electromagnetic spectrum.
- A self made easy Acronym to memorize the electromagnetic spectrum in decreasing order of its frequenc

**Gandhiji's X-rays Used Vigorously In Medical Research**

Here the first of each word indicates: G- gamma rays , X- rays , Ultraviolet rays ,Visible rays , I- Infrare radiations , M- Microwaves and R- Radio waves

- EM waves also carry energy, momentum.

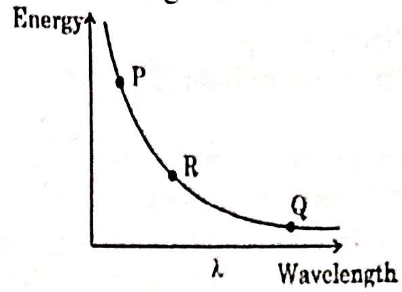
## The Electromagnetic Spectrum

| Type | Frequency Range (Hz) | Wavelength Range | Production | Detection | Uses |
|---|---|---|---|---|---|
| Radio waves | $5\times10^5$ Hz to $10^8$ Hz | >0.1m | Rapid acceleration and de-accelerations of electrons in aerials/antenna. | Receiver's aerials | In radio and television communication system.<br>In radio astronomy. |
| Micro waves | $10^9$ Hz to $10^{12}$ Hz | 0.1m to 1mm | Klystron value or magnetron value. | Point contact diodes. | In radar Systems.<br>In long distance communication systems.<br>In microwave ovens. |
| Infrared | $10^{11}$ Hz to $5\times10^{14}$ Hz | 1mm to 700nm | Vibration of atoms and molecules. | Thermopiles Bolometer, Infrared photographic film. | In remote control of TV or VCR.<br>In Green House.<br>In haze Photography.<br>Treatment of muscular complaints. |
| Visible Light | $4\times10^{14}$ Hz to $7\times10^{14}$ Hz | 7000nm to 400nm | Electron in atoms emit light when they move from one energy level to a lower energy level. | Human eye photocells, photographic film. | It Provides us the information of the world around us.<br>It can cause Chemical Reactions. |
| Ultra-violet | $10^{16}$ Hz to $10^{17}$ | 400nm to 1nm | Inner shell electrons in atoms moving from one energy level to a lower level. | Photocells, photographic film. | In food Preservation.<br>In the study of invisible writings, forged documents and finger prints.<br>In the study of molecular structure. |
| X-rays | $10^{16}$ Hz to $10^{19}$ | 1nm to $10^{-3}$ nm | X-ray tubes or inner shell electrons. | Photographic film, Geiger tubes, Ionization chamber. | In medical diagnosis.<br>In the study of crystals structure.<br>In engineering.<br>In detective departments.<br>In radio therapies. |
| Gamma rays | $10^{18}$ Hz to $10^{22}$ Hz | $<10^{-3}$ nm | Radioactive decay of the nucleus. | Photographic film, Geiger tubes, Ionization Chamber | In radio Therapy.<br>In manufacture of polyethylene from ethylene.<br>To initiate some nuclear reactions.<br>To preserve food stuff. |

## MULTIPLE CHOICE QUESTIONS

Q1 To dissociate an oxygen molecule into two oxygen atoms 5eV of energy is required. 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.

Q2: The given diagram exhibits the relationship between the wavelength of electromagnetic waves and the energy of photon associated with them. The three points P,Q and R marked on the diagram may correspond respectively to:




a)X-rays, microwaves, UV radiation
b) X-rays, UV radiation, microwaves
c)UV radiation, microwaves, X-rays
d) microwaves, UV radiation, X-rays

Q3 Which one of the following correctly represents the change in wave characteristics (all in vacuum) from microwaves to X rays in electromagnetic spectrum?

| | Speed | Wavelength | Frequency |
|---|---|---|---|
| a) | Remains same | Decreases | Remains same |
| b) | Remains same | Decreases | Increases |
| c) | Increases | Increases | Decreases |
| d) | Remains same | Decreases | Remains same |

Q4 X rays are more harmful to human beings than ultraviolet radiations because X-rays:
a) Have frequency lower than that of ultraviolet radiations
b) Have wavelength smaller than that of ultraviolet radiations
c) Move faster than ultraviolet radiations in air
d) Are mechanical waves but ultraviolet radiations are electromagnetic waves

Q5 Displacement current exists only when
a) electric field is changing b) magnetic field is changing
c) electric field is constant d) magnetic field is constant

Q6 A welder wears special glasses to protect his eyes mostly from the harmful effect of
a) high intensity visible light b) infrared radiations
c) ultraviolet radiations d) radio waves

Q7 An electromagnetic wave of frequency 3kHz is passing from vacuum to glass. The ratio of their frequency in vacuum and in glass is:
a) 3:1 b) 1:3 c) 1:4 d) 1:1

Q8 Which of the following electromagnetic waves has the highest momentum for a given energy?
a) Radio waves b) Microwaves c) Infrared rays d) Gamma rays

Q9 The source of an electromagnetic wave is always associated with:
a) A moving electric charge only b) An accelerating electric charge
c) A stationary electric charge d) A constant magnetic field

Q10 The ratio of the amplitudes of electric and magnetic fields in free space is equal to:
(c is the speed of light in vacuum)
a) 1 b) c c) $1/c^2$ d) $1/c$

## SOLUTIONS:

1) C Solution: E=hν , E=5 e V , so $\nu = 1.2\times 10^{15}$ Hz , so UV range
2) B X-rays , Micro and UV as wavelength decreases in this order
3) B In vacuum , speed remains the same and going from Micro to X rays frequency increase and wavelength decreases
4) B wavelength of X is smaller than UV