Physics 331 – Logistics, Timeline, etc.

Website: http://courses.washington.edu/phys331/
Lec: PAA110 (M 11:30-12:20PM)
OH: Thursday 4-5 pm at B437 or by appointment
Lab: Rm B260 (Sec A,B,C,D - T,W,F,M 130-420PM)
Text: Optics by Eugene Hecht, also see website

Today…

- Course Requirements
- Speed of light experiment
- Uncertainty analysis

Physics 331 – Logistics, Timeline, etc.

Course Requirements: Total eight labs

Must perform Speed of Light (SOL) + 5 other labs
Must submit lab reports on SOL + 5 (or more) labs
Must submit pre-lab-reports except SOL (+5 labs)

SOL lab due in 1 week (5%/late day deduction)
Others due in 2 weeks after lab completed (5%/late day deduction)
Pre-lab-reports due before each lab (no points for any delay)
Last submission day – Monday, (12/11/2015)

Exam: One in-class exam based on lecture materials (12/07/2015).

Nov. 11 Veterans Day (Wednesday) -> The Wednesday of Thanks Giving week (Nov 25)

Make-up lab: Monday and Tuesday labs (Nov. 23 and 24 th) of the Thanks Giving week (or regular lab-sections if you can find open spots)

Important: To be eligible for getting final grade for Physics 331a, you must ***submit the speed of light report by Monday (Oct. 26), and submit at least three full reports by Monday Nov. 16th.***

Course Grade:

SOL: 10%; Each other lab report worth 15%

Exam worth 10%

Pre-lab:5%

Grade = SOL+Top 5 of other Lab reports+ Exam+pre-lab-reports

= 10%+ 75%+ 10%+ 5%=100%

Writing Credit: To be eligible for writing credit, you must submit eight lab reports.

Physics 331 – Logistics, Timeline, etc.

Lab sign-up sheets will be handed out during lecture and will hang outside the lab door the rest of the week. Except weeks 1 and 2, two-three people per lab (1 and 4-person Labs are not allowed).

There are still **19** students singed up for the Tuesday lab (Try Friday or Wend).

Important Handouts (see Website):
http://courses.washington.edu/phys331/index.php

Lab writeups (and accompanying material) – please read before lab

Statistics Summary

Notes on Data Analysis and Experimental Uncertainty

Lab Practice and Writing Reports

Recommended Readings

Lectures will be placed on Web after class

1. Speed of light: Measure speed of light using time of flight method.

2. **Concave Diffraction Grating** A concave grating in a Rowland mount is used to determine the Rydberg constant for atomic hydrogen. The spectral resolution of the grating is investigated through a measurement of the spectrum of atomic deuterium.

3. **Fabry-Perot Interferometer** A modular mirror system is used to construct and investigate the properties of the most widely used type of multiple-beam interferometer. It is used to measure the mode structure of HeNe lasers operating at $\lambda = 633$ nm and $\lambda = 544$ nm.

4. **Michelson Interferometer** A modular mirror system is used to set up and investigate the properties of an historically significant interferometer. Interference patterns are observed for three types of light sources: a laser, an incandescent lamp (white-light), and a sodium lamp. The yellow sodium D lines are used to illustrate the Fourier transform properties of the interferometer.

5. **Fraunhofer and Fresnel Diffraction in One Dimension** Fraunhofer diffraction is "far-field" diffraction from a single slit and from equally spaced multiple slits. The patterns observed can be interpreted in terms of the Fourier transform of an aperture function. Fresnel Diffraction is "near-field" diffraction. We study the pattern from an adjustable-width slit and a half plane, and explore the transition from Fresnel diffraction to the Fraunhofer limit. A linear photodetector array is used to acquire a digitized output of the light intensity in the diffraction patterns. This allows a quantitative comparison with the theory.

6. **Reflection of Light at an Air-Dielectric(Glass) Interface** Reflection from a glass plate is studied as a function of the angle of incidence, the polarization and the wavelength. Time permitting, the same study can be made for a glass surface with an antireflection coating.

7. **Faraday Rotation** The rotation of the plane of polarization of light propagating along a magnetic field in a dispersive medium is studied as a function of magnetic field and compared to a simple theory.

8. **Holography** The relationship between a hologram and a diffraction pattern is explored by making and viewing transmission holograms with a HeNe laser. NOTE: you must complete at least one of the following experiments before attempting the holography experiment: Fabry-Perot interferometer, Michelson interferometer, or Fraunhofer and Fresnel diffraction.

Sign-up Sheet for Speed of Light

For this week only: Maximum group size = 4 persons

	Monday (AD) 1 October	Tuesday (AA) 2 October	Wednesday (AB) 3 October	Friday (AC) 5 October
Group 1				
Group 2				
Group 3				
Group 4				
Group 5				

Lab sign-up sheet

Optics Lab — Physics 331 Sign-up Sheet

	Monday1:30 ***AD***	***Tuesday 1:30*** ***AA***	***Wednesday1:30*** ***AB***	***Friday 1:30*** ***AC***
Fraunhofer & Fresnel Diffraction				
Fabry-Perot Interferometer				
Michelson Interferometer				
Concave Diffra… Grating				
Reflection from a Dielectric Surface				
Faraday Rotation				
Holography *Must complete Fabry-Perot or Michelson interfrometer*				

Please remember what you have signed up

Lab Safety

http://courses.washington.edu/phys331/lab_practice_and_report.pdf

Lab Practices, Precautions, Notebooks and Reports

Precautions

- **No food or drink** are permitted in the lab.
- **DO NOT LOOK DIRECTLY INTO ANY LASER BEAM OR ANY SPECULAR REFLECTION OF A LASER BEAM.** The lasers in the lab put out 2 mW, more than needed for permanent eye damage.
- ***DO NOT touch mirror surfaces, or any optical surface.*** If a component is dirty, please consult the Lab Manager.
- In the diffraction experiment (Exp. 5) do not focus the *unattenuated* (i.e., not dimmed with a polarizer) laser light to a point on the linear array. Focus the beam on an index card in place of the array, then remove the card after dimming the beam.
- Use special care with the spatial filter pinholes (1-d diffraction experiments use these).
- The curtains around each lab station can easily be pulled out of their tracks. To avoid this, gather the curtain in small bunches and pull a small portion of the curtain at any one time
- Avoid leaning on optical tables.
- Mirrors, lenses should be covered when experiments are finished. When in doubt, ASK FOR INSTRUCTIONS.

Report: Pre-Lab-Report and Lab Report

Pre-Lab-Report: Due when you sign-in the lab.

1. What's the general purpose of the experiment?
2. What are the quantities you will directly measure and how to measure?
3. What are the quantities you will derive from the measurement and how to derive it?

Example of pre-lab-report

http://courses.washington.edu/phys331/xu_11-12/Example_of_Pre-lab-reports.pdf

Lab Report

Lab report grading standards.

http://courses.washington.edu/phys331/Reports_grading_331.pdf

Academic Honesty

Students working together are encouraged to discuss their analysis and results with each other (and with other students) but must independently generate their own written reports.

The way in which you estimate your uncertainties must ALWAYS be clearly shown. If you copy text from the lab instructions, you are wasting space. You are asked to give a brief statement in the introduction; this means in *YOUR* words.

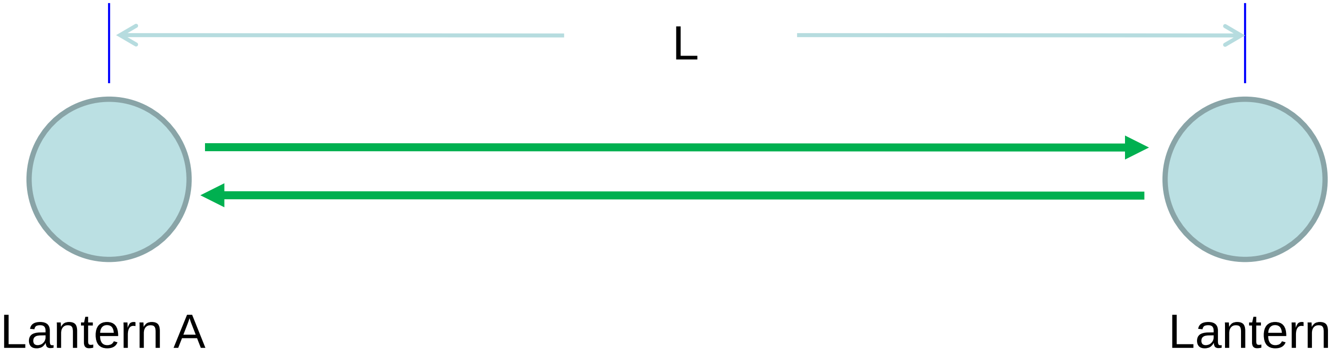
Lab Report (50 points)

Switch to grading policy……

http://courses.washington.edu/phys331/Report_Grading_standards.pdf

Speed of Light Experiment – History and Background

Galileo, 1638



$c=2L/\tau$

τ

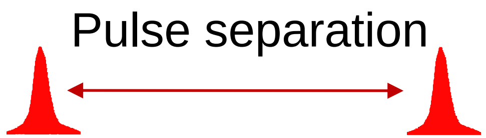
A feasible scheme?

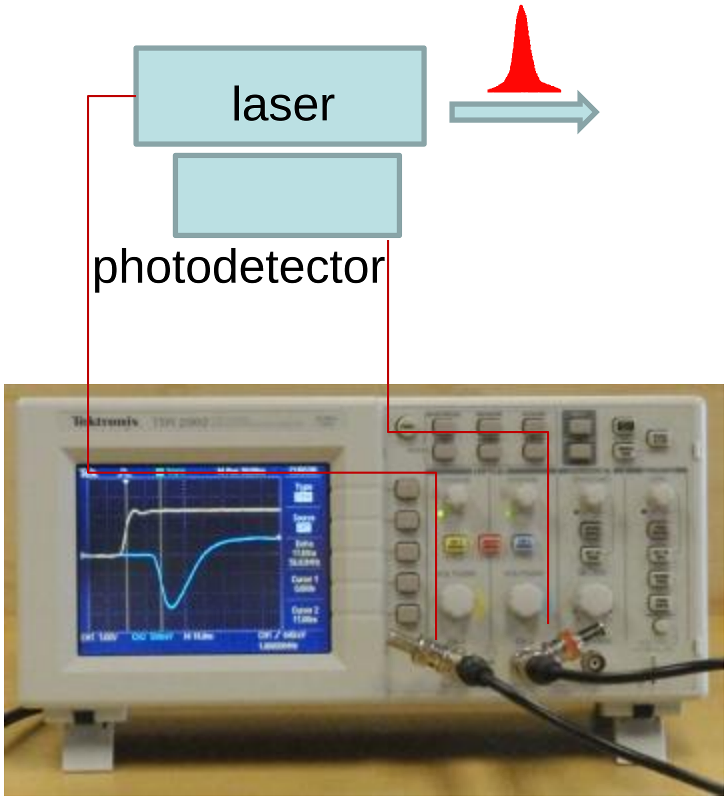
$c=\sim 3*10^8$ m/s; $L=3000$ m;
$\tau=2L/c=2*3000/(3*10^8)=2*10^{-5}$ s=0.02 ms

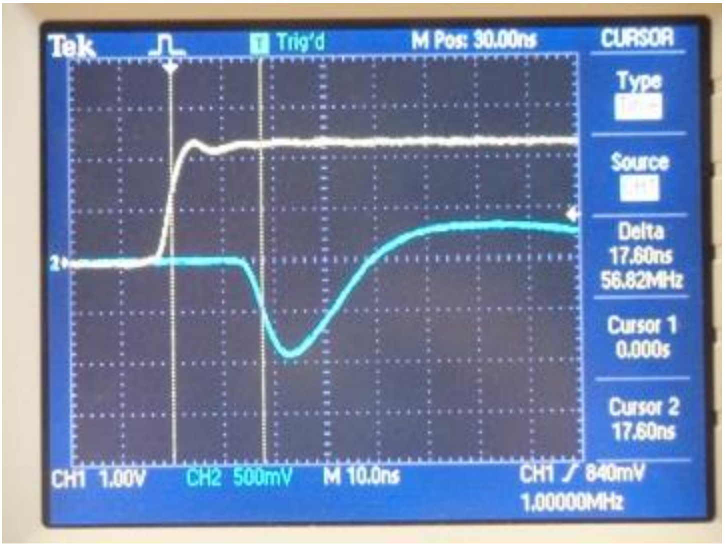
Mean response time T of college students:190 milliseconds
$T/\tau\sim 10^4$!!!—– not enough response time

Speed of Light Experiment - Schematic

Pulse laser: 1MHz repetition rate
Time separation between pulses:
1/pulse repetition rate =1 microsecond







Speed of Light Experiment - Schematic

$$c = L/\tau$$

L: the round trip of the light
τ: time for pulse to travel from laser output to detector

Experiment: measure a few pairs of (L, τ).

What will happen if L is too short?

Pulse separation

1 microsecond

What will happen if L is too long?

$c^* 10^{-6} = 300\text{m}$

Error Analysis: Types of Uncertainties

- Systematic uncertainty: due to the faults of measurement instruments or the techniques used in the expeirment.
  - If you measure the length of a table with a steel tape which has a kink in it, you will obtain a value which will appear to be too large by an amount equal to the loss in length resulting from the kink. On the other hand, a calibration error in the steel tape itself—an incorrect spacing of the markings—will produce a bias in one direction.

  Systematic uncertainty decreases the accuracy of an experiment

- Random uncertainty: associated with unpredictable variations in the experiment, or due to the deficiency in defining quantity be measured.
  - Electrical noise—from nearby circuits or equipment, thermal effects, or imperfect connections—may cause random fluctuations in the magnitude of a quantity measured by a voltmeter.
  - The length of a table may depend on which two points along the edge of the table the measurement is made. The "length" is imprecisely defined in such a case.

  Random uncertainty decreases the precision of an experiment

Error Analysis : Types of Uncertainties

These distinctions are illustrated in Fig. 1. You should avoid falling into the trap of thinking that because the uncertainty of a measurement is always the same, then it is systematic. Systematic uncertainty does *not* mean that the uncertainty is repeatable. What it means is that the uncertainty involves physics that has not been accounted for in the analysis—two very different ideas.

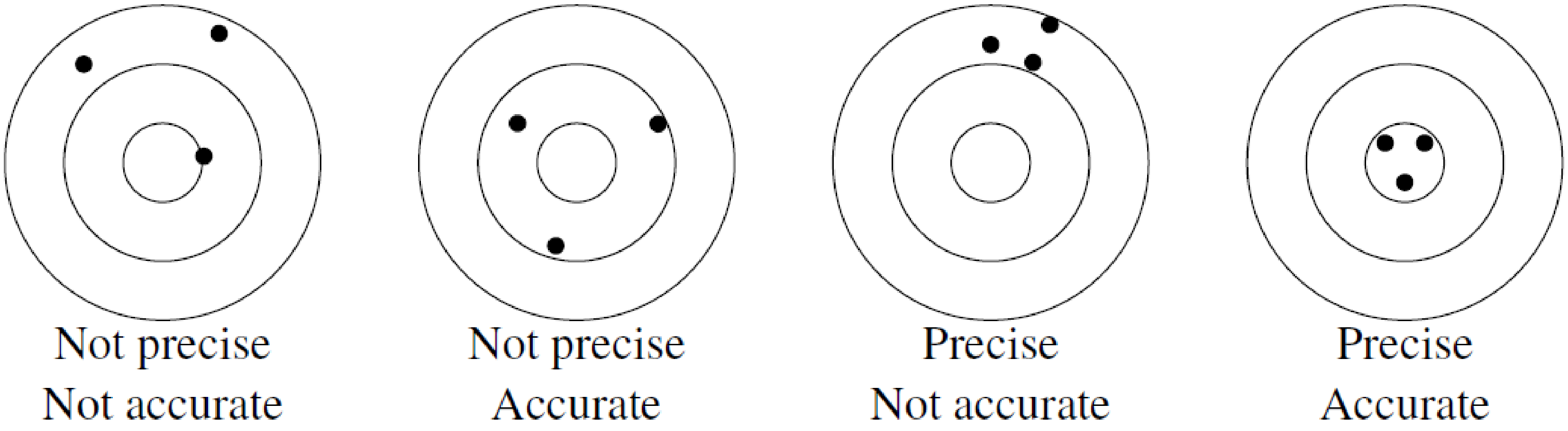


Figure 1: A "bulls-eye" plot showing the distinction between precision and accuracy in a measurement. The black dots represent data points taken in a measurement of a quantity whose true value is at the center of the circles.

Error Analysis: Types of Uncertainties

Example: measurement of a period of pendulum

	uncertainty
Use a clock that always runs fast.	systematic
Repetitive measurements with starting and stopping watching at different points.	random
Repetitive measurements with starting and stopping watching at different points. However, one always starts the clock early and stops the watch late.	Systematic + Random

Error Analysis: Mean, Standard Deviation, and Stand Deviation of the Mean

Example: Measure the length of the table

$x_1, x_2, x_3, \ldots, x_{N-1}, x_N$

$$\overline{x} = \frac{x_1 + x_2 + \ldots + x_N}{N} = \frac{1}{N}\sum_{i=1}^{N} x_i.$$

How much of individual measurements are scattered from the mean?

Variances   Standard deviation

For the case of equal uncertainties, an unbiased estimate of σ_n^2, the variance of an individual measurement of a sample of N measurements is (BR p.11 and p.54)

$$\sigma_n^2 = \frac{1}{N-1}\sum_{1}^{N}(x_n - \overline{x})^2,$$

and the variance in the mean of a sample of N measurements, $\sigma_{\overline{x}}^2$, is (BR p.54)

$$\sigma_{\overline{x}}^2 = \frac{1}{N}\sigma_n^2$$

Data Reduction and Error Analysis by Bevington and Robinson (BR).

Error Analysis – Stating the results

There are two common ways to state the uncertainty of a result: in terms of a σ, like the standard deviation of the mean σ_m, or in terms of a percent or fractional uncertainty, for which we reserve the symbol ϵ ("epsilon"). The relationship between ϵ and σ is as follows. Let the quantity of interest be x, then, by definition,

$$\epsilon_x \equiv \frac{\sigma_x}{x} . \tag{4}$$

the result: $\bar{X} \pm \sigma$

Error Analysis: Significant Digits

the result: $\bar{X} \pm \sigma$

- The uncertainty σ in the final result should have, at most, 2 digits, and more commonly 1 digit. Remember, all uncertainty calculations are *estimates*; there is no such thing as an "exact uncertainty". Use this rule: if the first digit of σ is 1, use 2 digits for sigma, e.g., $\sigma_x = 0.14$ g, or $\sigma_x = 0.3$ g, but *not* $\sigma_x = 0.34$ g.

  The result itself should be stated to the same precision as σ_x. For example, you should write 9.5 ± 0.3 g, or 9.52 ± 0.14 g, but not 9.52 ± 0.3 g.

- If σ is especially large, you will *lose* significant digits. For example, suppose that multiple measurements are made with an instrument that is precise to 3 digits, and mean value of 9.52 g is found, but for other reasons the data points varied so that the standard deviation of the mean was 2 g. The result would have to be reported as 9 ± 2 g.

  If the measurement is so bad that σ is larger than the value itself, you may have *no significant digits*, but only know the order of magnitude. This case is most common when the quantity in question is expected to be close to zero—such measurements may only give an upper or lower bound on the quantity.

- If σ is calculated to be much smaller than the smallest digit of your measurement, then assume that σ is equal to "1" of the smallest digit. For example, if a measurement of a mass gives exactly 9.52 g ten times, the result should be stated as $m = 9.52 \pm 0.01$ g. Thus you may need to round your uncertainty up to the least significant digit in your measurement.

Error Analysis – Error Propagation

Propagation of Errors

When the quantity being measured, let's call it u, is some combination of independent quantities which we will call $x, y, z, \cdots$, $u = u(x, y, z, \cdots)$, there is a simple general rule for calculating the uncertainty in u, σ_u, given the uncertainities $\sigma_x, \sigma_y, \sigma_z, \cdots$ in $x, y, z, \cdots$. This is

$$\sigma_u^2 = \left(\frac{\partial u}{\partial x}\right)^2_{\bar{x},\bar{y},\bar{z},} \sigma_x^2 + \left(\frac{\partial u}{\partial y}\right)^2_{\bar{x},\bar{y},\bar{z},} \sigma_y^2 + \left(\frac{\partial u}{\partial z}\right)^2_{\bar{x},\bar{y},\bar{z},} \sigma_z^2 + \cdots$$

Two examples of this rule are of particular interest. The first is the situation in which u is the sum or difference of the quantities $x, y, z, \cdots$, for example, $u = x + y - z$. The partial derivatives of u with respect to x, y and z are either +1 or –1 so the expression for the uncertainty of u reduces to (BR p.42)

$$\sigma_u^2 = \sigma_x^2 + \sigma_y^2 + \sigma_z^2$$

The square of the uncertainty of u is the sum of the squares of the uncertainties of x, y, and z.

Error Analysis – Error Propagation

The second example is that in which u can be expressed as the product and/or quotient of x, y, and z, for example, $u = \frac{xy}{z}$. It is a simple matter to show that the general expression reduces in this case to (BR p. 43)

$$\left(\frac{\sigma_u}{u}\right)^2 = \left(\frac{\sigma_x}{x}\right)^2 + \left(\frac{\sigma_y}{y}\right)^2 + \left(\frac{\sigma_z}{z}\right)^2$$

$$\varepsilon_u^{\ 2} = \varepsilon_x^{\ 2} + \varepsilon_y^{\ 2} + \varepsilon_z^{\ 2}$$

Thus the square of the *fractional* (or *relative*) uncertainly in u, $\frac{\sigma_u}{u}$, is the sum of the squares of the *fractional* (or *relative*) uncertainties in x, y, and z.

Table 1: Common formulas for propagating uncertainty. These equations can be combined in t cases of more complicated formulas, or the student may work directly from equation (6).

Functional Form	Formula	Uncertainty formula
Product or Quotient	$f = xy$ or $f = x/y$	$\epsilon_f = \sqrt{\epsilon_x^2 + \epsilon_y^2}$
Sum or Difference	$f = x + y$ or $f = x - y$	$\sigma_f = \sqrt{\sigma_x^2 + \sigma_y^2}$
Product of factors raised to powers	$f = x^m y^n$	$\epsilon_f = \sqrt{m^2\epsilon_x^2 + n^2\epsilon_y^2}$
Constant multipliers	$f = Kx$ (K =constant)	$\sigma_f = K\sigma_x$
Logarithmic functions	$f = \log_e(x)$	$\sigma_f = \epsilon_x$
	$f = \log_{10}(x)$	$\sigma_f = \log_{10}(e)\epsilon_x = 0.4343\epsilon_x$
Exponential functions	$f = e^x$	$\epsilon_f = \sigma_x$
	$f = 10^x$	$\epsilon_f = \log_e(10)\sigma_x = 2.303\sigma_x$

$$\sigma_u^2 = \left(\frac{\partial u}{\partial x}\right)^2_{\bar{x},\bar{y},\bar{z},} \sigma_x^2 + \left(\frac{\partial u}{\partial y}\right)^2_{\bar{x},\bar{y},\bar{z},} \sigma_y^2 + \left(\frac{\partial u}{\partial z}\right)^2_{\bar{x},\bar{y},\bar{z},} \sigma_z^2 + \cdots$$

Speed of Light Experiment – Obtaining *c*

$c = L/\tau$

$u = xy/z$

$$\left(\frac{\sigma_u}{u}\right)^2 = \left(\frac{\sigma_x}{x}\right)^2 + \left(\frac{\sigma_y}{y}\right)^2 + \left(\frac{\sigma_z}{z}\right)^2$$

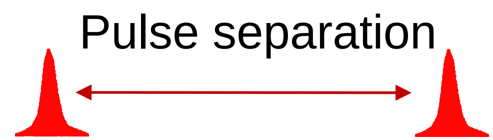
$$\left(\frac{\sigma_c}{c}\right)^2 = \left(\frac{\sigma_L}{L}\right)^2 + \left(\frac{\sigma_\tau}{\tau}\right)^2$$

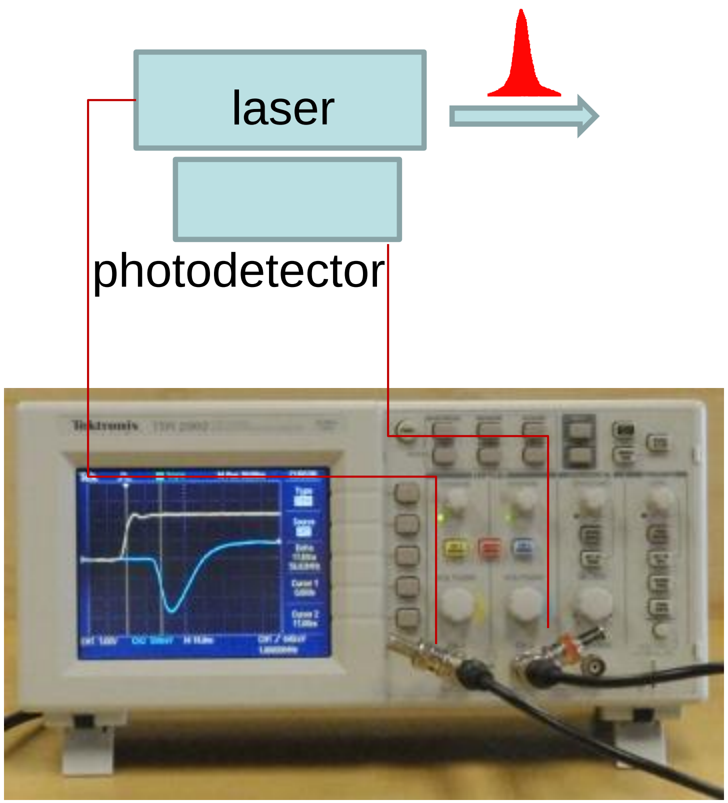
What is the error in the obtained value?

How does the error in each piece of the RHS contribute to the error in c?

Speed of Light Experiment - Schematic

Pulse laser: 1MHz repetition rate
Time separation between pulses:
1/pulse repetition rate =1 microsecond





$L = c\tau$

Example on Error Analysis

1. Error propagation and statistics

(a) (7 pts) An experiment to measure the speed of sound in a gas employs a tube of fixed length with a source at one end and a detector at the other. One end of the tube is measured to be at 8.13 m from a wall with an uncertainty of +- 2 cm and the other end is measured to be at 2.50 m from the same wall with an uncertainty of +- 2 cm. The transit time is measured to be 8.8 ms with an uncertainty of +-0.1 ms. What is the speed of sound for the gas in the tube and the uncertainty in its measurement?

Table 1: Common formulas for propagating uncertainty. These equations can be combined in t cases of more complicated formulas, or the student may work directly from equation (6).

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Product of factors raised to powers	$f = x^m y^n$	$\epsilon_f = \sqrt{m^2\epsilon_x^2 + n^2\epsilon_y^2}$
Constant multipliers	$f = Kx$ (K =constant)	$\sigma_f = K\sigma_x$
Logarithmic functions	$f = \log_e(x)$	$\sigma_f = \epsilon_x$
	$f = \log_{10}(x)$	$\sigma_f = \log_{10}(e)\epsilon_x = 0.4343\epsilon_x$
Exponential functions	$f = e^x$	$\epsilon_f = \sigma_x$
	$f = 10^x$	$\epsilon_f = \log_e(10)\sigma_x = 2.303\sigma_x$

Example on Error Analysis

1. Error propagation and statistics

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$$V = \frac{L}{\tau}$$

$$L = d_2 - d_1 = 8.13 - 2.50 = 5.63m$$

$$\tau = 8.8ms$$

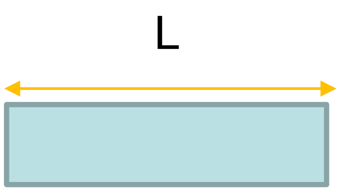
$$V = \frac{5.63m/s}{8.8\times10^{-3}} = 639.8m/s$$

$$\sigma_L = \sqrt{\sigma_{d_1}^2 + \sigma_{d_2}^2}$$

$$\sigma_\tau = 0.1ms$$

$$\frac{\sigma_V}{V} = \sqrt{\left(\frac{\sigma_L}{L}\right)^2 + \left(\frac{\sigma_\tau}{\tau}\right)^2} = 0.012$$

$$\sigma_V = 7.68m/s$$



$$V = (640 \pm 8)m/s$$

Example on Error Analysis

(b) (3 pts) After making 10 measurements of the speed of light, an experimenter determined that the uncertainty could be described as entirely statistical, with an uncertainty in the mean of 3.0×10^8 cm/s. How many measurements would it take to give a final uncertainty in the *mean* of 1.0×10^8 cm/s?

How much of individual measurements are scattered from the mean?

Variances Standard deviation

For the case of equal uncertainties, an unbiased estimate of σ_n^2, the variance of an individual measurement of a sample of N measurements is (BR p.11 and p.54)

$$\sigma_n^2 = \frac{1}{N-1}\sum_1^N (x_n - \bar{x})^2,$$

and the variance in the mean of a sample of N measurements, $\sigma_{\bar{x}}^2$, is (BR p.54)

$$\sigma_{\bar{x}}^2 = \frac{1}{N}\sigma_n^2$$

Data Reduction and Error Analysis by Bevington and Robinson (BR).

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$$\sigma_{\bar{x}}^2 = \frac{1}{N}\sigma_n^2$$

$$3\times10^8 cm/s = \frac{\sigma}{\sqrt{10}}$$

$$1\times10^8 cm/s = \frac{\sigma}{\sqrt{N}}$$

$$3 = \frac{\sqrt{N}}{\sqrt{10}}$$

N=90