ELECTRICITY AND MAGNETISM

(e-content for Physics)

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MAGNETIC PROPERTIES OF MATERIALS-I

Unlike electric polarization, which is always in the same direction as E, the magnetic behavior of materials depends on their nature of magnetization M, and other parameters such as magnetic susceptibility and permeablility. Broadly , three kinds of materials are studied viz; paramagnets which possess magnetization parallel to B, diamagnets which align antiparallel to B. A few materials called ferromagnets get magnetized permanently when coming under the influence of external magnetic field.

Magnetisation:

1) The net dipole moment of all the randomly distributed dipoles is zero. But when the external magnetic field induced by current through the conductor is applied on to a specimen, it induces an overall magnetic moment called the magnetic polarization or magnetization.

2) It is defined as the vector sum of all the magnetic moments in unit volume of the matter is called Magnetisation M.

$\vec{M} = \frac{m}{V}$ where m represents the magnetic moment of the volume V.

3) It is basically in the direction of applied field and hence it is a vector .
4) Its S.I. unit is Ampere/metre.
5) The linear current density is numerically equal to magnetization i.e. J=M Where J represents the linear current density of surface current through a closed conductor.

Magnetic field intensity:

1) The magnetic field intensity at any point is the force experienced by a unit north pole placed at that point.
2) It is a vector quantity having the same direction as the magnetic field B or M
3) It is an auxiliary vector introduced to take into account the intensity of magnetic field as linearly related with free current.

$\vec{H} = \frac{\vec{B}}{\mu_0} - \vec{M}$ so that $\oint \vec{H}.d\vec{l} = I_{free}$

The above expression is the Ampere's circuital law for H vector.

4) It is analogous to the displacement current D in electrostatics. Thus, H vector can be taken as the cause of magnetic induction or B vector, since it is directly related to current . When magnetic field is created then it is the agent for causing magnetization of any material. These three magnetic vectors are closely related .

Magnetic Susceptibility:

1) For isotropic linear para and diamagnetic materials, it is found that magnetization M is proportional to the magnetic field intensity H.

   $\vec{M} \propto \vec{H} \Rightarrow \vec{M} = \chi_m \vec{H}$

   Where χ_m is the magnetic susceptibility of the material.

2) Thus it is defined as the ratio of M to H i.e. $\chi_m = \frac{\vec{M}}{\vec{H}}$

3) It is regarded as the intensity of magnetization acquired by the material for unit field strength.
4) It has no unit i.e. it is dimensionless.
5) It serves as the basis for classification of materials

   χ_m =+ve for para

   =-ve for dia

   =+ve and high value for ferro.

   In ferromagnetic materials M is not directly proportional to H, so χ_m is not a const as even if H=0, M is not equal to 0 .

Magnetic permeability:

1) It is a parameter which measures the degree of penetration of magnetic field through the substance.
2) We have

$$\vec{B} = \mu_0(\vec{H} + \vec{M})$$
$$= \mu_0(\vec{H} + \chi_m \vec{M})$$
$$= \mu_0(1 + \chi_m)\vec{H}$$
$$= \mu \vec{H}$$

where $\mu = \mu_0(1+\chi_m)$ is the magnetic permeability of the material.

3) It is defined as the ratio of magnetic induction to the intensity of magnetizing field.
4) It is a dimensionless quantity.
5) For vaccum $\chi_m = 0 \Rightarrow \mu = \mu_0$

   Hence magnetic induction in vaccum is

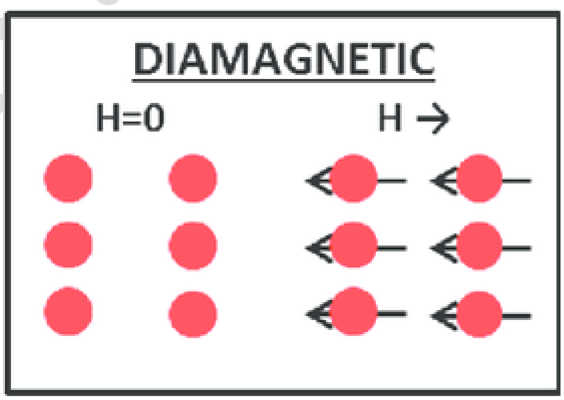
   $B_0 = \mu_0 H$

   $\Rightarrow \frac{B}{B_0} = \frac{\mu}{\mu_0} = \mu_r$

   This quantity is known as relative permeability of the material.

Diamagnetism

1) It is a property by virtue of which a material acquires magnetization in a direction opposite to the applied magnetic field.
2) The individual atoms of a diamagnetic material do not possess a permanent magnetic moment.

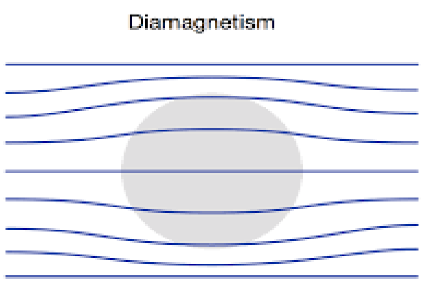


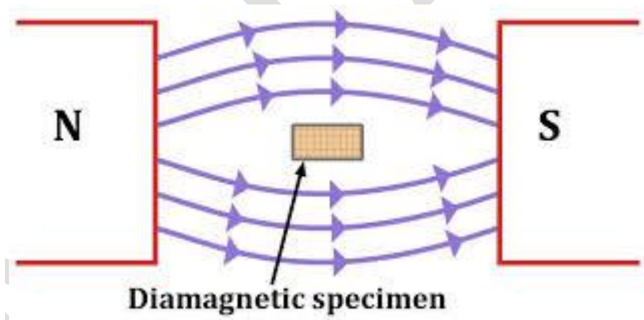
3) When an external applied field of intensity H_0 is applied, the atoms acquire an induced magnetic moment in a direction opposite to the applied one. Thus

it amounts to a net magnetization which follows the linearity relation and it vanishes as and when field is removed. This implies that these materials do not contain permanent magnetic dipoles.

4) Examples of diamagnetic materials are Antimony, Bismuth, Mercury, Gold etc.

5) These materials repel the magnetic lines of forces so that the net magnetic flux density is less than outside i.e. $B_{in} < B_{out}$ shown in the figures below





6) The magnetic susceptibility is having a negative value i.e. $\chi_m < 0$ which shows that it opposes the magnetization . it is independent of temperature.

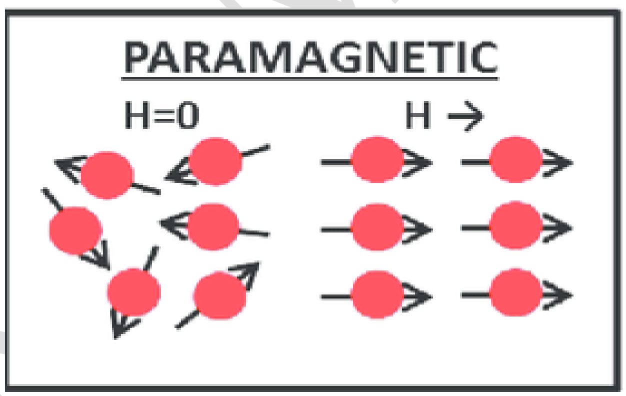
7) The magnetic permeability is having value less than 1 i.e. $\mu_r < 1$**.**

8) **The phenomenon of diamagnetism can be explained using the electron theory of magnetism:** if a material is diamagnetic, that means it is having and even number of electrons so that each electron is paired. Every electron revolving around the nucleus in addition to orbital motion , also possess spin motions. The resultant magnetic dipole moment of the atom is zero. Hence the applied magnetic field do not tend to align it along its direction, rather it just modifies its path. The electron moving in a direction so as to produce magnetic field in same dircection as the applied field is slowed down, while

the other is accelerated in accordance with Lenz's law. Thus the material acquires an effective small value of M opposite to B or H.

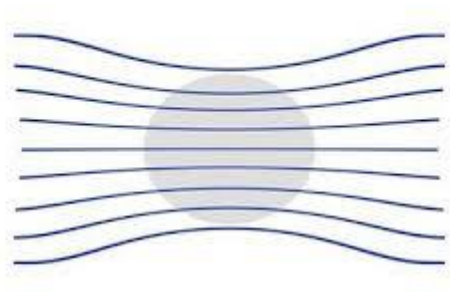
Paramagnetism

1) It is such a phenomenon which causes a material to align itself along the direction of applied electric field so that it possess a net magnetization.
2) The individual atoms of paramagnetic materials possess a magnetic moment of its own but the dipoles are randomly oriented so that their vector sum, that is magnetization is zero.
3) In the presence of external field H_0 , the dipoles tend to orient along the direction of H_0 , resulting in a net positive magnetization.



4) The common examples of paramagnetic materials are Pt, Al,$Fe_2 0_3$, $FeSO_4$, $NiSO_4$.
5) A paramagnetic material attract the magnetic lines of forces, so that the magnetic flux density inside the material is greater than outside i.e. $B_{in} > B_{out}$

Paramagnetism



6) Paramagnetic susceptibility is a +ve quantity and is inversely proportional to temperature

$\chi_m \propto \frac{1}{T} \Rightarrow \chi_m = \frac{C}{T}$ Curie law, where C is Curie constant.

$\chi_m = \frac{C}{T-\theta}$, Curie-Weiss Law , θ is called paramagnetic Curie temperature.

Suscepibility is independent of magnitude of applied field.

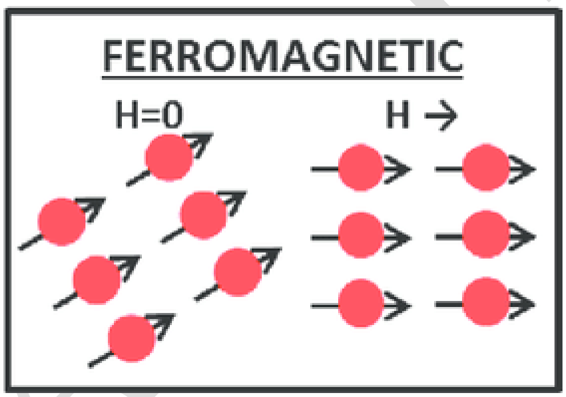
7) The value of permeability is slightly greater than 1 $\mu_r > 1$.

8) **Explanation based on electron theory:**

Inside the paramagnetic material, the atoms possess intrinsic magnetic moment, so that atoms can be considered as magnetic dipoles oriented in different directions making $\vec{M} = 0$. The electrons must be in odd numbers, so that their spin do not cancel each other. When we apply a magnetic field , these atomic dipoles align with its axis parallel to the external field resulting in an appreciable magnetization induced within . Since $\vec{M}$ and $\vec{B}$ are in the same direction in these materials χ_m is positive but as temperature increases, it gets difficult to align in a particular direction.

Ferromagnetism

1) We know that the magnetizing field H is the cause of magnetic field B created in any region around a current carrying wire. Ferromagnetism is a property by virtue of which any material under the effect of magnetic field , gets magnetized permanently.
2) Ferromagnetic material possess a non zero value of magnetization M even if the field is removed. This means that the magnetic dipole inside the material retain the property because a strong internal field develops inside.



3) When placed in magnetic field H_0, these become strongly magnetized with high +ve value of M and direction same as applied field .
4) A few of ferromagnets are Fe, Co, Ni, Gd(Gadoinium).
5) The magnetic lines of forces gets attracted strongly towards a ferromagnetic material . $B_{in} >> B_{out}$.
6) Once magnetized , it exhibits the property even in the absence of H, this property of ferromagnets is called spontaneous magnetization.
7) Its magnetic susceptibility is very high +ve quantity $\chi_m >> 1$ and is inversely proportional to temperature. It obeys the Curie Weiss Law

$\chi_m = \frac{C}{T-\theta}$, where C is Curie constant.

T> θ the material becomes paramagnetic.

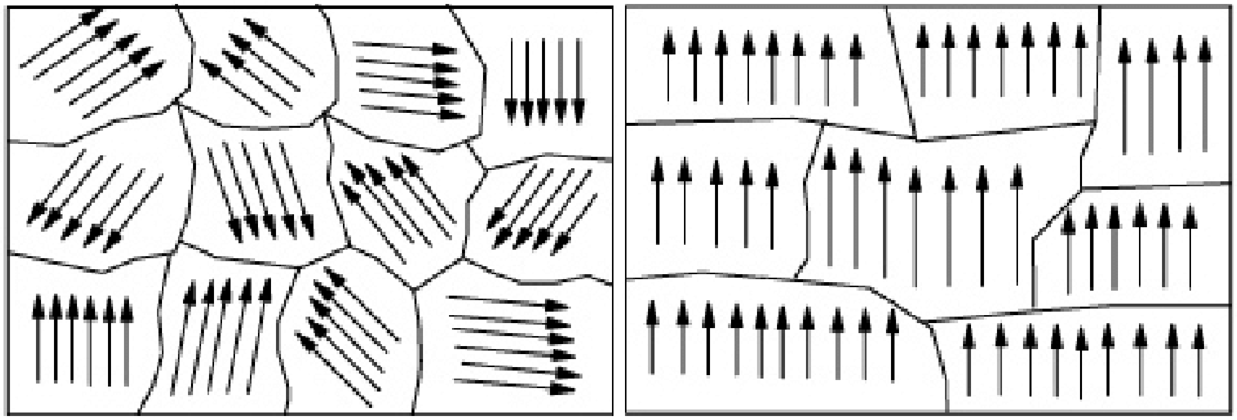
T< θ, it behaves as a ferromagnet.

This property shift towards paramagnetic behavior after a certain temperature is θ which is regarded as paramagnetic Curie temperature

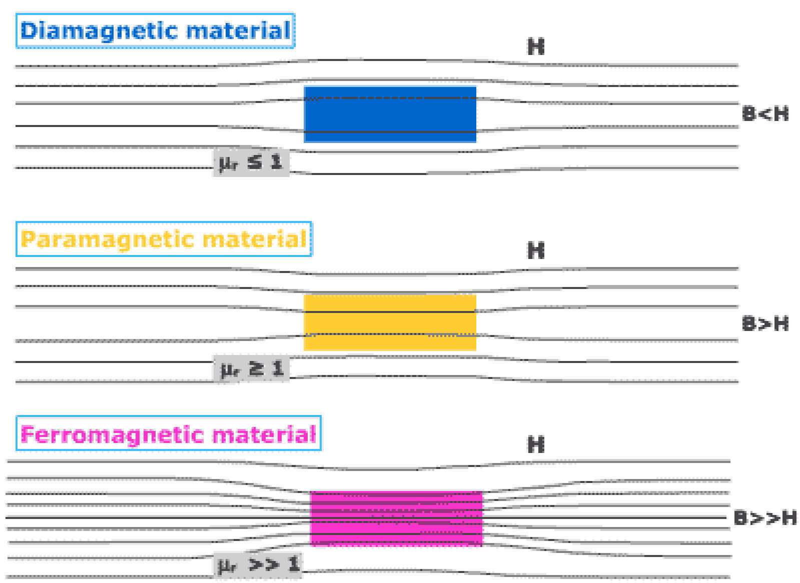
Susceptibility is independent of magnitude of applied field.

8) The relative permeability of ferromagnetic material is very high as compared to para and diamagnets . $\mu_r >> 1$
9) This property originates due to a net permanent magnetic moment in the atom or molecules of the materials which are randomly oriented unless it is magnetized. The magnetic moment is due to spin of the electrons and the interaction between neighbouring magnetic dipoles . this is called spin exchange interaction which is present even if H=0. A diagmagnet is found to be containing several domains in which all the dipoles are oriented in any particular specified direction. The total magnetic moment of a sample is the vector sum of magnetic moment of all the domains . Thus, when it comes

under the influence of external field , it becomes strongly magnetized.



Comparison of permeability between Diamagnetic, Paramagnetic & Ferromagnetic materials



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