# Lecture 1 Summary
## 8/23/98

- Administrative
  - Class Overview
  - Class Size
  - Class Logistics
  - Lab Topics
  - Expectations
- Lab Practices
  - Measurement
  - Presentation
- Magnetometry
  - Units
  - Basic Concepts



# Class Mission

## IS

- Train students in "best practice"
- Introduce methods in
  - materials characterization
    - magnetic
    - structural
  - magnetic devices
    - fabrication
    - testing
- Support institutional memory & policy: *(heavily web based)*

## IS NOT

- Theory/Math course
  - Magnetism: 18-715
- Project Course
- Capstone Design (U-Grad's)

# Class Size

- Facilities allow **12** students
- Preference given to:
  – Incoming grad students
  – Students who will train other students
  – Students who will use this in their research
- Return Survey by 5PM on Tuesday



# Lectures and Labs

See web page

# Logistics

See http://www.ece.cmu.edu/~jbain/39-717

- Lectures
  - Mon 2:30 -4PM/PH A18A
  - Notes on Web Site
- Labs
  - Demos: Thu 9-12AM/Meet PH A19C
  - Training: 2 hrs/wk arranged with TA
  - Indep work and Write-up 4-6 hours/week
  - Write-ups due in two weeks
- Grades
  - Lab Write-ups
  - Final Exam (practical)
- Equip Types
  - mode I:
    - demo only
  - mode II:
    - operate with supervision
    - don't check out
  - mode III:
    - fully independent operation



# Uncertainty and Laboratory Practice

- Examples:
  - "The anisotropy was 34.67 kJ/m$^3$..."
  - "The lattice parameter was 0.3142 nm..."
- Note
  - 0.01/34.67 = 0.03% (N)
  - .0001/0.3142 = 0.03% (Y)
- Rules
  - *X.YY* implies ± 0.01
  - error bars, greater of:
    - standard deviation from multiple, identical tries:

$$\sigma = \sqrt{\frac{\sum_i (x_i - \bar{x})^2}{N-1}}$$

    - estimated total errors: percentages added

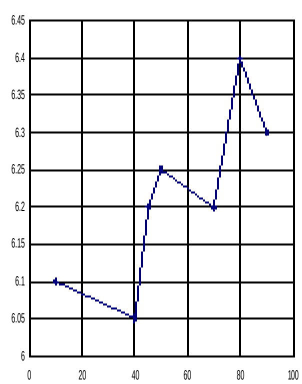
# Graphical Presentation

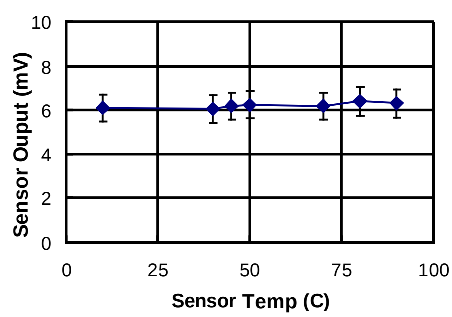
- Don't Leave ANY ambiguity
- Don't Overstate
- Don't Understate
- Don't Mislead
- Observe Aesthetic Aspects

See: "The Visual Display of Quantitative Information, Edward R. Tufte, Graphic Press, Cheshire Connecticut (1983).



# The Good, The Bad and The Ugly



# Magnetic Units

- SI System:

  $\bar{B} = \mu_0(\bar{H} + \bar{M})$

  - B [=] V-s/m$^2$ (Tesla)
  - H [=] A/m
  - M [=] A/m
  - $u_0$ [=] V-s/A-m (Henry/m)

- cgs System

  $\bar{B} = \bar{H} + 4\pi\bar{M}$

  - B [=] Gauss
  - H [=] Oe
  - M [=] emu/cc



# Experimental Facts

## Ampere's Law

$\oint_C \bar{H} \cdot d\bar{l} = \int_S \bar{J} \cdot d\bar{a}$ or $\nabla \times \bar{H} = \bar{J}$

Common Form:

$\oint_C \bar{H} \cdot d\bar{l} = Ni$

$N$ = number of turns

## Faraday's Law

$\oint_C \bar{E} \cdot d\bar{l} = \frac{d}{dt} \int_S \bar{B} \cdot d\bar{a}$ or $\nabla \times \bar{E} = -\frac{d\bar{B}}{dt}$

Common Form:

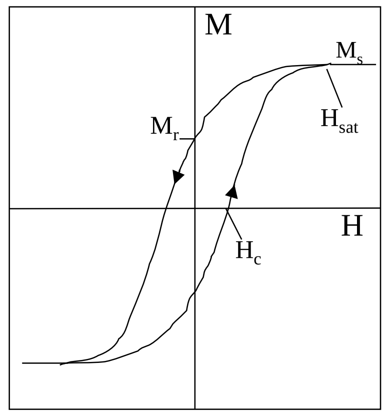
$V = -\frac{d\phi}{dt}$

$\phi = B \cdot A$

# Magnetometry I

Features

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






# Magnetometry II

Practice

1: Measure magnetic moment (extensive)

2: Measure volume (extensive)

3: Calculate moment/volume (intensive)

- Errors in both measurements make precision greater than 5% in magnetization level challenging

# Magnetometry III:

## Moment Density

- Magnetization is moment density: $m[=]\mathrm{A\cdot m^2}$
- Measurement can be
  - induced voltage:

$$V = -\frac{d\phi}{dt}[=]\frac{\mathrm{V\cdot s}}{\mathrm{s}}$$

$$\phi = B\cdot A[=]\frac{\mathrm{V\cdot s}}{\mathrm{m^2}}\cdot\mathrm{m^2}\ \text{or Wb}$$

$$B = \mu_0(H+M)[=]\frac{\mathrm{V\cdot s}}{\mathrm{m^2}}\ \text{or T}$$

  - force:

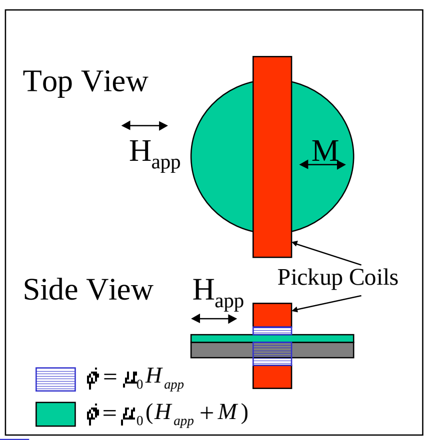
$$F = \mu_0\nabla(\bar{m}\cdot\bar{H})[=]\frac{\mathrm{V\cdot s}}{\mathrm{A\cdot m}}\left(\frac{1}{\mathrm{m}}\right)(\mathrm{A\cdot m^2})\frac{\mathrm{A}}{\mathrm{m}}\ \text{or}\ \mathrm{V\cdot A\cdot m\cdot s}\ \text{or N}$$



# Magnetometry IV:

## B-H Loopers

- Aspects
  - Induced voltage pickup
  - Only for soft materials
  - Fields
    - < 16 kA/m (200 Oe)
    - AC (10 Hz)



# Magnetometry V:

## Soft Films

- Easy Axis vs. Hard Axis
  - Can apply field along each one
  - Determined by directional energy variation
  - Simplest form: uniaxial anisotropy, $K_u$

$$E = K_u \sin^2 \theta$$

(J/m[3]) (J/m[3])