Modern Experimental Physics
Introduction for Physics 401 students

Fall 2018
Eugene V. Colla
Outline

• Goals of the course
• Experiments
• Teamwork
• Schedule and assignments
• Your working mode
Physics 403. The goals of the course.

• **Primary:** Learn how to “do” research
  - Each project is a mini-research effort
  - How are experiments actually carried out
  - Use of modern tools and modern analysis and data-recording techniques
  - Learn how to document your work

• **Secondary:** Learn some modern physics
  - Many experiments were once Nobel-prize-worthy efforts
  - They touch on important themes in the development of modern physics
  - Some will provide the insight to understand advanced courses
  - Some are just too new to be discussed in textbooks
Primary. Each project is a mini-research effort

Step 1. Preparing:
- Sample preparation
- Wiring the setup
- Testing electronics

Preparing the samples for ferroelectric measurements
Courtesy of Emily Zarndt & Mike Skulski (F11)

Step 2. Taking data:
If problems – go back to Step 1.

Standing waves resonances in Second Sound experiment
Courtesy of Mae Hwee Teo and Vernie Redmon (F11)
Primary. Each project is a mini-research effort

Step 3. Data Analysis
If data is “bad” or not enough data point – go back to Step 2

Plot of coincidence rate for 22Na against the angle between detectors A and B. The fit is a Gaussian function centred at 179.30° with a full width at half maximum (FWHM) of 14.75°. Courtesy of Bi Ran and Thomas Woodroof

Physics 403. The goals of the course.

Step 4. Writing report and preparing the talk

Range of alpha particles in gas
Author #1 and Author #2

Cosmic Ray Muon Lifetime Measurement
Author #1 and Author #2
September 15, 2011

Abstract
Over the course of two months, this experiment aims to observe and analyze the decay process of cosmic muons. During this portion of the experiment, our group set up the experimental apparatus, acquired the first set of data, roughly measured the mean lifetime, and calculated the Fermi constant $G_F$. From this first run of data, the mean lifetime was measured as $\tau = 2.32 \pm 0.0832 \mu s$, yielding $G_F = (1.132 \pm 0.0287) \times 10^{-5} \text{ GeV}$. These results are fairly in line with the accepted mean lifetime of 2.197 $\mu$s and Fermi constant of $1.166 \times 10^{-5}$ GeV, and suggest that the first cycle of the experiment was successful.

Theory
Muons were first discovered by the Carl D. Anderson and Seth Neddermeyer at Caltech, in 1936. During their study of cosmic radiation, muons were noticed by the different curvature they follow when compared to any other charged particle when applied a magnetic field. First assumed to be a meson with an intermediate mass between the mass of an electron and a proton, muons can exist...
Primary. How are experiments actually carried out?

The procedures are not all written out.

The questions are not in the back of the chapter.

The answers are not in the back of the book.

You will have to learn to guide your own activities.
Physics 403. The goals of the course.

**Primary. Use of modern tools and modern analysis and data-recording techniques**

- Lock-in amplifiers
- Digital scopes
- Precise DMM’s
- Multichannel analyzers
- Cryogenic equipment
- Temperature controllers
- Sample preparation equipment
- Microscopes
- Modern optical equipment
- etc.
Phase Transitions in Barium Titanate
Mae Hwee Teo and Noble Redmon
University of Illinois at Urbana-Champaign
10.5.2011

Abstract
Barium titanate is a ferroelectric, a unique type of material which exhibits polarization in the absence of a coercive field. As the name suggests ferroelectrics are similar in phenomenon to ferromagnets. They display spontaneous polarization (or in the case of ferromagnets, magnetization) below a critical temperature, domains, and hysteresis. Barium titanate also has two other polarized phases with transitions well below the temperature. In this experiment, a polarizing microscope is used to study the nature of the phases of barium titanate.

Introduction
History

In 1920 Joseph Valasek presented his research at the meeting of the American Physical Society. In his presentation, he stated that in relation to Rochelle salts, “the dielectric displacement D, electric...
Many experiments were once Nobel-prize-worthy efforts.

1913. Heike Kamerlingh Onnes
"for his investigations on the properties of matter at low temperatures which led, inter alia, to the production of liquid helium".

1961. Rudolf Ludwig Mössbauer
"for his researches concerning the resonance absorption of gamma radiation and his discovery in this connection of the effect which bears his name."

1961. Rudolf Ludwig Mössbauer
"for his researches concerning the resonance absorption of gamma radiation and his discovery in this connection of the effect which bears his name."

1973. Ivar Giaever
"for their experimental discoveries regarding tunneling phenomena in semiconductors and superconductors, respectively"

1976. Pyotr Leonidovich Kapitsa
"for his basic inventions and discoveries in the area of low-temperature physics"

1986. Gerd Binnig
"for their design of the scanning tunneling microscope"

1952. Felix Bloch and Edward Mills Purcell
"for their development of new methods for nuclear magnetic precision measurements and discoveries in connection therewith"

1961. Rudolf Ludwig Mössbauer
"for his researches concerning the resonance absorption of gamma radiation and his discovery in this connection of the effect which bears his name."

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1961. Rudolf Ludwig Mössbauer
"for his researches concerning the resonance absorption of gamma radiation and his discovery in this connection of the effect which bears his name."
All experiments are divided into three main groups: Condensed Matter (CM), Nuclear/Particle Physics (NP), Atomic/Molecular/Optics (AMO)

- **Condensed Matter (CM)**
  - Superconductivity
  - Tunneling in superconductors - new
  - Contactless detecting of the superconductivity. Penetration depth.
  - 2\textsuperscript{nd} sound in He4 superfluid state
  - Ferroelectrics and ferroelectric phase transition. Dielectric and pyroelectric study (Ferro1)
  - Optical Investigation of the ferroelectric phase transition and domain formation (Ferro2)
  - Polarization of the ferroelectrics. Hysteresis loops (Ferro3) – new
  - Low temperature thermometry. Sensors calibration.
  - Pulsed NMR
  - **Special Tools:**
    - Vacuum film deposition
    - Atomic Force Microscope
    - Polarizing microscope
Physics 403. Experiments

• **Nuclear / Particle (NP)**
  – Alpha particle range in gases
  – Cosmic ray muons:
  – Angular correlations in nuclear decay
  – Angular distribution of cosmic rays
  – Mössbauer spectroscopy
  – γ-rays spectroscopy

• **Atomic / Molecular / Optics (AMO)**
  – Optical pumping of rubidium gas
  – Berry’s phase
  – Quantum erasure
  – Quantum Entanglement
  – Florescence spectroscopy
Ferro1

(1) Sample preparation

(2) Samples on the cryostat stage

(3) Results:
    Temperature dependence of the dielectric constant of barium titanate

\[
\varepsilon'/1000 \quad 1K/min \quad 100Hz
\]

\[
\begin{array}{c|c|c|c|c|c|c|c|c}
T (K) & 150 & 200 & 250 & 300 & 350 & 400 & 450 & 500 \\
\hline
\varepsilon'/1000 & 0 & 3 & 6 & 9 & \epsilon_0 & \epsilon_{r} & \epsilon_{m} & \epsilon_{c}
\end{array}
\]

Ferro2

Setup

Idea of operating

Domains in tetragonal phase of BaTO

Courtesy of Dave Grych and Thomas Hymel (F10)

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Second sound

Idea of the experiment

T < 2.17K

Final result

Raw data

Velocity of the second sound in $^4$He

$U_2$ (m/s)

$T_p$ (K)

$T = 1.57K$

$R$ (µV)

$f$ (Hz)
Muon counting

Main stock of scintillators

Muons precession in magnetic field

Wiring

Courtesy of Deniz Köksal, Emily Zarndt
Energy transitions of Rb85 for 10.8 G. Double quantum transitions can be seen and occur when two photons are simultaneously absorbed. Courtesy of Natasha Sachdeva (S2011)
The “manuals”.

- Many are just guides
- A few purchased experiments have “real” manuals
- We serve as your guides ... like real research

An example of Lab manual
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<td><strong>Formal reports</strong></td>
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<td>motivation, organization of presentation; fielding questions</td>
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# Syllabus

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Assignment of experiments:
3 cycles with 2 experiments
- teams change after each cycle
- joint team reports and oral presentations

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<th>Cycle</th>
<th>Date</th>
<th>Nuclear / Particle</th>
<th>Condensed Matter</th>
<th>Atomic + CM</th>
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• Total 26 seats
• The course is more appropriate for juniors and seniors
• Prerequisite: Credit or concurrent registration in P486.
• Instructor Approval Required