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Unit-4 Magnetism

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CH. 4 MAGNETISM

MAGNET IZATION AND MAGNETIC SUSCEPT IBILITY

The relationship between the magnetization induced in a material M and the external field H is defined as $\mathbf{M} = \chi\mathbf{H}$. The parameter χ is known as the magnetic susceptibility of the material.

Because M and H have the same units, χ is dimensionless.

χ is positive for paramagnetic substances.

χ is negative for diamagnetic substances.

RELATIONSHIP OF B AND H

The relationship between B and H is given by $\mathbf{B} = \mu(\mathbf{H} + \mathbf{M})$,

where μ is a physical constant known as the permeability. In a vacuum, this is the permeability of free space, μo.

* LANGEVIN THEORY OF DIAMAGNETISM

It was first worked out by Paul Langevin in 1905. He gave theory to explain experimental results of Curie.

Diamagnetism is associated with the tendancy of electrical charges partially to shield the interior of a body from an applied magnetic field.

Consider electron revolving around the nucleus in a circular orbit of radius r and velocity v.

$$\therefore \text{Current, } I = e/T$$

$$T = 2\pi r/v$$

$$\therefore I = ev/2\pi r$$

magnitude of mag. dipole moment due to this current,

$$m = I \times \text{area of loop}$$

$$= I \cdot \pi r^2$$

$$m = \frac{ev}{2\pi r} \cdot \pi r^2$$

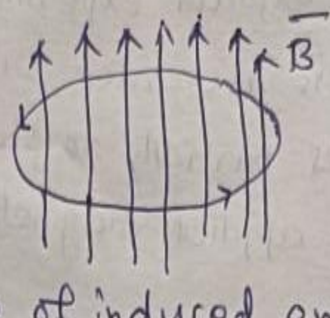
$$\therefore m = evr/2$$

$$\therefore m = \frac{e}{2m} mvr \qquad (m \rightarrow \text{mass of electron})$$

$$\therefore \bar{m} = \frac{e}{2m} \bar{l} \qquad (l \rightarrow \text{orbital angular momentum})$$

Due to negative charge on electron, the direction of magnetic moment is opposite to that of orbital angular momentum.

The flux through the closed loop $\phi = \pi r^2 B$ if we apply external magnetic field with magnitude B.



magnitude of induced emf in the circuit is ϵ.

$$\epsilon = -\frac{d\phi}{dt} = -\pi r^2 \frac{dB}{dt}$$

$$\epsilon = 2\pi r E$$

$$\therefore 2\pi r E = -\pi r^2 \frac{dB}{dt}$$

$$\bar{E} = -\frac{r}{2}\frac{d\bar{B}}{dt}$$

$$e\bar{E} = m\frac{d\bar{v}}{dt}$$

$$\frac{d\bar{v}}{dt} = \frac{e\bar{E}}{m} = -\frac{er}{2m}\frac{d\bar{B}}{dt}$$

$$\therefore \Delta\bar{v} = -\frac{er}{2m}\Delta\bar{B}$$

$$\Delta\bar{m} = \frac{er}{2}\Delta\bar{v}$$

$$\Delta M = -\frac{e^2 r^2}{4m}\Delta\bar{B}$$

But $\bar{B} = \mu_0\bar{H}$

$$\therefore \Delta\bar{m} = -\frac{\mu_0 e^2 r^2}{4m}\Delta\bar{H}$$

$$\Delta\bar{m} = \chi\Delta\bar{H}$$

For N atoms per unit volume,

$$\chi = -\frac{N \mu_0 e^2}{4m} \sum r^2$$

$$\sum r^2 = Z \langle r^2 \rangle \qquad (Z \rightarrow \text{atomic no.})$$

$$\langle r^2 \rangle = \langle x^2 \rangle + \langle y^2 \rangle$$

$$\langle R^2 \rangle = \langle x^2 \rangle + \langle y^2 \rangle + \langle z^2 \rangle$$

$$\therefore \langle r^2 \rangle = \frac{2}{3} \langle R^3 \rangle \qquad \left(\text{As } \langle x^2 \rangle = \langle y^2 \rangle = \langle z^2 \rangle \right.$$

$$\therefore \chi = -\frac{\mu_0 N Z e^2}{6m} \langle R^2 \rangle$$

It is Langevin's formula for susceptibility of the diamagnetic material.

Conclusions:

1) All substances exhibit diamagnetism though it is ~~they~~ ~~are~~ masked by other magnetic effects.

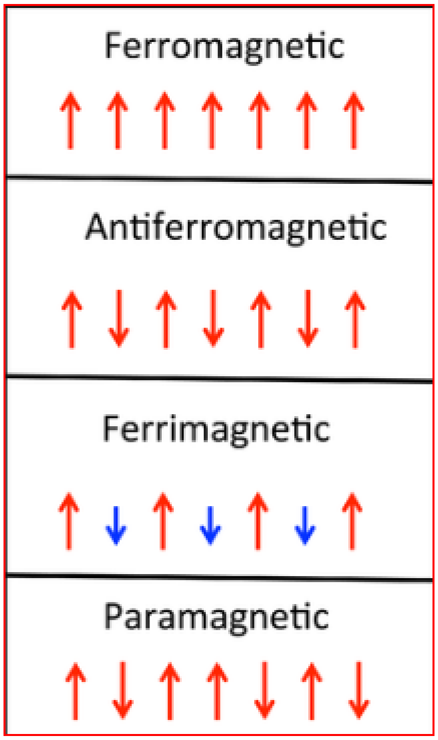
2) $\chi \propto Z$

3) If atom is bigger, susceptibility value is more.

4) susceptibility here is independent of temperature.

Ferromagnetism:

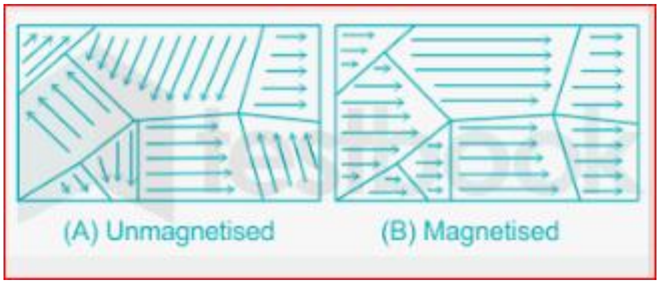
Ferromagnetism is the basic mechanism by which certain materials (such as iron) form permanent magnets, or are attracted to magnets. Ferromagnetism is the strongest type and is responsible for the common phenomenon of magnetism in magnets encountered in everyday life. Substances respond weakly to magnetic fields with three other types of magnetism—paramagnetism, diamagnetism, and antiferromagnetism—but the forces are usually so weak that they can be detected only by sensitive instruments in a laboratory. An everyday example of ferromagnetism is a refrigerator magnet used to hold notes on a refrigerator door. One of the requirements of ferromagnetic material is that ions and atoms should possess permanent magnetic moments. Some ions and atoms consist of the permanent magnetic moment that may be considered as a dipole that comprises a north pole separated from a south pole. Ferromagnetic materials contain unique magnetic moments that are aligned parallel to each other, all in the same direction Ferromagnetism is the only magnetization with all same direction moments.



Antiferromagnetism:

Materials having antiferromagnetism includes ferrous oxide, nickel oxide, chromium, and manganese fluoride. In antiferromagnetism, the forces between the adjacent atomic dipoles tend to possess signs opposite to that of ferromagnets.

Ferromagnetic domains:



This theory was proposed by Weiss in 1907. It explains the hysteresis and the properties of ferromagnetic materials. The volume of a domain may vary between 10^{-2} to 10^{-6} cm3.

Postulates of domain theory:

1. A ferromagnetic material is divided into a large number of small region called domains (0.1 to 1 of area)

2. In each domain the magnetic moments are in same direction.

3. But the magnetic moment varies from domain to domain and the net magnetization is zero,

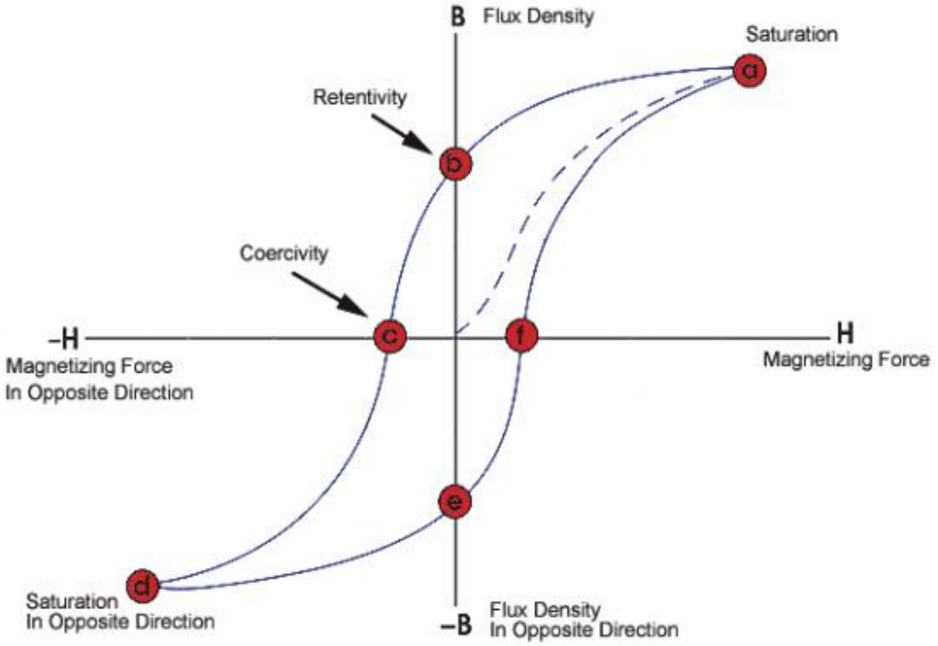
4. In the absence external magnetic field all the magnetic moments are in different direction.

5. When a magnetic field is applied, two process takes place(i) by the motion of domain walls and (ii) by the rotation of domains.

When a small amount of magnetic field is applied, the dipoles in the domains are aligned parallel to the applied magnetic field. It increases domain area by the motion of domain walls. If the applied magnetic field is further increased, the domains are rotated parallel to the field direction by the rotation of domains.

Hysterisis:

A hysteresis loop shows the relationship between the induced magnetic flux density (B) and the magnetizing force (H). It is often referred to as the B-H loop.



The loop is generated by measuring the magnetic flux of a ferromagnetic material while the magnetizing force is changed. A ferromagnetic material that has never been previously magnetized or has been thoroughly demagnetized will follow the dashed line as H is increased. The greater is the amount of magnetizing force/current applied (H+), the stronger is the magnetic field in the component (B+). At point "a" almost all of the magnetic domains are aligned and an additional increase in the magnetizing force produces very little increase in magnetic flux. The material reaches the point of magnetic saturation. When H is reduced to zero, the curve moves from point "a" to point "b." At this point, some magnetic flux remains in the material even though the magnetizing force is zero. This is the point of retentivity and indicates the remanence or level of residual magnetism in the material. (Some of the magnetic domains remain aligned but some have lost their alignment.) As the magnetizing force is reversed, the curve moves to point "c", where the flux reduces to zero. This is called the point of coercivity on the curve. (The reversed magnetizing force has flipped enough of the domains so that the net flux within the material is zero.) The force required to remove the residual magnetism from the material is called the coercive force or coercivity of the material. As the magnetizing force is increased in the negative direction, the material becomes magnetically saturated but in the opposite direction (point "d"). Reducing H to zero brings the curve to point "e." It has a level of residual magnetism equal to that achieved in the other direction. Increasing H back in the positive direction will return B to zero. The curve does not return to the origin of the graph because some force is required to remove the residual magnetism. The curve takes a different path from point "f" back to the saturation point.

Curie Temperature:

The Curie temperature (T_C), or Curie point, is the temperature above which certain materials lose their permanent magnetic properties, which can (in most cases) be replaced by induced magnetism. The Curie temperature is named after Pierre Curie, who showed that magnetism was lost at a critical temperature.

$$\chi = C / T$$

where, χ is the magnetic susceptibility, C is the material-specific Curie constant

Ferromagnetic materials, above a certain temperature known as Curie temperature (T_C), become paramagnetic.

$$\chi = C / T - T_c$$

Neel Temperature:

Antiferromagnetic materials, above a certain temperature known as Neel temperature (T_N), become paramagnetic.

Superconductivity:

Superconductivity was discovered in 1911 by the Dutch physicist Heike Kamerlingh Onnes. He found that the electrical resistivity of a mercury wire disappears suddenly when it is cooled below a temperature of about 4 K (−269 °C). He soon discovered that a superconducting material can be returned to the normal (i.e. nonsuperconducting) state either by passing a sufficiently large current through it or by applying a sufficiently strong magnetic field to it.

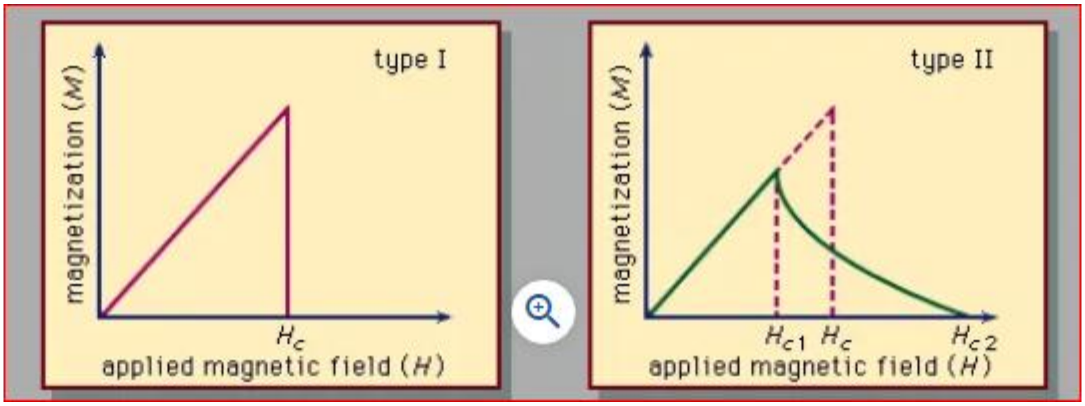
In 1933 it was discovered that a superconductor is highly diamagnetic; it is strongly repelled by and tends to expel a magnetic field. This phenomenon, which is very strong in superconductors, is called **the Meissner effect** for one of the two men who discovered it.

In 1957 such a theory was presented by the physicists John Bardeen, Leon N. Cooper, and John Robert Schrieffer of the United States; it won for them the Nobel Prize for Physics in 1972. It is now called the BCS theory in their honour and most later theoretical work is based on it.

In 1962 the British physicist Brian D. Josephson predicted that two superconducting objects placed in electric contact would display certain remarkable electromagnetic properties. These properties have since been observed in a wide variety of experiments, demonstrating quantum mechanical effects on a macroscopic scale.

If the magnetic field is applied in the same way to the same type of sample at a temperature above the transition temperature and is then held at a fixed value while the sample is cooled. It is found that the sample expels the magnetic flux as it becomes superconducting. This is called the Meissner effect. Complete expulsion of the magnetic flux (a complete Meissner effect) occurs in this way for certain superconductors, called type I superconductors, but only for samples that have the described geometry. For samples of other shapes, including hollow structures, some of the magnetic flux can be trapped, producing an incomplete or partial Meissner effect.

Type II superconductors have a different magnetic behaviour. Examples of materials of this type are niobium and vanadium (the only type II superconductors among the chemical elements) and some alloys and compounds, including the high-*Tc* compounds. As a sample of this type, in the form of a long, thin cylinder or ellipsoid, is exposed to a decreasing magnetic field that is axially oriented with the sample, the increase of magnetization, instead of occurring suddenly at the critical field (*Hc*), sets in gradually. Beginning at the upper critical field (*Hc*2), it is completed at a lower critical field (*Hc*1). If the sample is of some other shape, is hollow, or is inhomogeneous or strained, some magnetic flux remains trapped, and some magnetization of the sample remains after the applied field is completely removed.



Type-I superconductors strictly follow the Meissner effect. On the other hand, Type II superconductors do not follow the Meissner effect.

Type-I superconductors have only one critical field i.e Hc. On the other hand, Type II superconductors have two critical fields i.e Hc1 and Hc2.

Type-I superconductors act as a good conductor at room temperature. On the other hand, Type II superconductors are not particularly good conductors at room temperature.

Applications of Superconductivity:

1. Superconducting magnets are used for accelerating the particles in the Large Hadron Collider.
2. SQUIDs (superconducting quantum interference devices) are used in the production of highly sensitive magnetometers. They are generally used for the detection of land mines.
3. Superconducting magnets are also used in Magnetic Resonance Imaging (MRI) machines.
4. Superconducting cables are also used in place of ordinary cable lines to avoid power loss.
5. Maglev trains work on the superconducting magnetic levitation phenomenon.