

CHAPTER 20:

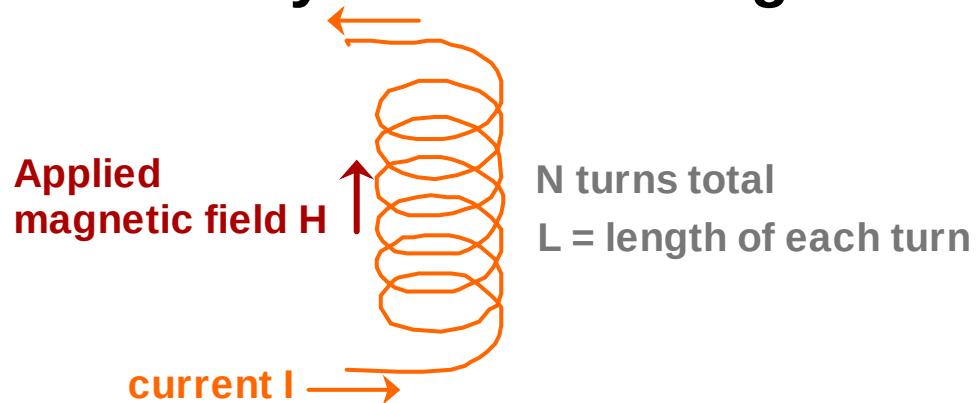
MAGNETIC PROPERTIES

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 :

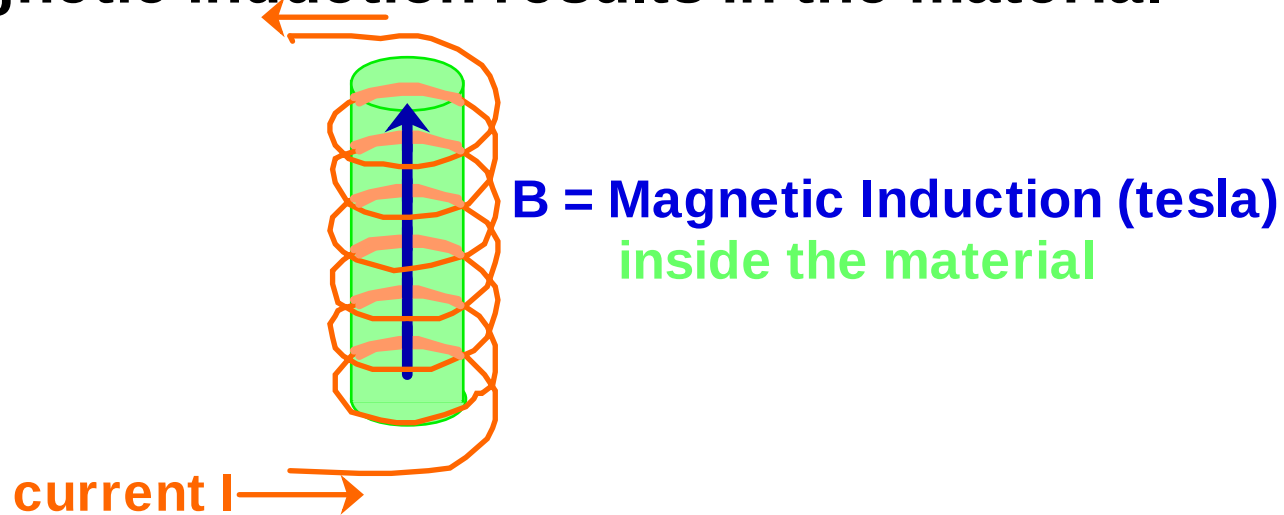
$$H = \frac{NI}{L}$$

current

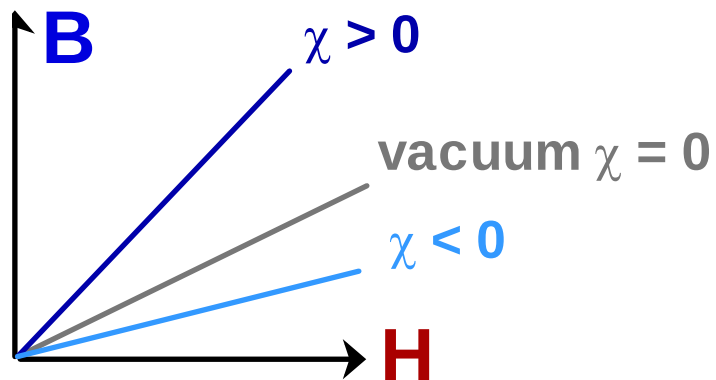
applied magnetic field
units = (ampere-turns/m)

RESPONSE TO A MAGNETIC FIELD

- Magnetic induction results in the material



- Magnetic susceptibility, χ (dimensionless)

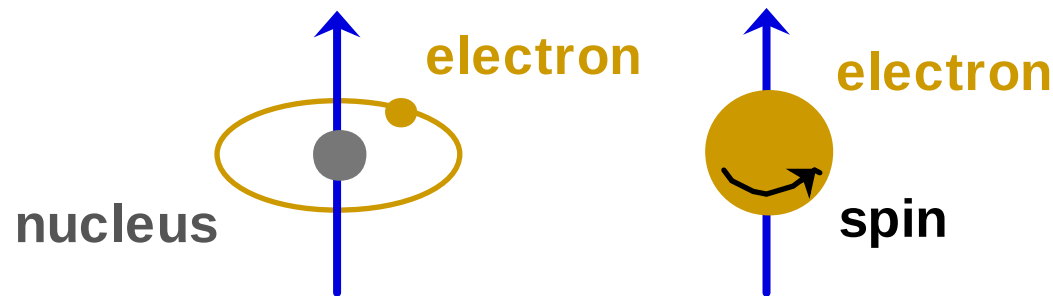


χ measures the material response relative to a vacuum.

MAGNETIC SUSCEPTIBILITY

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

magnetic moments



Adapted from Fig. 20.4, Callister 6e.

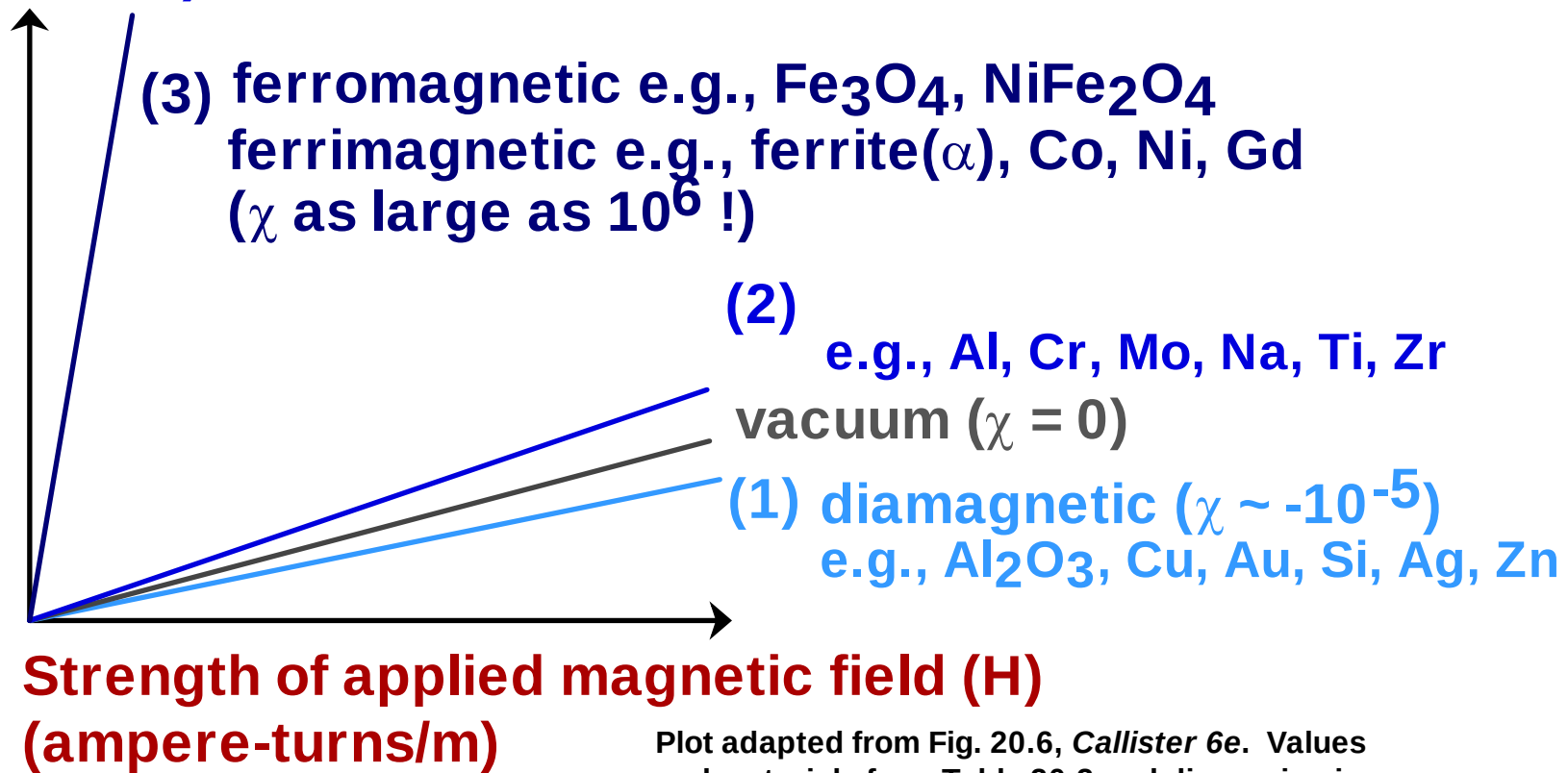
- Net magnetic moment:
--sum of moments from all electrons.
- Three types of response...

3 TYPES OF MAGNETISM

$$B = (1 + \chi)\mu_0 H$$

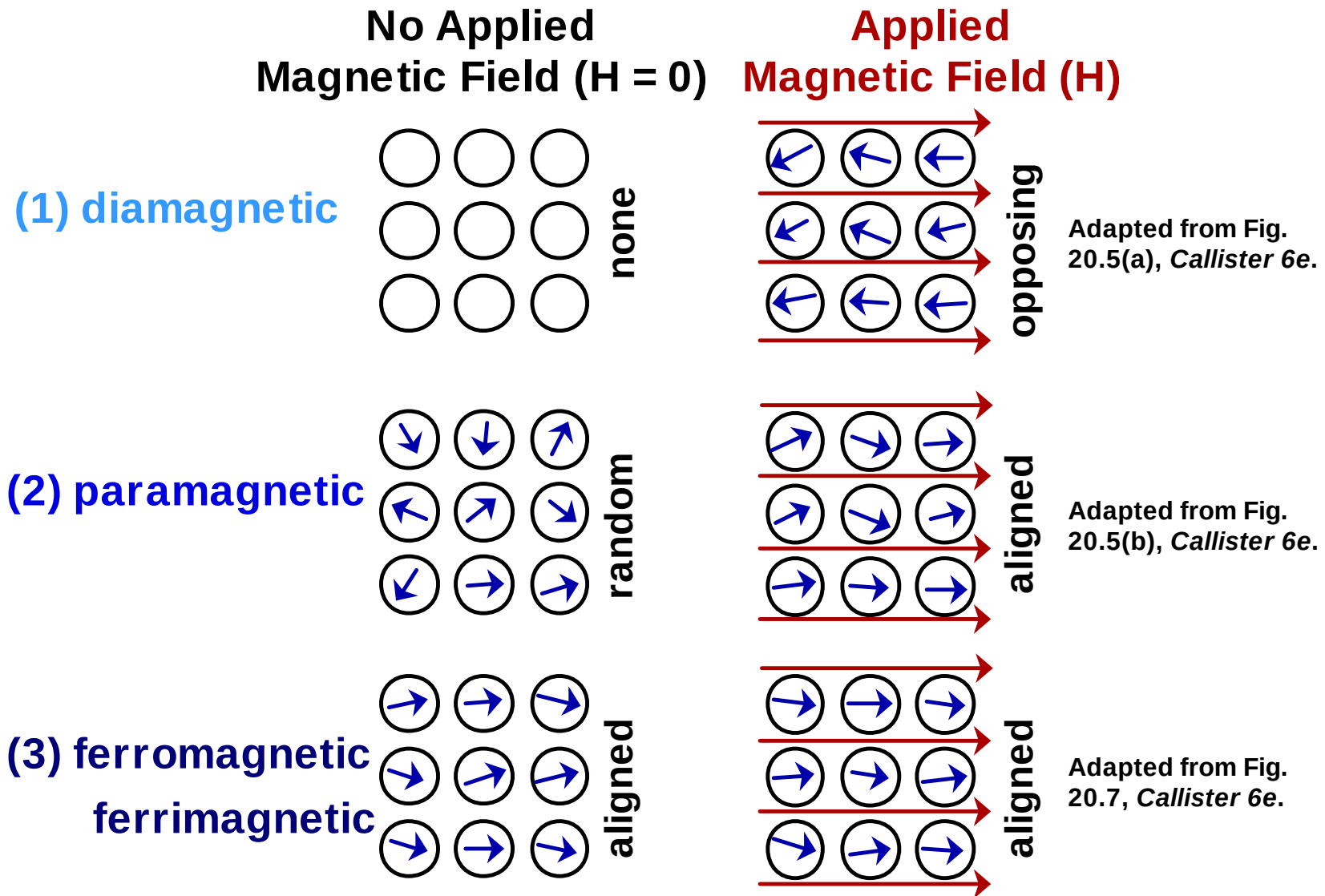
permeability of a vacuum:
(1.26×10^{-6} Henries/m)

Magnetic induction
(B--tesla)



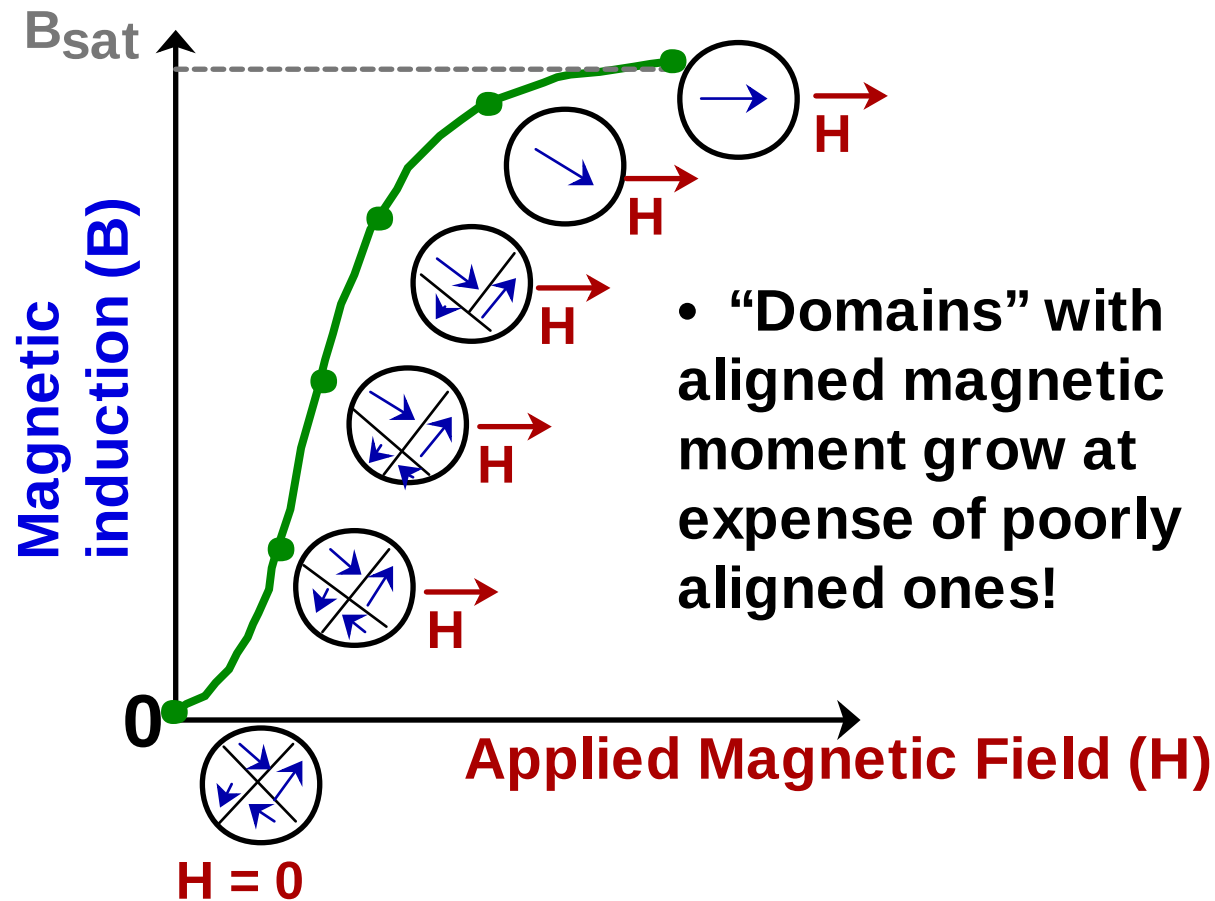
Plot adapted from Fig. 20.6, *Callister 6e*. Values and materials from Table 20.2 and discussion in Section 20.4, *Callister 6e*.

MAGNETIC MOMENTS FOR 3 TYPES



FERRO- & FERRI-MAGNETIC MATERIALS

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



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:**

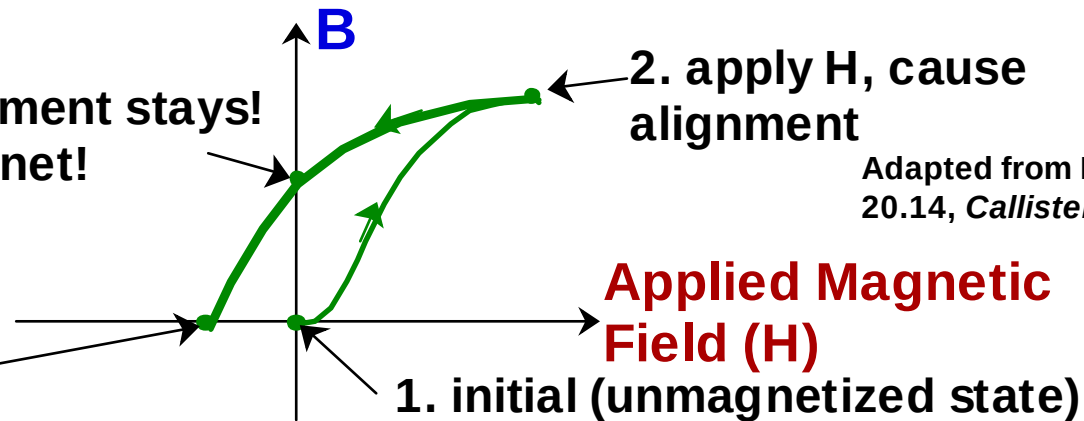
3. remove H, alignment stays!
-> permanent magnet!

2. apply H, cause alignment

Adapted from Fig. 20.14, Callister 6e.

4. Coercivity, H_c :

Negative H needed to demagnetize!



- **Hard vs Soft Magnets**

large coercivity

--good for perm magnets

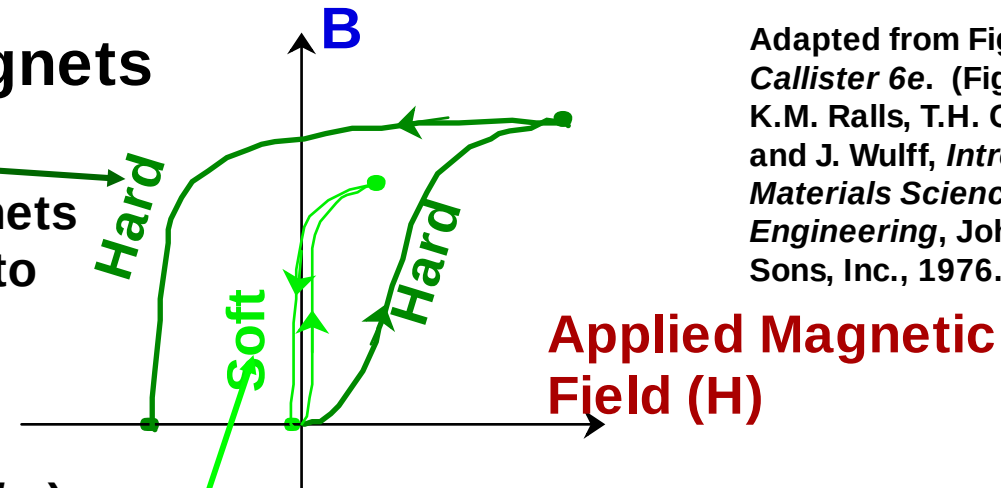
--add particles/voids to

make domain walls

hard to move (e.g.,

tungsten steel:

$H_c = 5900$ amp-turn/m)



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

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.)

MAGNETIC STORAGE

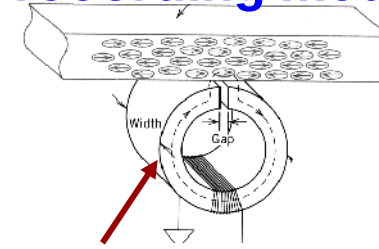
- Information is stored by magnetizing material.
- Head can...

- 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.
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from International Business
Machines Corporation.

recording medium



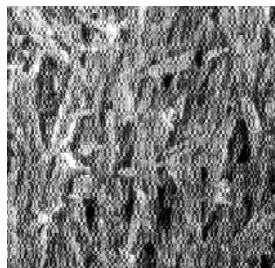
recording head

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:

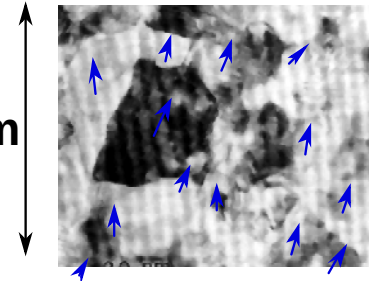
- Particulate: needle-shaped $\gamma\text{-Fe}_2\text{O}_3$. +/- mag. moment along axis. (tape, floppy)

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



$\sim 2.5\mu\text{m}$

- Thin film: CoPtCr or CoCrTa alloy. Domains are $\sim 10\text{-}30\text{nm}$! (hard drive)



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 -Fe₂O₃ 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.