Junior Laboratory

PHYC 307L, Spring 2024

Webpage: https://physics.unm.edu/Courses/Becerra/Phys307LSp24/

Lectures: Mondays, 13:00-13:50 pm, Room PAIS 1140

Lab Sessions: : Room PAIS 1405

- Monday 14:00-16:50pm

Instructor: Francisco Elohim Becerra
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Teaching Assistants:
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Office: PAIS, room XX

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Office: PAIS, room XX

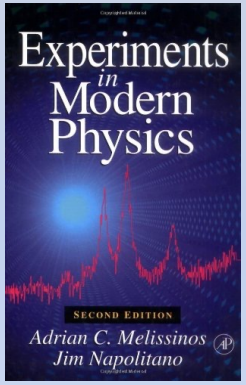
Office hours: arrange meeting with instructor or TA via email.

Junior Lab 307L

- **Description**

  Lab course: experiments in modern physics for advanced undergraduates. Students will perform seminal experiments related to:

  - Quantization
  - Atomic structure
  - Wave-particle duality
  - Measurement of fundamental constants



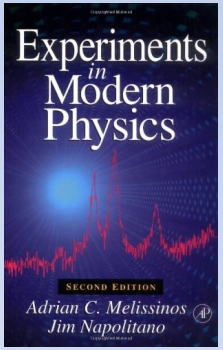
- **Goals**
  - Obtain experience of a modern physics laboratory
  - Verify fundamental concepts in modern physics
  - Learn how to document work
  - Learn how to estimate errors: data and error analysis
  - Communication skills: how to present your results

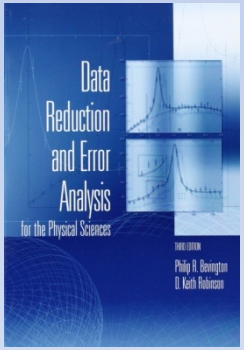
Course Materials

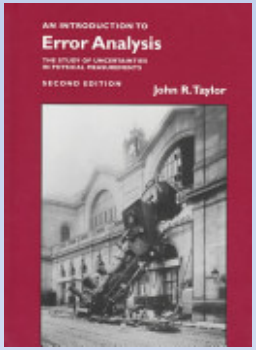
- **Textbook**

There are many good books. Some of the most useful ones:

- *"Experiments in Modern Physics"* A. C. Melissinos and J. Napolitano.
- *"Data Reduction and Error Analysis for the Physical Sciences"* P. R. Bevington
- *"An Introduction to Error Analysis"* J. R. Taylor







- **Other resources**
  - Books; Journal articles; Web (See class page for additional material)

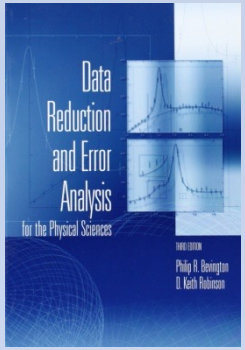
Junior Lab 307L

- **Course Structure**
  - One lecture per week
  - One lab session per week
  - **6 experiments** plus one lab session in circuits and oscilloscope
  - **Lab notebook** (6 experiments + oscilloscope/RC circuits)
  - **2 formal reports** (for 2 experiments)
  - **Oral Presentation**
  - **Homework**

Lectures

- **Monday from 1:00 pm to 1:50 pm**

- **Topics:** Statistics, data and error analysis
  - Basic elements of statistics
  - Probability distributions
  - Error propagation and error analysis
  - Data analysis
  - Curve fitting
  - Hypothesis testing and Monte Carlo Simulations



Homework

Statistics; Data analysis and plotting; Error analysis; Line and Curve fitting; (Techniques in experimental physics)

Lab Sessions

6 experiments from 10 available. (Two-week period. Schedule in advance)

Choose 4 from a set of 7 experiments and 2 from a set of 3 experiments

Before doing the experiment

- Read the lab guide and supplemental material
- Investigate, Study, and Understand the physics, the equipment and the experimental procedure
- State the objectives of each experiment in your lab notebook
- Make a plan of the procedure to obtain data and perform calibrations

For the experiment

- Read manual of the equipment and supplementary *
- Make sure that the equipment works

Keep a clear, organized and complete lab notebook (see guidelines)

- Detailed experimental procedure and Data Collection
- Data and Error Analysis

** By design, the lab guides are brief, and students are expected to investigate more in depth the physics, theory, and technical aspects of the experiments.*

Lab Notebook

- **Dedicated Lab Notebook for the lab**
  - Bound notebook
  - Use ink, and do not tear out pages. (Cross out sections not to be reviewed)
- **For each experiment (see guide in class website for specific details)**
  - **Description** of objectives
  - **Discussion** of physics behind the experiment
  - **Detailed description of experimental procedure** and techniques, original diagrams and plots.
  - **Answer all questions and complete all parts** of guide
  - **Data collection, and data and error analysis.** Include graphs
  - **Detailed calculations, propagation of errors and estimated uncertainties**
  - **Results with uncertainties** with units, and comparison with accepted values.

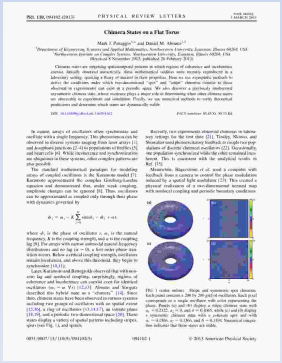
2 Formal Reports

Formal reports are based on experiments that you performed.

Should follow the style of a scientific journal (Typed, one or two columns).

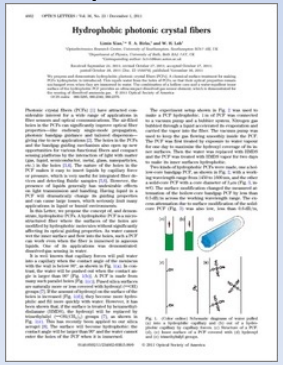
- **Main sections (see guide in class website for specific details)**
  - **Abstract**: concise description of methods and results.
  - **Introduction**: motivation, background and summary of experiment
  - **Methods**: description of experimental methods and calibrations
  - **Data**: present the data, use plots and/or tables
  - **Results and data analysis**: describe how the data analysis was done and present your results with errors
  - **Discussion**
  - **Conclusion**
  - **References**
  - **Appendix if necessary**

Phys. Rev. Lett.


PHYSICAL REVIEW LETTERS

Chimera States on a Flat Torus

Opt. Lett.


Hydrophobic photonic crystal fibers

- **Purpose**
  - Gain familiarity with formal writing style of scientific journals

Oral Presentation

12-minute Oral Presentation based on an experiment. It will be followed by questions from students, TA, and instructor.

- **Suggested outline**
  - Motivation
  - Theoretical background
  - Brief description of the experiment
  - Brief description of data collection process
  - Results and discussion with error analysis
  - Application of the physics learned in technology /fundamental research
  - Conclusion
- **Purpose**
  - Strengthen your communication skills
  - Think how to present your results to a broad audience and defend your ideas

Grading

Tentative schedule (subject to revision)

Lab notebooks revision/Formal reports	
1st	02/26 (M) Lab notebook (Exp. 1 & 2) 02/28 (W) Draft 1st Formal Report (email 5pm)
	03/19 (M) 1st Formal Report (email 5pm)
2nd	04/01 (M) Lab notebook (Exp.) 3 and 4
3rd	04/29 (M) Lab notebook (Exp.) 5 and 6 05/01 (W) 2nd Formal Report (email 5pm)

Lab Notebook	**40%**
2 Formal Reports	**40%**
Homework	**10%**
Oral Presentation	**10%**
Total	**100%**

Late work policy:

Late work assignments will be accepted but with a 15% penalty for each day past the deadline. So, any work handed-in within 24 hrs of the deadline will carry a 15% penalty, one handed-in within 48 hrs will carry a 30% penalty, as so on.

Oral presentations at the end of the semester

Please check course website for updates

Lab Safety

- **Footwear**.- Closed-toed shoes with a covered heal (tennis shoes, leather shoes, etc.)
- **Electrical**.- Some experiments use HV supplies. Look for damaged cables or faulty connections.
- **No food or drinks**.- Do not eat or drink in the laboratory. Any spill can cause irreversible damage to equipment and can cause an accident when working with or near HV equipment.
- **Broken or nonworking equipment**.- Report any nonfunctioning equipment to the lab instructor or the TA.
- **Secure rooms**.- Close the door behind you when you leave or you go out of the laboratory for a short period of time (some experiments use HV and/or radioactive materials).

Lab Safety

- **Broken glass**.- Do not deposit chipped or broken glass in normal trash containers. Use a glass bin.
- **No loose ends**.- Tie your shoelaces and long hair must be tied back.
- **House keeping**.- Clean up and make sure everything is safe before you leave. Keep your work area in order. Do not block passages or exits with cables or equipment.
- **Report any accident or concern to the instructor or TA**
- **Before doing an experiment**.- Talk to the instructor or TA about the safety concerns of each experiment and any special instructions for working with sensitive equipment.
- **Laser-based experiments**.- Read specifications. Use laser-safety glasses.
- **Use caution when handling radioactive material**.

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Measurements and Uncertainty

Measurement and Uncertainty

Goal of an experiment

1.- Perform a measurement of a parameter.

All measurements are subject to uncertainties.

- **Accuracy**: how close is the experimental result from the true value. (correctness of a result)
- **Precision**: is a measure of how well the result has been determined, without any reference to the true value

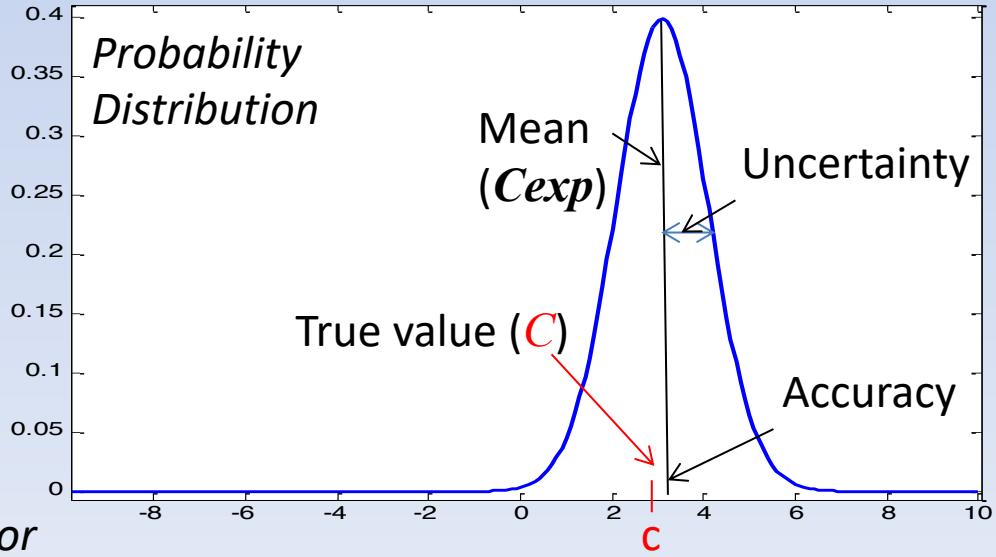
2.- Hypothesis testing: Confidence level; Goodness of the fit?

Example: speed of light

$$c_{\exp} = (3.09 \pm 0.15) \times 10^8 \, m/s$$

Best value (mean) — Uncertainty — Units

$$\textbf{Precision} = \frac{0.15}{3.09} \approx 5\%$$



Use no more that 2 significant digits in the error

Statistical and Systematic Uncertainty

Measurements **cannot** be performed with **zero error (uncertainty)**.

(a) Statistical errors. Random fluctuations: (in either direction)

Due to Intrinsic noise of random processes, precision device limitations, etc…

(b) **Systematic errors.** Inaccuracies: (consistently in one direction)

Reproducible inaccuracies resulting in a bias of our measurement result.
Due to the instruments or experimental conditions (calibrations)

Always Report measurement result with estimated uncertainty

Any measurement has limitations. Uncertainties specify these limitations.

Report separately or add in quadrature:

$$(\delta c)^2 = (\delta statistical)^2 + (\delta systematic)^2$$

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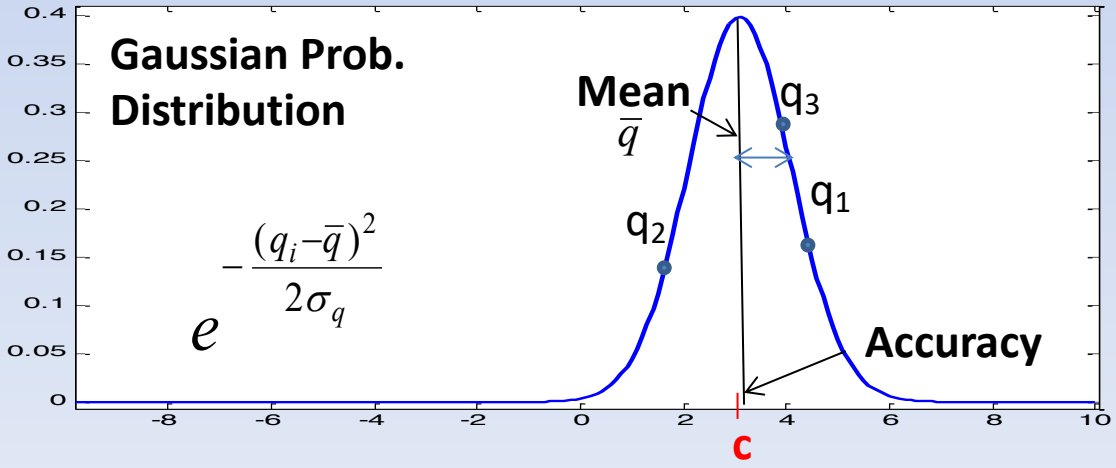
Statistical errors
Repeated measurements are distributed according to a **Normal (Gaussian)** about the mean.



Measurement: Mean and Variance

(*small systematic errors*)

Assume *N* measurements $\{q_1, q_2, \ldots q_N\}$ of the physical quantity q_{True} .

The best estimate of q_{True} is the **Mean**:

$$\bar{q} = \frac{1}{N}\sum_{i=1}^{N} q_i$$

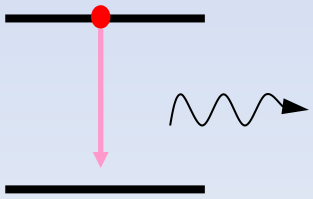
Variance: estimate of uncertainty:

$$\text{variance} = \sigma_q{}^2 = \frac{1}{N-1}\sum_{i=1}^{N}(q_i - \bar{q})^2$$

- Statistical error is σ_q , the **Standard Deviation**.
- The factor "N-1" results from having determined $\bar{q}$ from the same data.

Example: Time an atom decays and emits a photon:

Data (N=16): t={20,17,24,23,25,31,25,24,23,26,19,23,26,29,28,23} ns.



(a) $\bar{t} = 24.12 ns$

(b) $\sigma_t = \sqrt{\frac{1}{15}\sum_{i=1}^{16}(t_i - \bar{t})^2} = 3.59$

$$t_{\exp} = (24.1 \pm 3.6) ns$$

$$t_{\exp} = \bar{t} \pm \sigma_t$$

Error propagation

(multi-variable function "q")

Suppose $q=q(x_1, x_2, x_3, \ldots x_N)$ where $\{x_i\}$ are independent (uncorrelated) quantities or variables, each one with an error σ_i. These errors contribute to an error in q.

- The error σ_q in q due to $\{\sigma_i\}$ is:

$$\sigma_q^{\,2} = \sum_{i=1}^{N} \left(\frac{\partial q}{\partial x_i} \right)^2 \sigma_i^{\,2}$$

(x_i uncorrelated variables)

Example: Determine R when measuring I and V: $V = IR$ $R = \frac{V}{I}$

$$I_{\exp} = (1.29 \pm 0.45)\,A$$

$$V_{\exp} = (3.3 \pm 0.5)\,V$$

$$R = \frac{\bar{V}}{\bar{I}} = 2.55\Omega$$

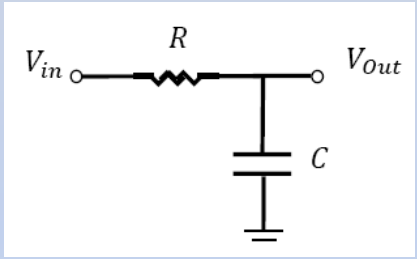
$$\sigma_R^{\,2} = \underbrace{\left(\frac{\partial R}{\partial V}\sigma_V \right)^2 \Big|_{\bar{V},\bar{I}}}_{0.15} + \underbrace{\left(\frac{\partial R}{\partial I}\sigma_I \right)^2 \Big|_{\bar{V},\bar{I}}}_{0.79} = 0.946\Omega^2$$

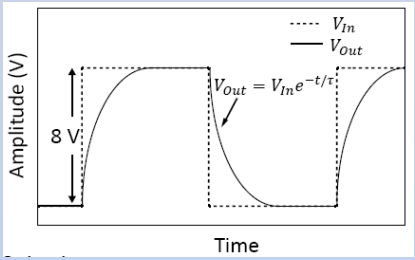
$$\sigma_R = 0.97\Omega$$

RC circuits and the Oscilloscope

- **RC circuits: time and frequency response**

  Measurement Transient response of RC circuits to step voltages



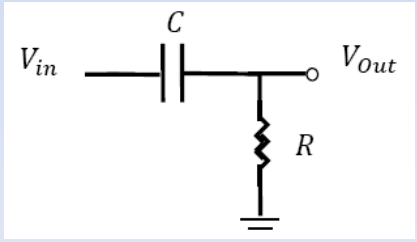


- **Frequency response of RC circuits to AC signals.**

  Study response of RC circuits to sinusoidal signals; cutoff frequency

- **Frequency and time response of RC circuit type II**

  Study response of RC circuit below



6 Lab Experiments & 2 Formal Reports

- **Complete all parts of the experiments with data and error analysis**

Lab notebook: proof that the experiment was carried out in the manner described in the scientific paper or in the lab report.

All the details of the experiment, results and analysis must be in the lab notebook. Any person should be able to repeat your experiment based only on your lab notebook.

All experiments require detailed calculations, derivations and complete error analysis, regardless of whether you are doing the formal report for a particular experiment.

Probability Content (Gaussian errors)

If Systematic errors are small:

Errors distributed as Gaussian with variance $\sigma_q^{\,2}$.

- Observed a value $\overline{q}$ -> q_{True} as N -> ∞
- Probability of measuring q within

Confidence Level

$\left(q_{True}, q_{True} \pm \sigma_q\right)$ is 68%

$\left(q_{True}, q_{True} \pm 2\sigma_q\right)$ is 95.5%

$\left(q_{True}, q_{True} \pm 3\sigma_q\right)$ is 99.7%

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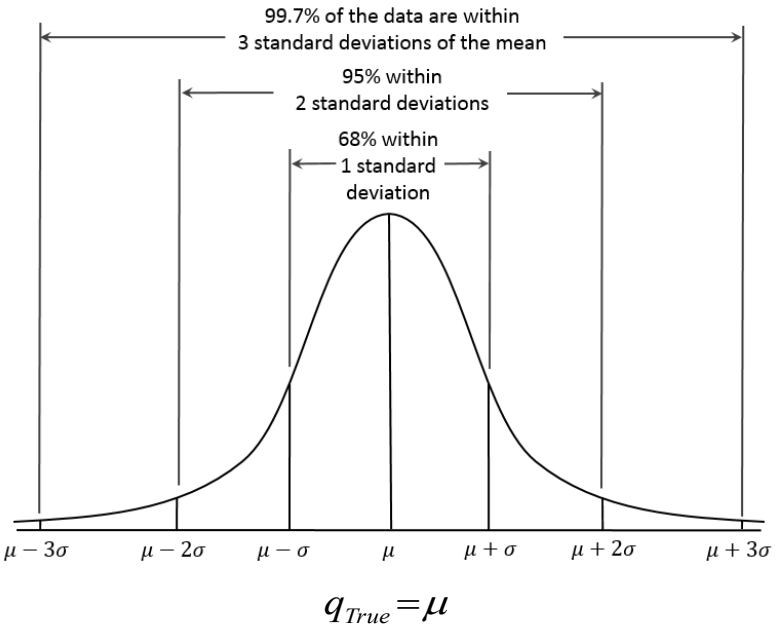

$q_{True} = \mu$

If q_{Exp} differs from q_{True} by >3 σ_q:
probability of happening ~0.3% (very unlikely)
(1) Unknown systematic
(2) Theory is not complete or is wrong