# Junior Laboratory

## PHYC 307L, Spring 2025

Webpage: https://www.unm.edu/~fbecerra/Phys307LSp25/

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

**Lab Sessions**: : Room PAIS 1405

- Monday 14:00-16:50pm

**Instructor**: Francisco Elohim Becerra
email: fbecerra@unm.edu
Office: PAIS, room 2514

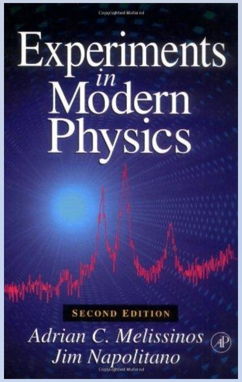
**Teaching Assistants**:
Yinjuan Zhai. email: yjzhai@unm.edu
Office: PAIS, room XX

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

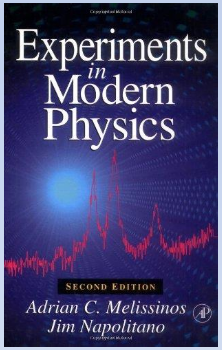
- ## Textbook

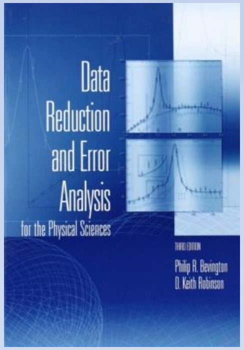
There are many good books. Some of the most useful ones:

• <u>*“Experiments in Modern Physics”*</u> A. C. Melissinos and J. Napolitano.

• <u>*“Data Reduction and Error Analysis for the Physical Sciences”*</u> P. R. Bevington

• <u>*“An Introduction to Error Analysis”*</u> J. R. Taylor





- ## Other resources

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

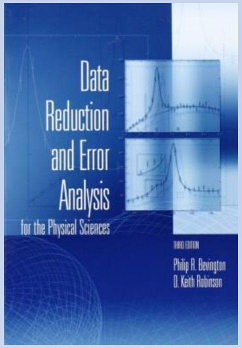
# Junior Lab 307L

- ## 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/Statement and Discussion** of objectives
  - **Background: Discussion** of physics and techniques 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

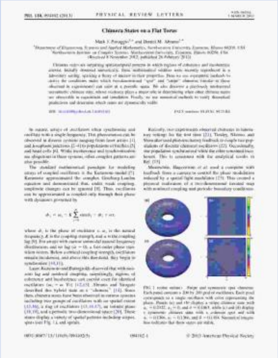
# 2 Formal Reports

Formal reports are based on experiments that you performed.

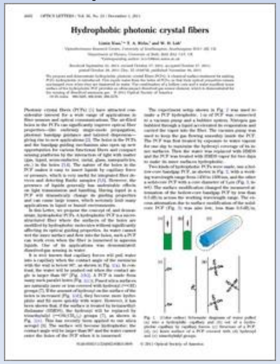
Should follow the style of a scientific journal (Typed, one or two columns).

- **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.*


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** | 03/03 (M) Lab notebook (Exp. 1 & 2)<br>03/05 (W) Draft 1st Formal Report (email 5pm) |
| | 03/24 (M) 1st Formal Report (email 5pm) |
| **2nd** | 04/07 (M) Lab notebook (Exp. 3 and 4) |
| **3rd** | 05/05 (M) Lab notebook (Exp. 5 and 6)<br>05/07s (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**.

# Junior Laboratory

## PHYC 307L, Spring 2025

Webpage:

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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.

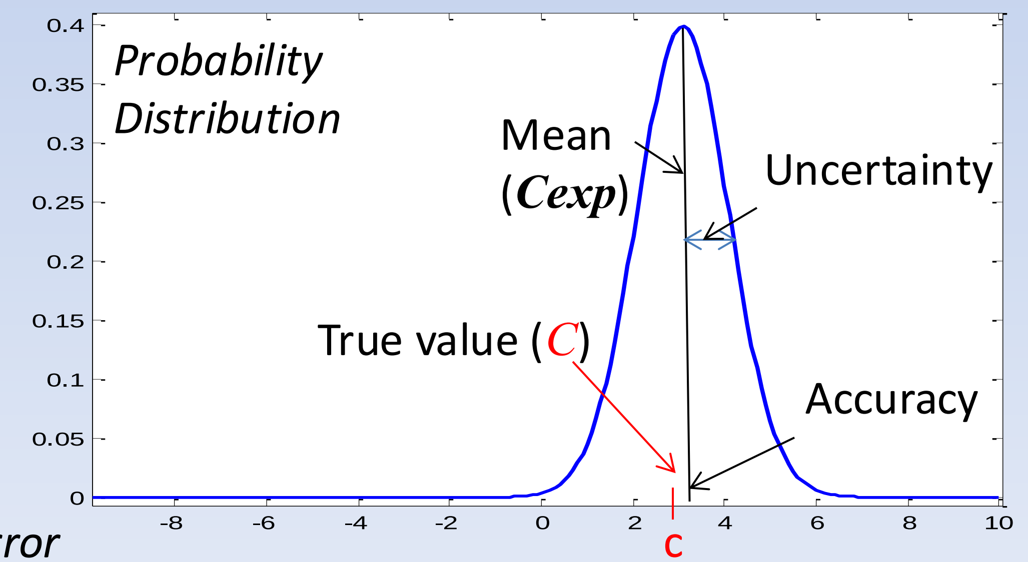
**2.- Hypothesis testing**: Confidence level; Goodness of the fit?

**Example: speed of light**

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

Best value (mean)    Uncertainty    Units

**Precision** $= \dfrac{0.15}{3.09} \approx 5\%$




*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:*

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

# Statistical and Systematic Uncertainty

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

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

(b) **Systematic errors.** <u>Inaccuracies:</u> (consistently in one direction)

Reproducible inaccuracies resulting in a bias of our measurement result.
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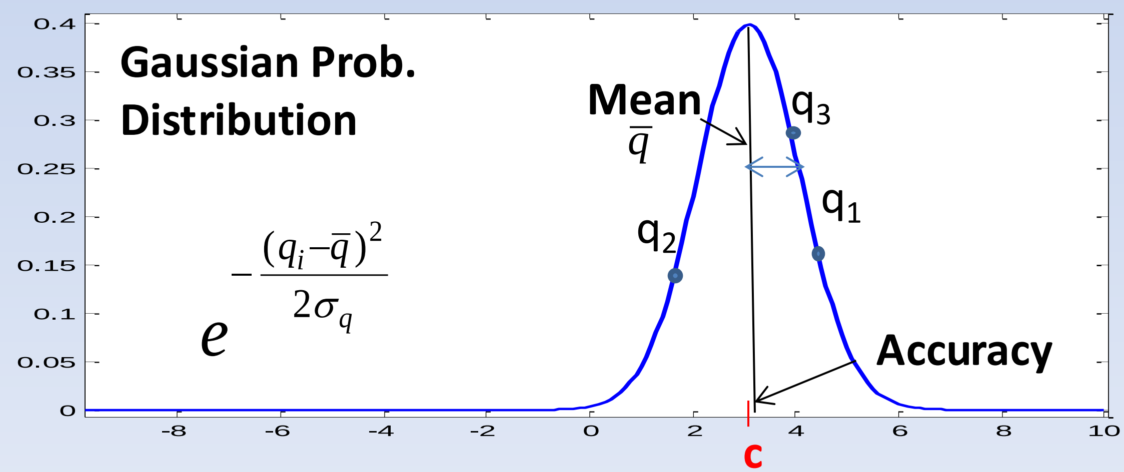
**Always Report measurement result with estimated uncertainty**

**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**:

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

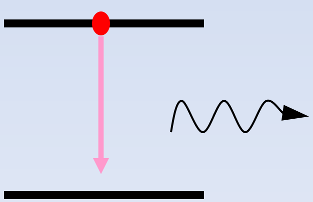
**Variance:** estimate of uncertainty:

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

- Statistical error is $\sigma_q$, 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)** $\sigma_t = \sqrt{\frac{1}{15}\sum_{i=1}^{16}(t_i - \bar{t})^2} = 3.59$

$$\boxed{\begin{aligned} t_{\exp} &= (24.1 \pm 3.6) ns \\ t_{\exp} &= \bar{t} \pm \sigma_t \end{aligned}}$$

# 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 $\sigma_i$. These errors contribute to an error in $q$.

•The error $\sigma_q$ in $q$ due to $\{\sigma_i\}$ is:

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

($x_i$ uncorrelated variables)

**Example:** Determine R when measuring I and V: $V = IR$ $\qquad R = \dfrac{V}{I}$

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

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

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

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

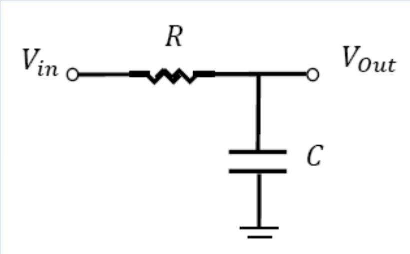
$$0.15 < 0.79$$

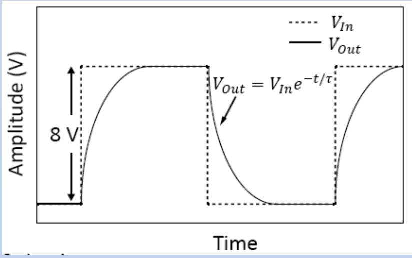
$$\sigma_R = 0.97\Omega$$

# RC circuits and the Oscilloscope

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

Measurement Transient response of RC circuits to step voltages



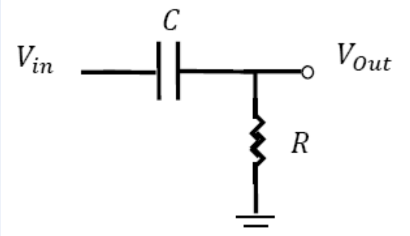




- **Frequency response of RC circuits to AC signals.**

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

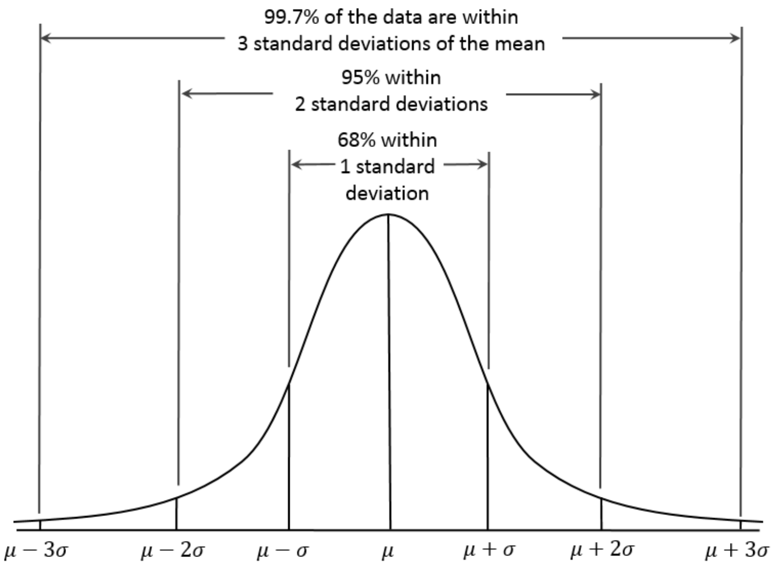
***Confidence Level***

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

***wiki***




$q_{True} = \mu$

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