MATERIAL SCIENCE

CLASS 2: UNIT II

MAGNETIC MATERIALS

Syllabus

UNIT II - Magnetic Materials

- *Types of magnetic materials – Paramagnetic materials – Langevin theory of paramagnetism – Weiss theory of paramagnetism – Quantum theory of paramagnetism – Ferromagnetic materials – Ferromagnetic domains – Origin of domains – Exchange integral - Weiss theory of ferromagnetism*
- *Antiferromagnetism – Neel temperature – Molecular field theory of antiferromagnetism – Ferrimagnetic materials*.

MAGNET

What is a magnet?

A *magnet* is a tool that will attract metal (iron, nickel, or cobalt).



About magnetism

Magnetism is an invisible force. It pulls metal objects which are magnetic towards a magnet. There are lots of different types of magnets. These include.....



horseshoe magnets,



bar magnets and...

circular magnets.



Properties of magnets

- If a material is **magnetic**, it has the ability to exert forces on magnets or other magnetic materials nearby.

- A **permanent magnet** is a material that keeps its magnetic properties.



Bar magnet | Horseshoe magnet | Magnetic materials

Magnetic and Non-Magnetic

Which materials are magnetic and which are non-magnetic?





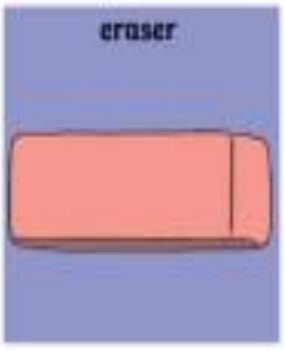












What are the two poles in a magnet called?

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The most common term which are related to magnetic property .

1. Magnetic moment μ_m :



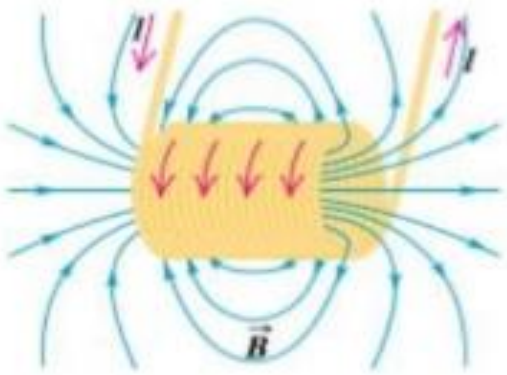
➢A vector quantity associated with the magnetic properties of electric current loops or, more generally, magnets. It is equal to the amount of current flowing through the loop multiplied by the area encompassed by the loop, and its direction is established by the **right hand rule** for rotations $\mu m = IA\ Um$

Um = A unit vector induced from loop as right hand rules

Magnetic field or Intensity

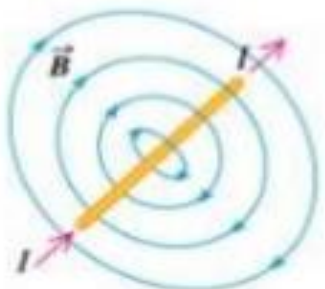
- A field of force associated with changing **electric fields**, as when electric charges are in motion. Magnetic fields exert deflective forces on moving electric charges.
- Most **magnets** have magnetic fields as a result of the spinning motion of the electrons orbiting the atoms of which they are composed; **electromagnets** create such fields from electric current moving through coils

total magnetic field B in the material is given by



$$B = \mu_0(H + M)$$

$$H = B/\mu_0$$



Magnetic susceptibility χ_m

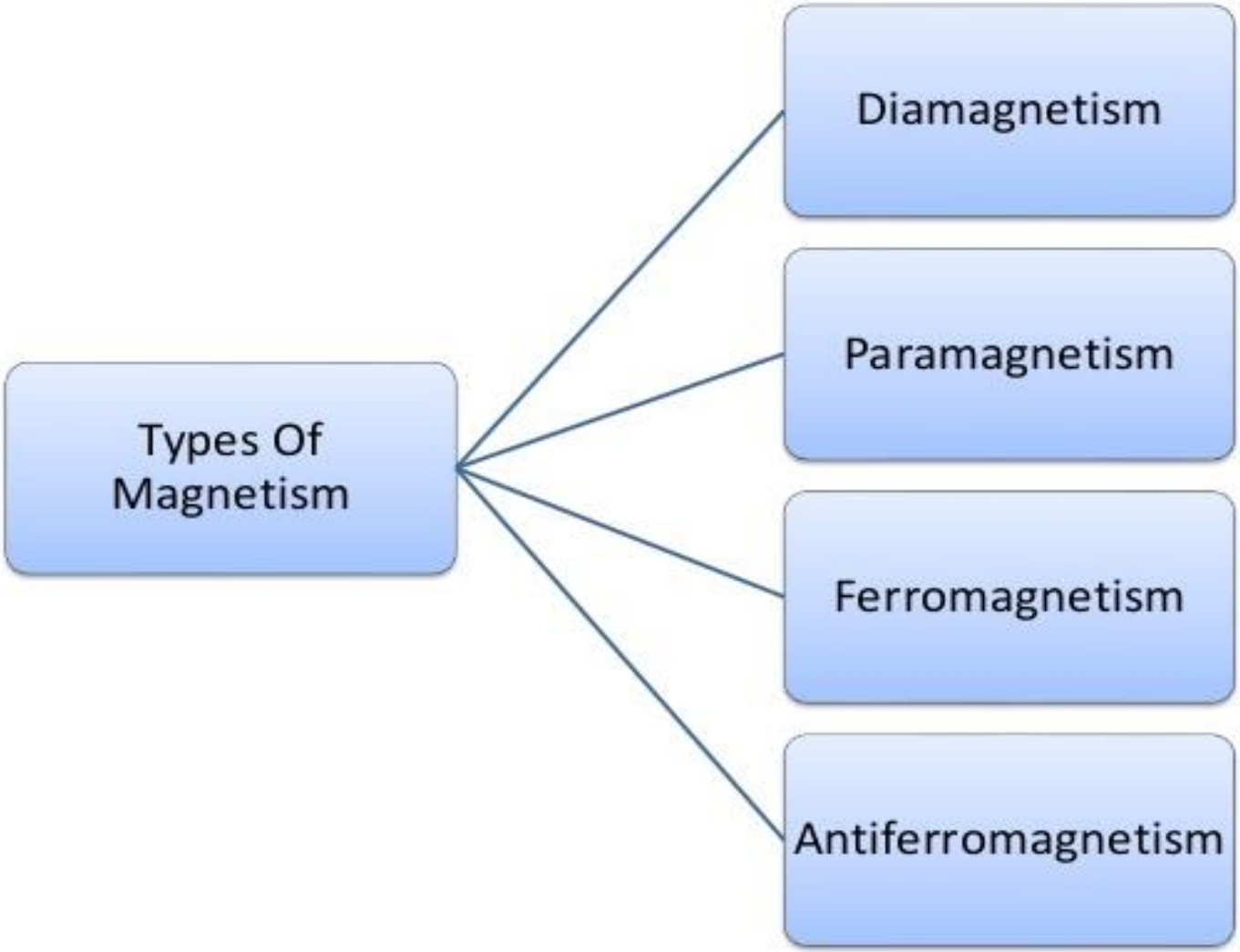
➢In electromagnetism, the **magnetic susceptibility** χ_m is a dimensionless proportionality constant that indicates the degree of magnetization of a material in response to an applied magnetic field.

$$\mathbf{M} = \chi_v \mathbf{H}$$

➢The Relation Between χ_m and μ_r ,

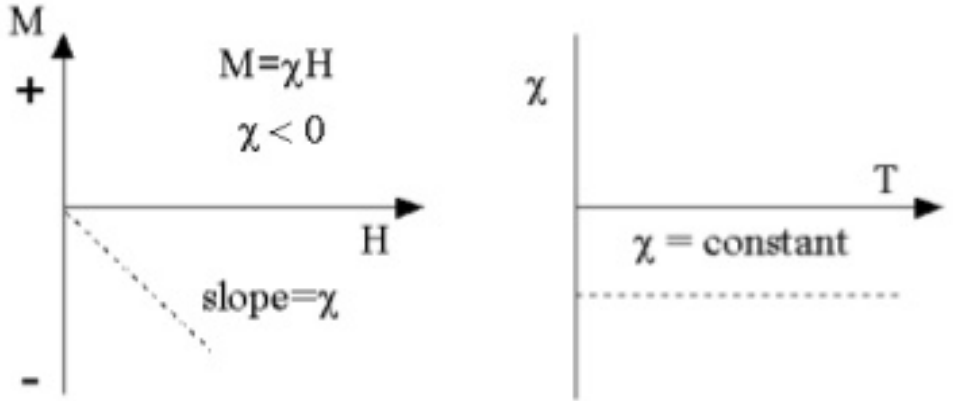
$$\mu = \mu_0(1 + \chi_v)$$

$$\mu_r = 1 + \chi_m$$


Types Of Magnetism
Diamagnetism
Paramagnetism
Ferromagnetism
Antiferromagnetism

Diamagnetism

➢Diamagnetism is a fundamental property of all matter, although it is usually very weak. It is due to the non-cooperative behavior of orbiting electrons when exposed to an applied magnetic field. Diamagnetic substances are composed of atoms which have no net magnetic moments (ie., all the orbital shells are filled and there are no unpaired electrons). However, when exposed to a field, a negative magnetization is produced and thus the susceptibility is negative. If we plot M vs H, we see:



Diamagnetism

Properties of Diamagnetic Materials

- They do not have a permanent dipoles moment.
- Magnetic effects are very weak and hence, often masked by other kind of magnetism.
- The megnetisation becomes zero on removal of the external field.
- The susceptibility of a diamagnetic material is negative.
- The susceptibility is independent of temperature and external field.

Properties of Diamagnetic Materials

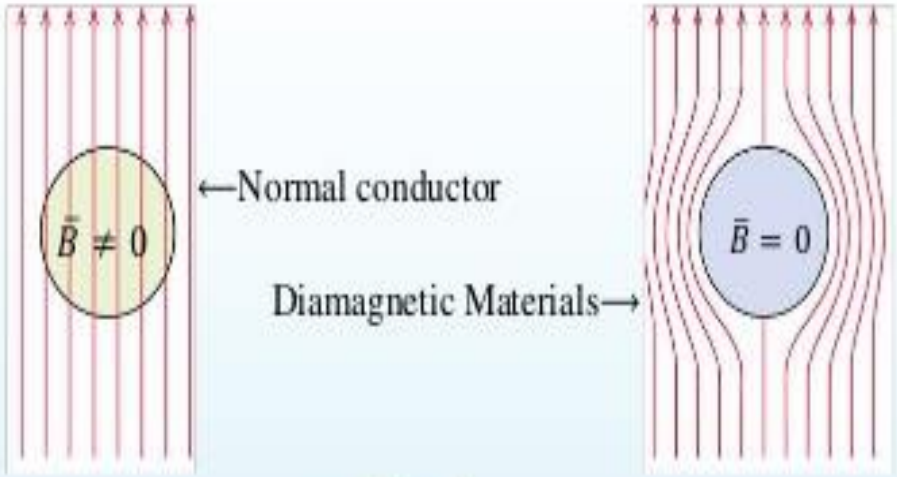


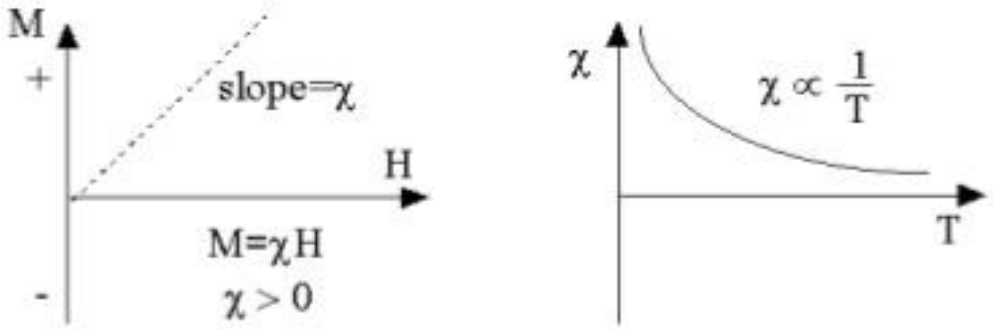
Fig. 2.

- They repel the magnetic lines of force. The existence of this behavior in a diamagnetic material is shown in Fig. 2.

Examples: Copper, Gold, Mercury, Silver and Zinc.

Paramagnetism

➢This class of materials, some of the atoms or ions in the material have a net magnetic moment due to unpaired electrons in partially filled orbitals. One of the most important atoms with unpaired electrons is iron. However, the individual magnetic moments do not interact magnetically, and like diamagnetism, the magnetization is zero when the field is removed. In the presence of a field, there is now a partial alignment of the atomic magnetic moments in the direction of the field, resulting in a net positive magnetization and positive susceptibility.



Paramagnetism

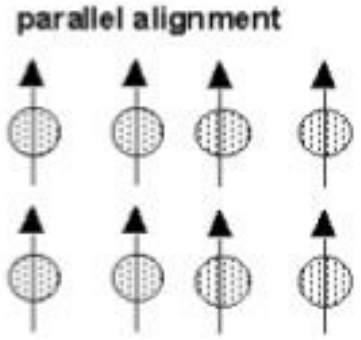
Properties of Paramagnetic Materials

- Paramagnetic material possess a permanent dipole moment.
- The attract the magnetic lines of force.
- The susceptibility is positive and depends on temperature:
  $\chi = \frac{C}{T}$, Equation is known as the Curie law of paramagnetism.
- Paramagnetic susceptibility is inversely proportional to temperature.

Examples: Aluminum, chromium, sodium, titanium, zirconium, etc.

Ferromagnetism

➢When you think of magnetic materials, you probably think of iron, nickel or magnetite. Unlike paramagnetic materials, the atomic moments in these materials exhibit very strong interactions. These interactions are produced by electronic exchange forces and result in a parallel or antiparallel alignment of atomic moments. Exchange forces are very large, equivalent to a field on the order of 1000 Tesla, or approximately a 100 million times the strength of the earth's field.



Ferromagnetism

Properties of Ferromagnetic Materials

- The magnetic dipoles are arranged parallel to each other. The spin arrangement is shown in Fig. 5.

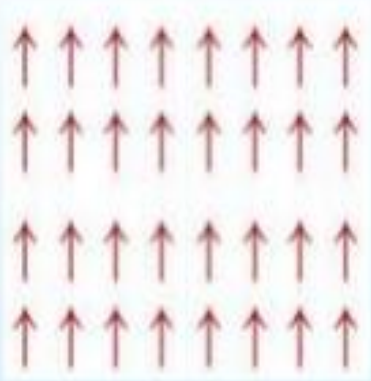


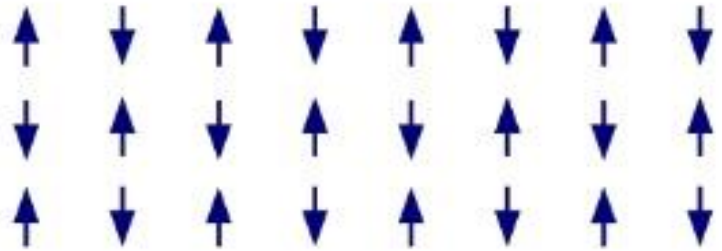
Fig. 5. Ferromagnetic materials-spin arrangement

Properties of Ferromagnetic Materials

- They have characteristic temperature, namely, ferromagnetic Curie temperature(θ_f). Materials below θ_f behave as ferromagnetic materials and obey hysteretic curve. A material behave as a paramagnetic when it is above θ_f.
- They possess permanent dipole moment.
- The susceptibility of a ferromagnetic material is
  $\chi = \frac{C}{T-\theta}$, shown as Curie-Weiss law.

Examples: Iron, Cobalt, Nickel.

Antiferromagnetism



➢the magnetic moments of atoms or molecules, usually related to the spins of electrons, align in a regular pattern with neighboring spins (on different sublattices) pointing in opposite directions. This is, like ferromagnetism and ferrimagnetism, a manifestation of ordered magnetism. Generally, antiferromagnetic order may exist at sufficiently low temperatures, vanishing at and above a certain temperature, the Néel temperature (named after Louis Néel, who had first identified this type of magnetic ordering).Above the Néel temperature, the material is typically paramagnetic.

Properties of Antiferromagnetic Materials

- The dipoles are aligned anti-parallel as shown in Fig. 7.
- When the temperature increases, susceptibility increase and reaches a maximum at a temperature known as Neel temperature beyond which it decreases.
- The value of susceptibility is positive and is very small when T is greater then the Neel temperature, T_N.

$$\chi = \frac{C}{T+\theta}$$

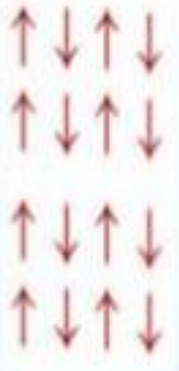


Fig. 7.

Examples: ferrous oxide, manganese oxide, manganese sulphite, chromium oxide, etc.

Ferrimagnetic Materials

- A special case of antiferromagnetic materials.
- The magnetic dipoles are antiparallel.
- However, their magnitudes are not equal.
- Hence, they produce a large magnetisation even for a small applied external field.

Properties of Ferrimagnetic Materials

- The dipoles are antiparallel as shown in Fig. 8. However, the dipoles are not equal in magnitude.

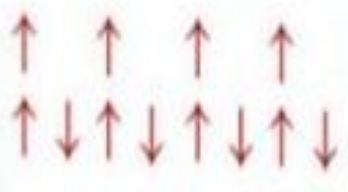


Fig. 8.

- Net magnetization is larger even for a small external field.
- The susceptibility is positive and vary large when the temperature is higher than T_N,

$$\chi = \frac{C}{T \pm \theta}$$

- They behave as paramagnetic and ferromagnetic materials respectively above and below Curie temperature.

BASIC DEFINITIONS

Magnetic Field or Magnetic Induction (B)

- *Magnet or Electromagnet produces a Magnetic field. The field where the magnet attracts or repels magnetic materials such as iron, steel, etc. it may be defined as a force on a moving charge,*
- ***F = q x v x B***

Where

- *F = Force,*
- *V = Speed of Particles,*
- *B = magnitude of the field.*

BASIC DEFINITIONS

Magnetic Field Strength (H)

- *The amount of magnetizing force (how much force it has to magnetize, magnetic materials such as iron, steel, etc) is called Magnetic field strength which is denoted by (H). It is inversely proportional to the length of wire and directly proportional to the current passing through it. The SI unit of Magnetic Field Strength is Ampere/meter (A/m) and it is a vector quantity and the SI formula for Magnetic Field strength is*
- ***H = NI / 1c***

  Where 1c = magnetic path in meter.

BASIC DEFINITIONS

Magnetic Flux (Φ)

- *In simple words, Magnetic field x area perpendicular to the magnetic field (B) is called Magnetic Flux which is denoted by Φ or $Φ_m$ or $Φ_B$. Or it is the amount of magnetic field or magnetic lines of force passing through a surface like conducting area, space, air, etc. The SI Unit of magnetic flux is Wb (Weber). The Formula for finding magnetic flux in the SI system is;*
- ***Φ = BAc***

Where

- *Ac = area in m^2*
- *And CGS unit and formula for Magnetic Flux is Maxwell (M) and Φ = BAc Ac = area in cm^2 respectively.*

BASIC DEFINITIONS

- ***Magnetization (M)***

The state of a material being magnetized or the process in which magnetic materials are magnetized. It is the density of permanent magnet or electromagnet dipole moments in magnetic materials. Or the magnetic moment (m) per unit volume (v) by a magnetic field is called Magnetization. The SI Unit of Magnetization is Ampere/meter (A/m) and it is also a vector quantity. The SI formula for Magnetization is

- ***M = m/V***

Where,

- *m = Total magnetic moment and V= volume in m^3.*
- *The CGS unit and formula of Magnetization is Emu/cm^3 and M = m/V respectively, where, m = Total magnetic moment, V = volume in cm^3 and EMU = Electromagnetic units. It may also be defined in term of M = (N/V) x m → M = nm ……. (N/V) = n. Where, "m" is the magnetic moment and "n" is the number density of magnetic moments.*

Quantity	Symbol	SI Unit	SI Equation	CGS Unit	CGS Equation	Conversion Factor
Magnetic Field	B	Tesla (T)	$B = \mu_o(H+M)$	Gauss G	$B = H+4\pi M$	$1T = 10^4G$
Magnetic Field Strength	H	Ampere/meter (A/m)	$H = NI/1c$ 1c = magnetic path in m	Oersted Oe	$H = 0.4\pi NI/1c$ 1c = magnetic path in cm	$1A/m = 4\pi x10^{-3}$ Oe
Magnetic Flux	Φ	Weber (Wb)	$\Phi = BAc$ Ac = area in m^2	Maxwell M	$\Phi = BAc$ Ac = area in cm^2	$1Wb = 10^8M$
Magnetization	M	Ampere/meter (A/m)	$M = m/V$ M = Total magnetic moment, V = volume in m^3	Emu/cm^3 Where EMU = Electromagnetic units	$M = m/V$ M =Total magnetic moment, V = volume in cm^3	$1A/m = 10^{-3}$ emu/cm^3
Magnetic Permeability of vacuum	μ_o	Newton/$Ampere^2$	$\mu_o = 4\pi x10^{-7} \approx 1.2566370614$ $H{\cdot}m^{-1}$	1	-	$4\pi x10^{-7}$
Inductance	L	Henry	$L = \mu_o \mu N^2 Ac/1c$ N = Turns Ac = Area in m^2 1c = magnetic path in m	Henry	$L = 0.4\pi \mu N^2 Ac/1c \times 10^{-8}$ N =Turns Ac = Area in cm^2 1c = magnetic path in cm	1
Voltage or EMF	V	Volt	$V = -N d\Phi/dt$ N =Turns	Volt	$V = -10^{-8} x N x d\Phi/dt$ N=Turns	1

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