



## ENGINEERING PHYSICS

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# ENGINEERING PHYSICS

## Unit 5 : Quantum mechanical treatment of Magnetic materials and Delectrics

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### Class #46

- *Review of magnetic fields and magnetic moments*
- *Concept of Magnetisation*
- *Magnetic Permeability & Susceptibility*
- *Classification based on permeability & Susceptibility*

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## Unit 5 : Magnetic materials

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### ➤ *Suggested Reading*

1. *Quantum Physics of Atoms Nuclei and Molecules, Robert Eisberg, Robert Resnick, Wiley, 2nd edition, Ch 14, 2006.*
2. *Learning material prepared by the Department of Physics*

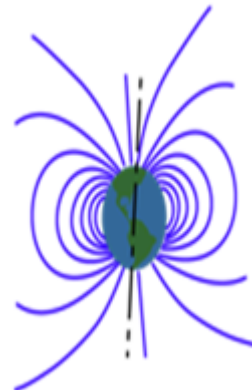
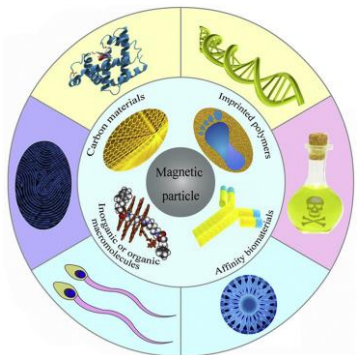
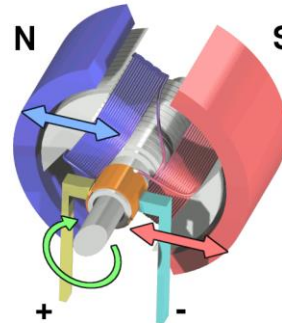
### ➤ *Reference Videos*

<https://nptel.ac.in/courses/113/106/113106039/>

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## Concept of Magnetic fields

### *Magnetic fields and magnetic forces around us*



Images courtesy Wikipedia

<https://doi.org/10.1016/j.trac.2019.115674>

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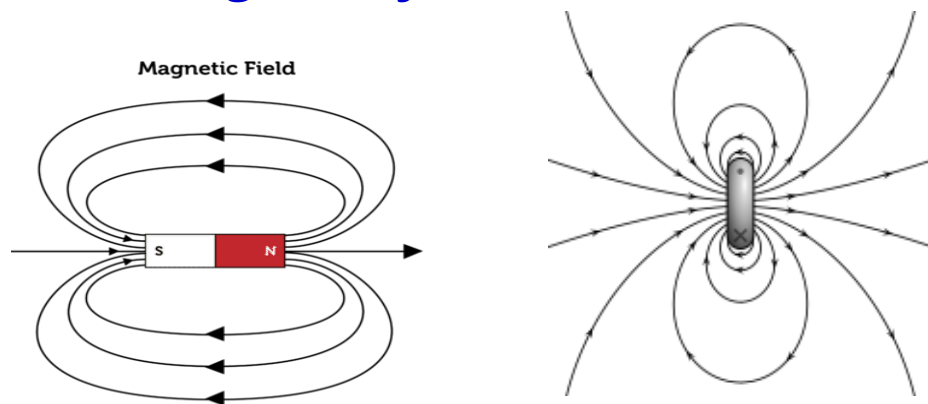
## Concept of Magnetic fields

- *Magnetic field*

$$\vec{F}_B = q \vec{v} \times \vec{B}$$

- *Magnetic mono poles do not exist*
- *Magnetic dipoles*
- *Fields can be expressed in terms of the flux lines*
- *Flux lines are continuous from the north pole to the south pole*

### Magnetic field lines



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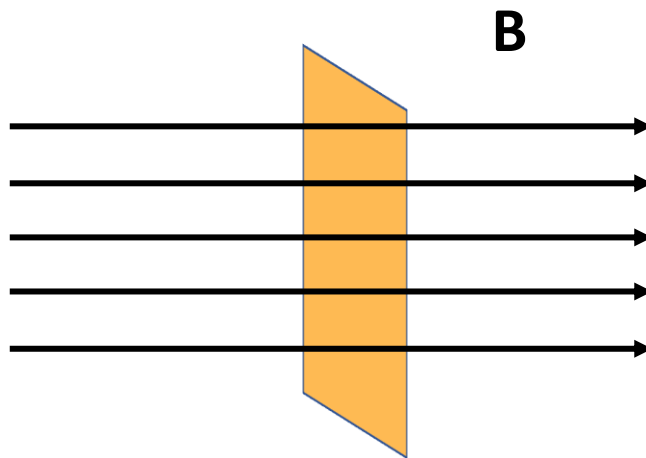
## Magnetic flux density B

### *Magnetic Flux density*

- *Measure of magnetic field lines per unit area*
- *Vector quantity denoted by **B***

$$\vec{B} = \frac{\Phi}{A} \text{ ----- } \text{Wb/m}^2 = \text{Tesla}$$

- *Magnetic flux density depends on the applied field strength **H***



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## Magnetic Dipole moment

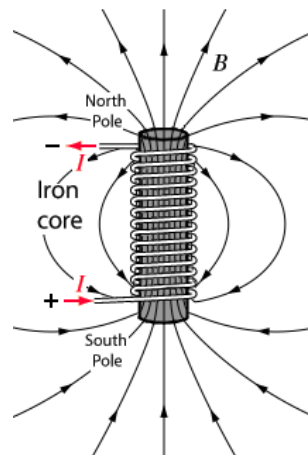
- *Magnetic dipole moment  $\mu$*

- *Torque is given by*

$$\vec{\tau} = \vec{\mu} \times \vec{B}$$

- *Magnetic interaction energy is given by*

$$E_m = -\vec{\mu} \cdot \vec{B}$$

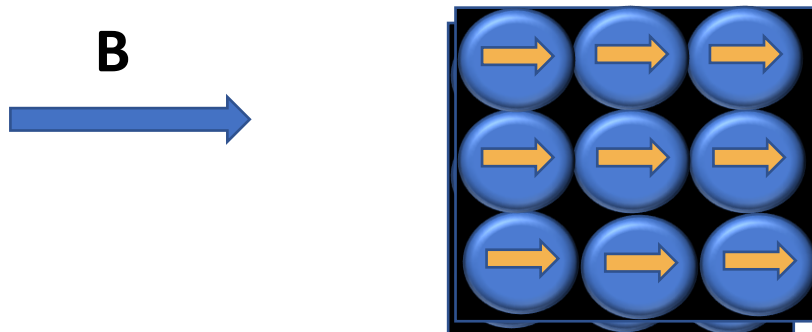


Images courtesy Wikipedia

### *Magnetisation*

- *Dipole moment per unit volume of the material.*
- $M = \frac{\mu}{V}$
- *Intensity of magnetization depends on applied magnetic field  $H$*
- $M \propto H$
- $M = \chi_m H$  or  $\chi_m = M/H$

$\chi_m$  is called magnetic susceptibility – ability to get magnetised



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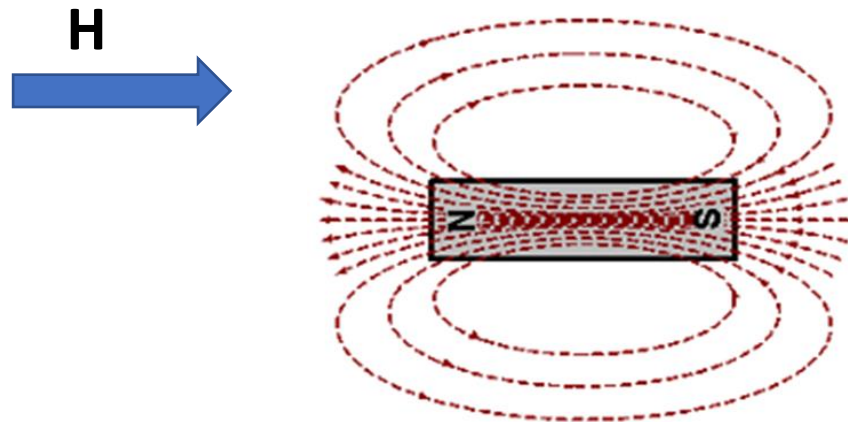
## Magnetic permeability ( $\mu$ )

*Consider unmagnetized bar of a magnetic material*

*Magnetic field lines emanate from north pole and enter the south pole*

$$B = \mu H$$

*where,  $\mu$  is magnetic permeability also called absolute Permeability of the medium*



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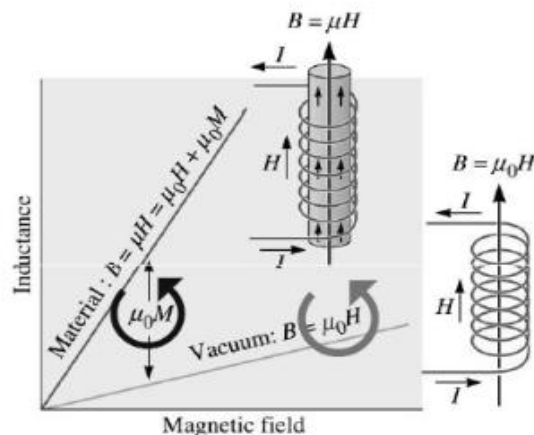
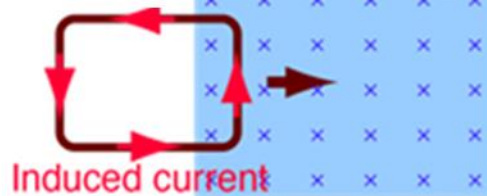
## Magnetic permeability ( $\mu$ )

- Consider a long solenoid of length  $l$  with air as the core and having  $n$  turns.
- Magnetic field strength is given by

$$H = \frac{nI}{l}$$

- Magnetic flux density  $B_o = \mu_o H$
- $\mu_o$  is permeability of free space/Vacuum =  $4\pi \times 10^{-7} \text{ H/m}$

Coil of area  $A$  and  $n$  turns



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## Magnetic permeability ( $\mu$ )

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*When a material of susceptibility  $\chi_m$  is introduced inside the solenoid*

*Total magnetic flux of the system is*

$$B = \mu_o H + \mu_o M$$

$$= \mu_o (H + M)$$

$$B = \mu_o (1 + \chi_m) H$$

*Defining relative permeability  $\mu_r = (1 + \chi_m)$*

*Permeability of any given medium is assessed relative to  $\mu_o$*

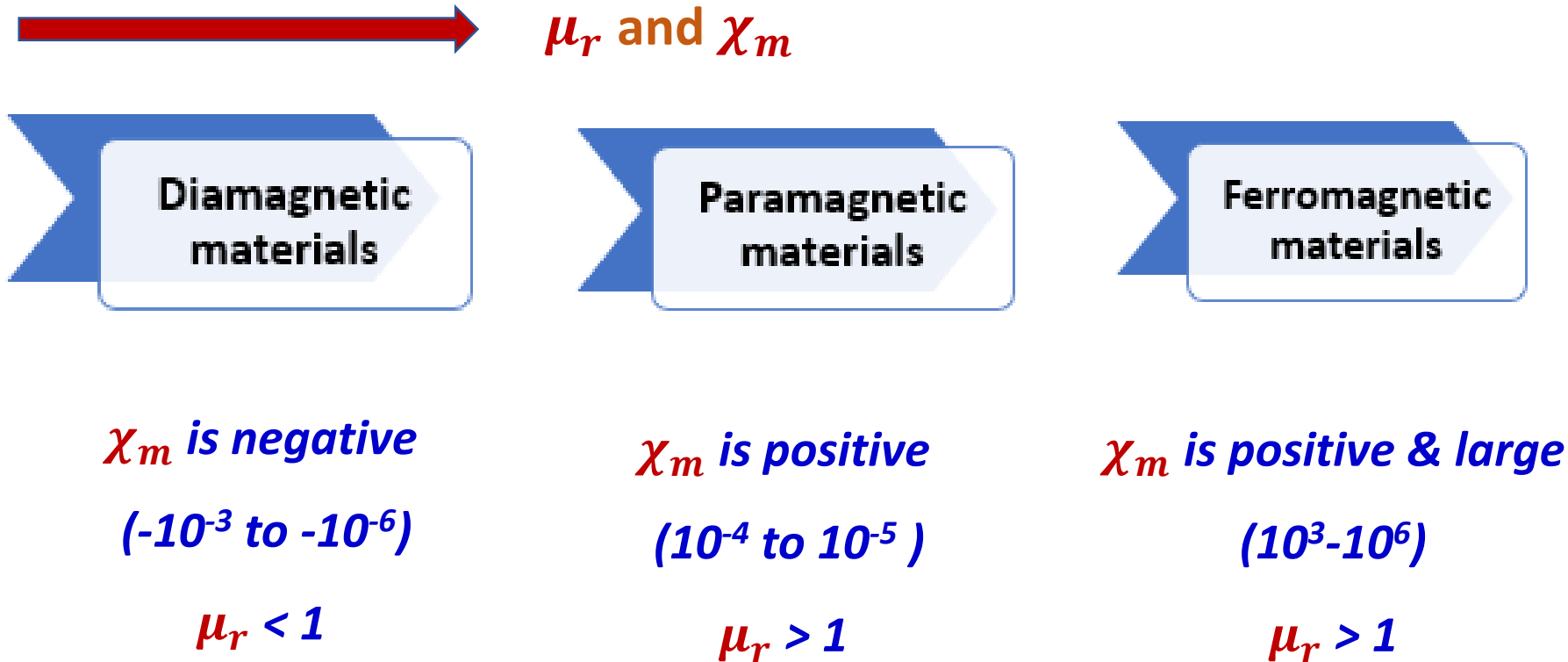
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*Example: If  $\mu_r = 3$  for a given medium, then permeability of the medium is 3 times the permeability of free space*

$$\mu = \mu_o \mu_r$$

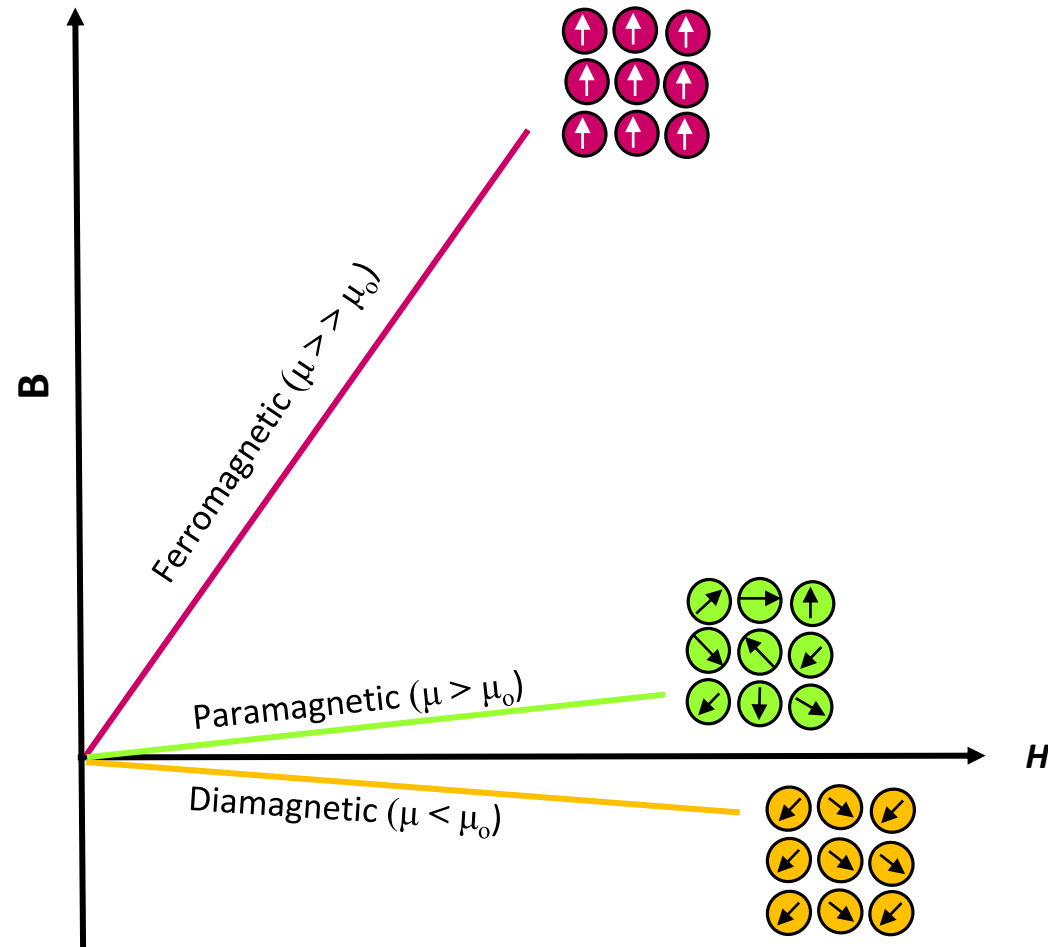
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## Classification based on $\mu_r$ and $\chi_m$



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## Graph - B versus H



The concepts which are correct are....

1. Magnetic monopoles do not exist
2. Magnetic dipoles exist
3. Magnetic susceptibility is same for all magnetic materials
4. Diamagnetic materials possess large magnetic susceptibility
5. Magnetic permeability of any medium is expressed in terms of permeability of free space



# THANK YOU

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