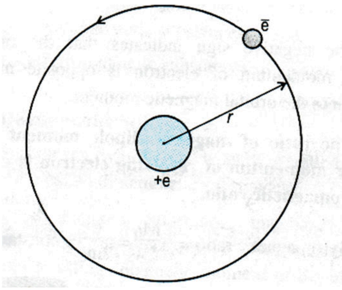
# MAGNETISM



**MAGNETIC DIPOLE MOMENT OF A REVOLVING ELECTRON**:

An atom consists of a positively charged heavy nucleus around which negatively charged electrons are revolving in a circular orbit.

Let r be the radius of revolution of the electron and v its orbital velocity. Then, magnitude of magnetic moment




$M_o = IA = \frac{Q}{T}\pi r^2 = \frac{e}{2\pi r/v} . \pi r^2 = \boxed{\frac{evr}{2}}$

Direction if from South to North (this case into the paper)

$M_o = \frac{evr}{2} = \frac{e}{2m}\ mvr = \frac{e}{2m} . L_o$ (where Lo=orbital angular momentum)

$\vec{M_o} = -\frac{e}{2m} . \vec{L_o}$ (m=mass of electron)

The negative sign indicates that the orbital angular momentum is oppositely directed to the orbital magnetic moment.

NOTE: Gyromagnetic ratio = $\frac{Mo}{Lo} = \frac{e}{2m} = 8.8 \times 10^{10}$ C/kg

NOTE: The circular orbit of the electron produces an orbital magnetic moment. In addition, an electron has spin magnetic moment.

**MAGNETIZATION:**

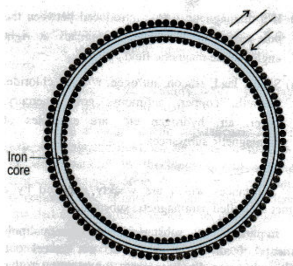
The net magnetic dipole moment per unit volume is called as the magnetization ($\vec{Mz}$) of the sample.

Magnetization ($\vec{Mz}$) = $\frac{\text{Net magnetic moment}}{\text{Volume}} = \frac{M_{net}}{\text{Volume}}$

SI unit: A/m Dimensions: $[M^0L^{-1}T^0I^1]$

NOTE: Complete alignment of the atomic dipole moment is called saturation of the sample.

- ***Magnetization of Paramagnetic substance (Curie's Law)***
  Magnetization of a paramagnetic sample is directly proportional to the external magnetic field and inversely proportional to the absolute temperature.
  $Mz \propto Bext$ and $Mz \propto 1/T$
  Therefore, $Mz \propto Bext / T$
  Thus,
  $$\boxed{Mz = C \times \frac{Bext}{T}}$$
  This is known as Curie's Law and C is called Curie constant.
- ***Magnetization of Ferromagnetic substance***.
  Consider a Toroid with an iron core. Let the toroid coil have n turns per unit length and carries a current I.
  The magnetic field inside the coil would be
  $B_O = \mu_O\, n\, I$ where
  $\mu_O$=permeability of vacuum

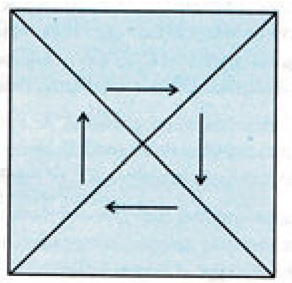



  However with the iron core the magnetic field inside the coil would be $B = B_O + B_M$ (where BM = magnetic field due to core)
  $B_M = \mu_O M_Z$ and $B_O = \mu_O H$ , where H=magnetic intensity=nI
  SI unit of H: A/m Dimension : $[M^0L^{-1}T^0I^1]$
  Thus, $B=\mu_O(H + M_Z)$ where $M_Z=\chi H$ and $\chi$: magnetic susceptibility
  Thus, $B=\mu_O(1+\chi)H = \mu_O\mu_r H = \mu H$ ,
  where $\mu_r = 1+\chi$ = relative magnetic permeability & is dimensionless quantity
  NOTE: $\mu = \mu_O\mu_r = \mu_O(1 + \chi)$

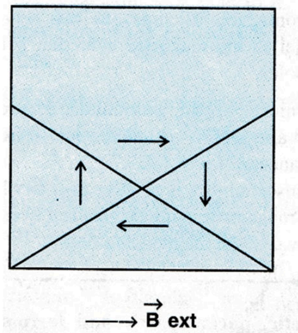
**FERROMAGNETISM on basis of DOMAIN THEORY:**

Ferromagnetism is explained bases on domain theory proposed by Weiss. According to domain theory, a ferromagnetic material contains large number of small regions or domains (about 1mm, with $10^{11}$ atoms). In this region all magnetic moments are aligned in the same direction.

In the absence of any external magnetic field, the different domains are oriented at random, so that the magnetic fields of the domains cancel each other and substance does not show magnetic properties.



**Unmagnetised state**

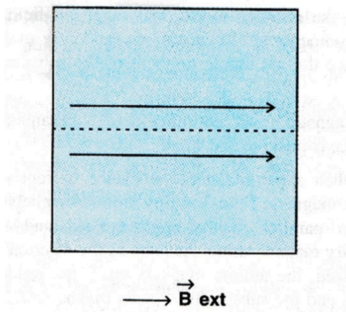



**In a weak magnetic field**

When externally applied magnetic field is weak, the individual atomic magnets tend to align parallel to the direction of the external field. The domain wall thus shifts in the direction of the applied field. With the removal of the external magnetic field, the boundaries return to their original positions and the material loses its magnetism.

When the external applied magnetic field is string, the dipole moments of the non-aligned domains abruptly rotate in the direction of the applied field. This process is referred as flipping or domain rotation. The removal of the external field does not set the domain boundaries back to the original position; hence the material gets permanent magnetic properties.

(The degree of magnetization also depends on the temperature of the substance).




: **In a strong magnetic field**

**CURIE TEMPERATURE:**

It is observed that when ferromagnetic substance is heated, its magnetization decreases with increase in temperature. At a particular temperature it looses its magnetization completely. This temperature at which the domain structure is destroyed and ferromagnetic substance looses its magnetism is called ***curie temperature***.

At higher temperature, the exchange coupling between the atomic magnets in each domain breaks completely and all the atomic dipoles get randomly oriented.

Above the curie temperature, ferromagnetic substance is converted into a paramagnetic substance.

The curie temperature is different for different ferromagnetic materials. e.g. IRON is 1043K.

| | Property | Diamagnetic substances | Paramagnetic substances | Ferromagnetic substances |
|---|---|---|---|---|
| 1. | *Effect of magnets* | They are feebly repelled by magnets. | They are feebly attracted by magnets. | They are strongly attracted by magnets. |
| 2. | *In external magnetic field* | Acquire feeble magnetisation in the opposite direction of the magnetising field. | Acquire feeble magnetisation in the direction of the magnetising field. | Acquire strong magnetisation in the direction of the magnetising field. |
| 3. | *In a non-uniform magnetic field* | Tend to move slowly from stronger to weaker parts of the field. | Tend to move slowly from weaker to stronger parts of the field. | Tend to move quickly from weaker to stronger parts of the field. |
| 4. | *In a uniform magnetic field* | A freely suspended diamagnetic rod aligns itself perpendicular to the field. | A freely suspended paramagnetic rod aligns itself parallel to the field. | A freely suspended ferromagnetic rod aligns itself parallel to the field. |
| 5. | *Susceptibility value* ($\chi_m$) | Susceptibility is small and negative. $-1 \leq \chi_m < 0$ | Susceptibility is small and positive. $0 < \chi_m < \varepsilon$, where $\varepsilon$ is a small number | Susceptibility is very large and positive. $\chi_m > 1000$ |
| 6. | *Relative permeability value* ($\mu_r$) | Slightly less than 1 $0 \leq \mu_r < 1$ | Slightly greater than 1 $1 < \mu_r < 1 + \varepsilon$ | Of the order of thousands $\mu_r > 1000$ |
| 7. | *Permeability value* ($\mu$) | $\mu < \mu_0$ | $\mu > \mu_0$ | $\mu >> \mu_0$ |
| 8. | *Effect of temperature* | Susceptibility is independent of temperature. | Susceptibility varies inversely as temperature : $\chi_m \propto \frac{1}{T}$. | Susceptibility decreases with temperature in a complex manner. $\chi_m \propto \frac{1}{T - T_C} (T > T_C)$ |
| 9. | *Removal of magnetising field* | Magnetisation lasts as long as the magnetising field is applied. | As soon as the magnetising field is removed, magnetisation is lost. | Magnetisation is retained even after the magnetising field is removed. |
| 10. | *Variation of M with H* | *M* changes linearly with *H*. | *M* changes linearly with *H* and attains saturation at low temperature and in very strong fields. | *M* changes with *H* non-linearly and ultimately attains saturation. |
| 11. | *Hysteresis effect* | *B*-vector shows no hysteresis. | *B*-vector shows no hysteresis. | *B*-vector shows hysteresis. |
| 12. | *Physical state of the material* | Solid, liquid or gas. | Solid, liquid or gas. | Normally solids only. |
| 13. | *Examples* | Bi, Cu, Pb, Si, $N_2$(at STP), $H_2O$, NaCl | Al, Na, Ca, $O_2$(at STP), $CuCl_2$ | Fe, Ni, Co, Gd, $Fe_2O_3$, Alnico. |