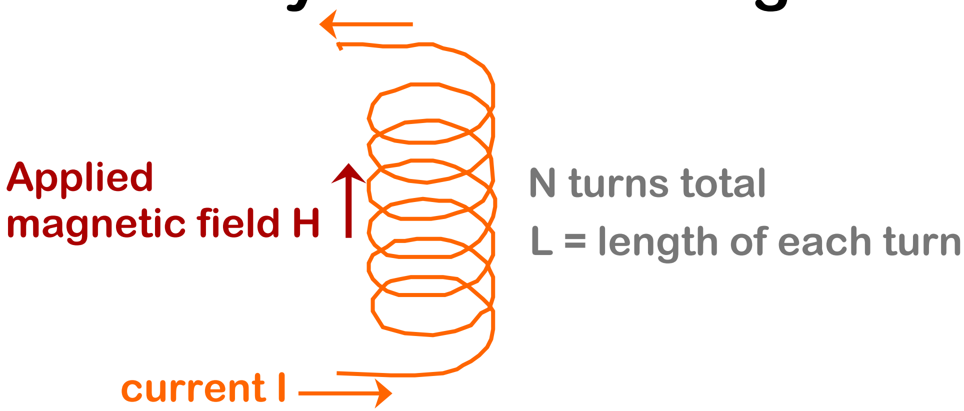
CHAPTER 20: MAGNETIC PROPERTIES

ISSUES TO ADDRESS...

- How do we measure magnetic properties?
- What are the atomic reasons for magnetism?
- How are magnetic material classified?
- Materials design for magnetic storage.

APPLIED MAGNETIC FIELD

- Created by current through a coil:



- Relation for the applied magnetic field, H:

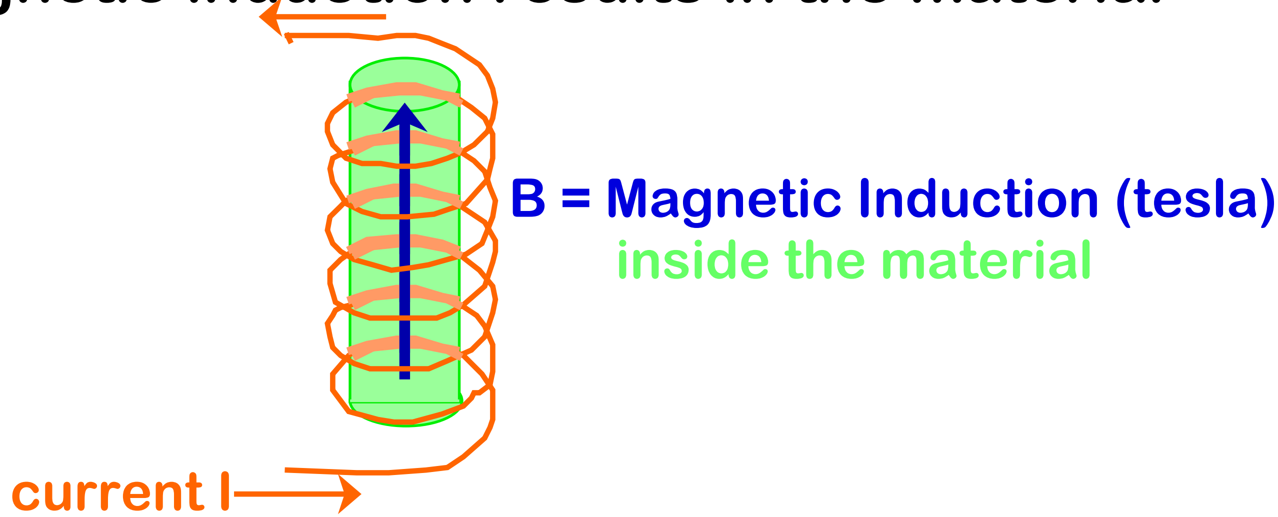
$$H = \frac{NI}{L}$$

current

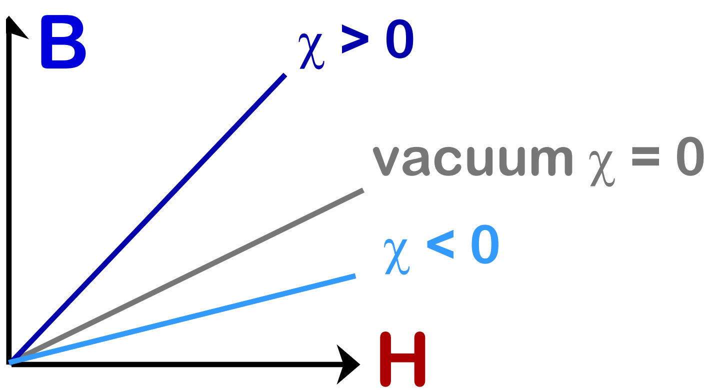
applied magnetic field
units = (ampere-turns/m)

RESPONSE TO A MAGNETIC FIELD

- **Magnetic induction results in the material**



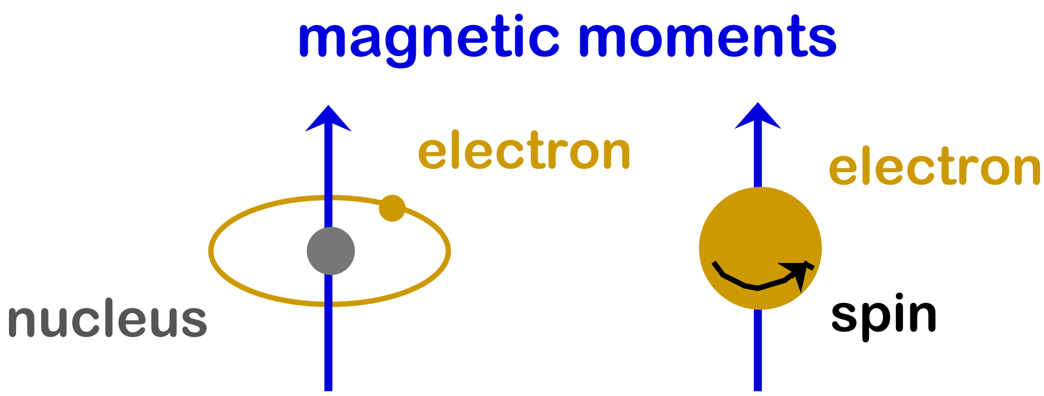
- **Magnetic susceptibility, χ (dimensionless)**



χ measures the material response relative to a vacuum.

MAGNETIC SUSCEPTIBILITY

- Measures the response of electrons to a magnetic field.
- Electrons produce magnetic moments:



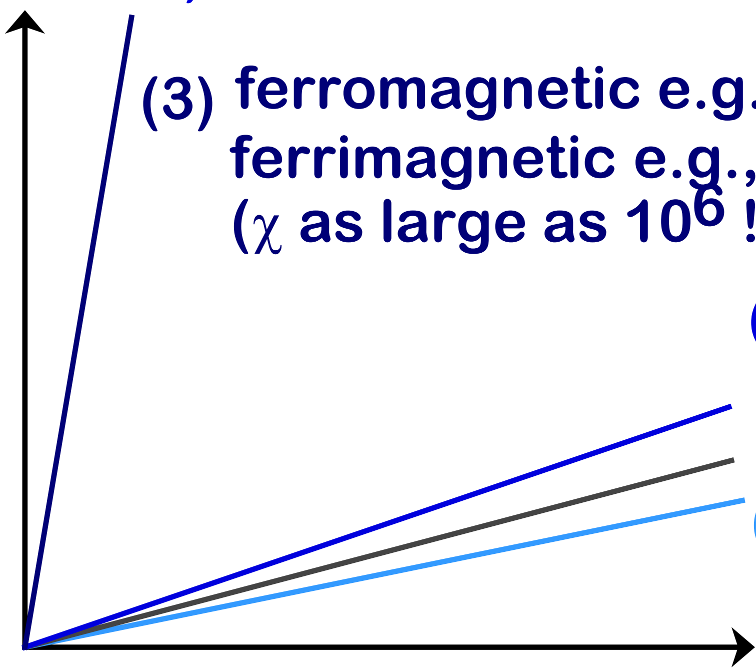
Adapted from Fig. 20.4, *Callister 6e*.

- Net magnetic moment:
  --sum of moments from all electrons.
- Three types of response...

3 TYPES OF MAGNETISM

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

permeability of a vacuum: (1.26 x 10^{-6} Henries/m)



Plot adapted from Fig. 20.6, *Callister 6e*. Values and materials from Table 20.2 and discussion in Section 20.4, *Callister 6e*.

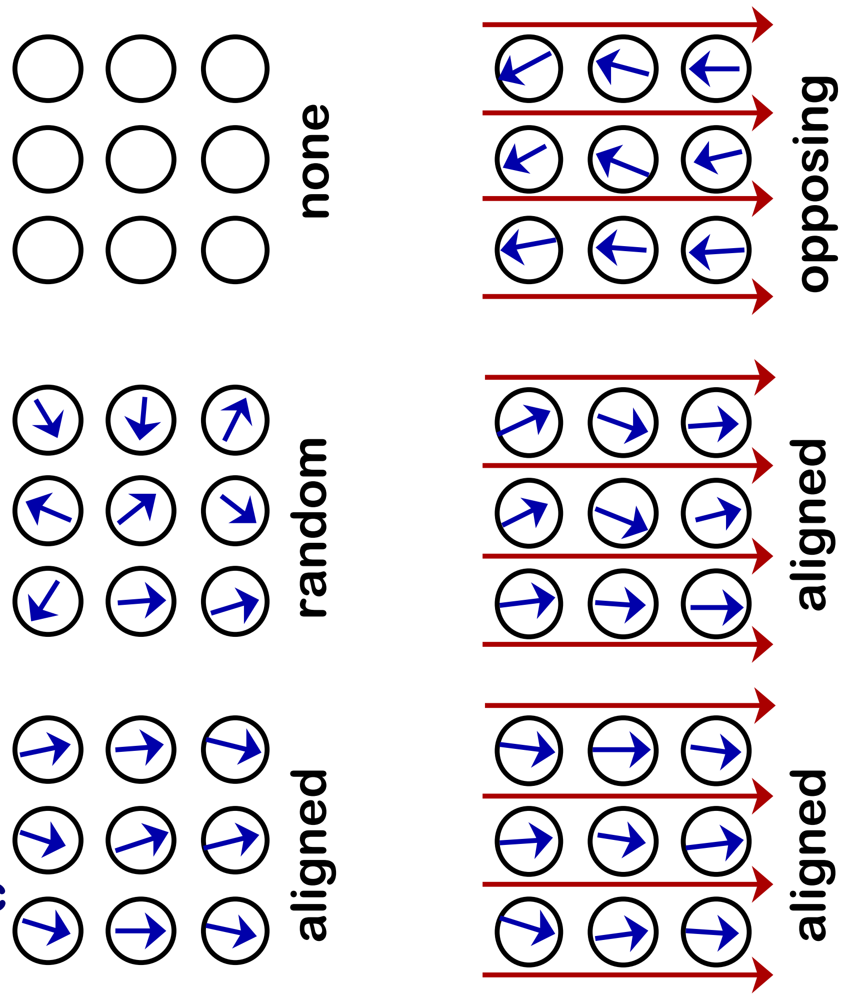
MAGNETIC MOMENTS FOR 3 TYPES

No Applied Magnetic Field (H = 0) | Applied Magnetic Field (H)

(1) diamagnetic

(2) paramagnetic

(3) ferromagnetic
ferrimagnetic



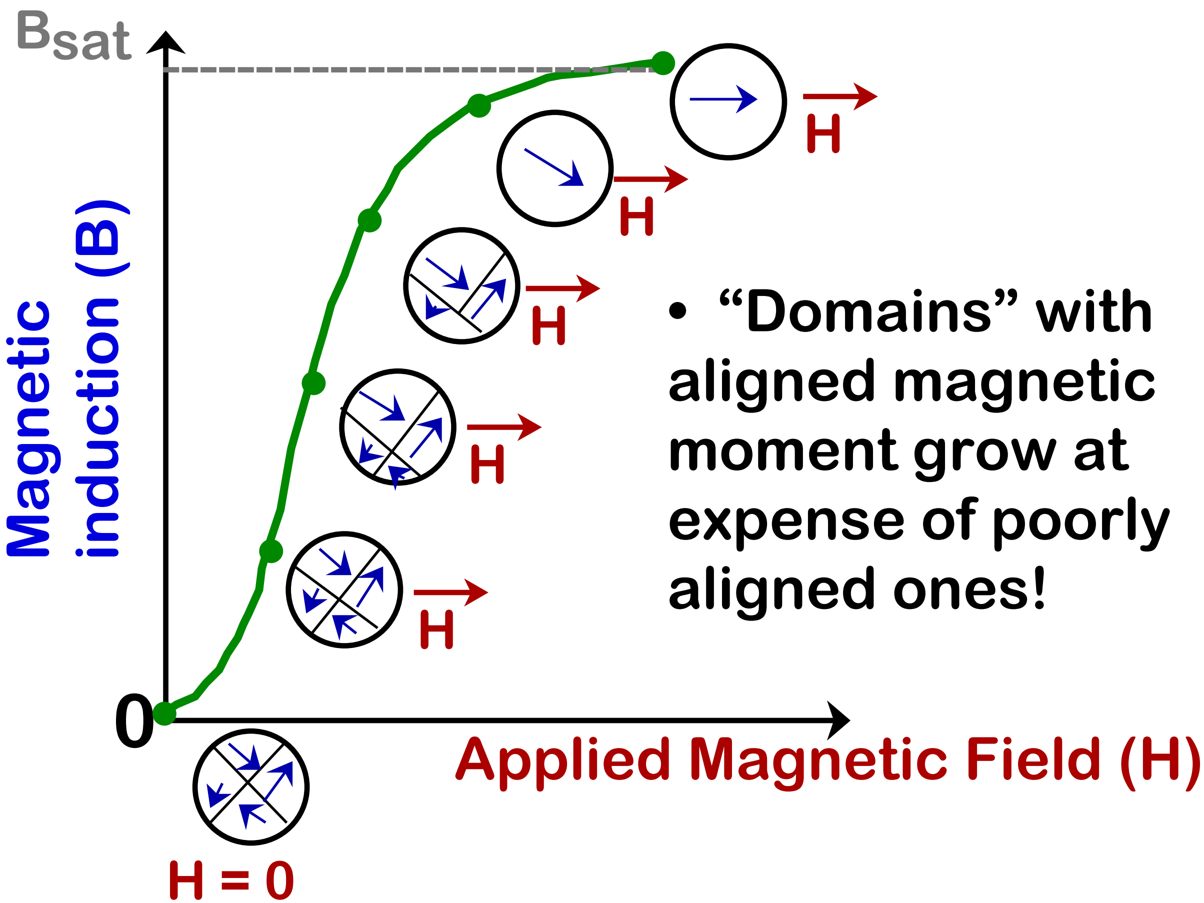
Adapted from Fig. 20.5(a), *Callister 6e.*

Adapted from Fig. 20.5(b), *Callister 6e.*

Adapted from Fig. 20.7, *Callister 6e.*

FERRO- & FERRI-MAGNETIC MATERIALS

- **As the applied field (H) increases...**
  --the magnetic moment aligns with H.



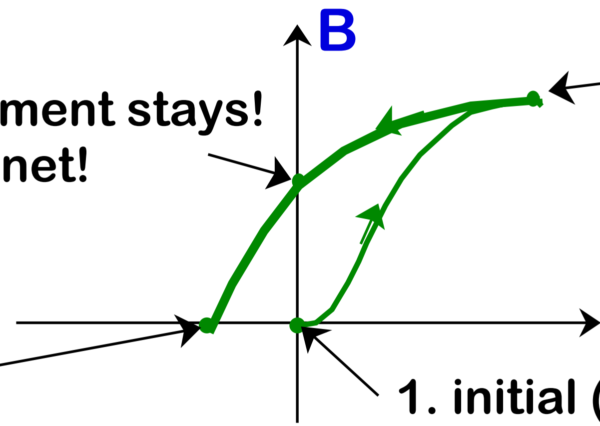
- **"Domains" with aligned magnetic moment grow at expense of poorly aligned ones!**

Adapted from Fig. 20.13, *Callister 6e.* (Fig. 20.13 adapted from O.H. Wyatt and D. Dew-Hughes, *Metals, Ceramics, and Polymers*, Cambridge University Press, 1974.)

PERMANENT MAGNETS

- **Process:**

3. remove H, alignment stays!
-> permanent magnet!



2. apply H, cause alignment

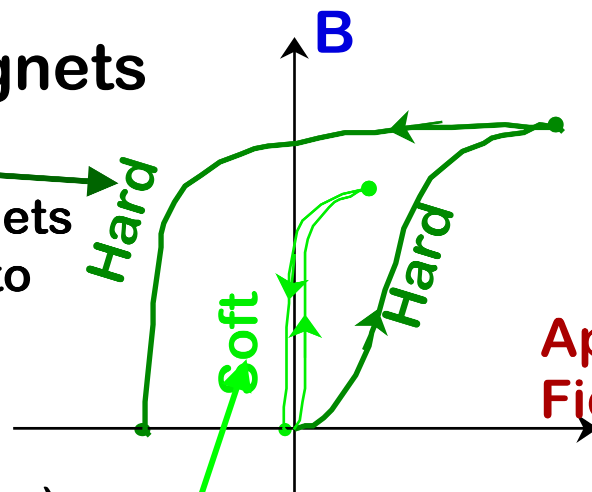
Adapted from Fig. 20.14, *Callister 6e*.

1. initial (unmagnetized state)

4. Coercivity, H_C:
Negative H needed to demagnitize!

- **Hard vs Soft Magnets**

large coercivity
--good for perm magnets
--add particles/voids to make domain walls hard to move (e.g., tungsten steel: H_C = 5900 amp-turn/m)



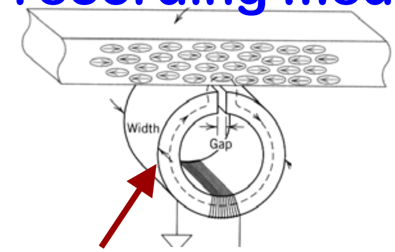
Adapted from Fig. 20.16, *Callister 6e*. (Fig. 20.16 from K.M. Ralls, T.H. Courtney, and J. Wulff, *Introduction to Materials Science and Engineering*, John Wiley and Sons, Inc., 1976.)

small coercivity--good for elec. motors (e.g., commercial iron 99.95 Fe)

MAGNETIC STORAGE

- Information is stored by magnetizing material.
- Head can...
  - --apply magnetic field H & align domains (i.e., magnetize the medium).
  - --detect a change in the magnetization of the medium.

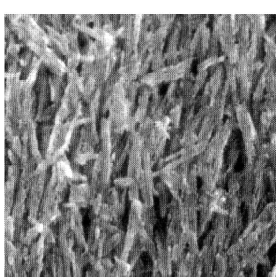
Simulation of hard drive courtesy Martin Chen. Reprinted with permission from International Business Machines Corporation.



Adapted from Fig. 20.18, *Callister 6e*. (Fig. 20.18 from J.U. Lemke, *MRS Bulletin*, Vol. XV, No. 3, p. 31, 1990.)

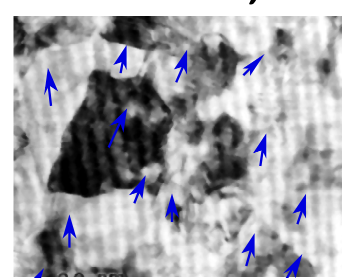
- Two media types:
  - --Particulate: needle-shaped γ-Fe_2O_3. +/- mag. moment along axis. (tape, floppy)
  - --Thin film: CoPtCr or CoCrTa alloy. Domains are ~ 10-30nm! (hard drive)

Adapted from Fig. 20.19, *Callister 6e*. (Fig. 20.19 courtesy P. Rayner and N.L. Head, IBM Corporation.)



~2.5μm

~60nm



Adapted from Fig. 20.20(a), *Callister 6e*. (Fig. 20.20(a) from M.R. Kim, S. Guruswamy, and K.E. Johnson, *J. Appl. Phys.*, Vol. 74 (7), p. 4646, 1993.)

SUMMARY

- A magnetic field can be produced by:
  --putting a current through a coil.
- Magnetic induction:
  --occurs when a material is subjected to a magnetic field.
  --is a change in magnetic moment from electrons.
- Types of material response to a field are:
  --ferri- or ferro-magnetic (large magnetic induction)
  --paramagnetic (poor magnetic induction)
  --diamagnetic (opposing magnetic moment)
- Hard magnets: large coercivity.
- Soft magnets: small coercivity.
- Magnetic storage media:
  --particulate γ-Fe_2O_3 in polymeric film (tape or floppy)
  --thin film CoPtCr or CoCrTa on glass disk (hard drive)

Note: For materials selection cases related to a magnet coil, see slides 22-11 to 22-15.