# Lecture 4 Summary
# 9/14/98

## Vibrating Sample Magnetometry

### Magnetic Hysteresis
- Relevance to Data Storage
- Phenomenology
- Physics

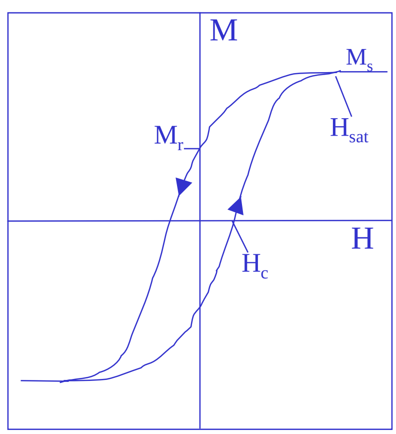
### Measurement Issues
- Calibration
- Precision
- Background
  - Holders
  - Substrates
- Shape Effects



# Magnetic Hysteresis

Features

- Hysteresis Loops
  - Vertical Scale
    - $M_r$, $M_s$
  - Horizontal Scale
    - $H_c$, $H_k$, $H_{sat}$
  - Shape
    - $S = M_r/M_s$
    - $S^* = 1 - \frac{1}{dM/dH}\frac{M_r}{H_c}$



# Relevance of Magnetic Hysteresis to Data Storage

- Media properties determine bit spacings and signal levels

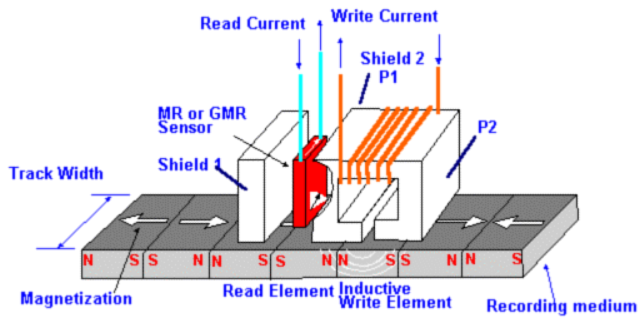
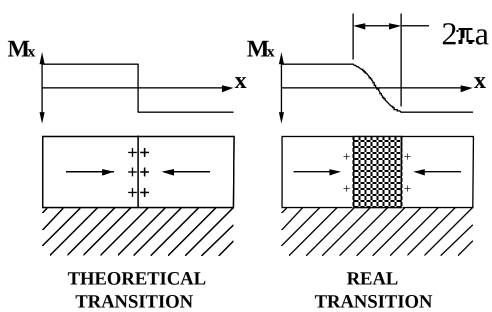





Fig from http://www.storage.ibm.com/oem/mrheads/mainmrhead.htm



# Bit Spacings I




Demagnetization Limited

$$a_{min} = \frac{M_r \delta}{2\pi H_c}$$

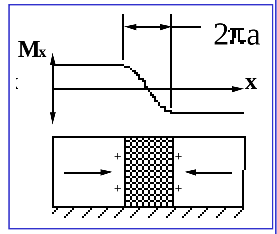
Write Process Limited

$$a_{min} = \sqrt{\frac{2}{\sqrt{3}} \frac{M_r \delta d}{\pi H_c}}$$

# Bit Spacings II

- For an ArcTan Transition… $M(x) = \frac{2M_s}{\pi}\tan^{-1}\frac{x}{a}$
- A sharper profile means higher density… $\left.\frac{dM(x)}{dx}\right|_{x=0} = \frac{2M_s}{\pi a}$
- This depends on a the medium response ... $\left.\frac{dM(x)}{dx}\right|_{x=0} = \left.\frac{\partial M(x)}{\partial H}\right|_{x=0} \cdot \left.\frac{\partial H}{\partial x}\right|_{x=0}$
- Which can be described by S* $\left.\frac{\partial M(x)}{\partial H}\right|_{x=0} = \frac{M_r}{H_c(1-S^*)}$

  S* -> 1 => Ideal Transition






# Signal Levels

$$\rho = \rho_0 + \frac{\Delta\rho_0}{2}\sin\theta$$

$$\rho = \rho_0 + \Delta\rho_0\left(\frac{H}{H_k}\right)$$

where $\sin\theta = \left(\frac{H}{H_k}\right)$

and $\left(\frac{H}{H_k}\right) \propto \frac{M_r\delta}{M_s t}$

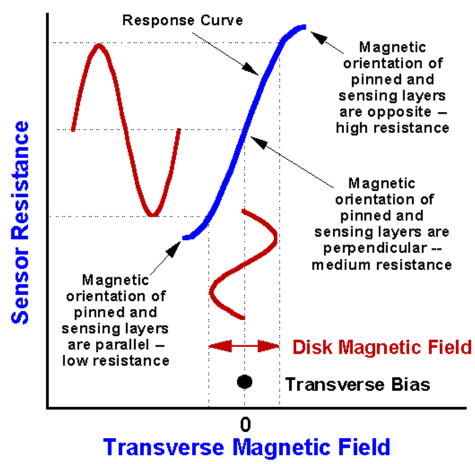



Fig from http://www.storage.ibm.com/oem/mrheads/mainmrhead.htm

# Phenomenology of Hysteresis

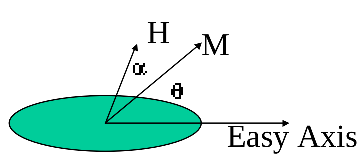
- State of system is history dependent
- Simplest view is a collection of two state objects that can be flipped
- Reality is more complicated: many body problem/average behavior
- Energy is dissipated in traversing loop: must be positive
- Major loops are repeatable



# Physics of Hysteresis

- Hopping Energy Barrier

$$E = -\mu_0 M_s H \cos(\theta - \alpha) + K_u \sin^2 \theta$$




Note: $I = \mu_0 M$

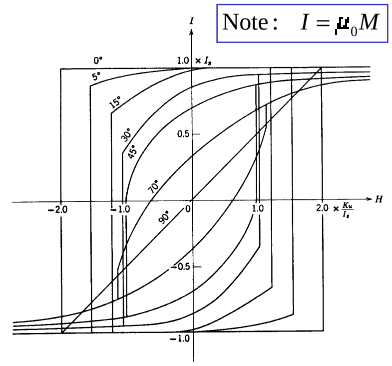
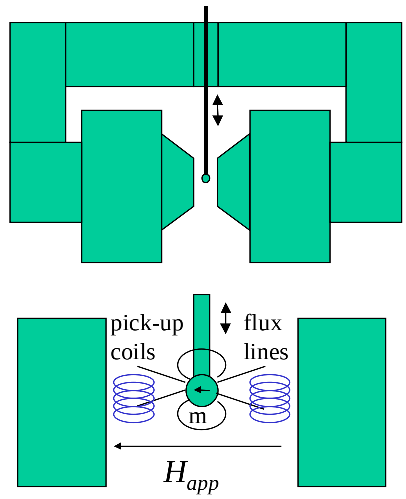



Fig. 14.3. Magnetization curves of substances with uniaxial anisotropy; irreversible rotation magnetization is assumed (numerical values signify the values of $\theta_0$).

S. Chikazumi, "Physics of Magnetism",
R.E. Krieger Publishing Co., Malabar FL (1986) p. 284

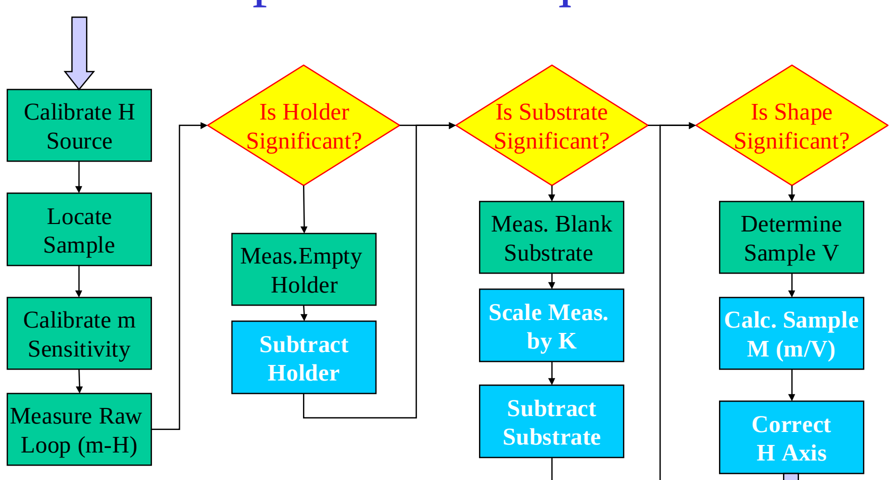
# Vibrating Sample Magnetometry

- Components
  - Large electromagnet
    - spatially uniform field
    - variable field
  - Sample holder
    - vibrates to give signal
    - "non-magnetic"
  - Pick-up coils
    - Induced voltage
    - Non uniform sensitivity






# Proper VSM Sequence




$$K = \frac{V_{sub}(dummy)}{V_{sub}(sample)} = \frac{mass_{sub}(dummy)}{mass_{sub}(sample)}$$

# Important Points Re: Sequence

- Raw loop may be very different from intrinsic material properties
- Order is important
  - calibrate
  - then remove m background
  - then correct H axis
- Several scans may be needed in addition to raw loop
  - empty holder
  - blank substrate

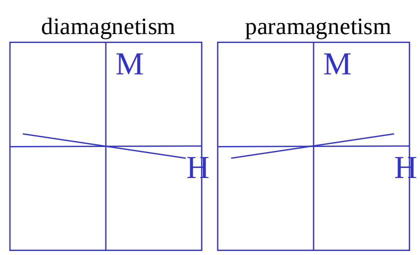
- Technique is sensitive to volume
- Important to consider product of
  - susceptibility
  - volume
  - field

  to determine size of effect



# Holder/Substrate Contributions

- Diamagnetic contribution
  - from all substances
  - atomic analog of Lenz' law
  - negative susceptibility
- Paramagnetic
  - from substances with magnetic atoms
  - positive susceptibility



# Susceptibility Sizes

- Definitions for $\chi$ (unitless)

$B = \mu_0 (H + M)$ — B Definition

$M = \chi H$ — $\chi$ Definition

$B = \mu_0 (1 + \chi) H$ — Substituting…

$\mu_r = (1 + \chi)$ — $\mu_r$ Definition

$B = \mu_0 \mu_r H = \mu H$ — $\mu$ Definition

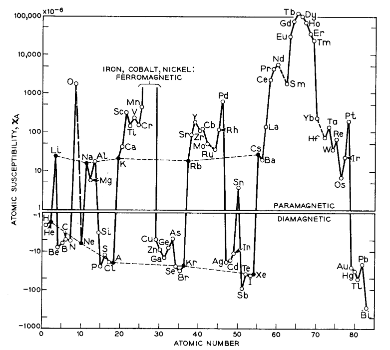



FIG. 10–19. Atomic susceptibilities of the elements at room temperature. Dotted lines connect alkali atoms and rare gases.

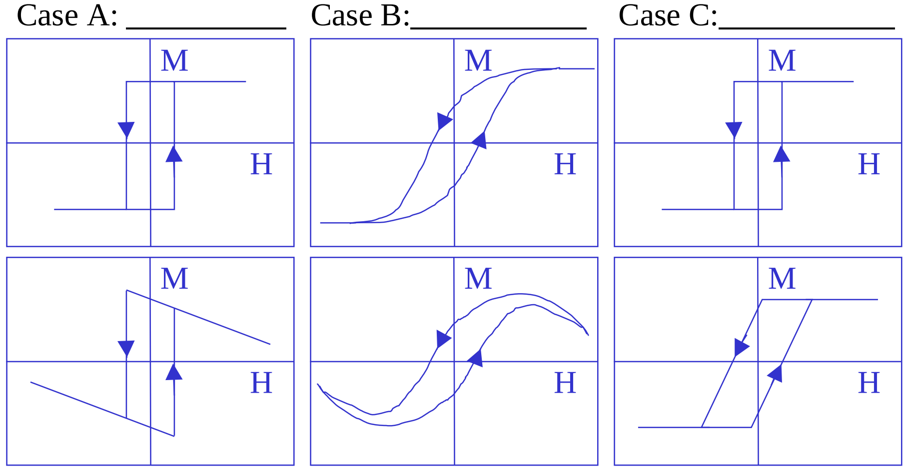
(Note : for comparison only; $\chi_A = \chi \left[ \frac{\text{emu}}{\text{cm}^3 \text{Oe}} \right] \frac{A.W.}{\rho}$, in cgs)

From R.M. Bozorth, "Ferromagnetism", IEEE Press Piscataway , NJ (1993) p. 456.

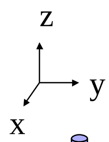


# Example Loop Distortions

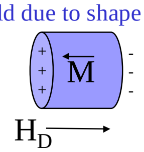
Case A: ___________ Case B:____________ Case C:____________



# Demagnetizing Fields




- $H_D$: Field due to shape of sample




$$\bar{H}_D = -\mathbf{N} \cdot \bar{M}$$

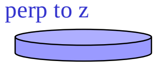
$$\mathbf{N} = \begin{pmatrix} N_x & 0 & 0 \\ 0 & N_y & 0 \\ 0 & 0 & N_z \end{pmatrix}$$

$$H_{eff} = H_{app} + H_D$$

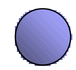
$$H_{eff,x} = H_{app,x} - N_x M_x = H_{app,x} - N_x \frac{m_x}{V}$$

$$\mathbf{N} = \begin{pmatrix} 1/2 & 0 & 0 \\ 0 & 1/2 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$ Rod, parallel to z

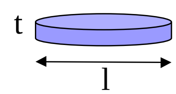
$$\mathbf{N} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$ Inf. Plate, perp to z



$$\mathbf{N} = \begin{pmatrix} 1/3 & 0 & 0 \\ 0 & 1/3 & 0 \\ 0 & 0 & 1/3 \end{pmatrix}$$ Sphere



$$\mathbf{N} = \begin{pmatrix} t/l & 0 & 0 \\ 0 & t/l & 0 \\ 0 & 0 & 1-2t/l \end{pmatrix}$$ Thin Film, perp to z




$$\sum N_i = 1$$

See S. Chikazumi, "Physics of Magnetism",
R.E. Krieger Publishing Co., Malabar FL (1986) p. 21-2
for more complicated cases