Magnetic materials

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Summary

- Source of magnetic field – magnetic moment
- In materials, magnetic moment arises due to electron
  - Orbital angular momentum
  - Spin angular momentum
- In the presence of external magnetic field (H), orbital and spin magnetic moment (m_l , m_s) get changed such that
  - $\Delta\overrightarrow{m_l} \propto -\vec{H}$
  - $\Delta\overrightarrow{m_s} \propto \vec{H}$ and
  - $\Delta\overrightarrow{m_s} \gg \Delta\overrightarrow{m_l}$
- Classification
  - Diamagnetic material
  - Paramagnetic material
  - Ferromagnetic material

Classification

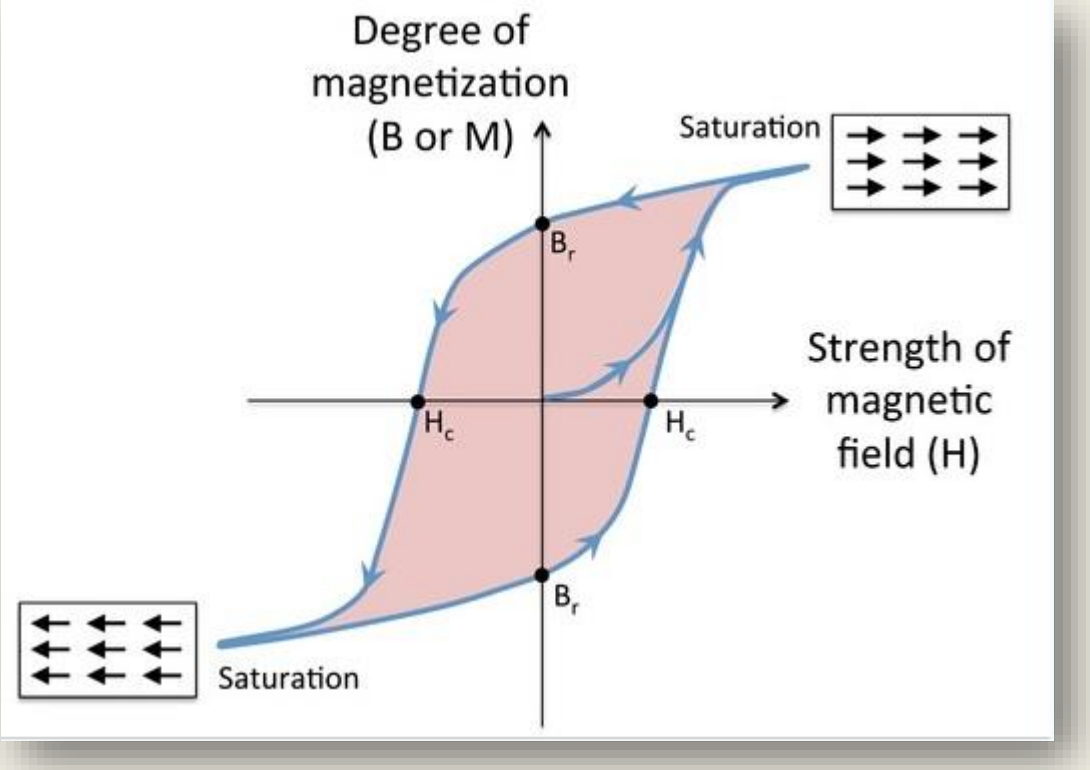
- Diamagnetic material
  - Fully filled orbitals
  - $\Delta\overrightarrow{m_s} = 0$ while $\Delta\overrightarrow{m_l} \propto -\vec{H}$: distortion of orbitals
  - Magnetization $\vec{M} \propto -\vec{H}$
  - $\overrightarrow{B_{in}} < \overrightarrow{B_{out}}$
  - Negative susceptibility (χ)
  - Independent of temperature
- Paramagnetic material
  - Unpaired electrons in orbital : exists dipole moment of atoms
  - $\Delta\overrightarrow{m_s} \neq 0$: alignment of moment in the direction of field
  - Magnetization $\vec{M} \propto \vec{H}$
  - $\overrightarrow{B_{in}} > \overrightarrow{B_{out}}$
  - Positive susceptibility
  - Temperature dependent , $\chi(T) = C/T$

Magnetic materials

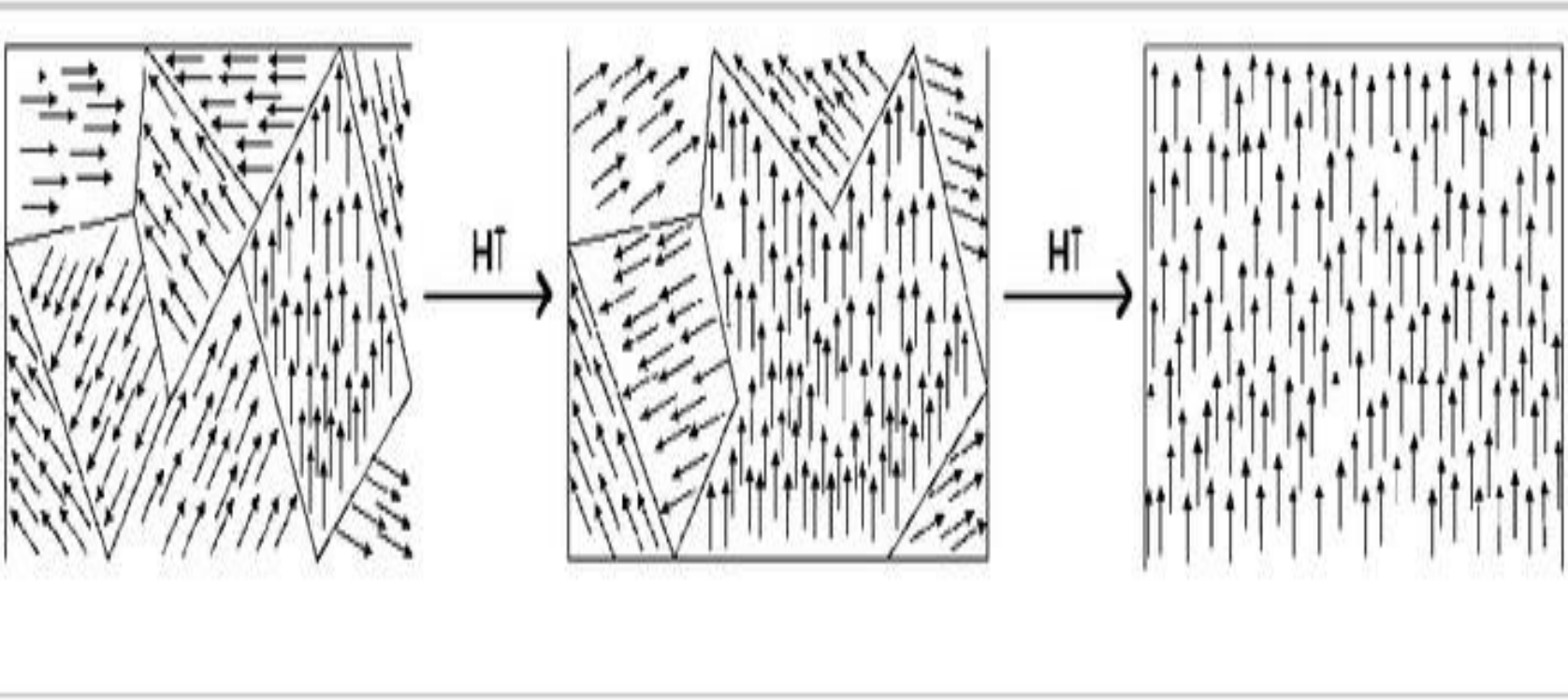
- Definition of terms
- Classification of magnetic materials and properties
- Domain theory of ferromagnetism
- Hard and soft magnetic materials
- **Conductors**: Classical free electron theory (Lorentz–Drude theory), Electrical conductivity
- **Superconductors**: Definition, Meissner effect, Type I & II superconductors.

Ferromagnetic material

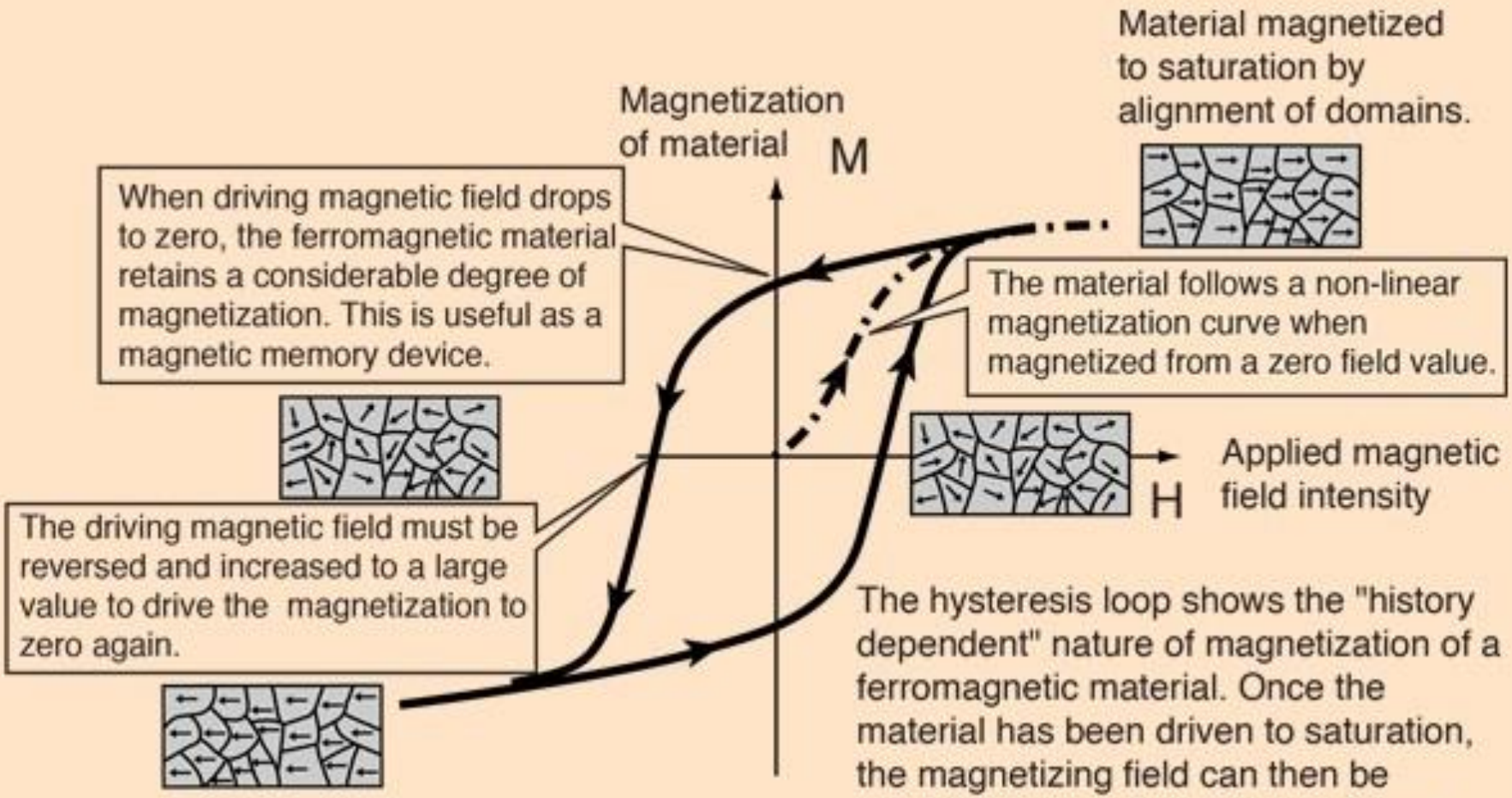
- Spontaneous magnetization
- Show hysteresis
- $\chi(T) = C/(T - T_c)$: Curie-Weiss law



Domain theory of ferromagnetic material

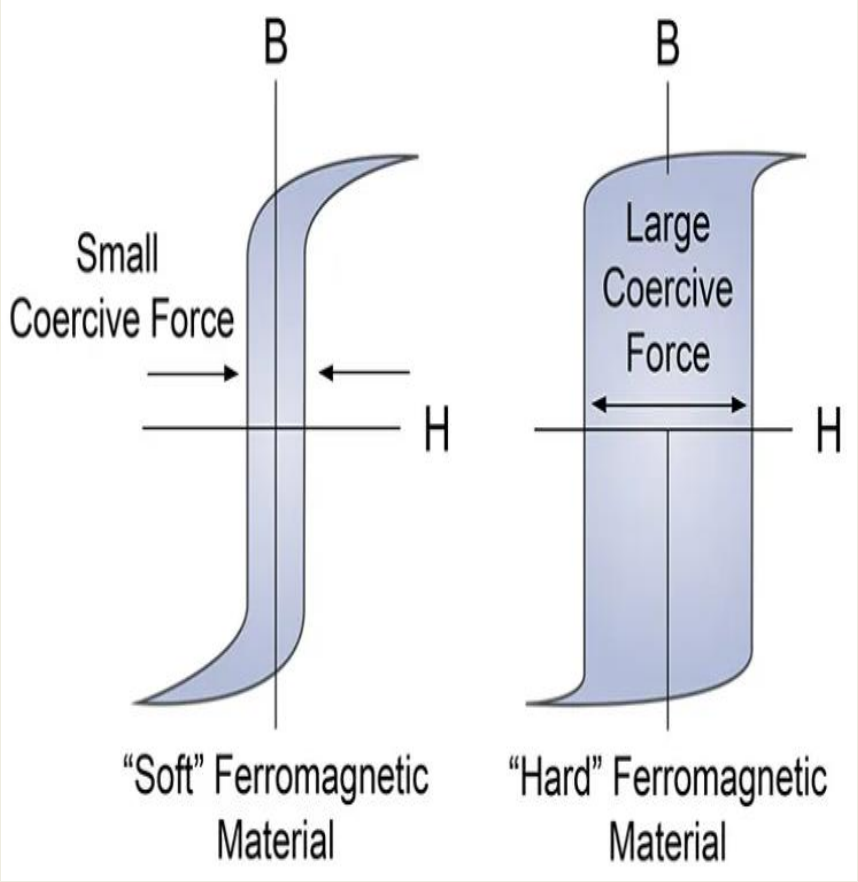


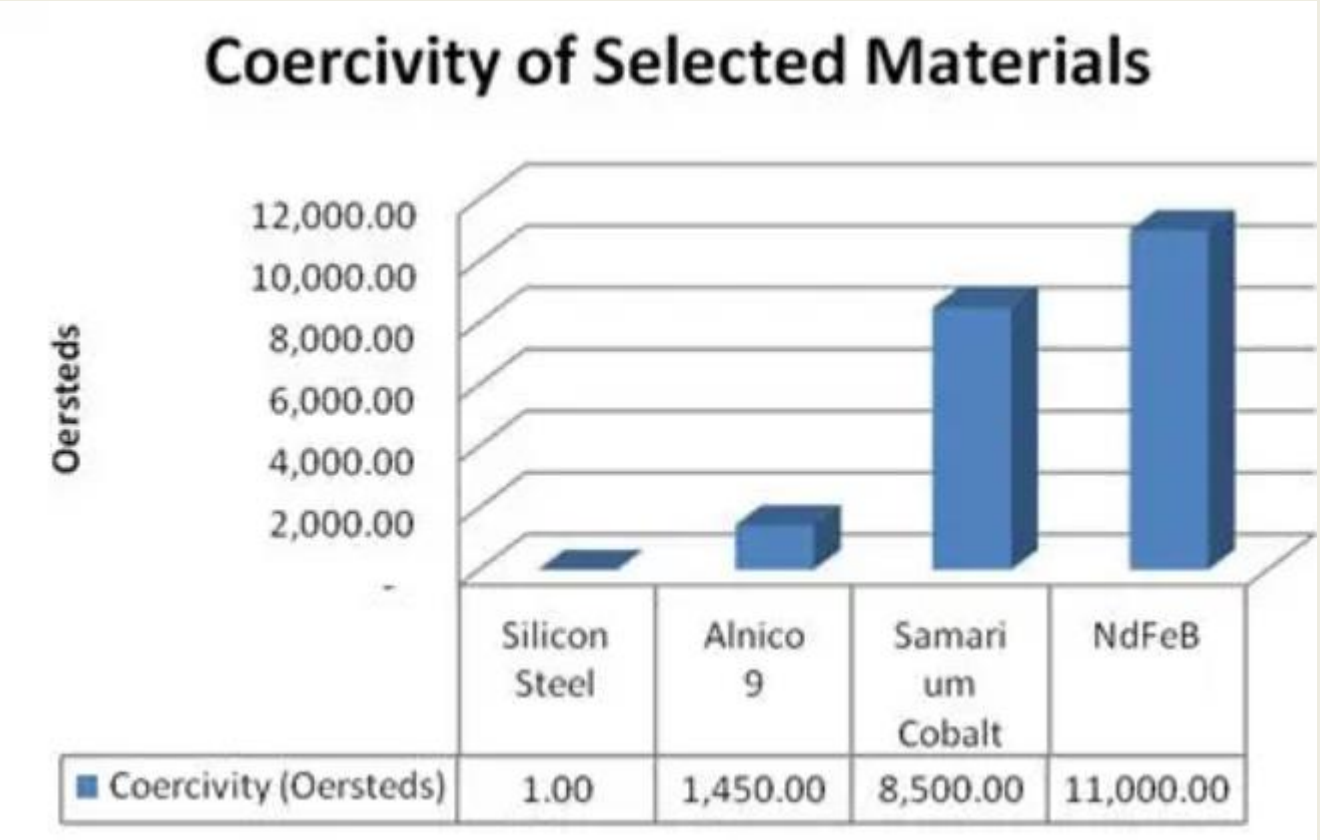
Hysteresis Loop

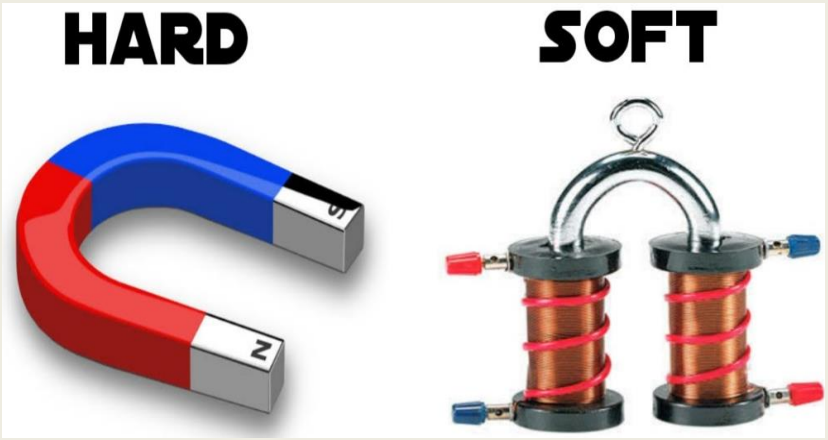


Hard and soft magnetic materials

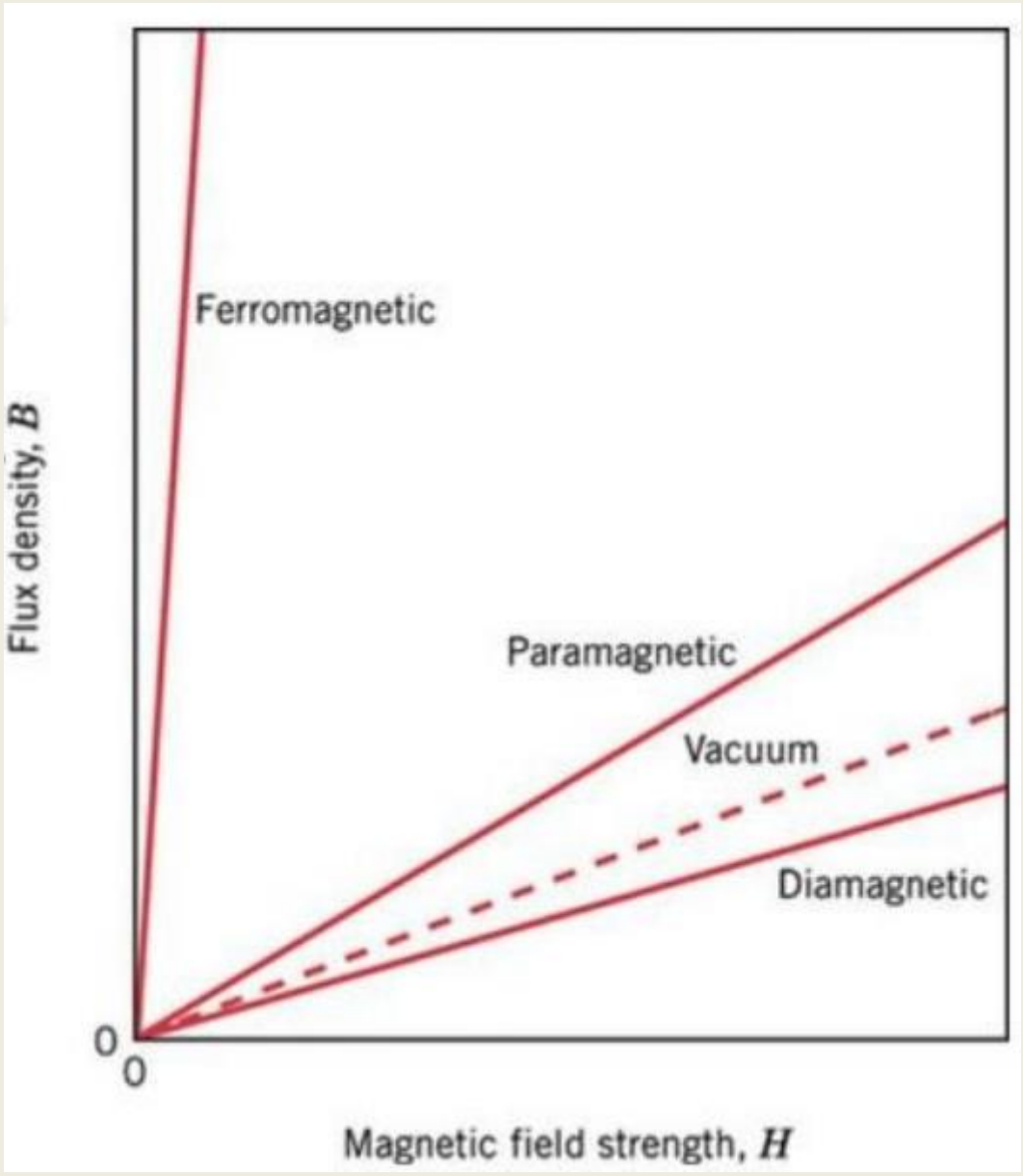
- Magnetic materials with strong Coercivity are called **hard magnets**
  - Cannot easily demagnetized
  - Large BH product/hysteresis loss
  - Used as permanent magnets
  - Ex- Iron-nickel-aluminum alloy, copper-nickel-cobalt alloy, copper-nickel-iron alloy
- Magnets with weak Coercivity are called **soft magnets**
  - Can easily be demagnetized
  - Small BH product/hysteresis loss
  - Used in electromagnet in a motor, cores of transformer, Radars
  - Iron, Iron-silicon alloy, ferrous-nickel alloy, ferrites

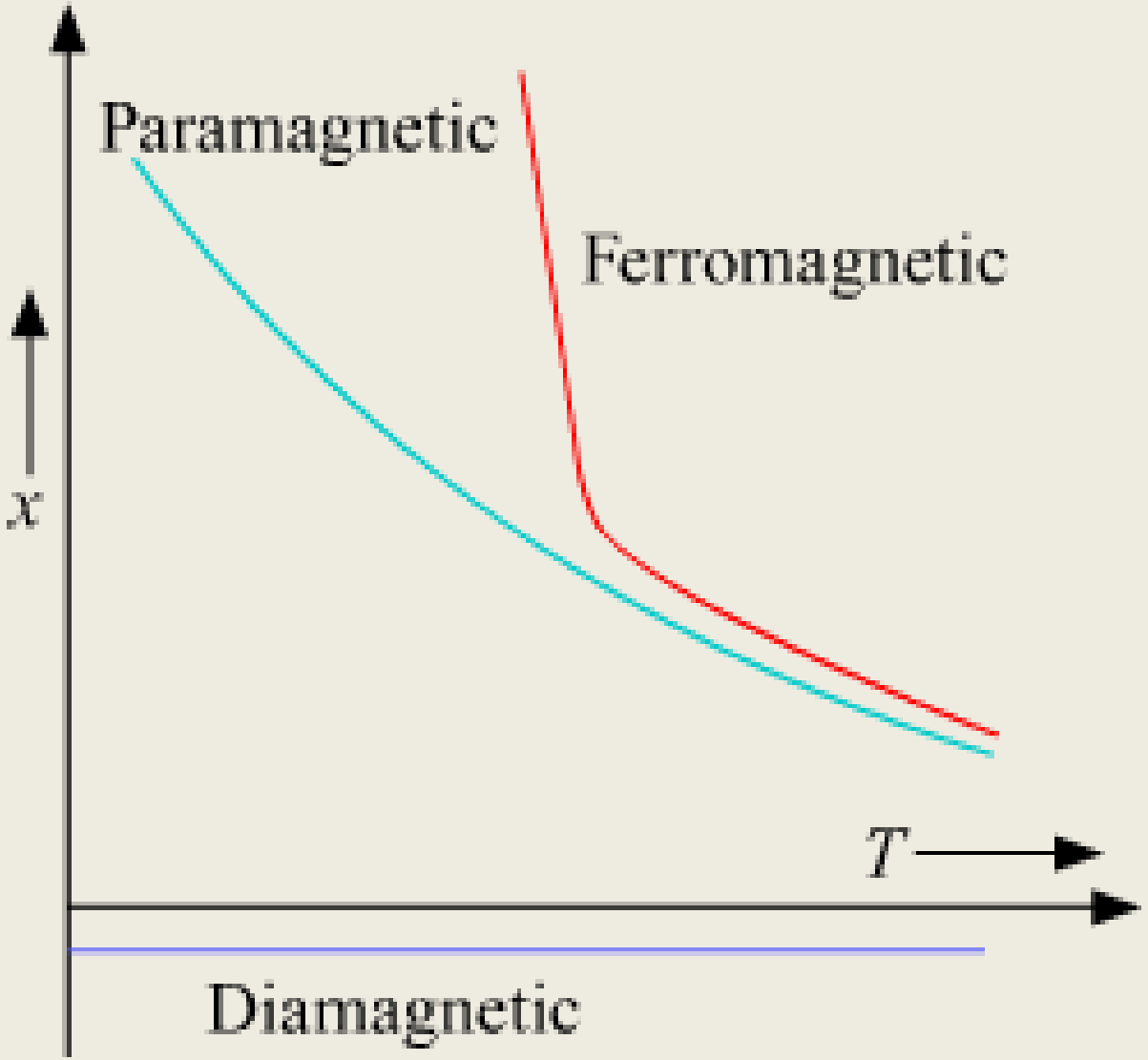



Coercivity of Selected Materials
Oersteds
12,000.00
10,000.00
8,000.00
6,000.00
4,000.00
2,000.00
-
Silicon Steel
Alnico 9
Samarium Cobalt
NdFeB
Coercivity (Oersteds)
1.00
1,450.00
8,500.00
11,000.00


HARD
SOFT
S
N

Material	Initial Relative Permeability
Magnetite, powdered	1.5
Steel	50
Cobalt	70
Nickel	110
Iron (99.8%) annealed	150
78 Permalloy	8,000
Mu-metal	20,000
Ferrites (various)	100 – 20,000


Ferromagnetic
Paramagnetic
Vacuum
Diamagnetic
Flux density, B
0
0
Magnetic field strength, H


Paramagnetic
Ferromagnetic
x
T
Diamagnetic

Room temperature magnetic susceptibility

Diamagnetics		*Paramagnetics*	
Material	*Susceptibility χ_m (volume) (SI units)*	*Material*	*Susceptibility χ_m (volume) (SI units)*
Aluminum oxide	-1.81×10^{-5}	Aluminum	2.07×10^{-5}
Copper	-0.96×10^{-5}	Chromium	3.13×10^{-4}
Gold	-3.44×10^{-5}	Chromium chloride	1.51×10^{-3}
Mercury	-2.85×10^{-5}	Manganese sulfate	3.70×10^{-3}
Silicon	-0.41×10^{-5}	Molybdenum	1.19×10^{-4}
Silver	-2.38×10^{-5}	Sodium	8.48×10^{-6}
Sodium chloride	-1.41×10^{-5}	Titanium	1.81×10^{-4}
Zinc	-1.56×10^{-5}	Zirconium	1.09×10^{-4}

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- Properties of magnetic materials
- Domain theory of ferromagnetism
- Hard and soft magnetic materials