M.Sc. (Physics) - SEM-2
Paper 202

Magnetism

There are three types of magnetic materials

1. Dia magnetic material
2. Para magnetic material
3. Ferromagnetic material.

This characterization is done when we study the response of materials in the presense of magnetic field.

Diamagnetic Materials :— Material are made up of atoms, which again consist of a positively charged nucleus surrounded by negatively charged e⁻s revolving around it in different orbits. These electrons have an orbital magnetic moment due to its orbital motion = $\left(\mu_B = \frac{e}{m_0} \cdot \frac{h}{2\pi}\right)$ amp-m^3, also it has spin moment associated with the spin of electrons. Spin is an intrinsic property of e⁻s like charge, mass etc. and we can visualise as e⁻ is spinning but its not the exact picture, and this spin is also associated with a moment. So the total sum of the orbital magnetic moments and spin magnetic moment of all the electrons of the atom gives the total magnetic moment of the atom.

The diamagnetic materials are those whose total magnetic moment (adding vectorially) is zero. It mean the atoms does not have an intrinsic magnetic moment. When we apply magnetic field magnetic dipoles get induced. According to Lenz's law the induced mag. moments are directed opposited to the external magnetic field Hence these dipoles will produce a magnetic field in a direction opposite ~~to the~~ of the applied field. And such media will be pushed from the regions of high magnetic field to a smaller magnetic field in an inhomogeneous field. This force of repulsion is very small as the magnetic susceptibility (χ) is small. and χ is independent of temperature.

→ χ is small
→ χ is independent of temp
→ This magnetisation disappears when external field is removed.

So in case of Diamagnets the orientation of the planes of the orbits may be such that the vector sum of the magnetic moments of all the electrons in an atom was zero in the absence of mag. field. ~~and~~ ~~so~~.

So,

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

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

$$|\chi_m| \ll 1 \quad \text{or} \quad \chi_m < 0$$

M = magnetisation, H = field strength

thus in this case permeability μ is approx. equal to absolute permeability μ_0.

Paramagnetic materials :— In this case the planes of the orbits of the e⁻s are oriented in such a way that the atom as a whole possesses a net magnetic moment. or it has a non zero permanent magnetic moment. Here atoms with odd no. of electrons have a net magnetic moment. In bulk matter these individual dipoles are aligned randomly and hence magnetization is zero. i.e. although individual atoms have a dipole moment in bulk material these are all aligned randomly so if we add these moments vectorially sum is zero. So the material is not magnetized. On applying an external magnetic field, there is a torque on ~~of~~ the magnetic moments, which leads to partial alignment of the moments. This effect is counter balanced ~~partly by the~~ partially by the thermal ~~agitation or~~ energy of the atoms because of finite temp, so there is ~~a~~ partial alignment of the moments not complete alignment due to finite temperature of the material.

→ Due to this partial alignment the material gets magnetised in the presence of external magnetic field. and its direction is along the direction of the applied field. This leads to an attraction and medium gets attracted towards stronger field in an inhomogeneous field, unlike Diamagnetic material. Here magnetisation depends on temp. as the magnetic tries to align the ~~ra~~dipoles towards the mag. field the thermal motion of dipoles tries to randomize the dipoles, so in this case magnetization decreases with increasing temperature.

So, we can write for Paramagnets expression for paramagnetic susceptibility derived by P. Curie

$$\chi_m = C\frac{\mu_0}{T} \qquad C = \text{curie constant.}$$

or $\chi_m \propto \frac{1}{T}$

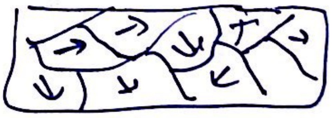
~~Since $\vec{M} = \chi_m \vec{H}$ here χ_m~~

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

here $\mu \gtrsim \mu_0$, μ is slightly greater than μ_0. where as in Diamagnets $\mu \lesssim \mu_0$ almost equal to μ_0 but slightly less than it.

Ferromagnetic Materials :→ In this case also like paramagnets they have an intrinsic mag. dipole moment primarily due to electron spin. In such material the interaction bet. adjacent dipoles is very strong and there exist an exchange interaction. This ~~the leads~~ interaction leads to a minimum energy when neighbouring moments are parallel to each other. (↑↑↑↑). So there is a strong tendency when material tries to minimise its energy it get's subdivided into small-small regions called domains in which magnetic moments are aligned in same directions ~~but~~ individually but not same in all different domains. ~~Here when external field is applied~~ and spontaneous magnetization of each domain is high.

Domain area ~ 10^{-8} to 10^{-12} m^3



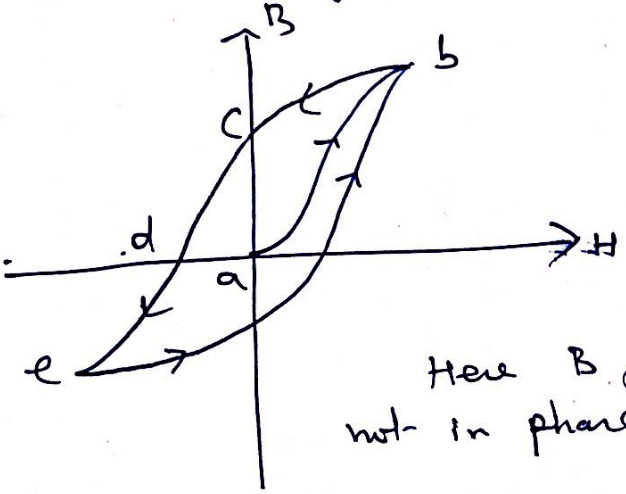
These domains ajust themselves to minimise to total energy. And net magnetisation is zero. When the external field is applied size of domain whose net mag. moment is in the direction of the field increases ~~or~~ (only five elements are ferromagnetic Fe, Co, Ni, Gadolinum Dysprosium)

The size of domain increases and so the magnetisation. These material also show hysteresis property.

The curie temp T_c here is such that for $T > T_c$ the substance becomes paramagnet.

for Iron $T_c \sim 1040$ K

So the ferromagnets have more prominent properties of paramagnetic types.



Here B field and H are not in phase B lag behinds H.

C → even after $H = 0$, B is finite, (**Remence** $= B_r$)

d → Coercive field (Value of reverse field H required to drive $B \to 0$ value)

So for Ferromagnets $\chi \to$ very large +ve

other two types of materials are special cases of Ferromagnets —

④ Antiferromagnets → χ is small, +ve an when $T > T_N$, $\chi = \frac{C}{T+\theta}$

⑤ Ferrimagnets → χ very large +ve, at $T > T_N$

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

a detailed comparison is on nex page.

Table 1. Distinction between magnetic materials

Type	Magnitude of susceptibility	Temperature dependence	Special remark	Examples
Diamagnetic	Small, negative	Independent	There are no permanent dipoles, consequently magnetic effects are very small	Organic materials light elements
	Intermediate negative	Varies with field and temperature below 20 K		Alkali earths Bismuth
	Large negative	Exists only below critical temperature T_c		Superconducting materials
Paramagnetic	Small, positive	Independent	They possess permanent dipoles which, in the absence of field, are randomly oriented so that net magnetisation in any given direction is zero.	Alkali metals Transition metals
	Large, positive	$\chi = \frac{C}{T - \theta}$		Rare earths
Ferromagnetic	Very large positive	$T > T_c$; $\chi = \frac{C}{T - \theta}$ (see art. 12.4)	Due to the large internal field, the permanent dipoles are strongly aligned in the same direction and consequently a large spontaneous magnetisation results even in the absence of an applied field.	Some transition and rare earth metals
Antiferromagnetic	Small, positive	When $T > T_N$ $\chi = \frac{C}{T + \theta}$ (see art. 12.7)	The magnetic ions on lattice site A will be aligned antiparallel to those on lattice site B because the molecular field is negative. Also $M_A = M_B$	Salts of transition elements
Ferrimagnetic	Very large, positive	At $T > T_N$, $\chi = \frac{C}{T \pm \theta}$ (See art. 12.8)	It is a special case of antiferromagnetics in which opposed moments are of different magnitudes and a large magnetisation thereby results	Ferrites