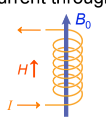
Chapter 20: Magnetic Properties

ISSUES TO ADDRESS...

- What are the important magnetic properties?
- ____?
- How are magnetic materials classified?
- How does ______________________________?
- What is superconductivity and how do magnetic fields effect the behavior of superconductors?

Generation of a Magnetic Field -- Vacuum

- Created by current through a coil:



N = _______________
ℓ = length of each turn (m)
I = _______________
H = applied magnetic field (ampere-turns/m)
B_0 = magnetic flux density in a vacuum (________)

- Computation of the applied magnetic field, H:

$$H = \frac{N I}{\ell}$$

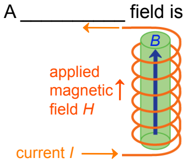
- Computation of the ________________ in a vacuum, B_0:

$$B_0 = \mu_0 H$$

μ_0: permeability of a vacuum (1.257×10^{-6} Henry/m)

Generation of a Magnetic Field -- within a Solid Material

- A __________ field is induced in the material



B = Magnetic __________ (tesla) inside the material

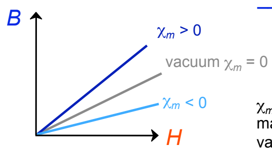
$$B = \mu H$$

μ: permeability of a solid

- Relative permeability (____________) $\mu_r = \dfrac{\mu}{\mu_0}$

Generation of a Magnetic Field -- within a Solid Material (cont.)

- ________________ $M = \chi_m H$ ← Magnetic susceptibility (dimensionless)
- B in terms of H and M $\quad B = \mu_0 H + \mu_0 M$
- Combining the above two equations:



________________ $= (1 + \chi_m)\mu_0 H$

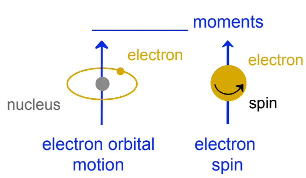
μ_0: permeability of a vacuum: (1.26×10^{-6} Henry/m)

χ_m is a measure of a material's magnetic response relative to a vacuum

Chapter 20 -

Origins of Magnetic Moments

- Magnetic moments arise from _____________ and the spins on electrons.

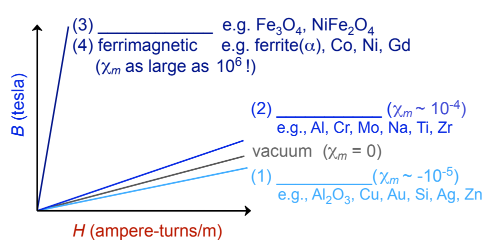


Adapted from Fig. 20.4, *Callister & Rethwisch 8e.*

- Net _________________________:
  -- sum of moments from all electrons.
- Four types of response...

Chapter 20 - 5

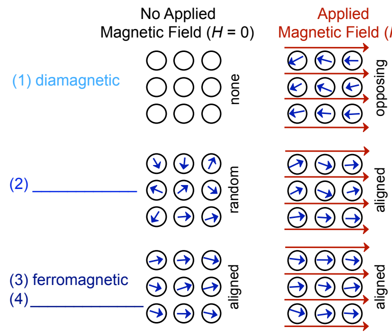
Types of Magnetism



Plot adapted from Fig. 20.6, *Callister & Rethwisch 8e.* Values and materials from Table 20.2 and discussion in Section 20.4, *Callister & Rethwisch 8e.*

Chapter 20 - 6

Magnetic Responses for 4 Types



Adapted from Fig. 20.5(a), *Callister & Rethwisch 8e.*

Adapted from Fig. 20.5(b), *Callister & Rethwisch 8e.*

Adapted from Fig. 20.7, *Callister & Rethwisch 8e.*

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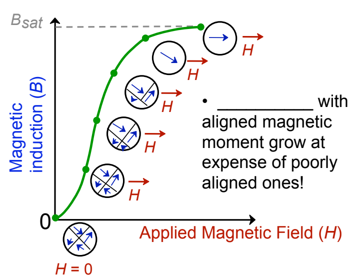
Domains in Ferromagnetic & Ferrimagnetic Materials

- As the applied field (H) increases the __________ domains change shape and size by movement of domain boundaries.



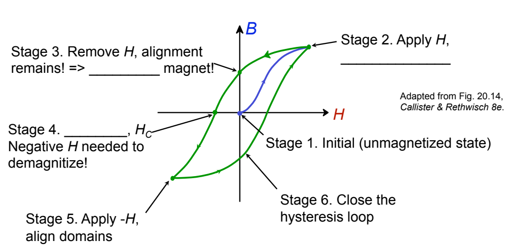
- __________ with aligned magnetic moment grow at expense of poorly aligned ones!

Adapted from Fig. 20.13, *Callister & Rethwisch 8e.* (Fig. 20.13 adapted from O.H. Wyatt and D. Dew-Hughes, *Metals, Ceramics, and Polymers*, Cambridge University Press, 1974.)

Chapter 20 - 8

Hysteresis and Permanent Magnetization

- The magnetic hysteresis phenomenon



Adapted from Fig. 20.14, *Callister & Rethwisch 8e.*

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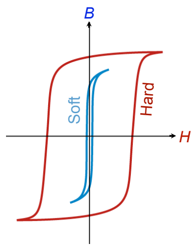
Hard and Soft Magnetic Materials

_____ magnetic materials:
-- _____ coercivities
-- used for permanent magnets
-- add particles/voids to inhibit domain wall motion
-- example: tungsten steel -- H_c = 5900 amp-turn/m)

_______ magnetic materials:
-- _____ coercivities
-- used for electric motors
-- example: commercial iron 99.95 Fe



Adapted from Fig. 20.19, *Callister & Rethwisch 8e.* (Fig. 20.19 from K.M. Ralls, T.H. Courtney, and J. Wulff, *Introduction to Materials Science and Engineering*, John Wiley and Sons, Inc., 1976.)

Chapter 20 - 10

Magnetic Storage

- Digitized data in the form of ___________ are transferred to and recorded digitally on a magnetic medium (tape or disk)
- This transference is accomplished by a recording system that consists of a ________________
  - -- "write" or record data by applying a magnetic field that aligns domains in small regions of the ________ medium
  - -- "read" or ________ data from medium by sensing changes in magnetization

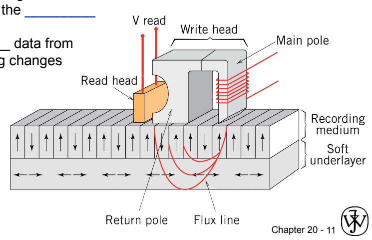


Fig. 20.23, *Callister & Rethwisch 8e.*

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Magnetic Storage Media Types

- Hard disk drives (___________/perpendicular media):
  - -- CoCr alloy grains (darker regions) separated by oxide grain boundary segregant layer (lighter regions)
  - -- ___________ direction of each grain is perpendicular to plane of disk

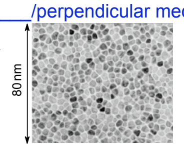
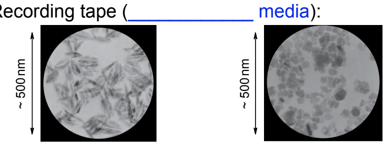


Fig. 20.25, *Callister & Rethwisch 8e.* (Fig. 20.25 from Seagate Recording Media)

- Recording tape (_____________ media):



-- ________ (needle-shaped) ferromagnetic metal alloy particles

-- Tabular (plate-shaped) ferrimagnetic barium-ferrite particles

Fig. 20.24, *Callister & Rethwisch 8e.* (Fig. 20.24 courtesy Fuji Film Inc., Recording Media Division)

Chapter 20 - 12

Superconductivity

Found in 26 metals and hundreds of alloys & compounds

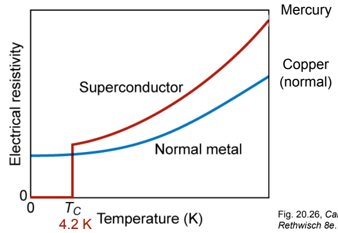


Fig. 20.26, *Callister & Rethwisch 8e.*

- T_C = critical temperature
  = temperature below which material is superconductive

Chapter 20 - 13

Critical Properties of Superconductive Materials

T_C = _________________ - if $T > T_C$ not superconducting
J_C = critical current density - if $J > J_C$ not superconducting
H_C = critical magnetic field - if $H > H_C$ not superconducting

$$H_C(T) = H_C(0)\left(1 - \frac{T^2}{T_C^2}\right)$$

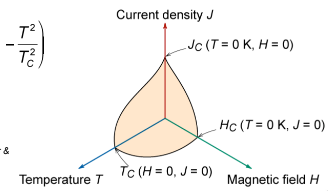


Fig. 20.27, *Callister & Rethwisch 8e.*

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Meissner Effect

- ____________________ expel magnetic fields

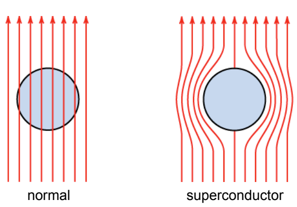

Fig. 20.28, *Callister & Rethwisch 8e.*

- This is why a ______________ will float above a magnet

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Advances in Superconductivity

- Research in ____________ materials was stagnant for many years.
  - Everyone assumed $T_{C,max}$ was about 23 K
  - Many theories said it was impossible to increase T_C beyond this value
- ____ - new materials were discovered with T_C > 30 K
  - ceramics of form $Ba_{1-x} K_x BiO_{3-y}$
  - Started enormous race
    - $Y Ba_2Cu_3O_{7-x}$ T_C = 90 K
    - $Tl_2Ba_2Ca_2Cu_3O_x$ T_C = 122 K
    - difficult to make since oxidation state is very important
- The major problem is that these ceramic materials are inherently brittle.

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Summary

- A magnetic field is produced when a current flows through a wire coil.
- Magnetic induction (B):
  -- an internal magnetic field is induced in a material that is situated within an external magnetic field (H).
  -- magnetic moments result from electron interactions with the applied magnetic field
- Types of material responses to magnetic fields are:
  -- ferrimagnetic and ferromagnetic (large magnetic susceptibilities)
  -- paramagnetic (small and positive magnetic susceptibilities)
  -- diamagnetic (small and negative magnetic susceptibilities)
- Types of ferrimagnetic and ferromagnetic materials:
  -- Hard: large coercivities
  -- Soft: small coercivities
- Magnetic storage media:
  -- particulate barium-ferrite in polymeric film (tape)
  -- thin film Co-Cr alloy (hard drive)

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