Senior Laboratory

PHYC 493L, Spring 2021

Classes: MW, 10 am – 2 pm

Location: PAIS 1417

Instructor: Tara Drake
Email: drakete@unm.edu
Office: PAIS 2234 and CHTM 118B

Teaching Assistant: Amir Khabbazi Oskouei
Email: akhabbazioskouei@unm.edu

Error in Measurement

Research Group	Reported value
Yale	15
Waterloo	15
UNM	12
UCSB	15

Error in Measurement

Research Group	Reported value
Yale	15 ± 7
Waterloo	15 ± 8
UNM	12 ± 2
UCSB	15 ± 4

Error in Measurement

Research Group	Reported value
Yale	15 ± 7 g/cm^3
Waterloo	15 ± 8 g/cm^3
UNM	12 ± 2 g/cm^3
UCSB	15 ± 4 g/cm^3

Density of gold = 19.3 g/cm^3
Density of lead = 11.4 g/cm^3

Error in Measurement

Research Group	Reported value
Yale	15 ± 7 g/cm^3
Waterloo	15 ± 8 g/cm^3
UNM	12 ± 2 g/cm^3
UCSB	15 ± 4 g/cm^3

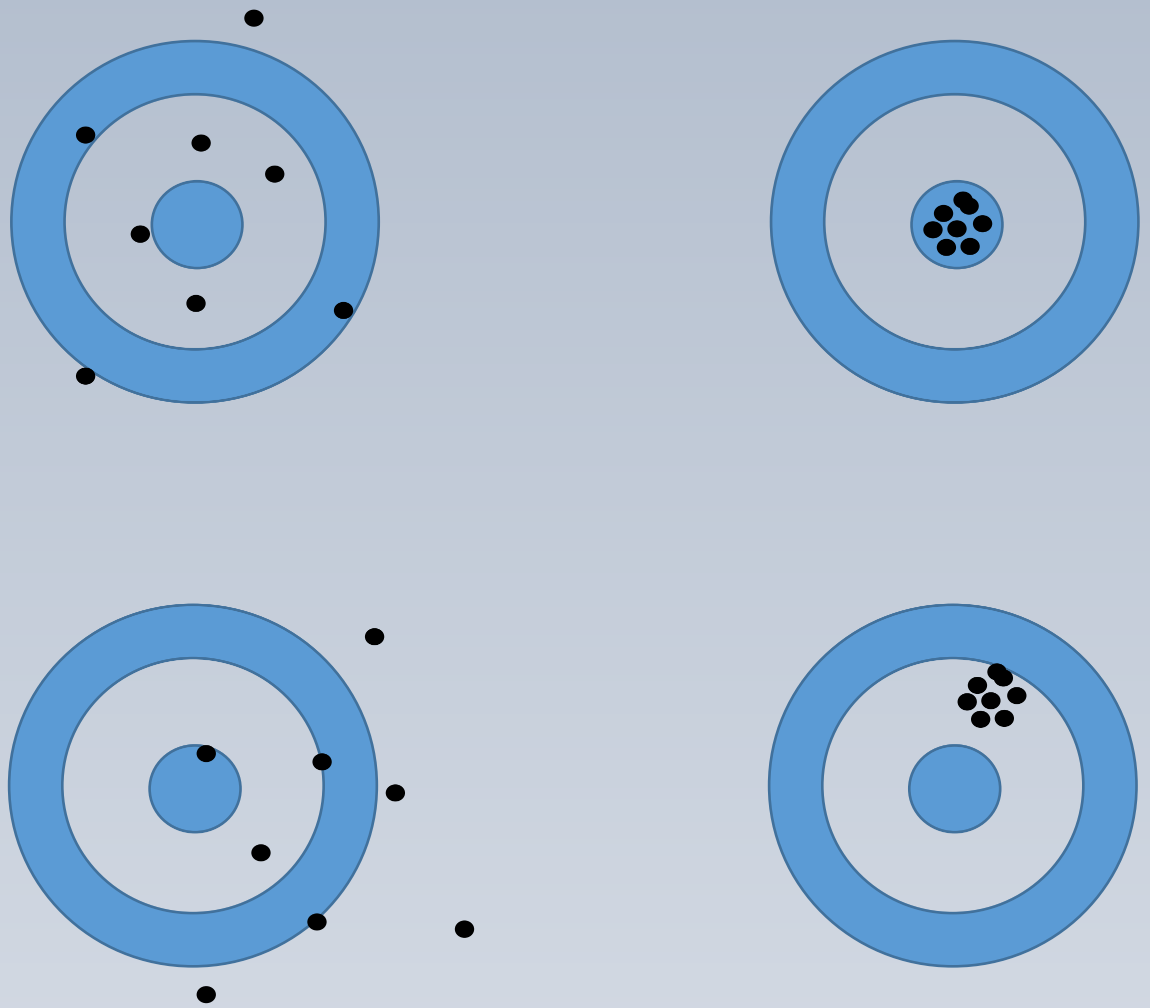
Density of gold = 19.3 g/cm^3
Density of lead = 11.4 g/cm^3

Conclusion: It is very important to understand the reported errors on the UNM measurement.

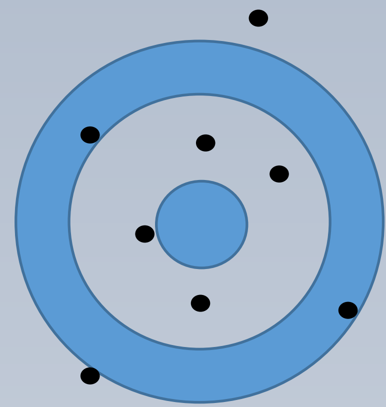
Uncertainty is Necessary

- In research, a measurement without the uncertainty quoted is wrong.
- “Error” does not mean mistake
- Important related ideas:
  - Error and Uncertainty
  - Accuracy vs. Precision
  - Statistical vs. Systematic Uncertainty
  - Significant Figures
  - Resolution
  - Uncertainty in fitted data: errors on parameters vs. goodness of fit

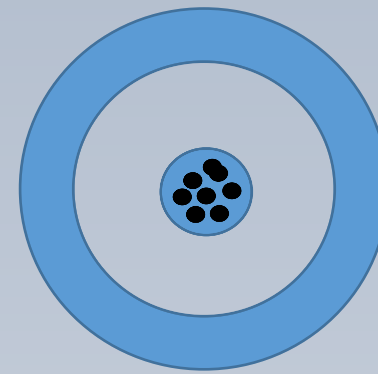
A word on Precision and Accuracy



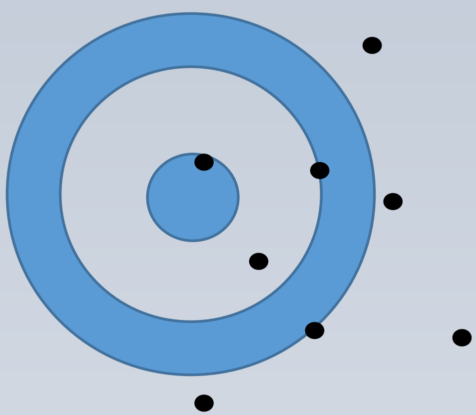
A word on Precision and Accuracy



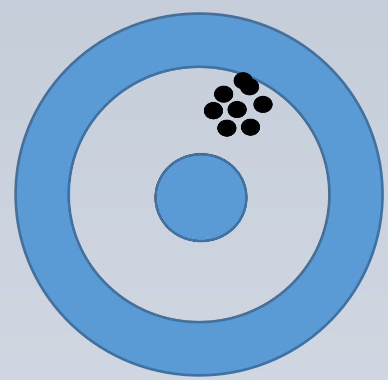
Large statistical uncertainty
Small systematic uncertainty



Small statistical uncertainty
Small systematic uncertainty

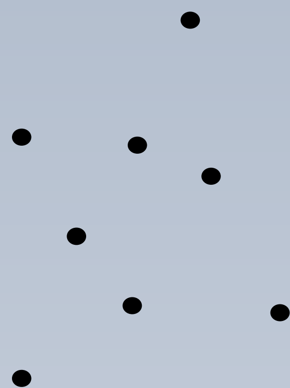


Large statistical uncertainty
Large systematic uncertainty



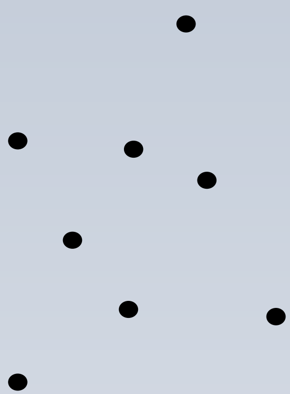
Small statistical uncertainty
Large systematic uncertainty

A word on Precision and Accuracy

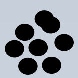


Large statistical uncertainty
systematic uncertainty = ??

Small statistical uncertainty
systematic uncertainty = ??



Large statistical uncertainty
systematic uncertainty = ??



Small statistical uncertainty
systematic uncertainty = ??

It is always necessary to evaluate experimental/systematic sources of error/uncertainty, no matter how “good” your data.

Precision scientists often use “blinds” to prevent researchers from biasing data while it is being taken.

“We have learned a lot from experience about how to handle some of the ways we fool ourselves. One example: Millikan measured the charge on an electron by an experiment with falling oil drops, and got an answer which we now know not to be quite right. It's a little bit off because he had the incorrect value for the viscosity of air. It's interesting to look at the history of measurements of the charge of an electron, after Millikan. If you plot them as a function of time, you find that one is a little bit bigger than Millikan's, and the next one's a little bit bigger than that, and the next one's a little bit bigger than that, until finally they settle down to a number which is higher.

“Why didn't they discover the new number was higher right away? It's a thing that scientists are ashamed of—this history—because it's apparent that people did things like this: When they got a number that was too high above Millikan's, they thought something must be wrong—and they would look for and find a reason why something might be wrong. When they got a number close to Millikan's value they didn't look so hard. And so they eliminated the numbers that were too far off, and did other things like that ...”

--Richard Feynman, 1974

How to report uncertainties

- Either:

$$3.0 \pm 0.7 \text{ cm, or}$$

$$3.0(7) \text{ cm}$$

- Almost always rounded to one sig fig:

$$3.0052 \pm 0.0004 \text{ cm}$$

- Last sig fig in answer should usually be same OOM as uncertainty

~~3.0 ± 0.0004 cm~~

Mathematics of Error Propagation

Addition of measurements

10.7(3) ft + 9.3(4) ft

Addition of measurements

10.7(3) ft + 9.3(4) ft

= 20.0(5) ft

*Error reported = $\sqrt{(error1)^2 + (error2)^2}$

*for uncertainties which are **independent** and **random**

Subtraction of measurements

10.7(3) ft - 9.3(4) ft

Subtraction of measurements

10.7(3) ft - 9.3(4) ft

= 1.4(5) ft

Error reported = $\sqrt{(error1)^2 + (error2)^2}$

Note: Subtraction of large and similarly valued measurements can lead to a big increase in fractional uncertainty

Multiplication or Division of measurements

1.4(1) kg * 3.5(5) m/s^2

Multiplication or Division of measurements

1.4(1) kg * 3.5(5) m/s^2

= 4.9(8) N

$$z = x * y$$

$$\frac{dz}{z} = \sqrt{\left(\frac{dx}{x}\right)^2 + \left(\frac{dy}{y}\right)^2}$$

(for uncertainties which are **independent** and **random**)

General formula for error propagation

y = f(x)

$$\delta y = \left|\frac{dy}{dx}\right| * \delta x$$

y = f(x_1,x_2,…,x_N)

$$\delta y = \sqrt{\left(\left|\frac{\partial y}{\partial x_1}\right| * \delta x_1\right)^2 + \cdots + \left(\left|\frac{\partial y}{\partial x_N}\right| * \delta x_N\right)^2}$$

(for uncertainties which are **independent** and **random**)

Reporting uncertainty in your lab reports

- When reporting uncertainties, tell the reader where they come from. (You do not need to include the calculations in the report—but it needs to be in your lab notebook.) These could be:
  - The error bar on a fit. (A fit (to the expected function) gives a rate of 4.0(1) liters/s.)
  - The resolution of an instrument you used to measure. ("The analyzer had a resolution bandwidth of 100 kHz.")
  - The standard deviation on repeated measurements. (We measure 100(9) counts per minute.)
- Most often, one source of uncertainty dominates the uncertainty in your results. Learn to identify this!

Homework #1

Handout will be emailed on Wednesday (2/10), due 2/17 (1 week) by email.

Should be quick (~1 hr), testing comprehension.

Slides will be posted 2/10.

Do you need extra time to finish experiment 1?

- Last day of module 1 is 2/17.
- Extra time will be available next week.
- Amir and I will work out the exact times later this week.
- Email me if you think this applies to you.
- Email me with any other concerns.

Are you symptomatic/exposed to symptoms/worried/in need of advice?

Call:

Student Health and Counseling (SHAC)

(505) 277-3136, select option **7**

Error Analysis: an excellent reference