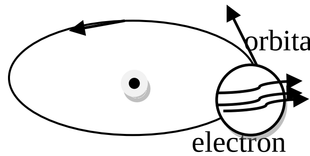
MAGNETIC MATERIALS

Origin of magnetic moment in magnetic materials:

Magnetic materials are the materials which are having **permanent magnetic moment**. The magnetic moment arises in two different ways.



1. **Due to orbital motion of the electron:**

When the electrons are revolving round the nucleus in the circular orbit, it is consider to be equivalent to a closed current loop capable of producing a magnetic field with a north pole and south pole known as magnetic dipole. The orbital magnetic moment is known as

$$M_L = \frac{e\hbar}{2m} L$$

L-orbital angular momentum

2. **Due to spin motion of the electron:**

In addition to the orbital motion of the electrons the electrons are capable of spinning on their own axix.This in tern equivalent to a current loop and produce a magnetic dipole. The magnetic moment is given by

$$M_S = g \frac{e\hbar}{2m} S$$

S-Spin angular momentum

g-lande-g-factor

$\frac{e\hbar}{2m}$ =19.27 x 10^{-24} Amp-m^2

In general in atoms two electrons form pairs with opposite spins, thus if atom is having even number of electrons the spin magnetic moments will cancel with each other and the resultant magnetic moment will become zero. Therefore to get a resultant magnetic moment the atom should posses unpaired electron or odd number of electrons.

Magnetization:

In the magnetic materials like iron, nickel cobalt, though the atoms are having unpaired electrons and magnetic dipoles, the dipoles will be orienting randomly and the resultant dipole moment will be zero. In order to align the dipoles along a particular direction the material should be subjected to an external magnetic field. Then the dipoles will be started orienting along the field direction. This process is Known as magnetization.

Permeability (μ):

The amount of magnetic lines of forces penetrating through a material.

$$\mu = \frac{B}{H}$$

Relative permeability (μ_r):

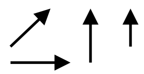
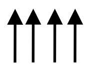
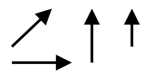
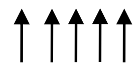
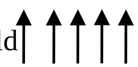
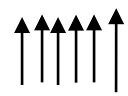
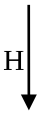
It is the ratio between the permeability of material to the permeability of free space

$$\mu_r = \frac{\mu}{\mu_0}$$

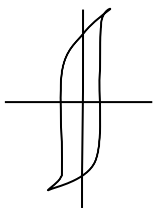
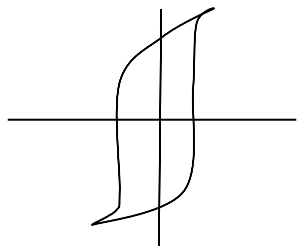
Magnetic susceptibility (χ):

It is the ration of the magnetization produced in the sample to the external field strength.

$$\chi = \frac{M}{H}$$

Magnetic materials	**Paramagnetic**	**Ferromagnetic**	**Diamagnetic**
Magnetic moment	The atoms in the materials posses **unpaired** electrons. Therefore a **resultant spin magnetic moment**	The atoms in the materials posses **unpaired** electrons. Therefore a **resultant spin magnetic moment**	The atoms in the materials posses **paired** electrons. Therefore a **resultant spin magnetic moment is zero** But in the presence of the external magnetic field orbital magnetic moment increases.
magnetization	In the absence of the external magnetic field, the dipoles will be orienting randomly  No field After application of the external field they will be aligned along the field direction  H	In the absence of the external magnetic field, the dipoles will be orienting randomly After application of the external field they will be aligned along the field direction. Though the field is removed the alignment will be persisting   H No field No Field 	In the absence of the external magnetic field, the dipoles will be orienting randomly After application of the external field they will be aligned in the direction opposite to that of the external field direction.  H 
Relative Permeability	$\mu_{r} > 1$ since it allows the magnetic lines of forces to pass through it	$\mu_{r} >> 1$ since it allows more magnetic lines of forces to pass through it	$\mu_{r} < 1$ since the alignment of the dipoles are in the opposite direction
Susceptibility	It is positive but small, it depends upon the temperature $\frac{C}{T} = \chi$, C= Curie const	It is positive but large ,it depends upon the temperature $\frac{C}{T-T_c} = \chi$, T_c= Curie Temp. The temperature at which ferromagnetic material becomes paramagnetic material	$\chi = -1$ independent of temperature
Example	Al,Pt,Mn,$Cucl_2$,etc.,	Fe,Ni,Co,Fe_2O_3,MnO, etc.,	Bi,Zn,H_2O,Au……

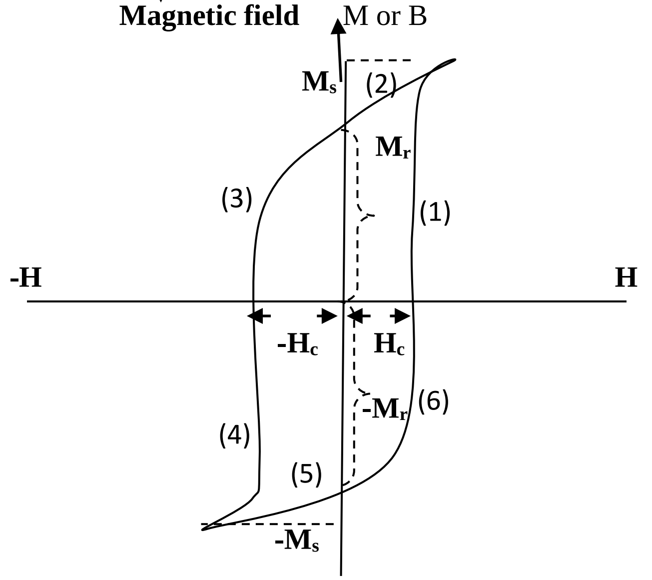
Hard and soft magnetic materials:

Soft magnetic materials	Hard magnetic materials
• These materials will get magnetized and demagnetized easily	• It is hard to magnetize and demagnetize these materials.
• Hysteresis loop area of these materials is usually less 	• The hysteresis loop area of these materials is broad as shown below 
• Since less energy is needed to magnetize and demagnetize these materials, Hysteresis loss here is less	• Since more energy is needed to magnetize and demagnetize these materials, Hysteresis loss in this case is more
• Permeability and susceptibility large, so these materials are magnetized and demagnetized easily	• Permeability and susceptibility are small, so it is hard to magnetize and demagnetize them.
• Coercivity and retentivity small	• Coercivity and retentivity large
• Used in electromagnetic machineries and transformers	• Used in magnets ,magnetic detectors, microphones, magnetic memories etc.,
• Ex: Ferrites, Garnites etc.,	• Ex: Plane carbon steel, cobalt steel, Al-Ni-Co alloy etc.,

Hysteresis loop or B-H curve or M-H curve:

("Lagging of effect behind the cause")

Magnetization **Magnetic field**



The importance of the ferromagnetic materials is the relation between the magnetization and the applied magnetic field known as hysteresis. It is explained in the following steps.

Step-1:

When the applied external field intensity **H=0,** the dipoles will be orienting randomly, and hence magnetization **M=0**, as **"H"** increases **"M"** also be increasing and attains maximum value called **saturation magnetization "M_s".**

Step-2:

If the applied external field reduces , magnetization also decreases, as **H =0 , "M"≠ 0,** some magnetization remains within the material , therefore the magnetization which is persisting even after the removal of the magnetic field is called remenant or **residual magnetization "M_r".**

Step-3:

In order to make the residual magnetization equal to zero, the magnetic field should be applied in the opposite direction, the reverse field which is applied in order to make **M_r=0** is called **coercive field "H_c"**.

Step-4:

If the fielf is increases in the same reverse direction, magnetization also increases and attains maximum value called saturation magnetization **"-M_s".**

Step-5:

If the applied external field reduces , magnetization also decreases, as **H =0 , "M"≠ 0,** some magnetization remains within the material , therefore the magnetization which is persisting even after the removal of the magnetic field is called remenant or **residual magnetization "-M_r".**

Step-6:
In order to make the residual magnetization equal to zero, the magnetic field should be applied in the opposite direction, the reverse field which is applied in order to make $\mathbf{M_r=0}$ is called **coercive field "$-\mathbf{H_c}$".**

Step-7:
If the field is increases in the same reverse direction, magnetization also increases and attains maximum value called saturation magnetization **"$\mathbf{M_s}$".**