Experimental Techniques of Optics

Spring 2016

PHYC 476,477, 302L

University of New Mexico

http://www.optics.unm.edu/sbahae/Optics Lab/

Pre-requisites:
302L: PHYC 302 or 330 or 262 or 160
476L/477L: PHYC 302 or PHYC/ECE 463 or 464
Please drop the course if you have not passed at least one of the pre-requisite courses.

Instructor: Mansoor Sheik-Bahae

Teaching Assistants:

Junwei Meng (Tiger) and Nathan Giannini

Lab Coordinator: Dr. Michael Hasselbeck

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Grading Policy

- Attendance, Interaction with TAs and Instructors during the lab sessions
- Lab Notebook (new)
- Lab Reports
- Oral Exam

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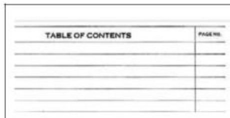
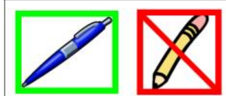
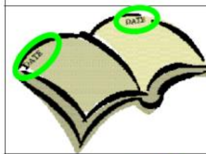
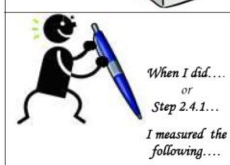
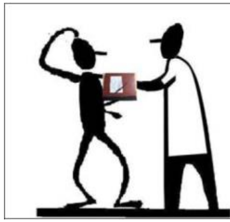
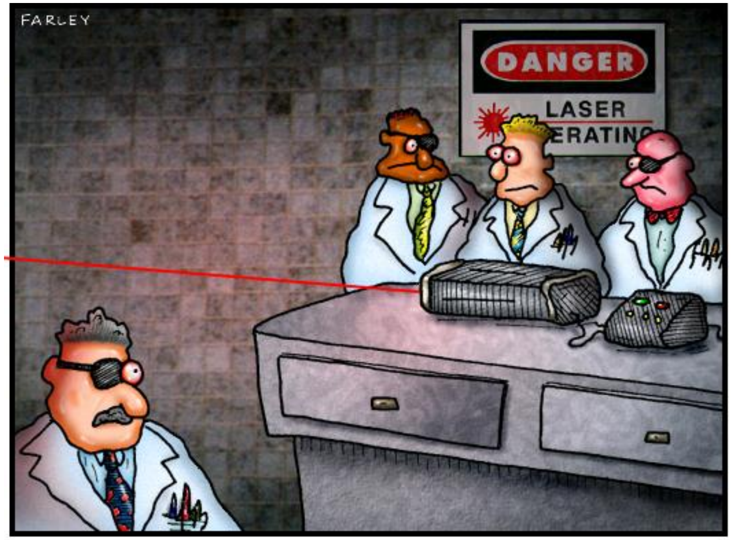
Lab Notebook

Rules for Maintaining your Laboratory Notebook

	Leave several pages blank at the beginning for a **Table of Contents** and update it when you start each new experiment or topic
	Always use pen and write neatly and clearly
	Date ***every*** page on the top <u>outside</u> corner
	Start each new topic (experiment, notes, calculation, etc.) on a right-side (odd numbered) page
TITLE DATE Objectives and/or purpose of experiment	Record the **TITLE** and **OBJECTIVES** of each experiment (or notes or calculations) at the top of the first page of the notebook dedicated to this topic.
R = Ω 3.526 R = ~~3.256~~ Ω 3.526 *miswrote*	If you make a mistake, <u>don't obliterate it</u>! You may need to read your mistake later – perhaps you were right the first time! Use a single cross out and EXPLAIN why it was an error.
	Data typed into the computer must be printed and <u>taped into your lab notebook</u>. Plots of data made in lab should also be printed and taped in your lab notebook.
	When you record an observation in your notebook, include an explanation of what you were doing at the time. If appropriate, you may just record the step number in the instructions followed by your observation.
	You must have your lab notebook signed by your lab instructor before you leave lab each day.

Lab Safety First



Peer pressure in the laser lab

All students enrolled are ***required*** to read the OSHA manual carefully. You will be asked to sign an "agreement of understanding" form on the first session of this course.

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Experiments

- Basic Optics Experiments (for 302L only)
- The Wavemeter
- Velocity Measurements by Optical Techniques
- Ray Tracing and Lens Aberrations
- Fiberoptics
- Modelocking a CW Laser
- Fourier Optics
- Polarization Study
- He-Ne Laser
- Diode-Pumped Solid-State (DPSS) Laser
- Nonlinear Optics (NEW; being developed)
- Ti:sapphire laser (NEW; being developed)

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Error Analysis

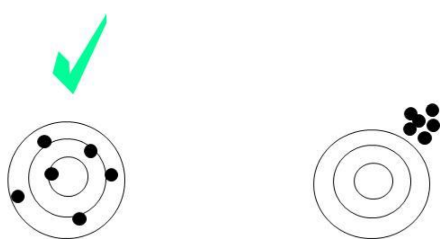
(how many significant figures?)

Is c=299 792 458 m/s exact?

- A measurement is not meaningful without an error estimate (uncertainty)
- No measurement is ever exact
- “Error” does NOT mean “blunder” or “mistake” (the latters can be corrected for)

“It is better to be roughly right than precisely wrong!”

Alan Greenspan
Former U.S. Federal Reserve Chairman



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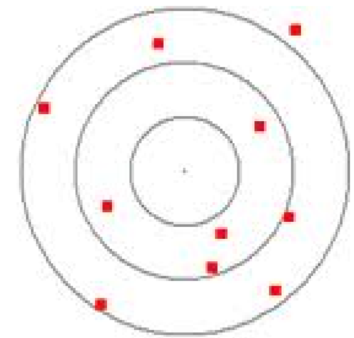
Types of Error

- **Statistical (Random) Errors:**

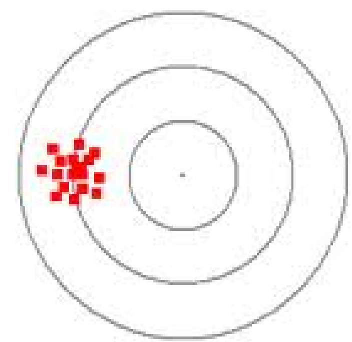
  Results from a random fluctuation in the process of measurement. Often quantifiable in terms of "number of measurements or trials". Tends to make measurements less ***precise***.



Random Error

- **Systematic Errors (Blunders?):**

  Results from a bias in the observation due to observing conditions or apparatus or technique or analysis. Tend to make measurements less ***accurate***.

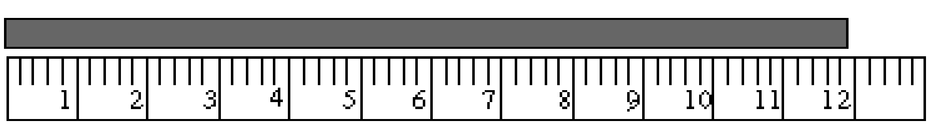


Systematic Error

- **Instrument Limitation Error:**

  Any measuring device can be used to within a degree of finesse.

12.65 ± 0.005



half of "least count"

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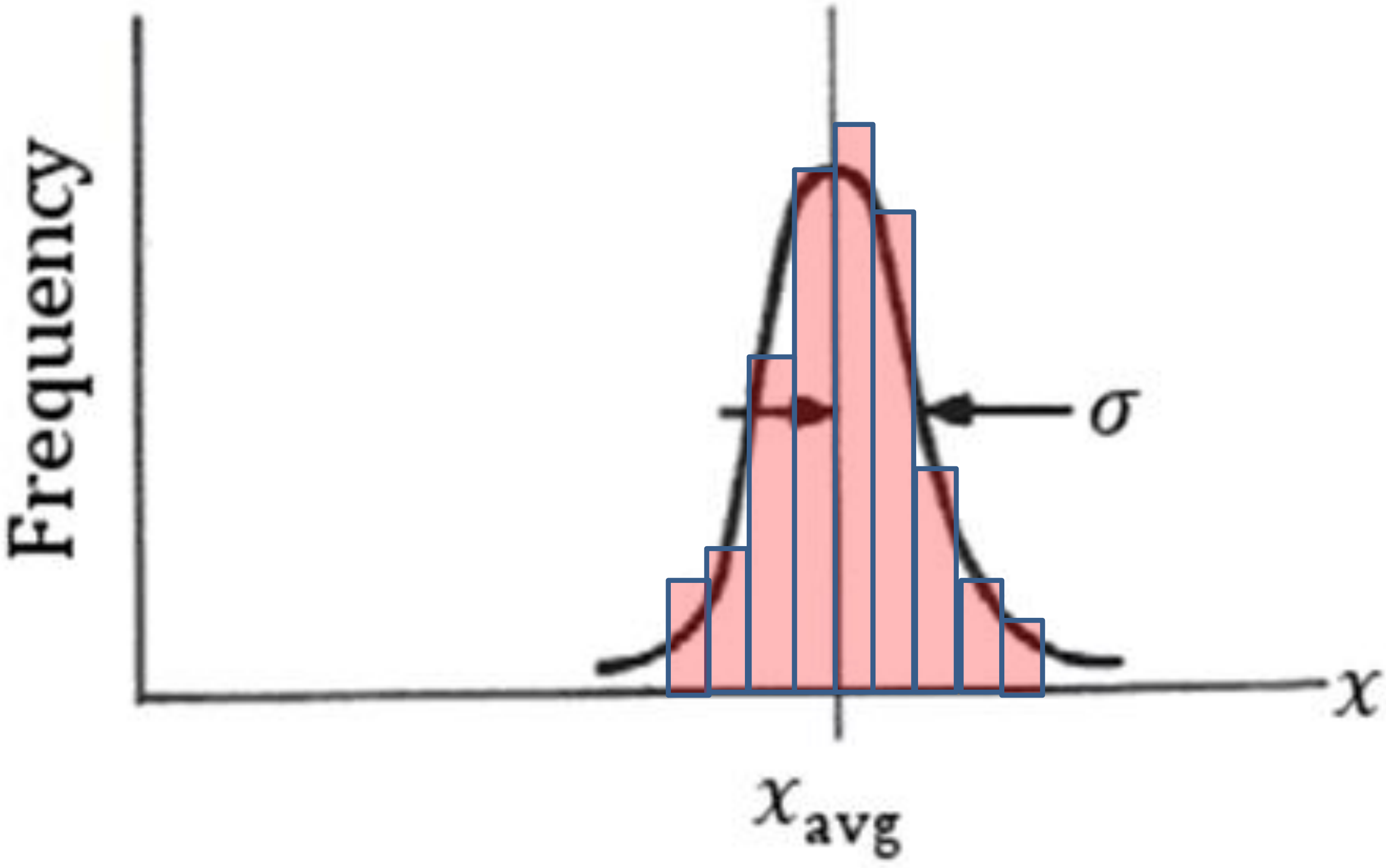
Measurement Histogram



Measurement Uncertainty

$$x_m = x_{ave} \pm \Delta x_{ave}$$

Mean (x_{avg})	The average of all values of x (the "best" value of x). This is the same as for small data sets.	$x_{avg} = \frac{\sum_{i=1}^{N} x_i}{N}$
Uncertainty in a measurement (Δx)	Uncertainty in a single measurement of x. The vast majority of your data lies in the range $x_{avg} \pm \sigma$	$\Delta x = \sigma = \sqrt{\frac{\sum_{i=1}^{N}(x_i - x_{avg})^2}{N}}$ (N-1)
Uncertainty in the Mean (Δx_{avg})	Uncertainty in the mean value of x. The actual value of x will be somewhere in a neighborhood around x_{avg}. This neighborhood of values is the uncertainty in the mean.	$\Delta x_{avg} = \frac{\sigma}{\sqrt{N}}$
Measured Value (x_m)	The final reported value of a measurement of x contains both the average value and the uncertainty in the mean.	$x_m = x_{avg} \pm \Delta x_{avg}$

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Error Propagation

- **If the parameter of interest $f = F(x, y, z, \ldots)$ depends on multiple measured parameters $x, y, z, \ldots$.**

- **The error in f, σ_f, depends on the function F, measured parameters $x, y, z, \ldots$, and their errors, $\sigma_x, \sigma_y, \sigma_z, \ldots$:**

$$\sigma_f = \sqrt{\left(\frac{\partial F}{\partial x}\right)^2 \sigma_x^2 + \left(\frac{\partial F}{\partial y}\right)^2 \sigma_y^2 + \left(\frac{\partial F}{\partial z}\right)^2 \sigma_z^2 + \ldots}$$

Errors from independent (un-correlated) parameters add in quadrature.

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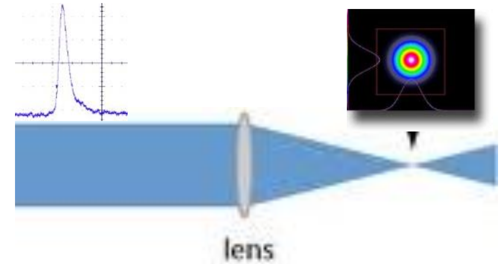
An Example:

Determine peak on-axis intensity of a pulsed laser beam:



$$I(W/cm^2) = \frac{E(joules)}{t_p(\sec)A(cm^2)} = K\frac{E}{t_p w^2}$$

K is a constant

$$\boxed{I(measured) = I_{ave} \pm \Delta I} \quad \text{with} \quad I_{ave} = K\frac{E_{ave}}{t_{p_{ave}} w_{ave}^2}$$

and

$$\Delta I = K\sqrt{\left(\frac{1}{t_p w^2}\right)_{ave}^2 (\Delta E)^2 + \left(\frac{E}{t_p^2 w^2}\right)_{ave}^2 (\Delta t_p)^2 + \left(\frac{2E}{t_p^2 w^3}\right)_{ave}^2 (\Delta w)^2} \quad \text{or} \quad \frac{\Delta I}{I} = \sqrt{\left(\frac{\Delta E}{E}\right)^2 + \left(\frac{\Delta t_p}{t_p}\right)^2 + \left(2\frac{\Delta w}{w}\right)^2}$$

- energy meter
- beam profiler
- fast photo-diode and scope

(calibration?)

input impendence?

For instance:

$E=(5.2\pm0.05)$ mJ $\qquad w=(120\pm2)$ µm $\qquad t_p=(11\pm1)$ ns

$$\frac{\Delta I}{I_{ave}} \approx 0.1$$

I (measured)$=2.1 \pm 0.2$ GW/cm^2

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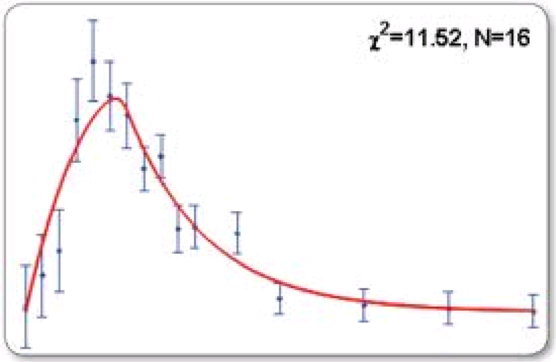
Data Fitting (comparing with theory)



"least squares" analysis

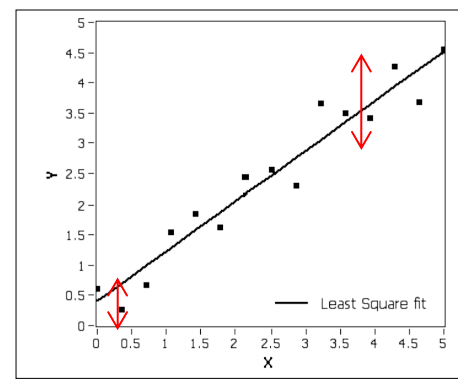
$$\chi^2 = \Sigma \frac{1}{\sigma_i^2}\left[y_i - f\left(x_i\right)\right]^2$$

weighted

Minimize χ^2

For linear fit (or power laws in log-log plots):

$$\chi^2 = \Sigma \frac{1}{\sigma_i^2}\left[y_i - f\left(x_i\right)\right]^2 = \Sigma \frac{1}{\sigma_i^2}\left[y_i - \left(mx_i + b\right)\right]^2$$



Graphics or data analysis softwares (Origin, Excel, ..) do this for you.

$$\frac{\partial \chi^2}{\partial m} = 0$$

$$\frac{\partial \chi^2}{\partial b} = 0$$

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Keep the lab and the equipment clean & organized

Absolutely no finger prints on optics please!!

"SPARE CHANGE, PROFESSOR?"

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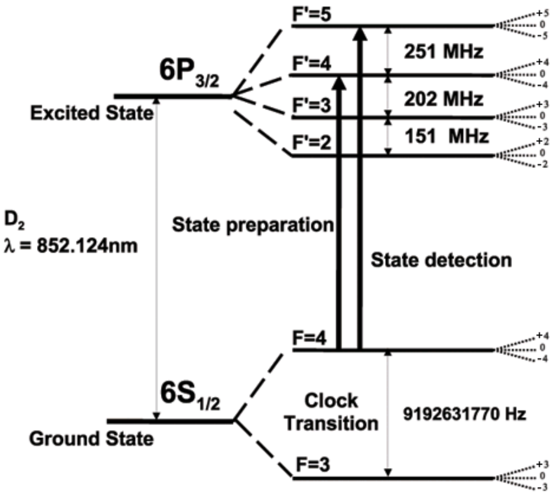
- The second (s) is now defined as 9 192 631 770 times the period of vibration of radiation from the cesium atom (Cs).



- In October 1983, the meter (m) was redefined as the distance traveled by light in vacuum during a time of 1/299 792 458 second.