# PHYSICS
# UNIT - 2

## Chapter 3: MAGNETISM

### Terms and Definitions

**Magnetizing Field (H)**

The magnetic field in which a material is kept is called magnetizing filed. The strength (or intensity) of magnetic field is denoted by H.
Its SI unit is ampere per meter (A/m).

**Magnetic Moment ($p_m$)**

Magnetic dipole moment of a bar magnet is given by $p_m = m.2l$

where m – pole strength, 2l – effective length of bar magnet.

The magnetic dipole moment of a current loop is given by $p_m = I.A$

where I – current in the loop, A – area of the loop.

Its unit is $A.m^2$

**Magnetization (M)**

The magnetic moment per unit volume developed inside a solid is called magnetization or intensity of magnetization.

$M = p_m / V$.

Its unit is A/m.

**Magnetic Susceptibility ($\chi$)**

Since the magnetization is induced by the applied magnetizing field, so M is proportional to H.

$M \alpha H$

$M = \chi H$ where $\chi$ is proportionality constant, known as **magnetic susceptibility.**

$\chi = M / H$

It is defined as magnetization produced in the material per unit applied magnetizing field.
It has no units.
(The magnetic susceptibility of a material is a measure of the ease with which the material can be magnetized)

**Magnetic flux ($\varphi$)**

The total number of magnetic lines of force passing through a given area is called magnetic flux through that area.
Its units are Weber (W)

**Magnetic Induction or magnetic flux density (B)**

The total number of magnetic lines of force per unit area is called magnetic induction or magnetic flux density.

$B = \varphi / A$.

Its SI unit is Weber / $m^2$ or Tesla (T)

Its CGS unit is Gauss (G) $10000 \text{ G} = 1 \text{Wb}/ \text{m}^2 = 1\text{T}$

### Relationship between B and H

When a material is kept in a magnetic field, two types of induction arise: one due to applied magnetizing field H and the other as a consequence of magnetization M of the material itself.

$B = \mu_o (H + M)$

where $\mu_o$ is permeability of free space $= 4 \pi \times 10^{-7}$ (henry / meter) (H/ m)

$$B = \mu_o (H + \chi H)$$
$$= \mu_o (1+ \chi) H$$
$$= \mu_o \mu_r H$$

where $\mu_r = 1+ \chi =$ relative permeability

Thus, $B = \mu H$

where $\mu$ = absolute permeability of the medium

For free space $M = 0$, therefore $B = \mu_o H$

## Origin of Magnetization

Magnetic properties of a solid arise because the atoms of solid act as tiny magnetic dipoles and they possess magnetic dipole moment. The magnetic moment of the atom arises from 3 sources:
(i) orbital motion of electron (ii) electron spin (iii) nuclear spin (too small hence neglected)
The resulting mag.moment of an atom is the sum of the orbital and spin magnetic moments of its electrons.
Different atomic dipoles may align themselves in different directions to give a net zero magnetic moment. When substance is placed in magnetic field, the atomoc dipoles are aligned in the direction of external magnetic field. Thus the material is magnetized.

## Types of Magnetic Materials

On the basis of their behavior in external mag.fields, Faraday classified the various substances into 3 categories:

(i) **Diamagnetic Substances:** These are substances which develop weak magnetization in a direction opposite to the magnetizing field. Such substances are weakly repelled by magnets.
Ex: Bismuth, copper, lead, zinc, tin, gold, silicon, water, sodium chloride.

**(ii)** **Paramagnetic Substances:** Paramagnetic substances are those which develop weak magnetization in the direction of magnetizing field. Such substances are weakly attracted by magnets
Ex: Manganese, Aluminum, Chromium, Platinum, Sodium, Copper chloride, Oxygen

**(iii)** **Ferromagnetic substances:** Ferromagnetic substances are those which develop strong magnetization in the direction of magnetizing field. They are strongly attracted by magnets.
Ex: Iron, Cobalt, Nickel, Gadolinium and alloys like alnico.

## Diamagnetism

In the absence of external magnetic field, the atoms in diamagnetic materials do not possess permanent magnetic moment (Fig a). In such material atoms consists of even number of electrons. The electrons of such atoms are paired with opposite spin (Fig c) so that the magnetic moments cancel each other.
When the material is placed in magnetic field, the orbital motion of electron undergoes changes and a magnetic moment is induced in the atoms in a direction opposite to the applied magnetic field (according to Lenz's Law). (Fig b). The material therefore gets magnetized in a direction opposite to the applied magnetic field. (M is opposite to H)

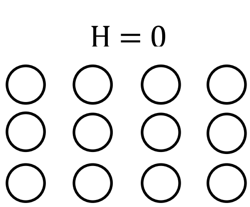


Fig a

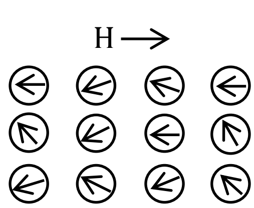


Fig b

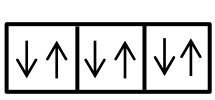


Fig c

## Properties of Diamagnetic Substances

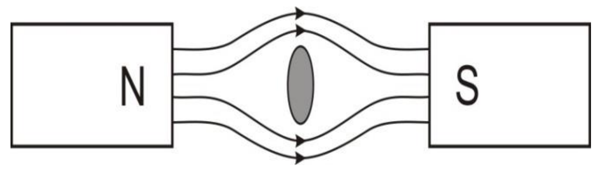



Fig a

- They do not have permanent magnetic dipoles.
- They repel magnetic lines of force.(Fig a)
- Susceptibility ($\chi$) is negative and has a small value.
- Susceptibility is almost independent of temperature.
- Relative permeability ($\mu_r$) is less than 1.
- The magnetization M is a linear function of applied magnetic field H.

## Paramagnetism

In paramagnetic materials the individual atoms have permanent magnetic dipole moment even in the absence of external magnetic field. It is exhibited in materials with atoms having odd number of electron. Since the shells are incomplete (Fig c), the electron spins are unbalanced and the atoms have a net magnetic moment.

In the absence of external magnetic field the individual atomic dipoles are randomly oriented (Fig a). Hence the net magnetization of the material is zero.

When an external magnetic field is applied, the atomic dipoles are reoriented almost in the direction of the applied field and the material attains non-zero magnetization in the direction of applied magnetic field (Fig. b)

If the external field is removed, the atomic dipoles return to their original orientations an magnetization of the material becomes zero.

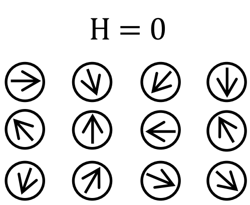



Fig a

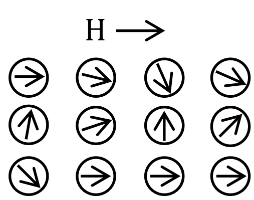



Fig b

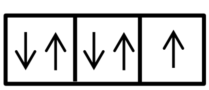


Fig c

## Properties of Paramagnetic Substances

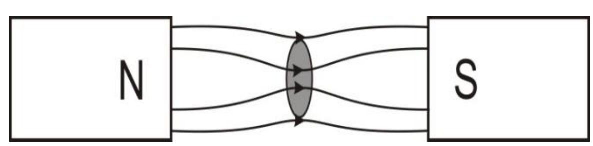


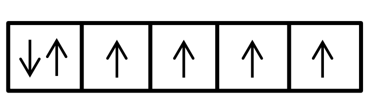

Fig a

- They have permanent magnetic dipoles.
- They weakly attract magnetic lines of force. (Fig a)
- Susceptibility ($\chi$) is positive and has a small value.
- Susceptibility varies inversely with temperature according to the following relation:
  $\chi = \frac{C}{T}$ where 'C' is Curie constant and 'T' is absolute temperature)
- Relative permeability ($\mu_r$) is slightly greater than 1.
- The magnetization M is a linear function of applied magnetic field H.
- Magnetization M is a linear function of mag.field H, when field is not too strong.

## Ferromagnetism

Ferromagnetism is found only in in a few elements which have partially filled 3d shells (in Fe, Co, Ni) or 4f shells (in Gd, Gadolinium).

The individual atoms possess large magnetic dipole moment because of unbalanced electron spins as shown in the figure.



In the absence of external magnetic field, the atomic dipoles are randomly oriented and magnetization of the material is zero. The material is said to be unmagnetized.
When external magnetic field is applied, all the atomic dipoles align themselves in the direction of the applied field giving rise to a large magnetization in the direction of the applied field.
When the external magnetic field is removed, some atomic dipoles continue to remain in the same orientation giving rise to magnetization even in the absence of external field. The material is now said to be magnetized and it behaves like a permanent magnet.

## **Properties of Ferromagnetic Substances**

- They have large permanent magnetic dipoles.
- They strongly attract magnetic lines of force.(Fig a)

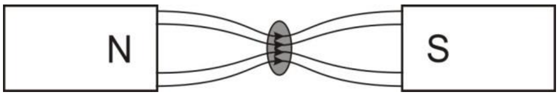
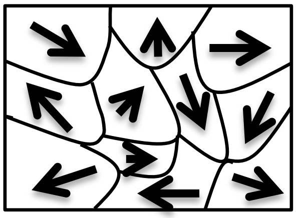



Fig a

- Susceptibility ($\chi$) is positive and has a large value.
- Susceptibility varies inversely with temperature according to the following relation:
  $\chi = \frac{C}{T - T_C}$ $\quad T > T_C$ $\quad$ where $T_C$ = Curie temperature
- Relative permeability ($\mu_r$) is very much greater than 1.
- They exhibit magnetization even in the absence of external magnetic field.
- The magnetization M does not vary linearly with applied magnetic field H.
- They show hysteresis effect.
- Above a certain temperature called Curie temperature, ferromagnetic substances behave like paramagnetic substances.
- They show domain structure.

**Domain theory of Ferromagnetism:**



Domains are small regions in a ferromagnetic material in which all the atomic dipoles are oriented in the same direction as shown in the figure.
The magnetic moments of different domains are in different directions. Hence net magnetization of the material is zero.
When a magnetic field is applied, the material gets magnetized due to the following mechanisms:
i) Domain growth: The domains that are parallel or nearly parallel to the direction of the applied magnetic field grow in size at the cost of other domains.
ii) Domain rotation: The magnetic moment of the domain is rotated in the direction of the applied field.
If external field is removed, the domains maintain their orientations and the material behaves as a permanent magnet.

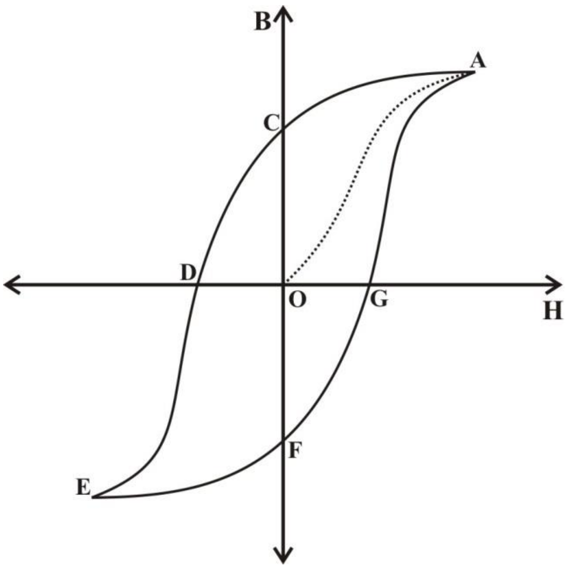
## **Hysteresis**

Hysteresis is defined as the lag in the changes of magnetization behind variations of the applied external magnetic field. It is a property shown by ferromagnetic materials.
We start with an unmagnetized [M=0 or B=0 ] ferromagnetic specimen. When this specimen is subjected to increasing or decreasing magnetic fields, the magnetic induction B varies as a function of H along a loop called **hysteresis loop** as shown in the figure.

The curve begins at the origin O. As H is increased, the induction B begins to increase and then attains a saturation value at point A.

If H is now decreased, B also decreases but following a path AC instead of original path AO. Thus B lags behind H. When H becomes zero, B does not become zero but has a value equal to OC. <u>This magnetic flux density remaining in the material when the applied field is made zero is called **retentivity or remenance** of the material.</u>

If magnetic field H is now increased in the reverse direction, the value of a B decreases along the path CD. It becomes zero when H attains a value equal to OD. <u>This value of applied field required to make the magnetic induction within the material zero is called **coercivity**</u>.




As the applied field H is increased further in the negative direction, saturation is ultimately reached in reverse direction at point E.

On reversing the variation of the field H, a curve similar to ACDE is traced through the points EFGA, yielding negative remanance OF and a positive coercivity OG. The loop ACDEFGA is called <u>**hystereris loop**</u>.

<u>**Hysteresis loss**</u>

When ferromagnetic material is made to pass through a cycle of magnetization, there is energy spent which is given out as heat. This is called <u>**hysteresis loss**</u>.

Hysteresis loss = Energy spent per cycle = $\oint HdB$

= Area of B-H Curve

## <u>Hard and Soft ferromagnetic materials</u>

Based on the area of hysteresis loop, the ferromagnetic materials are classified in two types **(i)** soft magnetic materials **(ii)** Hard magnetic materials

**(i)** <u>**Soft magnetic materials:**</u>

- Soft magnetic materials have low hysteresis loss due to small hysteresis loop area.
- These materials can be easily magnetized and demagnetized.
- The coercivity and retentivity are small.
- They have high values of permeability and susceptibility.
- The resistivity of these materials is very high and hence they have low eddy current loss.

<u>**Examples:**</u>

1. Iron – silicon alloy (silicon steel)
2. Nickel – iron alloy (permalloy)
3. Ni-Fe-Mo-Mn (supermalloy)
4. Ferrites

<u>**Applications:**</u> They are used in preparations of magnetic core materials used in transformers, electric motors magnetic amplifiers & magnetic switching circuits.

**(ii)**<u>**Hard magnetic materials:**</u>

- They are difficult to magnetize and demagnetize.

- Area of hysteresis loop is large and hence hysteresis loss is large.
- The coercivity and retentivity are large.
- They have small values of permeability and susceptibility

**Examples:**

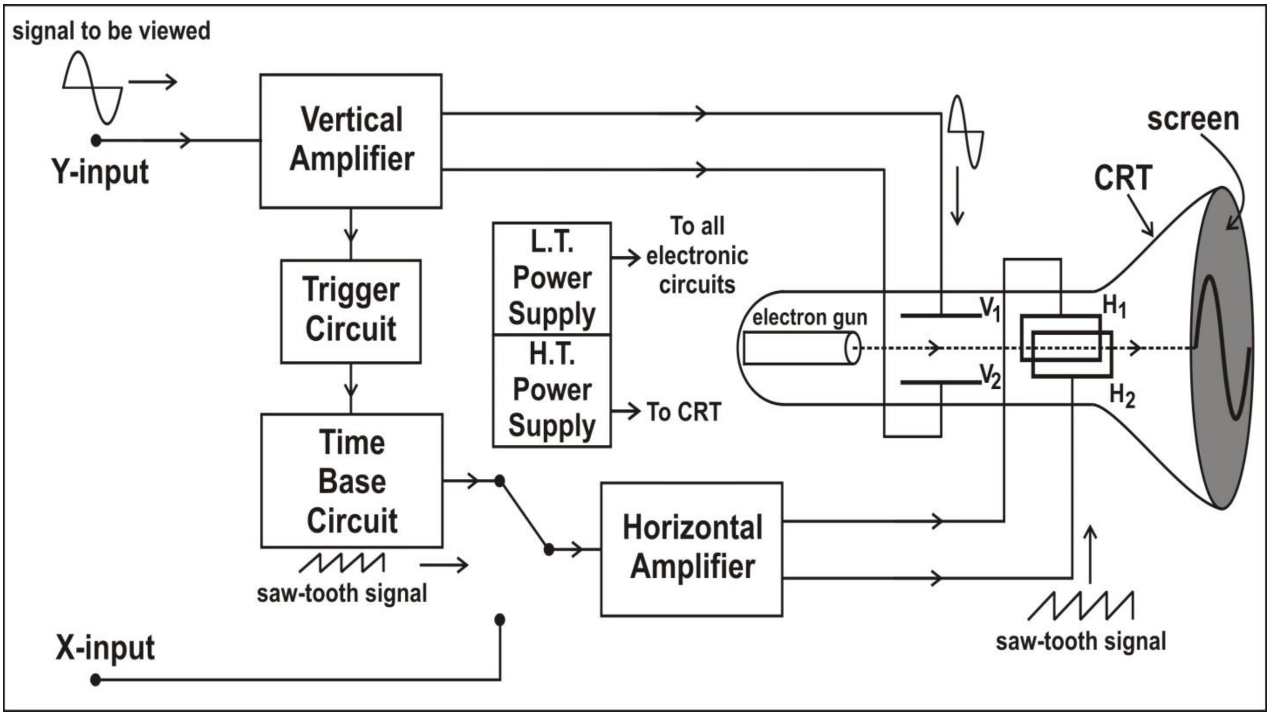
1) Carbon steel
2) Tungsten steel
3) Chromium steel
4) Alnico

**Applications:** They are used in preparation of permanent magnets in loud speakers, microphones, in moving coil meter, compass needle, etc.

## Cathode Ray Oscilloscope (CRO)

It is an electronic measuring instrument used for displaying and measuring electrical signals.

Block diagram of CRO




The block diagram of a CRO is shown in the above figure. The different parts of the CRO are:

i) Cathode Ray Tube (CRT): It is an evacuated glass tube containing the following components. It has an electron gun, which generates, accelerates and focuses an electron beam onto the screen. There are two sets of plates: Horizontal deflection plates $H_1$, $H_2$ (called X-plates), and Vertical deflection plates $V_1$, $V_2$ (called Y-plates). The electron beam passing between these plates can be deflected vertically and horizontally by applying suitable voltage to these plates. The screen has a fluorescent coating, so that wherever the electron beam strikes the screen, a glowing spot is produced.

ii) Vertical Circuits: The electrical signal, which is to be displayed on the screen, is applied at the Y-input of the CRO. The signal is amplified by the vertical amplifier and then given to the Y-plates. This signal causes the electron beam to move vertically up and down on the screen at a fast rate, thus producing a vertical trace on the screen.

iii) Horizontal Circuits: In order to properly display the shape of the applied signal, the electron beam must be made to simultaneously move horizontally from left to right at a uniform rate.

This is achieved by applying a saw-tooth (ramp) signal to the X-plates of the CRO. The saw-tooth signal is generated by the Time Base Circuit (TBC), amplified by the horizontal amplifier and then applied to the X-plates. This causes the electron beam to move on the CRO screen from left to right at a uniform rate, thus producing a horizontal trace on the screen.

Display of signal shape

When the signal to be displayed is applied to the Y-plates (through Y-input) and the saw-tooth signal is simultaneously applied to the X-plates, the electron beam is deflected along the resultant of these two signals and the shape of the applied signal is properly displayed on the screen.

iv) Trigger Circuit: In order to clearly display a stationary signal shape on the screen, the saw-tooth signal should start at the same point of the applied signal in every cycle. This is called as synchronization of the vertical and horizontal signals, and it is achieved by the trigger circuit.

v) Power Supply

(a) High tension (HT) supply: This section produces a very high dc voltage (1000V) which is required by the various components of the CRT.

(b) Low Tension (LT) supply: This section produces low dc voltage (upto 50V) which is required by the different electronic circuits, like TBC, vertical &horizontal amplifier, etc.