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](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/m³...”
  - “The lattice parameter was 0.3142 nm...”
- Note
  - 0.01/34.67 = 0.03% (N)
  - .0001/0.3142 = 0.03% (Y)
- Rules
  - $X \pm Y$ implies $\pm 0.01$
  - error bars, greater of:
    - standard deviation from multiple, identical tries:
      $$\sigma = \sqrt{\frac{\sum (x_i - \bar{x})^2}{N - 1}}$$
    - estimated total errors: percentages added

39-717: Laboratory Methods in Data Storage Research
Instructor: J.A. Bain
Graphical Presentation

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


The Good, The Bad and The Ugly
Magnetic Units

- **SI System:**
  \[ B = \mu_0 (H + M) \]
  - \( B \) \([=] \) V-s/m² (Tesla)
  - \( H \) \([=] \) A/m
  - \( M \) \([=] \) A/m
  - \( \mu_0 \) \([=] \) V-s/A-m (Henry/m)

- **cgs System:**
  \[ B = H + 4\pi M \]
  - \( B \) \([=] \) Gauss
  - \( H \) \([=] \) Oe
  - \( M \) \([=] \) emu/cc

Experimental Facts

**Ampere’s Law**
\[ \int_C \mathbf{H} \cdot d\mathbf{l} = \int_T J \cdot d\mathbf{l} \quad \text{or} \quad \nabla \times \mathbf{H} = \mathbf{J} \]

Common Form:
\[ \int_C \mathbf{H} \cdot d\mathbf{l} = N \mathbf{i} \]

\( N \) = number of turns

**Faraday’s Law**
\[ \int_C \mathbf{E} \cdot d\mathbf{l} = \frac{d}{dt} \int_C \mathbf{B} \cdot d\mathbf{a} \quad \text{or} \quad \nabla \times \mathbf{E} = -\frac{d\mathbf{B}}{dt} \]

Common Form:
\[ V = \frac{d\phi}{dt} \]

\( \phi = b \cdot A \)
Magnetometry I

Features

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

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: \( m = \text{A} \cdot \text{m}^{-2} \)
- Measurement can be
  - induced voltage:
    \[
    V = -\frac{d\phi}{dt} = \frac{V_{\text{m/s}}}{s}
    \]
    \[
    \phi = B \cdot A \quad \text{[Wb/m^2]} = \frac{V_{\text{s/m}}}{s} \quad \text{or} \quad 20 \text{mS/V}
    \]
    \[
    B = \mu_0 (H + M) \quad \text{[T]} = \frac{V_{\text{s/m}}}{m^2}
    \]
  - force:
    \[
    F = \mu_0 \nabla \left( m \cdot H \right) \quad \text{[N/m]} = \frac{V_{\text{s/m}}}{A \cdot m} \left( \frac{1}{m} \right) \frac{A}{m} = \frac{V_{\text{s/m}}}{A \cdot m \cdot s} \quad \text{or} \quad 2 \text{mS/N}
    \]

Magnetometry IV:
B-H Loopers

- Aspects
  - Induced voltage pickup
  - Only for soft materials
  - Fields
    - \(< 16 \text{ kA/m} (200 \text{ Oe})\)
    - \(\text{AC} (10 \text{ Hz})\)
Magnetometry V: Soft Films

- Easy Axis vs. Hard Axis
  - Can apply field along each one
  - Determined by directional energy variation
  - Simplest form: uniaxial anisotropy, $K_u$
    \[ E = K_u \sin^2 \theta \]
    \[ \text{(J/m}^2) \]  \[ \text{(J/m}^2) \]

\[ (\text{E.A.}) \]

\[ \text{(H.A.)} \]

\[ H_c \]

\[ H \]

\[ K \]

\[ M \]

\[ M \]

\[ M_i \]

\[ H_k \]