Introduction to Physics 1107/1110 Lab

Timetable 1110	
	Lab Sessions
Section 001	Wednesday 8:30 – 11:20
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Section 002	Friday 8:30 – 11:20
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Section 004	Friday 12:30 – 3:20
Pre-Lab Quiz	Tuesday due @11:59 pm

Please be on time as the start of the lab is the most important.

Details on how to do the lab and warnings about the trickier parts.

Timetable 1107	
	Lab Sessions
Section 003 ---- Section 004	Thursday 8:30 – 11:20 ---- Thursday 12:30 – 3:20
Pre-Lab Quiz	Wednesday due @11:59 pm

Please be on time as the start of the lab is the most important.

Details on how to do the lab and warnings about the trickier parts.

Pre-Lab Quiz

- Posted on *the assigned day of the week* before your lab date
- It will be available for 24 hours
- Once you start the quiz you will have 30 min to finish.
  - If you close the quiz the timer is still running.
- Make sure you read the whole lab and all the supplemental material BEFORE doing the quiz.

The first question is always:

> *The Conclusion of a scientific experiment is to answer the question (or questions) about a topic or concept posed in that experiment. What is the question (or questions) that you are trying to answer with this experiment?*

See section one of your lab manual for more details.

Lab Submissions

- Labs are done on provided worksheets and are due at the end of each session
- Graphs are done in Excel or Google Sheets (or any other graphing software), printed and attached to your lab
- Completed labs kept in folder in the Lab. Any labs that go missing will not be counted towards your final mark.

Grading

- Half of the labs are marked, chosen at random.
- The lowest lab quiz and report mark will be dropped.
- Missed labs count as **Zero**, marked or not.

Quick Blackboard Tour

Measurement, Uncertainty, and Significant Figures

Comparing Values

Graphing

Common Objectives or Goals in Physics Experiments are to:

- determine an experimental value for a physical quantity

  e.g.: what is the spring constant of the spring used in this lab?

- verify (confirm) a theoretical or an accepted value of a physical quantity

  e.g.: is the net force experienced by the stationary ring equal to zero?

- determine the relationship between two quantities

  e.g.: what is the relationship between displacement and time for a ball rolling up a ramp while it is only subject to gravity? What kind of motion does that imply?

- verify (confirm) a theoretical relationship between two quantities

  e.g.: is period of a simple pendulum proportional to square root of its length?

All of these are involved with making measurements

Measurement and Uncertainty

Whenever a measurement is made, there is an uncertainty associated with the measurement. The uncertainty arises due to the measuring device limitations, the conditions under which the experiment is carried out, and the experimenter's skill and experience.

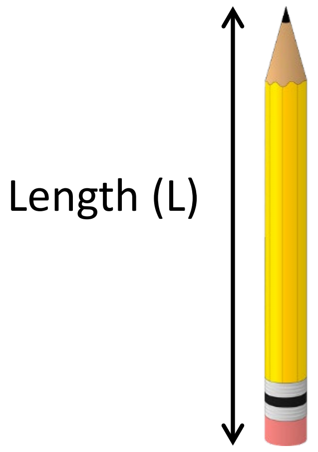
Therefore when quoting a quantitative result, you must be able to indicate

1) the precision of the result (how well you know it → number of digits)
2) the accuracy of the result (how confident you are in this result, or how much it could be off by.)

$$L = L \pm \delta L \equiv [(L - \delta L) , (L + \delta L)]$$

best estimate
Reasonable # of digits
(significant figures)

uncertainty in
estimated digit



Example: $L = 12.3 \pm 0.2$ cm $\equiv [12.1$ cm $, 12.5$ cm$]$

absolute uncertainty

How to record experimental measurements

- Use of **Significant Figures** and **Uncertainty**

The digits that are used to express the best estimate value in a measurement are called **significant figures**. Here “significant” means **scientifically meaningful**.

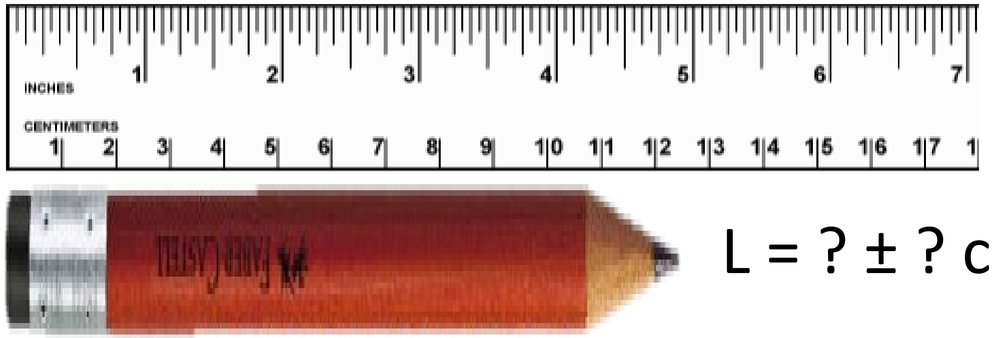
Significant figures in a measurement consist of all the **definite digits** and the **first estimated digit**.

$L = \boxed{12.}\boxed{3} \pm 0.\boxed{2}\ \text{cm}$

definite digits

Estimated digit

Uncertainty in the estimated digit



L = ? ± ? cm

The number of significant figures in a <u>value</u> tells how well you know that <u>value</u>. A larger number of sigfigs indicates a more precise measurement (and vice versa).

Uncertainty indicates how confident you are in the estimated digit, or shows the reasonable range that would include the TRUE value.

How to record experimental measurements

From previous slide:

Example: L = 12.3 ± 0.2 cm = 12.3 cm ± 1.6%

absolute uncertainty
1 significant figure only

percent uncertainty
(or relative uncertainty)

$$\frac{0.2}{12.3} \times 100\% = 1.6\%$$

percent uncertainty
Do Not round it to 1 sigfig.
2 to 4 sigfigs could be used
e.g.: 1.63% or 1.626%
But not 2%

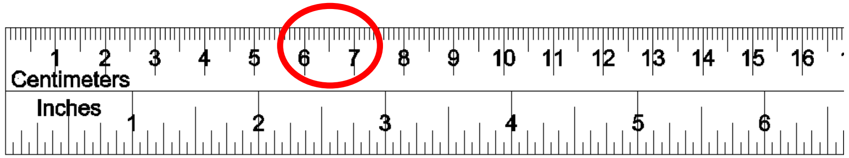
$$\% \text{ uncertainty} = \frac{\text{absolute uncertainty}}{\text{value}} \times 100\%$$

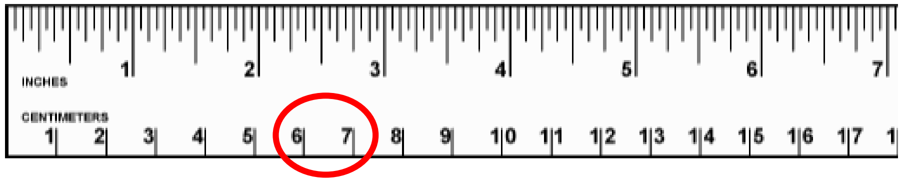
Sources of Uncertainty

- Reading uncertainty, instrumental limitations
- Random uncertainty
- Systematic uncertainty

Reading uncertainty

- Instrumental limitations (scales, how fine? Limited fineness!)

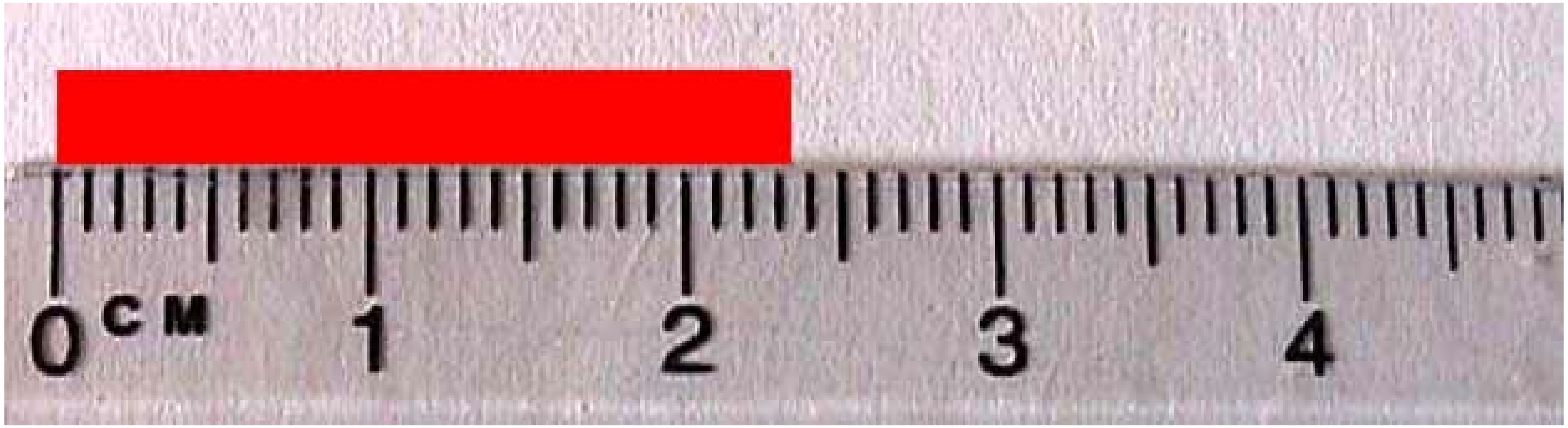




- Limitations imposed because of the conditions (nature) of measurement (a well-defined sharp edge object vs. a randomly shaped object) and also the experimenter’s skills and experience

- NOT “Human Error”

Reading uncertainties



What is the length of the red ribbon in millimeters, mm?

23.4 ± 0.2 mm

or 2.34 ± 0.02 cm

In the end always ask yourself → **Is This Reasonable?**

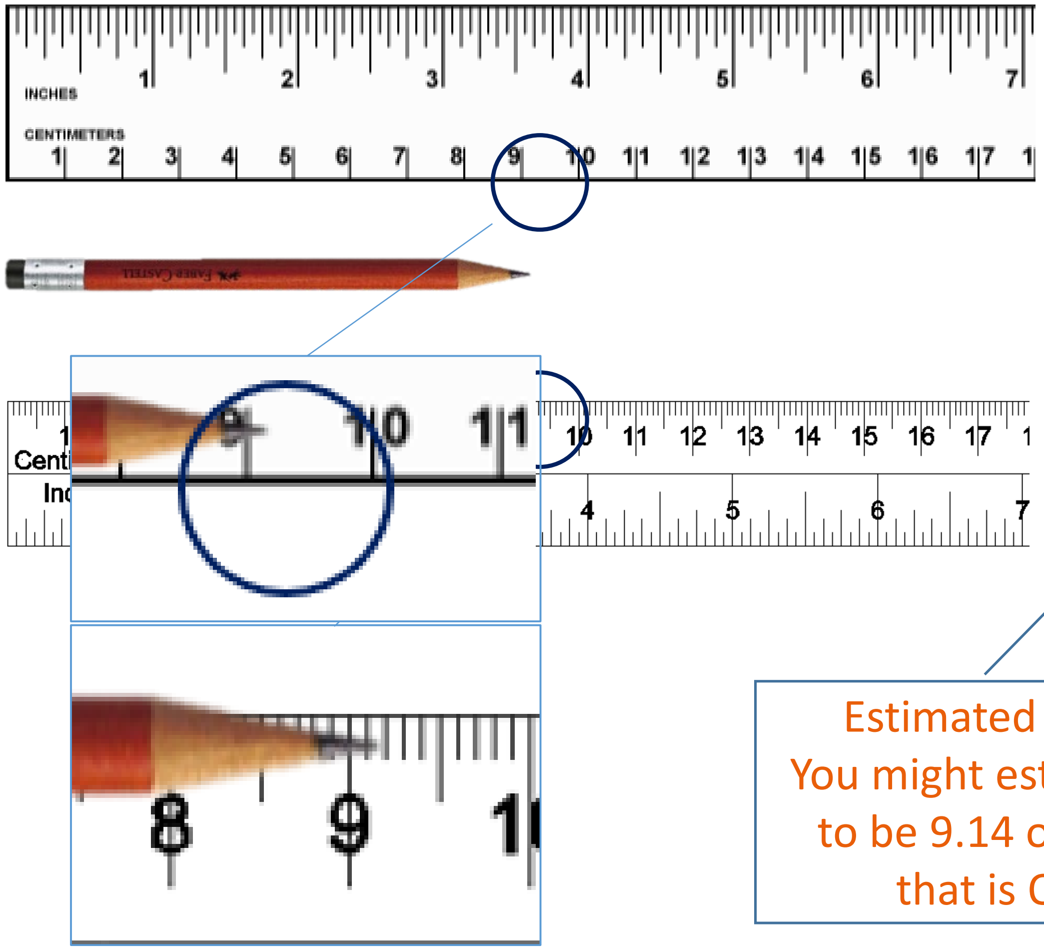
Reading uncertainties

→ Estimate the measurement

→ Estimate the error, the wiggle room you have

The known digit

The first estimated digit



9.2 ± 0.2 cm ≡ [9.0 cm - 9.4 cm]

9.15 ± 0.05 cm ≡ [9.10 cm - 9.20 cm]

Estimated digit!
You might estimate it to be 9.14 or 9.16, that is OK.

Practice: Reading Scales

Ruler Challenge Level 2

http://thephysicsaviary.com/Physics/Programs/Games/EstimatingRulerUseMS/

10 mL Graduated Cylinder Challenge Level 2

http://thephysicsaviary.com/Physics/Programs/Games/EstimatingGraduatedCylinderMS/

Read the Meter Challenge *(it's involved with a simple unit conversion mA to A)*

http://thephysicsaviary.com/Physics/Programs/Games/ReadTheMeter/

These and more can be found in **Essential Skills Lab** folder

Reading uncertainties

→Determine a range of reasonable values.

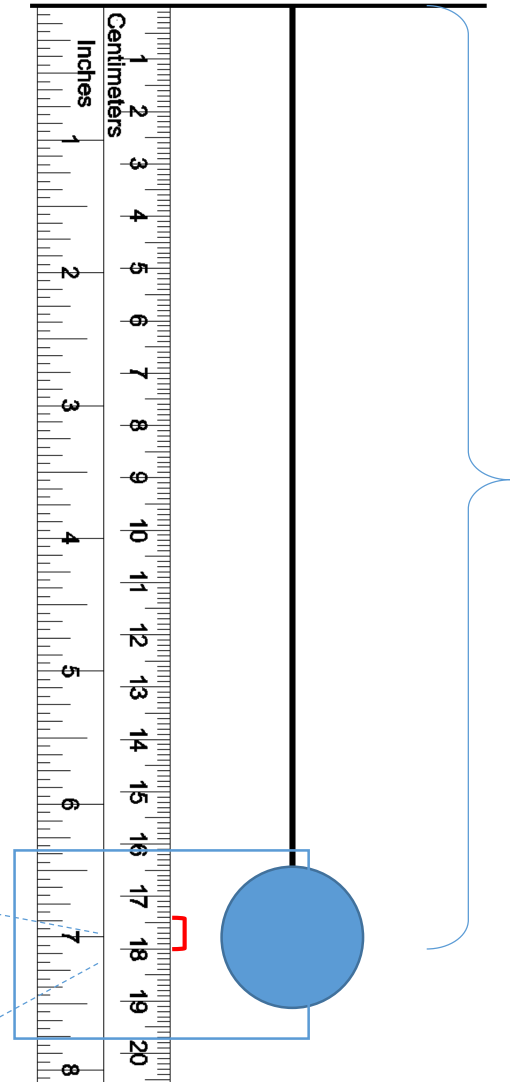
→[17.4 – 18.0] cm

→Midpoint is your best estimate

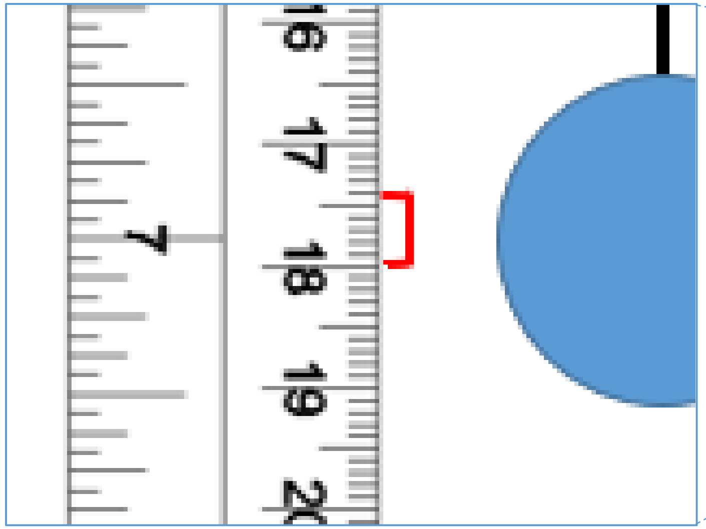
→(17.4 + 18.0) / 2 cm = 17.7 cm

→½ width is your error

→$|17.4 - 18.0|$ / 2 cm = 0.6 / 2 = 0.3 cm



L = 17.7 ± 0.3 cm



Reading uncertainties (Digital displays)

Digital Displays have

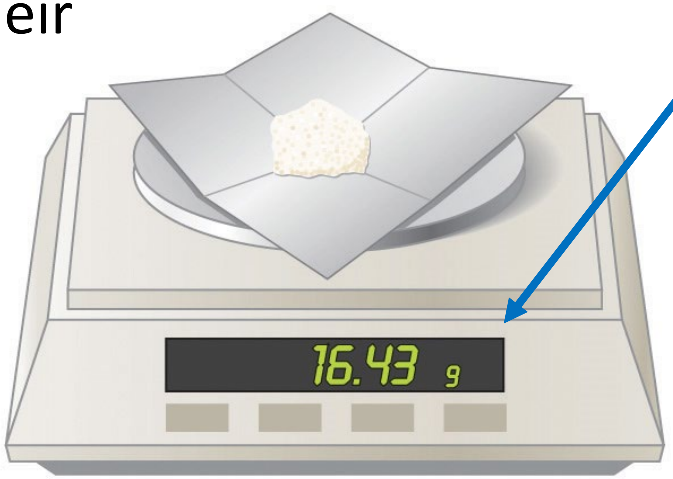
an error of 1 in their

smallest digit.

…Usually!

16.43 ± 0.01 g

?



?

23.4 ± 0.1 °C

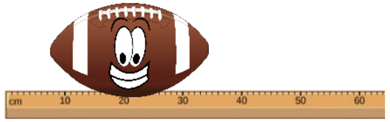
Exception!

for a manual stopwatch (digital or analog) your personal reaction time influences the uncertainty of timing!

Random uncertainty

While reading uncertainty provides you with an estimate of uncertainty when the object of measurement is reasonably well defined, in many cases the opposite is true!

For example, measuring the length of a football on a meterstick (where to read on the scale?),



or timing an event (when to start and stop the clock?)

Repeating these measurements may give somewhat different values. Those differences are due to random errors.

They could happen as a result of small changes in the experimental environment or slight unnoticed variations in measurement technique.

Random uncertainties Example

Objective: What is the time of travel (with uncertainty) for a toy car travelling a given distance?

Method:

- To find the average time we run three trials under the same conditions. Then find the average time and its uncertainty based on the variations in timing results. **Here is what we are after: $t_{avg} = t_{best-estimate} \pm \delta t_{avg}$**

Data:

Table 1 - time of travel of the toy car

	Trail 1, [s]	Trail 2, [s]	Trail 3, [s]
Time of travel	18.86	18.21	18.42

Calculations:

$$t_{best-estimate} = \frac{t_1 + t_2 + t_3}{3} = \frac{18.86 + 18.21 + 18.42}{3} = 18.4967\ s$$

$$\delta t_{avg} = \frac{largets\ variation}{2} = \frac{max - min}{2} = \frac{18.86 - 18.21}{2} = \frac{0.65}{2} = 0.325\ s$$

$$\delta t_{avg} = 0.3\ s$$

Absolute Uncertainty is always presented with ONLY 1 significant figure

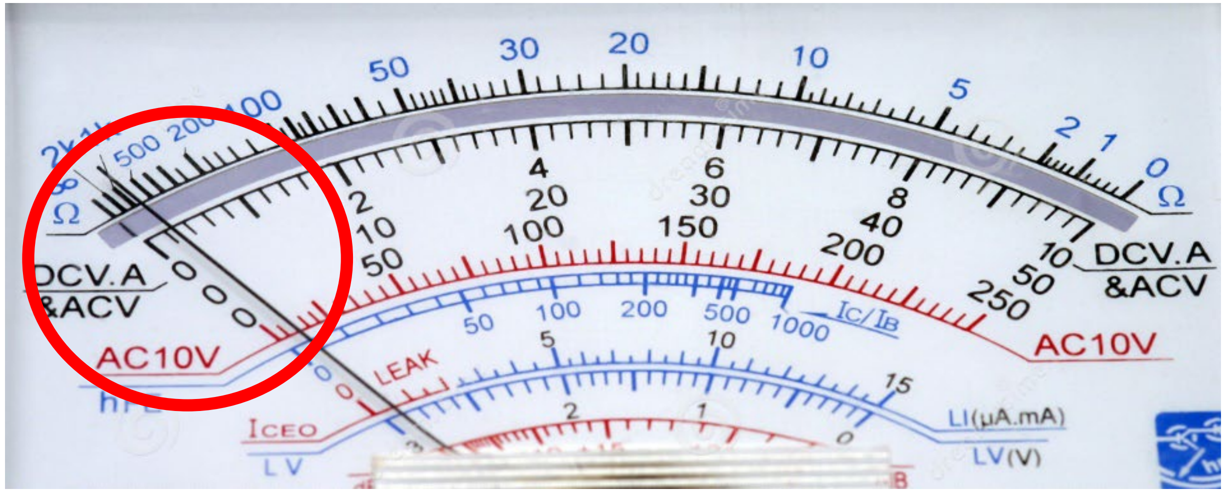
$$t_{avg} = 18.4\cancel{967} \pm 0.\underline{3}\ s$$

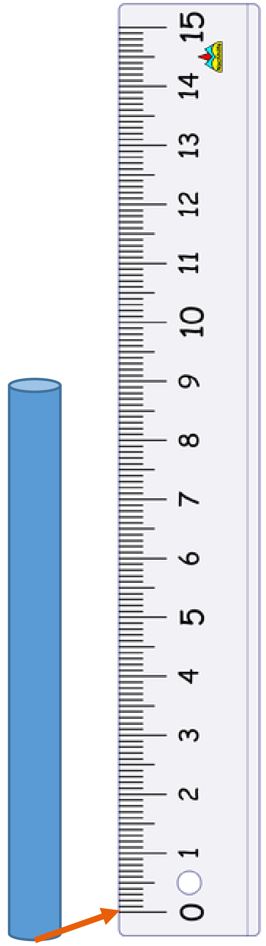
$$\boxed{t_{avg} = 18.5 \pm 0.3\ s}$$

Systematic uncertainties

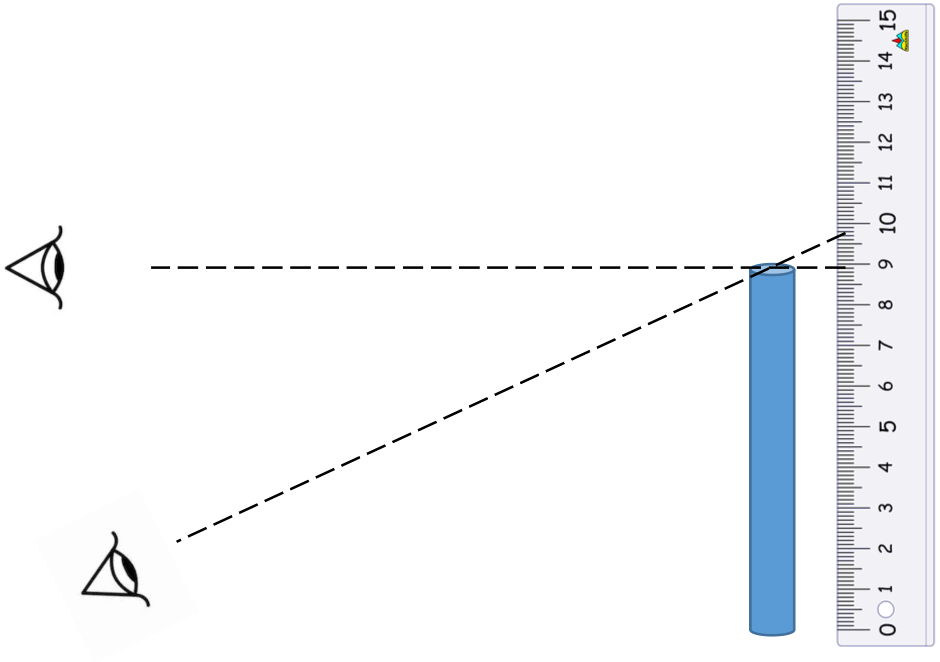
- mistaking the reference point for a measurement

- poorly calibrated measurement device





Systematic uncertainties (parallax)



Notes about how to quote a quantitative result

1. Maintain the standard form:

When quoting a measured value and its uncertainty, the absolute uncertainty should be 1 sigfig and the measured value is rounded to the same decimal place; in other words, the last digit of the measured value should be in the same place value as the single digit of the uncertainty.

Correct	incorrect	
35.14 ± 0.07	35 ± 0.05	4.56 ± 0.1
	35.**??** ± 0.05	4.6 ± 0.1
1458 ± 2	1458 ± 10	
	1460 ± 10	

How to track significant figures in calculations

The related material for **tracking significant figures** have been covered in:

- Section one of your lab manual (Blackboard > Labs)

Make sure you understand the concepts in it. You will be marked for using accurate sigfigs in your Labs.

Important Note: Tracking significant figures in calculations only matters when you DON'T have uncertainty explicitly present. However, when the uncertainties are present and you need to carry them through your calculations the rules of **Propagation of Uncertainty** will prevail! That means the correct number of significant figures in the final result is determined by the uncertainty of the final result. Examples will follow.

Significant Figures

>>> The number of significant figures can be determined by counting from the left and ignoring leading zeros.

0.089 has __2__ significant figures

4006 has __4__ significant figures

5.800 has __4__ significant figures

3400 has __2__ significant figures

How to track significant figures in calculations (NO uncertainties!)

Addition & subtraction: the number of decimal places in the result should be the same as the quantity in the calculation that has the fewest number of decimal places.

$23.654 - 3.\underline{28} = 20.37\cancel{4} = 20.\underline{37}$

$2.10 \times 10^4 + 1.02 \times 10^3 = 21.0 \times 10^3 + 1.02 \times 10^3$

$= (21.\underline{0} + 1.02) \times 10^3$

$= 22.0\cancel{2} \times 10^3 = 22.\underline{0} \times 10^3$

105 + .011 = 105.011 = _______

103.95 - 2.1 = 101.85 = _______

How to track significant figures in calculations (NO uncertainties!)

Multiplication or Division: The number of significant figures in the result should be the same as the quantity in the calculation that has the fewest number of significant figures.

$$\underline{6.8} / 2.35 = 2.8\cancel{93617021} = \underline{2.9}$$

Multiplication or Division by a Constant: Constants are treated as having an unlimited precision, or an infinite number of significant figures.

$2.37 / 2 = 1.19$ $\pi\,(1.2)^2 = 4.5$

Constants
- Numbers with infinite precision: 2, ½
- Universal Constants: π, e

How to track significant figures in calculations

As an exercise on these rules perform the calculations on **page 14** of your lab manual.

Propagating Uncertainties

Most often you can not measure the quantity of interest directly, and you need to measure two or more quantities, each with their own uncertainties. Then you combine those measurements in some mathematical calculations (operations) to solve for the quantity of interest.

e.g.: to determine average velocity v of a moving object along a straight line

you measure displacement: $x = x \pm \delta x$ and time of travel: $t = t \pm \delta t$

Then v is found by diving x by t $\quad v = x / t$

But what is δv, the uncertainty of the calculated v?

In the following slides you will see a review of the rules of propagation of uncertainty.

Propagating Uncertainties

Another example:

What is the area of this circular plate with its uncertainty?

Measured radius with its uncertainty

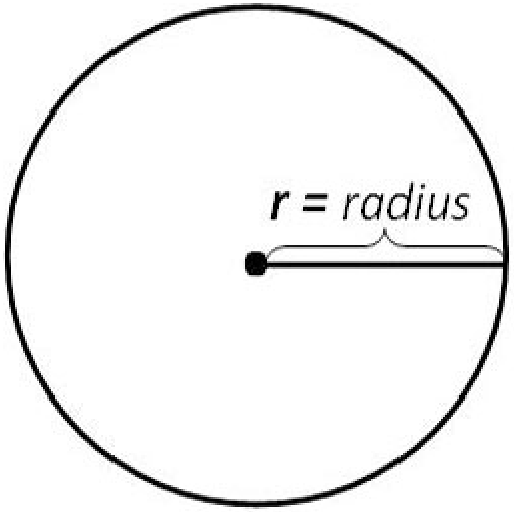
r = 12.4 ± 0.2 cm

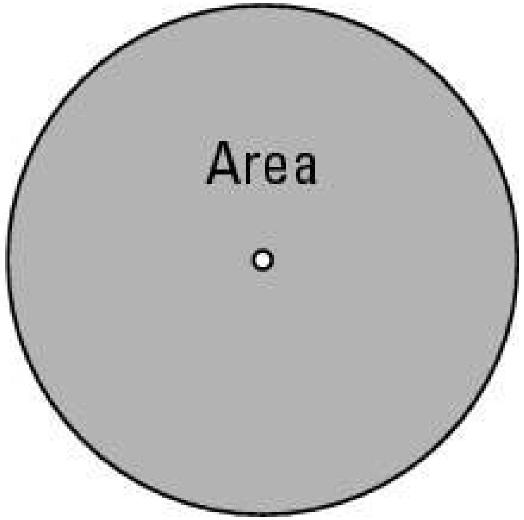
Perform a calculation with those uncertain numbers.

$$A = \pi r^2$$

Uncertainty in your answer

A = 483 ± ? cm^2





Propagating Uncertainties

Addition & subtraction: ♦ Uncertainties must be in **Absolute** form

♦ Add the absolute uncertainties.

$(23.6 \pm 0.6) + (112 \pm 2) = 135.6 \pm 2.6 = 136 \pm 3$

Multiplication or Division: ♦ Uncertainties must be in **Percent** form

♦ Add the percent uncertainties.

$$v = \frac{d}{t} = \frac{6.8 \pm 0.3\ cm}{2.15 \pm 0.08\ s} = \frac{6.8\ cm \pm 4.4\%}{2.15\ s \pm 3.7\%} = 3.1628\ cm/s \pm 8.1\%$$

$$v = 3.2 \pm 0.3\ cm/s$$

% uncertainty $= \frac{0.3}{6.8} \times 100\%$
$= 4.4117\% \sim 4.4\%$

absolute uncertainty $= 8.1\% \times 3.1628$
$= 0.256 \sim 0.3$

This example also shows the amount of details that you need to include in your calculations.

Propagating Uncertainties

Multiplication or Division: Add the percent uncertainties.

$$(2.45 \pm 0.03\ N) \times (6.3 \pm 0.2\ m)$$

$$= (2.45N \pm 1.22\%) \times (6.3\ s \pm 3.17\%)$$

$$= 15.435\ J \pm 4.39\%$$

$$= 15.435 \pm 0.6776\ J$$

$$= 15.4 \pm 0.7\ J$$

This example also shows the amount of details that you need to include in your calculations.

Propagating Uncertainties

Powers and Roots:

- Uncertainty must be in **Percent** form
- Multiply percent uncertainty by the exponent

$$(1.36 \pm 0.08\ m)^3 = (1.36\ m \pm 5.9\%)^3 = 2.5155\ m^3 \pm 17.7\% = 2.5 \pm 0.4\ m^3$$

$$\boxed{3 \times 5.9\%}$$

$$\sqrt{6.8 \pm 0.3} = (6.8 \pm 4.4\%)^{½} = 2.6077 \pm 2.2\% = 2.61 \pm 0.06$$

$$\boxed{½ \times 4.4\%}$$

Propagating Uncertainties

Multiplication or Division by a Constant:

When uncertainty is in **absolute** form multiply both the value and its uncertainty by the constant.

$\frac{1}{2}(1.36 \pm 0.07) = 0.68 \pm 0.035 = 0.68 \pm 0.04$

$\frac{1}{2}(1.36 \pm 0.01) = 0.68 \pm 0.005 = 0.680 \pm 0.005$

When uncertainty is in **percent** form multiply the value by the constant. **Percent uncertainty stays the same**.

$3(1.36 \pm 12\%) = 4.08 \pm 12\% = 4.1 \pm 0.5$

Propagating Uncertainties

Trigonometric Functions: **(Physics 1110 only!)**

The absolute uncertainty of the trigonometric function is equal to the absolute uncertainty of the angle times the derivative of the trigonometric function. Note that the absolute uncertainty of the angle must be in radians.

Definition:

$$\sin(\theta \pm \Delta\theta) = \sin\theta \pm (\Delta\theta \times \cos\theta)$$

$$\cos(\theta \pm \Delta\theta) = \cos\theta \pm (\Delta\theta \times \sin\theta)$$

e.g.: $\theta = 28.4° \pm 0.5° \rightarrow \sin\theta = \sin(28.4° \pm 0.5°) = \sin 28.4° \pm\ ?$

If $\theta = 28.4° \pm 0.5°$, then in radians it is $\theta = 0.496 \pm 0.009$ rad, then

$$\sin(28.4° \pm 0.5°) = \sin 0.496 \pm (0.009 \times \cos 0.496)$$
$$= 0.476 \pm 0.008$$

How to track significant figures in calculations

As an exercise on these rules perform the calculations on **page 18** of your lab manual.

Comparing Values (Numbers)

When an experiment is over, you often need to compare values (e.g.: a & b.) You will do this by stating the Absolute Difference and Percent (or Percentage) Difference as described below.

- Absolute Difference is simply the absolute value of the difference

$$\text{absolute difference} = |a - b| \quad \text{(absolute discrepancy)}$$

- Percent Difference is simply the absolute value of the difference divided by a reference value. (Reference value could be your result or the accepted value.)

$$\text{percent difference} = \frac{|a - b|}{a} \times 100\% \quad \text{(percent discrepancy)}$$

Comparing Values (Numbers)

Example: your result v_{exp} = 334 ± 7 m/s   accepted value v_{acc} = 340 m/s

The absolute difference is $|334 - 340| = 6m/s$

The percent difference is $$\frac{|334 - 340|}{334} \times 100\% = 2\%$$

This means your result is off from the accepted value by 2%

or more specifically: The accepted value is 2% more than your result

Note that Uncertainties **DO NOT** enter in calculation of percent difference

Comparing Values (Do they agree?)

Do the values that you compared agree?

Methods

1. Uncertainties Method (Best)

- When uncertainties are known, either through your own calculations, or they are provided as the expected experimental uncertainty in the experiment manual.

2. Significant Figure Method (No Other Options)

- If you don't know the experimental uncertainty

Comparing Values (Do they agree?)

Do the values that you compared agree?

1. **If the uncertainties of the values are known**, then the two values are said to agree if the values overlap when you consider their uncertainties. Remember that the uncertainty describes the range that each value could assume. Therefore, if those ranges overlap then the values are considered to be in agreement.

Use of **Absolute difference with absolute Uncertainties** method

Two values are in agreement if zero is a possible value in their difference when the range of the uncertainty is taken into account.

Example: Do 334 ± 7 m/s and 340 m/s agree? Yes because

Their absolute difference is: $|(334 \pm 7) - 340| = 6 \pm 7 \equiv [-1, 13]$ includes zero

OR $334 \pm 7 \equiv [327, 341]$ m/s which includes 340 m/s

Comparing Values (Do they agree?)

Do the values that you compared agree?

2. If the uncertainties are Not known

Use **Absolute Discrepancy with Significant Figures** method

Two values probably agree if their difference has one significant figure. **Note:** you must calculate their difference following significant figure rules.

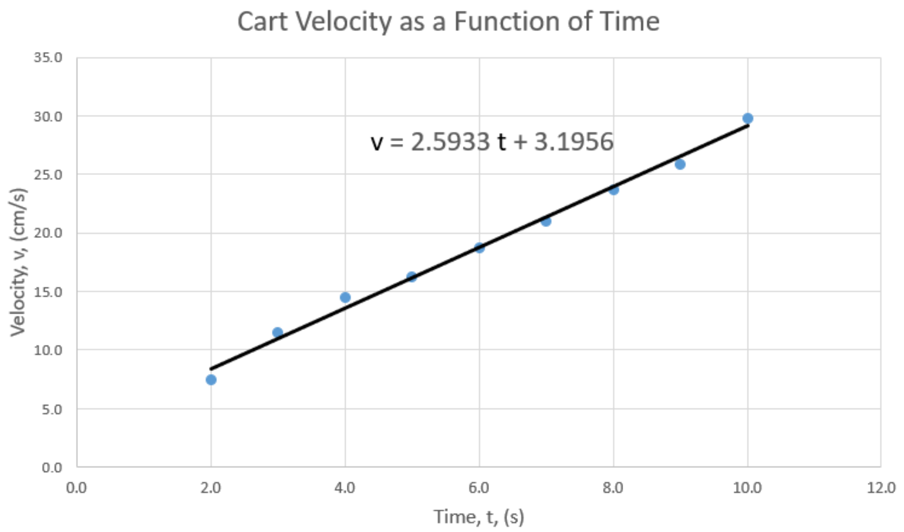
Example: Does 9.3 m/s^2 agree with 9.81 m/s^2 ?

Yes they probably agree, because their difference (to correct number of significant figures) is 0.5 m/s^2 (not 0.51!); and that has one significant figure.

What about 9.69 m/s^2 and 9.81 m/s^2 ?

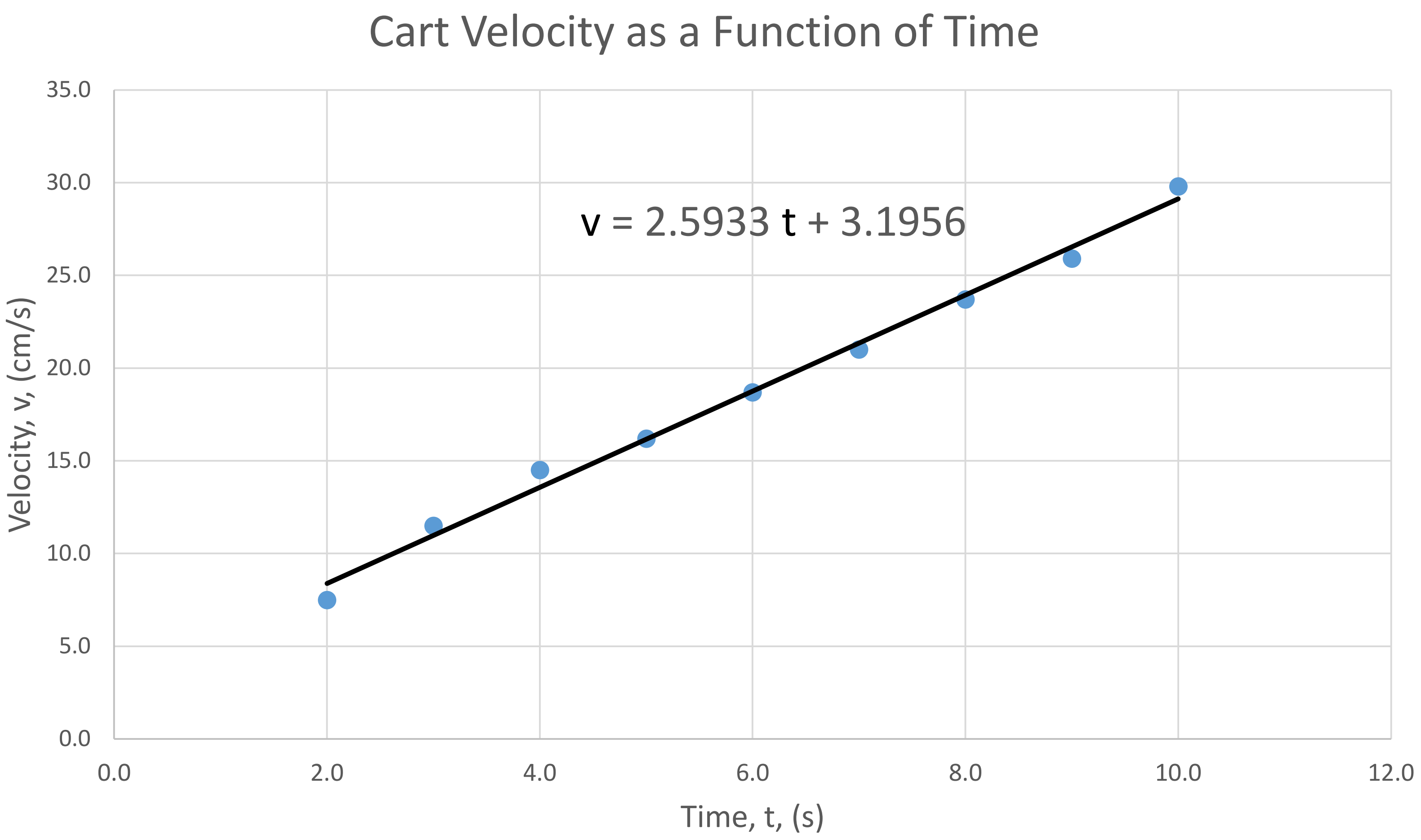
Graphing/Plotting Data

1. Must be done digitally (using a computer)
   - Excel
   - Google Sheets
   - Any other program as long as it has all the required elements
2. Must include the following Elements
   - Title
   - Axis labels with symbols and units
   - Axis numbers
   - Appropriate Scale
   - Data points (Scatter Plot, **Not** a line plot)
   - Line of best fit
   - Equation of line of best fit



Instructions for creating graphs using Excel or Google Sheets can be found in the lab introduction document near the end.

Graphing/Plotting Data



Details on how to make plots is in the Lab Intro Document, near the back.

Graphing/Plotting Data

Graphing Exercise

A stopwatch is used to time a toy car as it rolls across a tabletop. If the car is travelling at constant speed, its motion should be described by the equation,

$$d = d_0 + vt$$

Where *d* is the distance from the edge of the table, d_0 is the initial distance, *v* is the speed, and t is time. The data is given below.

Distance, d, (cm)	Time, t, (s)
20.0	0.21
30.0	0.62
40.0	0.98
50.0	1.37
60.0	1.81
70.0	2.27
80.0	2.69

Plot a graph of distance as a function of time to determine the speed and initial distance.

Speed: ____________

Initial distance: ____________