MAGNETIC MATERIAL

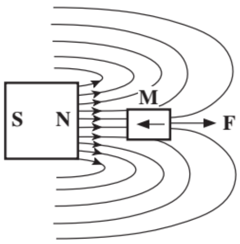
Classification

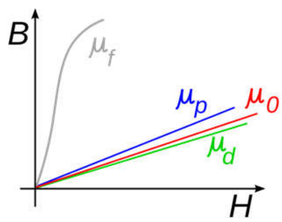
- Materials that does not have permanent magnetic dipoles: Diamagnetic
- Materials that have permanent magnetic dipoles.
  - Paramagnetic
  - Ferromagnetic
  - Antiferromagnetic
  - Ferrimagnetic

Diamagnetic

χ_m	χ_m versus Temp.	Comments and Examples
• Negative and small (-10^{-6}) • Negative and large (-1)	• T independent • Below a critical temp.	• Weakly magnetized when placed in an external magnetic field, in a direction opposite to the applied field. • Atoms of the materials have closed shells. • Organic materials, covalent solids, e.g., Si, Ge; some ionic solids, e.g., alkalihalides; some metals, e.g., Cu, Ag, Au • Superconductors

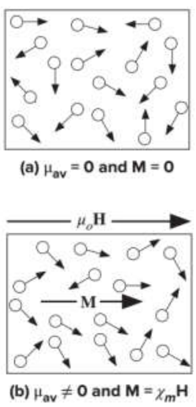
- When placed in a nonuniform magnetic field experiences a force toward smaller fields.

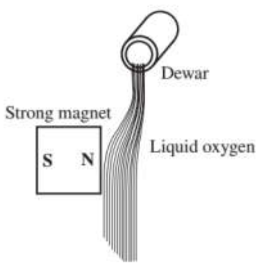


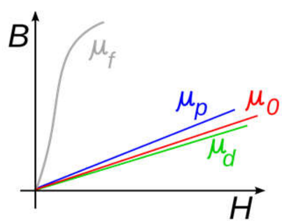


Paramagnetic

χ_m	χ_m versus Temperature	Comments and Examples
Positive and small (10^{-5}–10^{-4})	T independent	• Alignment of spins of conduction electros. • Alkali and transition metals.

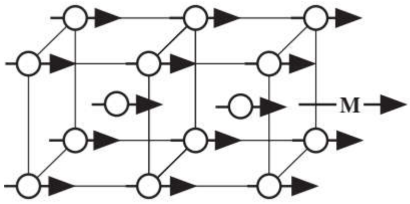


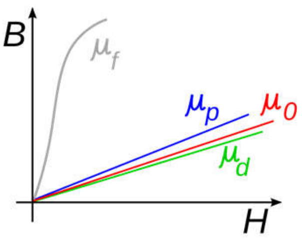




Ferromagnetic

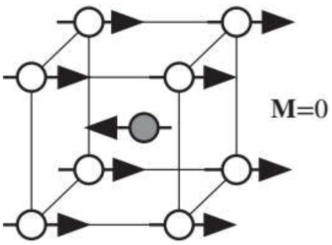
χ_m	χ_m versus Temperature	Comments and Examples
• Positive and very large	• Ferromagnetic below and paramagnetic above Curie temperature	• May possess a large permanent magnetization even in the absence of an applied field. • Some transition and rare earth materials, Fe, Co, Ni, Gd, Dy.





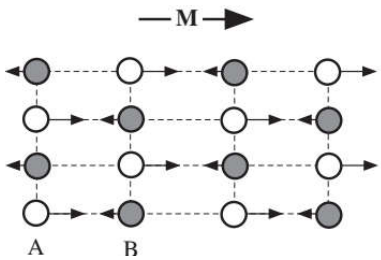
Antiferromagnetic

χ_m	χ_m versus Temperature	Comments and Examples
Positive and small	Antiferromagnetic below and paramagnetic above Néel temperature	• Cannot possess any magnetization in the absence of an applied field. • Mainly salts and oxides of transition metals, e.g., MnO, NiO, MnF_2, and some transition metals, α-Cr, Mn



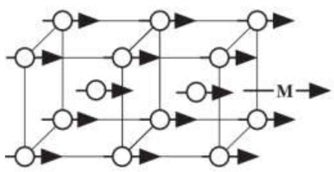
Ferrimagnetic

χ_m	χ_m versus Temperature	Comments and Examples
Positive and very large	Ferrimagnetic below and paramagnetic above Curie temperature	• May possess a large permanent magnetization even in the absence of an applied field. • Ferrites: Fe_3O_4

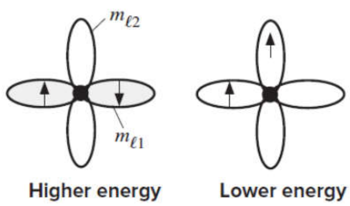


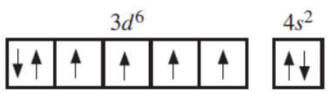
Origin of Ferromagnetism

- Magnetized iron crystal: atomic magnetic moments are aligned in the same direction → net magnetization along this direction.
- However, this is not alignment of bar magnets in an SNSN . . . fashion as the magnetic potential energy of interaction is small, indeed smaller than the thermal energy.



- **Hund's rule:**





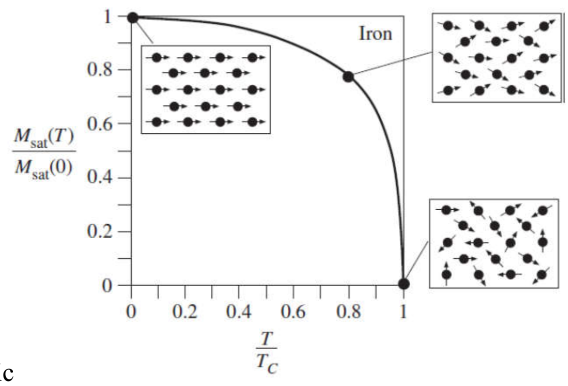
- An isolated Fe atom has four unpaired spins and a spin magnetic moment of 4β.
- $\beta = e\hbar/(2m_e)$ → Bohr magneton

Temperature Effect on Ferromagnetism

- As temperature increases, lattice vibrations become more energetic and leads to a frequent disruption of the alignments of the spins.

- The ferromagnetic behavior disappears at a critical temperature called the **Curie temperature:**

  Ferromagnetic → Paramagnetic



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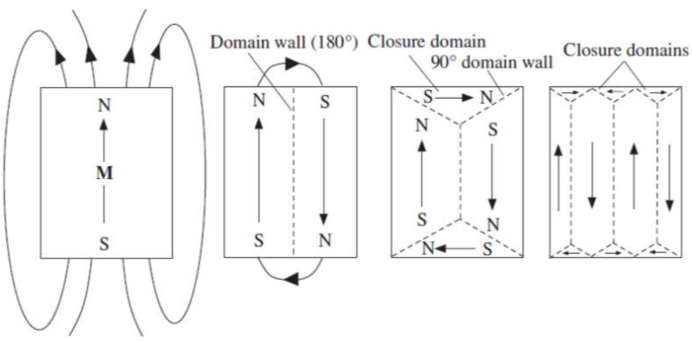
Magnetic Domains

- If a magnetized of iron is heated to above Curie temperature and then allowed to cool in the absence of a magnetic field, it will possess no net magnetization.
- The reason for the absence of net magnetization is due to the formation of **magnetic domains** that effectively cancel each other.
- A **magnetic domain** is a region of the crystal in which all the spin magnetic moments are aligned to produce a magnetic moment in one direction only.



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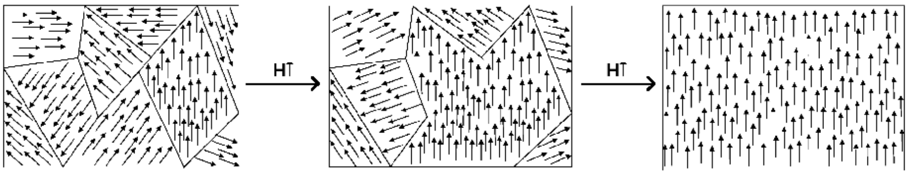
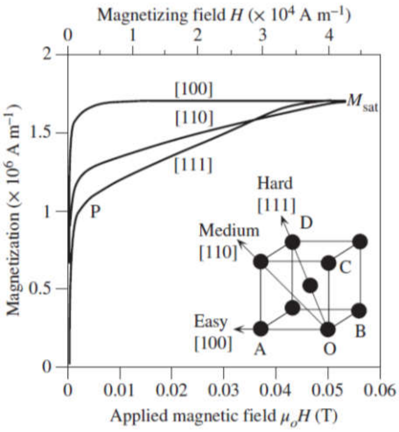
Externally Applied Field

- Rotation of orientation and increase in size of magnetic domains in response to an externally applied field.



Easy Directions & Anisotropy

- The magnetization of each domain is normally along one of the preferred directions in which the atomic spin alignments are easiest → Easy Directions.
- For iron, the magnetization is easiest along any one of six ⟨100⟩ directions (along cube edges).
- Ferromagnetic crystals exhibit magnetic anisotropy: magnetic properties are different along different crystal directions.
- **Iron (BCC):** the spins in a domain are most easily aligned in any of the six [100] directions → six edges of the cubic unit cell.



Class Test – 4

Day: 9 September 2019

Syllabus: Lectures 24–25

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