ENGINEERING PHYSICS

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ENGINEERING PHYSICS

Unit 5 : Quantum mechanical treatment of Magnetic materials and Dielectrics

Class #51

- Ferromagnetic materials
- B-H curve-hysteresis
    - Soft ferromagnetic materials
    - Hard ferromagnetic materials
- Antiferromagnetic materials
- Ferrimagnetic materials
- Graph – χ v/s T

- ***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***
  1. *https://nptel.ac.in/courses/115/105/115105099/*

Ferromagnetic materials

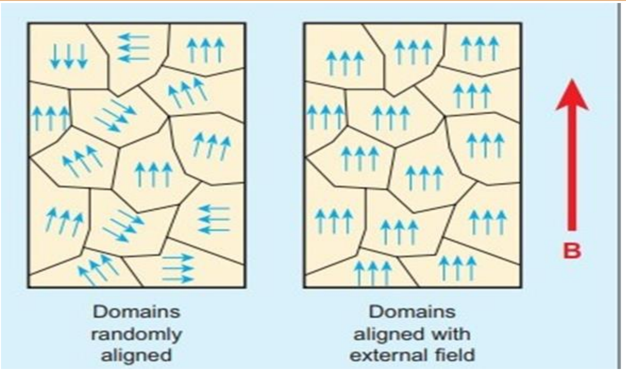
- *Large magnetic susceptibilities*
- *Presence of unpaired spins in the 3d shells*
- *Local molecular field result in a high ordering of spins*
- *Exhibit spontaneous magnetization and can be easily magnetized.*

[Ar]	↑↓	↑	↑	↑	↑	↑↓	Iron
			$3d^6$			$4s^2$	

Ferromagnetic materials

- *Magnetic domains giving rise to spontaneous magnetization.*
- *Favorable domains grow in size and the rest shrink in size in presence of external field*
- *Magnetic moments of the domains tend to align in the direction of the applied field*
- *Total field is given by*

$$H_T = H + H_m = H + \gamma M$$



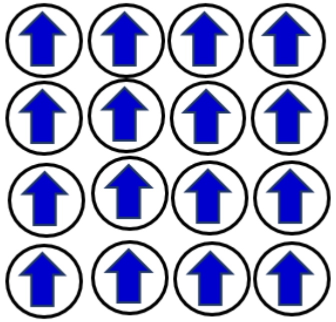
Effect of Temperature

- *As temperature increases, the magnetization decreases*
- *Phase change from ferromagnetic to paramagnetic behaviour above critical temperature T_c called Curie's temperature*

$$\chi = \frac{C}{T - T_c}$$

- *Curie temperature of these materials are very high*

Example: Cobalt - T_c>1000K, Fe - T_c >750K and Ni - T_c >350K



$T<T_c$ $\quad H = 0, M \neq 0$

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Hysteresis

- *Magnetic flux density (B) v/s applied field H forms a hysteresis loop*
- *Saturation magnetization – dipole alignment in the direction of applied field*
- *Retentivity : $B \neq 0$ when $H = 0$*
- *Coercivity : $B = 0, H \neq 0$*
- *Flipping of magnetisation in opposite directions*

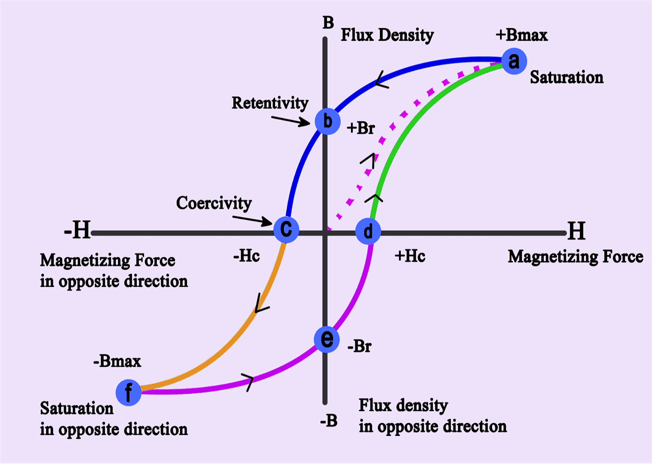

Image courtesy Hyperphysics, Wikipedia

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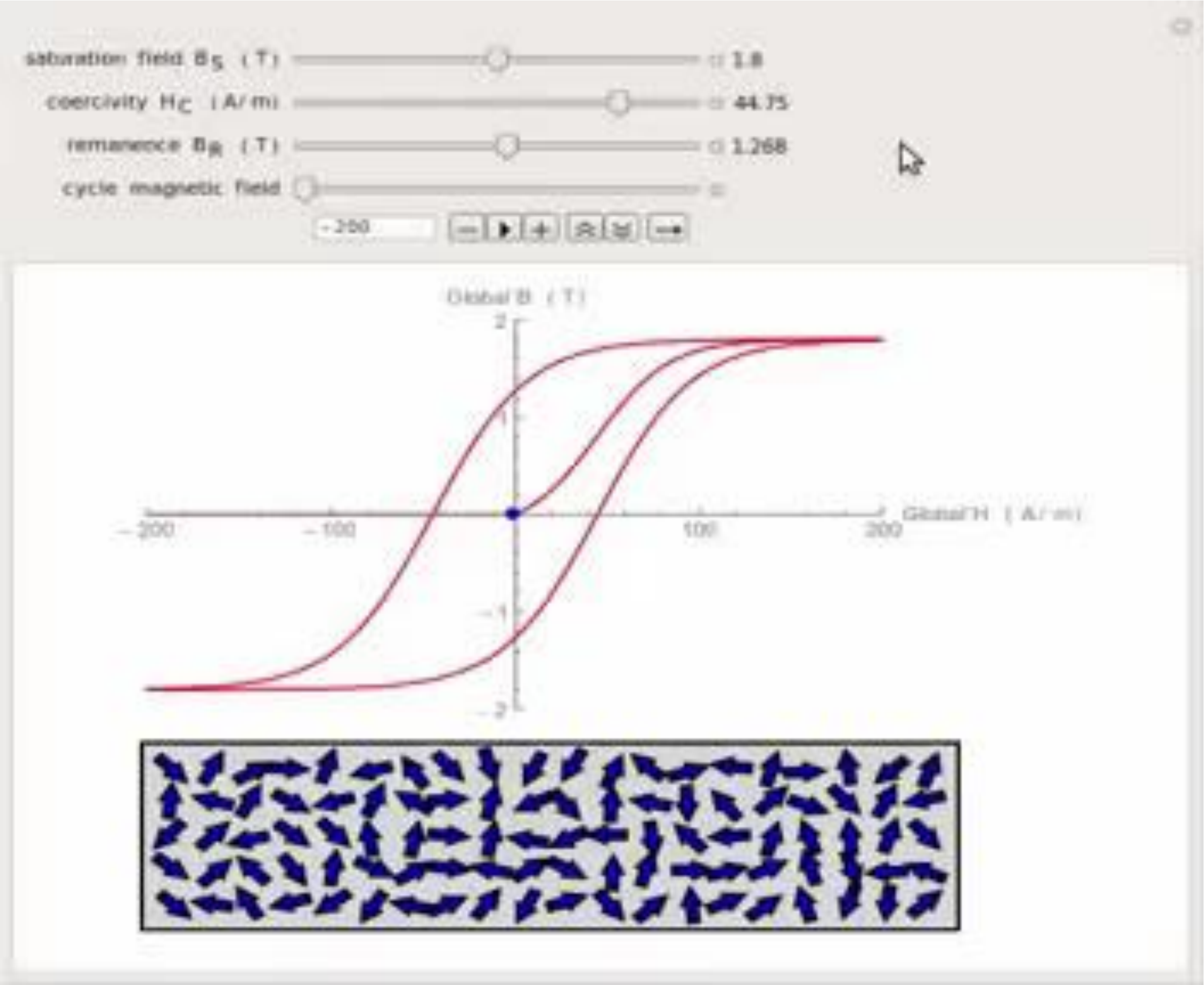
Hysterisis



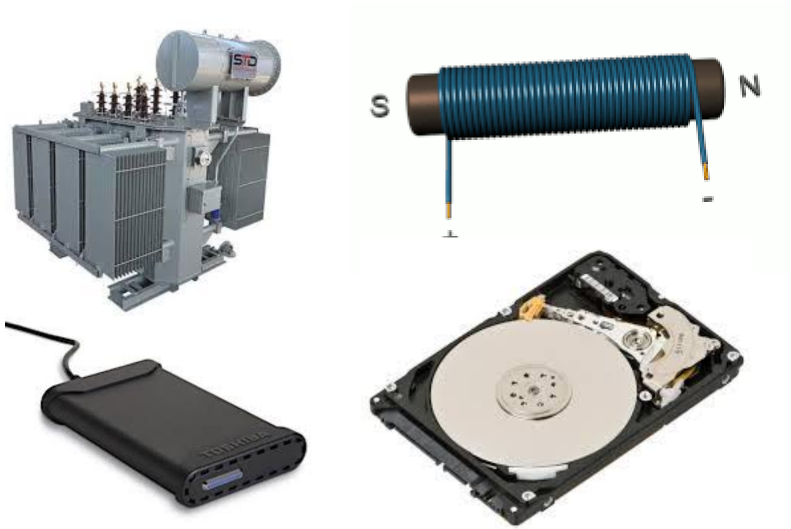
https://demonstrations.wolfram.com/MagneticHysteresis/

Examples & Applications

- *Curie temperature, Permeability, Coercive field and Remnant Magnetization.*
- *Hysteresis is always related to memory*
- *Memory is the previous experience of external fields and hence can be used as memory materials.*

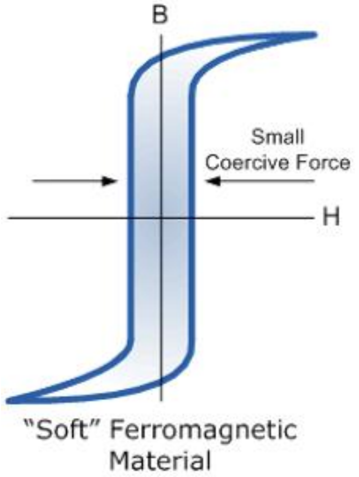
➢ *Examples*
  - *iron, nickel, cobalt*
  - *Cobalt alloys with rare earth elements - gadolinium, dysprosium, samarium and neodymium*

➢ *Some applications*



Soft Ferromagnetic materials

- *Easily magnetisable and demagnetisable*
- *Large saturation magnetisation*
- *Low coercive field (Coercivity is small)*
- *Hysteresis loop is narrow and has low losses*
- *Examples: Iron and Iron alloys*
- *Applications: Transformers, motors or inductors.*

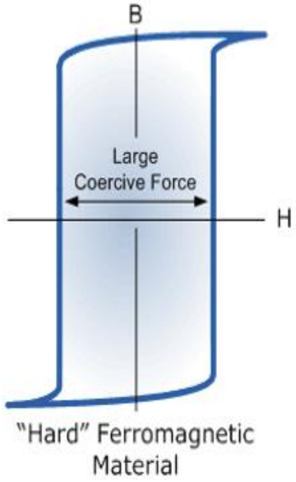


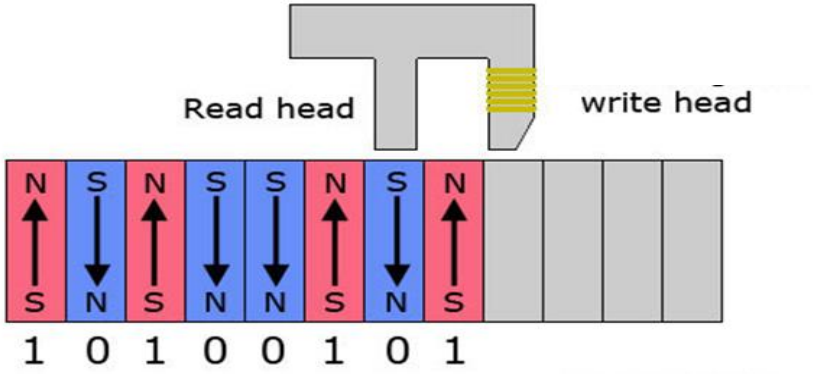
source: https://www.electronics-tutorials.ws/electromagnetism/magnetic-hysteresis.html

Hard Ferromagnetic materials

- ***Difficult to demagnetise***
- ***Exhibit very high retentivity and large coercivity.***
- ***Low permeability***
- ***Area under the hysteresis curve is large indicating the large amount of energy loss.***
- ***Hard, brittle and difficult to shape***

Applications : permanent magnets, Memory devices





source: https://www.electronics-tutorials.ws/electromagnetism/magnetic-hysteresis.html

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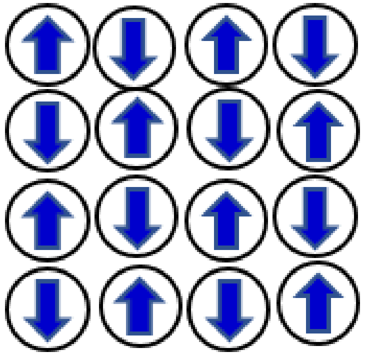
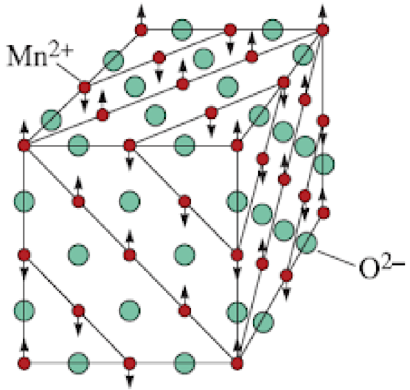
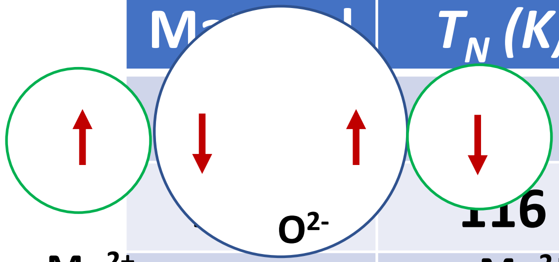
Antiferromagnetic materials

- *Exchange interaction is negative*
- *Equal dipole moments and antiparallel to one another*
- *Magnetization on each sub lattice will add to zero net Magnetization*
- *Net magnetisation is zero below a certain temperature called as the Neel temperature T_N.*
- *Above T_N the materials behave as paramagnetic.*





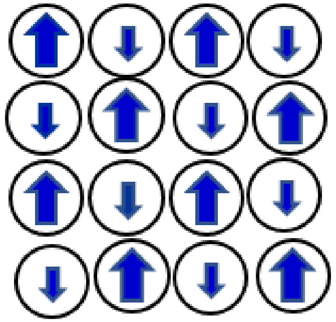
[illegible]	T_N (K)
[illegible]	[illegible]
[illegible]	116
NiO	523



Ref: The Science and Engineering of Materials by Donald R. Askeland, Pradeep P. Fulay, Wendelin J. Wrigh, Ch 20, 6th edition, 2011

Ferrimagnetic materials

- *Different magnetic moments-unequal & antiparallel*
- *Cations of two or more types*
- *Net magnetisation ≠ 0*
- *Exhibit spontaneous magnetisation*
- *Exhibit hysteresis when external field is applied.*
- *Temperature dependent - Above T_c the materials display paramagnetic behaviour.*



$T<T_c$

$H = 0, M \neq 0$

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Ferrimagnetic materials

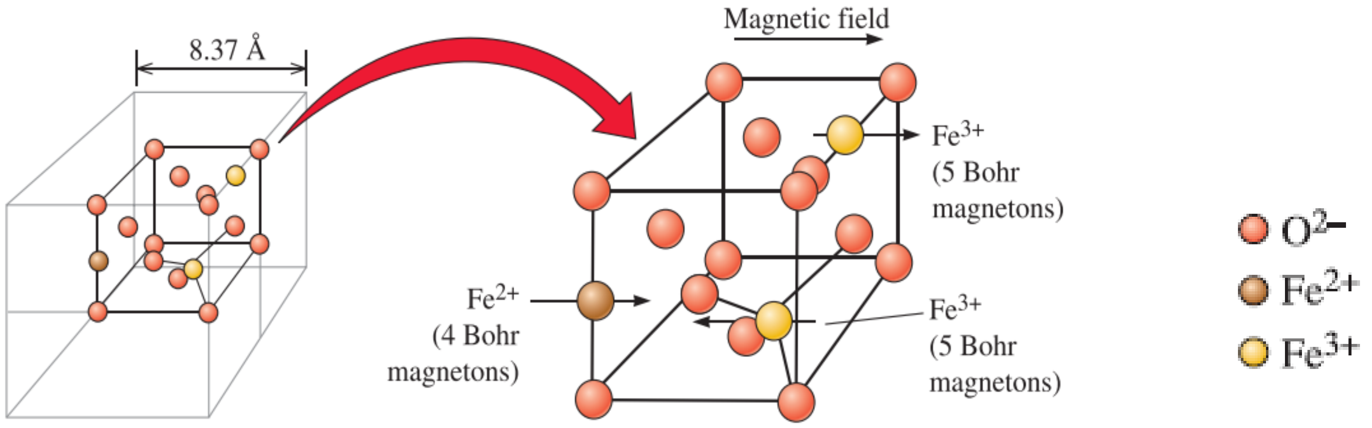
Example:

Fe_3O_4 - two different iron ions, Fe^{2+} and Fe^{3+} & O^{2-}

In each sub cell, $\mu=4\mu_B$ obtained from the Fe^{2+} ions

(magnetic moments from the two Fe^{3+} ions located at tetrahedral and octahedral sites are canceled by each other)

Other Examples are $NiFe_2O_4$, $CoFe_3O_4$, and $BaFe_{12}O_{19}$ etc.



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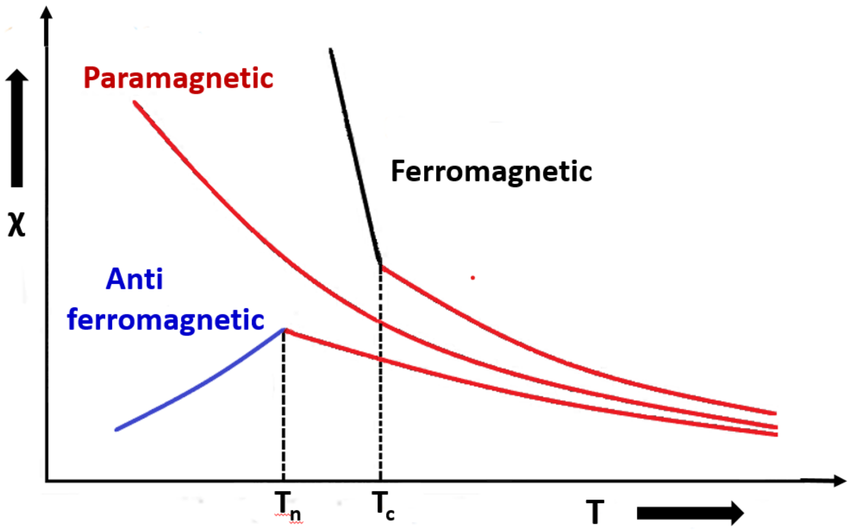
Magnetic susceptibility v/s Temperature

- *Paramagnetic materials - Curies law.*
- *Ferromagnetic materials - Curie Weiss law and exhibit a paramagnetic behaviour above the Curie temperature*
- *Anti-ferromagnetic materials – above T_N the material behaves as a paramagnetic material.*



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Class 51 .   Quiz …

The concepts which are correct are….

1. Above Curie's temperature, ferromagnetic material becomes paramagnetic
2. Net magnetization is zero in ferrimagnetic materials
3. Due to applied magnetic field, magnetic moments experience torque
4. Retentivity is the property of antiferromagnetic materials
5. The dipoles in ferrimagnetic materials are equal and parallel
6. Low coercive field is required to demagnetize the hard ferromagnetic material

THANK YOU

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