UNIT 3 MAGNETISM AND MAGNETIC EFFECTS OF ELECTRIC CURRENT

Warm greetings:

Dear students

Welcome all. In this section of physics class you get to learn about classification of magnetic materials. In this class we are going to discuss the following topics.

- Diamagnetic materials
- Paramagnetic materials and
- Ferromagnetic materials

Classification of magnetic materials:

The magnetic materials are generally classified into three types based on their behaviour in a magnetising field. They are

- diamagnetic,
- paramagnetic and
- ferromagnetic materials.

(a) Diamagnetic materials:

- The orbital motion of electrons around the nucleus produces a magnetic field perpendicular to the plane of the orbit.
- Thus each electron orbit has finite orbital magnetic dipole moment. Since the orbital planes of the other electrons are oriented in random manner, the vector sum of magnetic moments is zero and there is no resultant magnetic moment for each atom.
- In the presence of a uniform external magnetic field, some electrons are speeded up and some are slowed down.
- The electrons whose moments were anti-parallel are speeded up according to Lenz's law and this produces an induced magnetic moment in a direction opposite to the field.
- The induced moment disappears as soon as the external field is removed.
- When placed in a non-uniform magnetic field, the interaction between induced magnetic moment and the external field creates a force which tends to move the material from stronger part to weaker part of the external field.

- It means that diamagnetic material is repelled by the field. This action is called diamagnetic action and such materials are known as diamagnetic materials.
- Examples: Bismuth, Copper and Water etc.

The properties of diamagnetic materials are

i) Magnetic susceptibility is negative.

ii) Relative permeability is slightly less than unity.

iii) The magnetic field lines are repelled or expelled by diamagnetic materials when placed in a magnetic field.

iv) Susceptibility is nearly temperature independent.

(b) Paramagnetic materials:

- In some magnetic materials, each atom or molecule has net magnetic dipole moment which is the vector sum of orbital and spin magnetic moments of electrons.
- Due to the random orientation of these magnetic moments, the net magnetic moment of the materials is zero.
- In the presence of an external magnetic field, the torque acting on the atomic dipoles will align them in the field direction.
- As a result, there is net magnetic dipole moment induced in the direction of the applied field. The induced dipole moment is present as long as the external field exists.
- When placed in a non-uniform magnetic field, the paramagnetic materials will have a tendency to move from weaker to stronger part of the field.
- Materials which exhibit weak magnetism in the direction of the applied field are known as paramagnetic materials.
- Examples: Aluminium, Platinum, Chromium and Oxygen etc.

The properties of paramagnetic materials are:

i) Magnetic susceptibility is positive and small.

ii) Relative permeability is greater than unity.

iii) The magnetic field lines are attracted into the paramagnetic materials when placed in a magnetic field.

iv) Susceptibility is inversely proportional to temperature.

Curie's law

When temperature is increased, thermal vibration will upset the alignment of magnetic dipole moments. Therefore, the magnetic susceptibility decreases with increase in temperature. In many cases, the susceptibility of the materials is

$$\chi_m \propto \frac{1}{T} \text{ or } \chi_m = \frac{C}{T}$$

This relation is called Curie's law. Here C is called Curie constant and temperature *T* is in kelvin. The graph drawn between magnetic susceptibility and temperature is shown in Figure 3.19, which is a rectangular hyperbola.

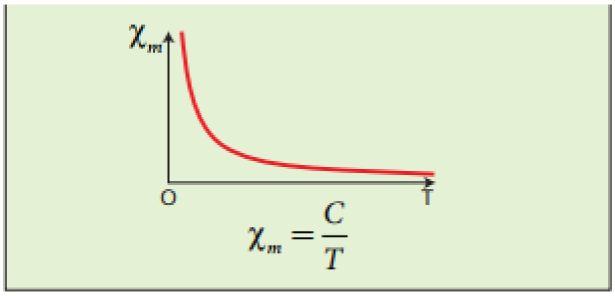


Figure 3.19 Curie's law – susceptibility vs temperature

(c) Ferromagnetic materials:

- An atom or a molecule in a ferromagnetic material possesses net magnetic dipole moment as in a paramagnetic material.
- A ferromagnetic material is made up of smaller regions, called ferromagnetic domains (Figure 3.20).
- Within each domain, the magnetic moments are spontaneously aligned in a direction.
- This alignment is caused by strong interaction arising from electron spin which depends on the inter-atomic distance. Each domain has net magnetisation in a direction.
- However the direction of magnetisation varies from domain to domain and thus net magnetisation of the specimen is zero.

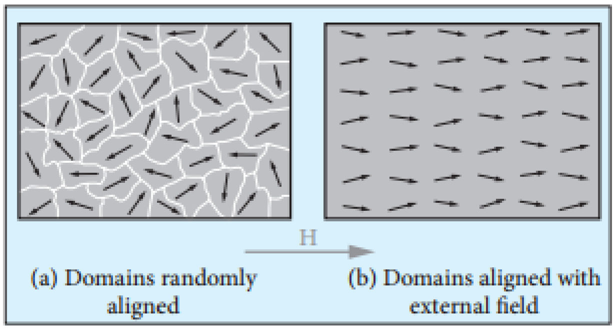


Figure 3.20 Magnetic domains – ferromagnetic materials

In the presence of external magnetic field, two processes take place

(1) The domains having magnetic moments parallel to the field grow bigger in size

(2) The other domains (not parallel to field) are rotated so that they are aligned with the field.

As a result of these mechanisms, there is a strong net magnetisation of the material in the direction of the applied field (Figure 3.21).

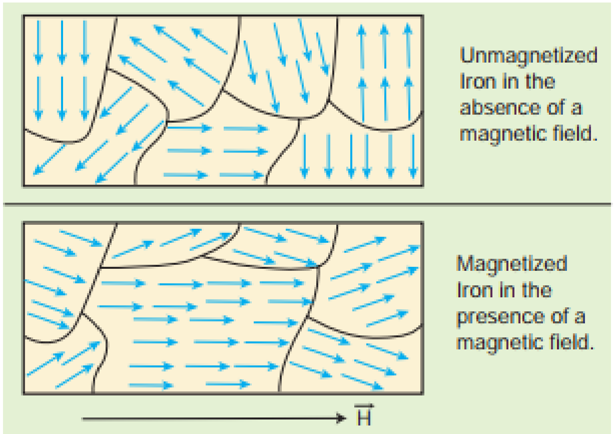


Figure 3.21 Processes of domain magnetization

- When placed in a non-uniform magnetic field, the ferromagnetic materials will have a strong tendency to move from weaker to stronger part of the field.
- Materials which exhibit strong magnetism in the direction of applied field are called ferromagnetic materials.
- Examples: Iron, Nickel and Cobalt.

The properties of ferromagnetic materials are:

i) Magnetic susceptibility is positive and large.

ii) Relative permeability is large.

iii) The magnetic field lines are strongly attracted into the ferromagnetic materials when placed in a magnetic field.

iv) Susceptibility is inversely proportional to temperature.

Curie-Weiss law:

As temperature increases, the ferromagnetism decreases due to the increased thermal agitation of the atomic dipoles. At a particular temperature, ferromagnetic material becomes paramagnetic. This temperature is known as Curie temperature T_C. The susceptibility of the material above the Curie temperature is given by

$$\chi_m = \frac{C}{T - T_C}$$

This relation is called Curie-Weiss law. The constant C is called Curie constant and temperature T is in kelvin scale. A plot of magnetic susceptibility with temperature is as shown in Figure 3.22.

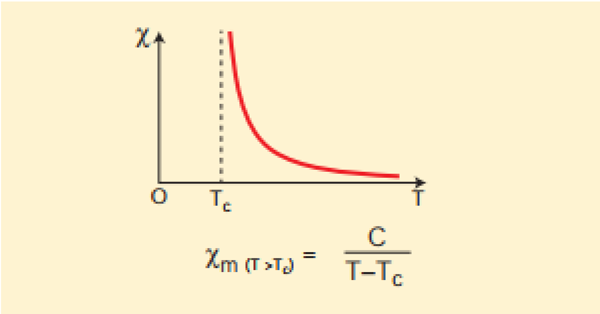
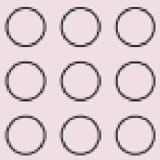
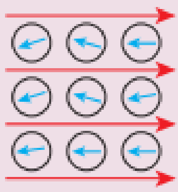
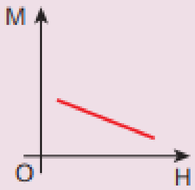
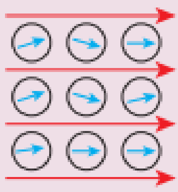
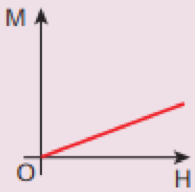
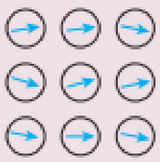
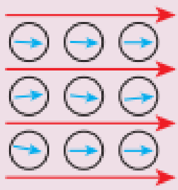
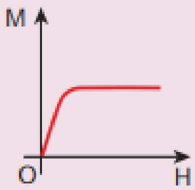
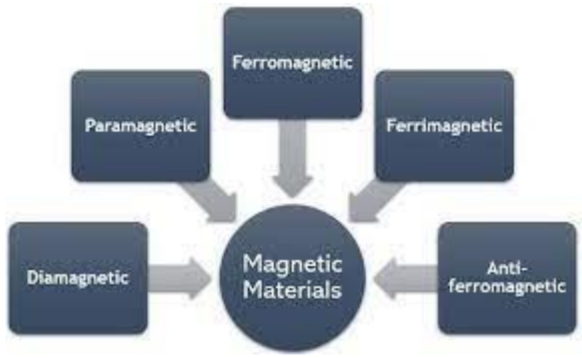


Figure 3.22 Curie-Weiss law – susceptibility vs temperature

Comparison of Types of Magnetism (NOT FOR EXAMINATION)					
Type of magnetism	Magnetising field is absent (H = 0)	Magnetising field is present ($H \neq 0$)	Magnetisation of the material	Susceptibility	Relative permeability
Diamagnetism	 (Zero magnetic moment)	 (Aligned opposite to the field)		Negative	Less than unity
Paramagnetism	 (Net magnetic moment but random alignment)	 (Aligned with the field)		Positive and small	Greater than unity
Ferromagnetism	 (Net magnetic moment in a domain but they are randomly aligned)	 (Aligned with the field)		Positive and large	Very large

Conclusion:



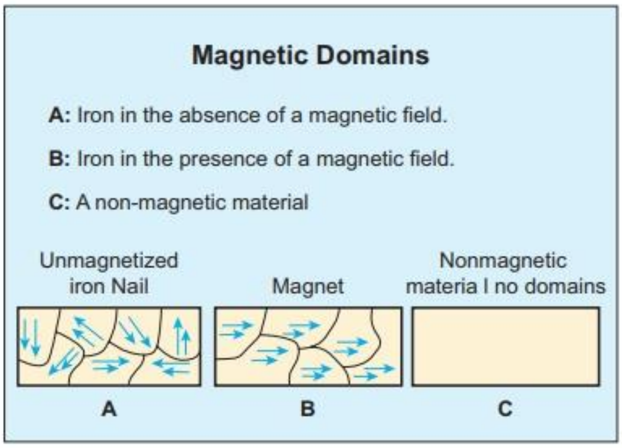


Figure 3.28 Processes of domain magnetization

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