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Permeability Concept

- For some materials, the *net magnetic dipole moment per unit volume* is proportional to the *H* field

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

magnetic susceptibility (dimensionless)

- the units of both ***M*** and ***H*** are A/m.

Permeability Concept (Cont'd)

- Assuming that $\underline{M} = \chi_m \underline{H}$
  we have

$$\underline{B} = \mu_0\left(\underline{H} + \underline{M}\right) = \mu_0\left(1 + \chi_m\right)\underline{H} = \mu\underline{H}$$

- The parameter μ is the ***permeability*** of the material.

Permeability Concept (Cont'd)

- The concepts of magnetization and magnetic dipole moment distribution are introduced to relate microscopic phenomena to the macroscopic fields.
- The introduction of *permeability* eliminates the need for us to explicitly consider microscopic effects.
- Knowing the *permeability* of a magnetic material tells us all we need to know from the point of view of macroscopic electromagnetics.

Relative Permeability

- The ***relative permeability*** of a magnetic material is the ratio of the permeability of the magnetic material to the permeability of free space

$$\mu_r = \frac{\mu}{\mu_0}$$

Diamagnetic Materials

- In the absence of applied magnetic field, each atom has net zero magnetic dipole moment.
- In the presence of an applied magnetic field, the angular velocities of the electronic orbits are changed.
- These induced magnetic dipole moments align themselves <u>opposite</u> to the applied field.
- Thus, $\chi_m < 0$ and $\mu_r < 1$.

Diamagnetic Materials (Cont'd)

- Usually, diamagnetism is a very miniscule effect in natural materials - that is $\mu_r \approx 1$.
- Diamagnetism can be a big effect in *superconductors* and in *artificial materials*.
- Diamagnetic materials are repelled from either pole of a magnet.

Paramagnetic Materials

- In the absence of applied magnetic field, each atom has net non-zero (but weak) magnetic dipole moment. These magnetic dipoles moments are randomly oriented so that the net macroscopic magnetization is zero.
- In the presence of an applied magnetic field, the magnetic dipoles align themselves with the applied field so that $\chi_m > 0$ and $\mu_r > 1$.

Paramagnetic Materials (Cont'd)

- Usually, paramagnetism is a very miniscule effect in natural materials - that is $\mu_r \approx 1$.
- Paramagnetic materials are (weakly) attracted to either pole of a magnet.

Ferromagnetic Materials

- Ferromagnetic materials include iron, nickel and cobalt and compounds containing these elements.
- In the absence of applied magnetic field, each atom has very strong magnetic dipole moments due to uncompensated electron spins.
- Regions of many atoms with aligned dipole moments called ***domains*** form.
- In the absence of applied magnetic field, the *domains* are randomly oriented so that the net macroscopic magnetization is zero.

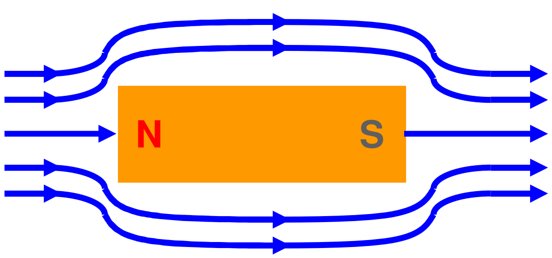
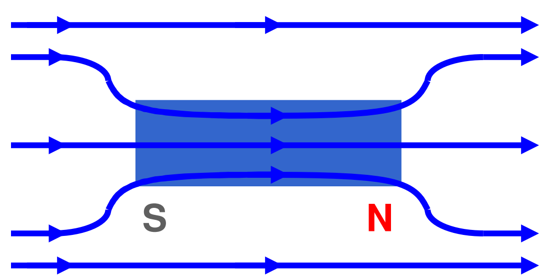
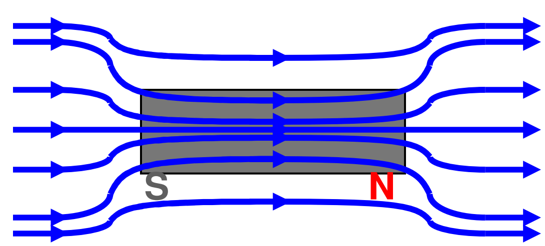
Ferromagnetic Materials (Cont'd)

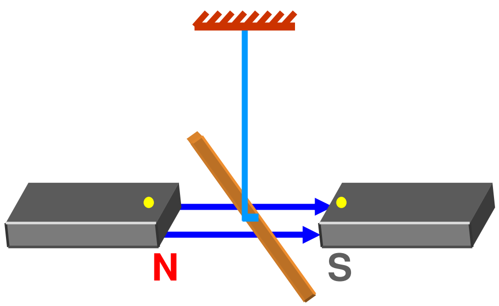
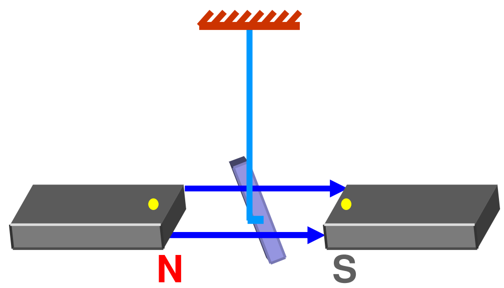
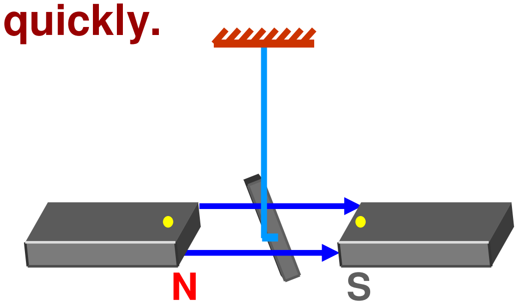
- In the presence of an applied magnetic field, the domains align themselves with the applied field.
- The effect is a very strong one with χ_m >> 0 and μ_r >> 1.
- Ferromagnetic materials are strongly attracted to either pole of a magnet.

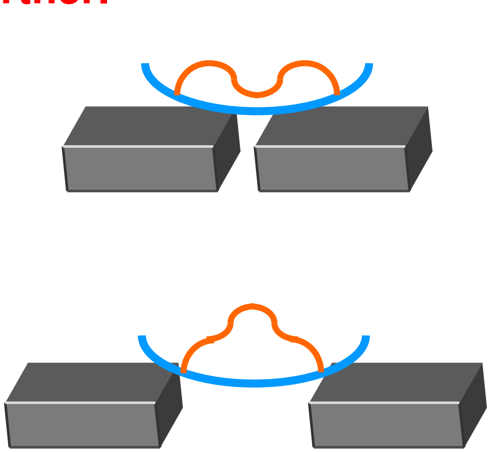
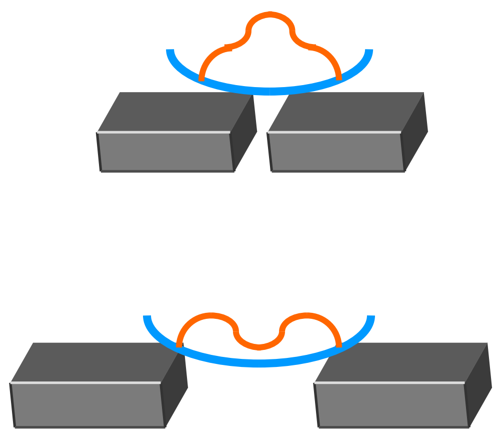
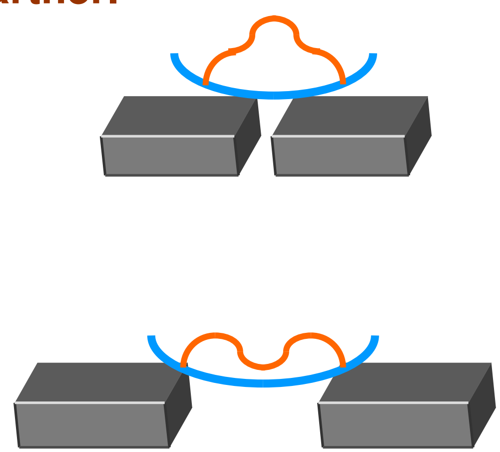
Ferromagnetic Materials (Cont'd)

- In ferromagnetic materials:
  - the permeability is much larger than the permeability of free space
  - the permeability is very non-linear
  - the permeability depends on the previous history of the material

Comparison of Dia, Para and Ferro Magnetic materials:

DIA	PARA	FERRO
1. Diamagnetic substances are those substances which are feebly repelled by a magnet. Eg. Antimony, Bismuth, Copper, Gold, Silver, Quartz, Mercury, Alcohol, water, Hydrogen, Air, Argon, etc.	Paramagnetic substances are those substances which are feebly attracted by a magnet. Eg. Aluminium, Chromium, Alkali and Alkaline earth metals, Platinum, Oxygen, etc.	Ferromagnetic substances are those substances which are strongly attracted by a magnet. Eg. Iron, Cobalt, Nickel, Gadolinium, Dysprosium, etc.
2. When placed in magnetic field, the lines of force tend to avoid the substance. 	The lines of force prefer to pass through the substance rather than air. 	The lines of force tend to crowd into the specimen. 

2. When placed in non-uniform magnetic field, it moves from stronger to weaker field (feeble repulsion).	When placed in non-uniform magnetic field, it moves from weaker to stronger field (feeble attraction).	When placed in non-uniform magnetic field, it moves from weaker to stronger field (strong attraction).
3. When a diamagnetic rod is freely suspended in a uniform magnetic field, it aligns itself in a direction perpendicular to the field.  	When a paramagnetic rod is freely suspended in a uniform magnetic field, it aligns itself in a direction parallel to the field.  	When a paramagnetic rod is freely suspended in a uniform magnetic field, it aligns itself in a direction parallel to the field very quickly. 

4. If diamagnetic liquid taken in a watch glass is placed in uniform magnetic field, it collects away from the centre when the magnetic poles are closer and collects at the centre when the magnetic poles are farther.	If paramagnetic liquid taken in a watch glass is placed in uniform magnetic field, it collects at the centre when the magnetic poles are closer and collects away from the centre when the magnetic poles are farther.	If ferromagnetic liquid taken in a watch glass is placed in uniform magnetic field, it collects at the centre when the magnetic poles are closer and collects away from the centre when the magnetic poles are farther.
		

5. When a diamagnetic substance is placed in a magnetic field, it is weakly magnetised in the direction opposite to the inducing field.	When a paramagnetic substance is placed in a magnetic field, it is weakly magnetised in the direction of the inducing field.	When a ferromagnetic substance is placed in a magnetic field, it is strongly magnetised in the direction of the inducing field.
6. Induced Dipole Moment (M) is a small – ve value.	Induced Dipole Moment (M) is a small + ve value.	Induced Dipole Moment (M) is a large + ve value.
7. Intensity of Magnetisation (I) has a small – ve value.	Intensity of Magnetisation (I) has a small + ve value.	Intensity of Magnetisation (I) has a large + ve value.
8. Magnetic permeability μ is always less than unity.	Magnetic permeability μ is more than unity.	Magnetic permeability μ is large i.e. much more than unity.

9. Magnetic susceptibility χ_m has a small – ve value.	Magnetic susceptibility χ_m has a small + ve value.	Magnetic susceptibility χ_m has a large + ve value.
10. They do not obey Curie's Law. i.e. their properties do not change with temperature.	They obey Curie's Law. They lose their magnetic properties with rise in temperature.	They obey Curie's Law. At a certain temperature called Curie Point, they lose ferromagnetic properties and behave like paramagnetic substances.

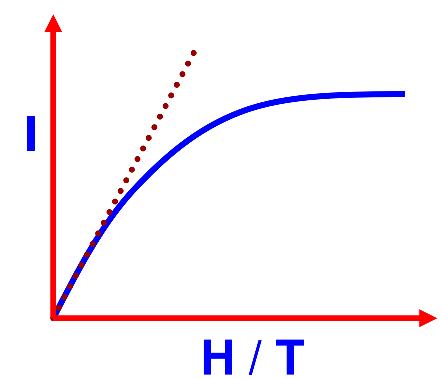
Curie's Law:

Magnetic susceptibility of a material varies inversely with the absolute temperature.

$I \propto H / T$ or $I / H \propto 1 / T$

$\chi_m \propto 1 / T$

$\chi_m = C / T$ (where C is Curie constant)



Curie temperature for iron is 1000 K, for cobalt 1400 K and for nickel 600 K.

Hysteresis Loop or Magnetisation Curve:

Intensity of Magnetisation (I) increases with increase in Magnetising Force (H) initially through OA and reaches saturation at A.

When H is decreased, I decreases but it does not come to zero at H = 0.

The residual magnetism (I) set up in the material represented by OB is called Retentivity.

To bring I to zero (to demagnetise completely), opposite (negative) magnetising force is applied. This magetising force represented by OC is called coercivity.

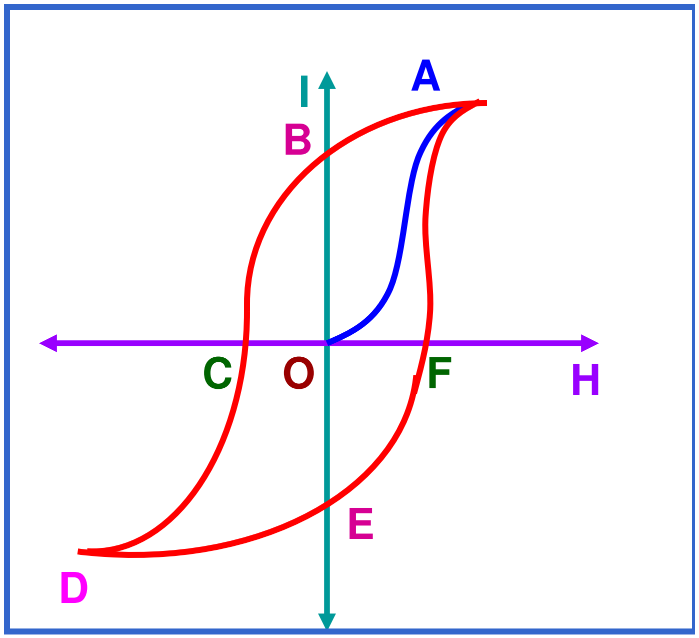
After reaching the saturation level D, when the magnetising force is reversed, the curve closes to the point A completing a cycle.

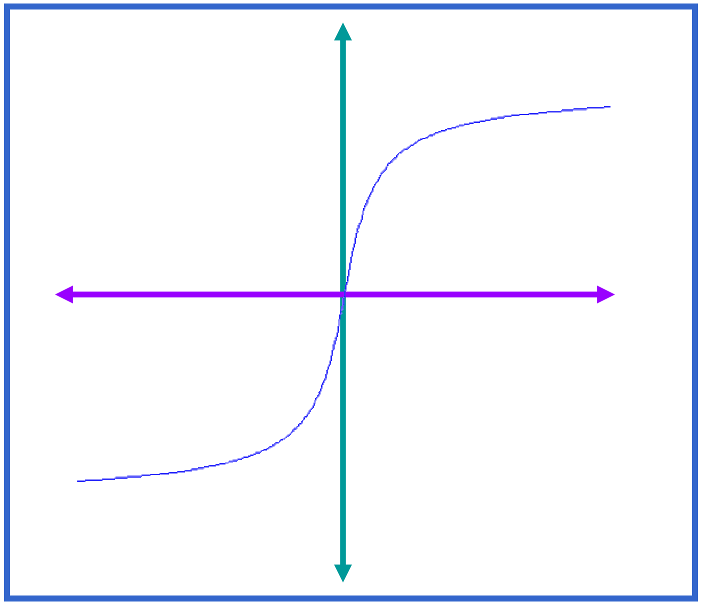
The loop ABCDEFA is called Hysteresis Loop.

The area of the loop gives the loss of energy due to the cycle of magnetisation and demagnetisation and is dissipated in the form of heat.

The material (like iron) having thin loop is used for making temporary magnets and that with thick loop (like steel) is used for permanent magnets.

End of Magnetism





Animating Hysteresis Loop:
CourtesY RAVINDER KUMAR

THANKS