Measurement Error

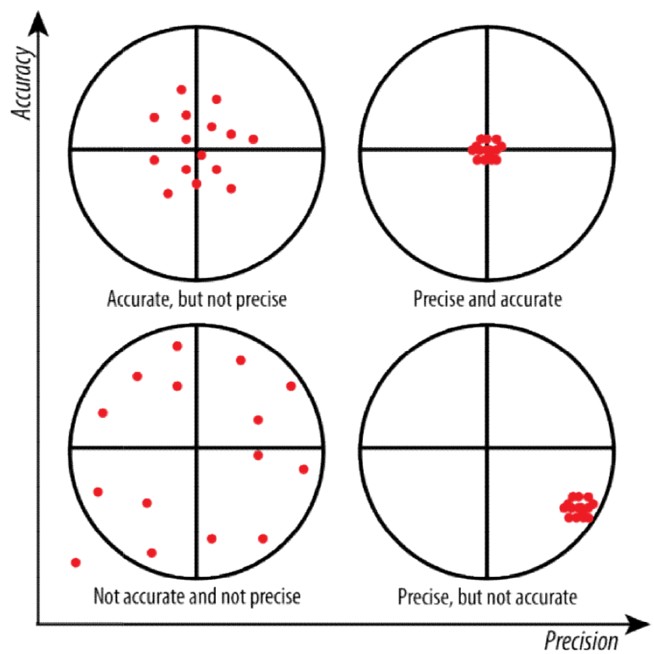
Why: Uncertainty is associated with the result of any measurement, so this lab will investigate the sources of uncertainty and how it can be quantified.

What: Several independent length and time measurements of the same object or event will be made in order to get an average and an uncertainty.

How: We use a piece of fruit, arbitrary length scale, and a traffic signal reaction timer.

Introduction

The word "error" in experimental science actually means "uncertainty" and is not pejorative. There is always some uncertainty in the result of any measurement and it is the <u>main</u> job of a scientist to quantify this uncertainty – that is the most valuable part of their work. There two kinds of measurement "error": Random error (which affects precision); Systematic error (which affects accuracy)



Random Error

This is the natural variation in multiple measurements where measured values may be scattered high and low compared to the true value and have no fixed or predictable pattern. Such random errors occur for various reasons, in particular because of our inability to completely isolate the experiment from (random) external influences.

By taking multiple measurements one can take an average with the reasoning that the average measurement will be close to the true value. More measurements will yield an average closer to the true value because random errors will tend to cancel out in taking the average. Random error affects the precision of a measurement, which one indicates by the number of digits given for the answer. The final result of any measurements should always be quoted with an uncertainty, which expresses the range over which single measurements vary due to random error.

After making N independent measurements, there is usually a scatter in the data, with a maximum and a minimum value. A simple way to estimate the uncertainty due to random error is to use the formula

$$[\text{Uncertainty}] = (\text{max} - \text{min}) / \sqrt{N}.$$

In our simple experiments, it makes little sense to use an uncertainty with more than one significant digit, so round up or down as needed to one significant figure.

A final result would be written:

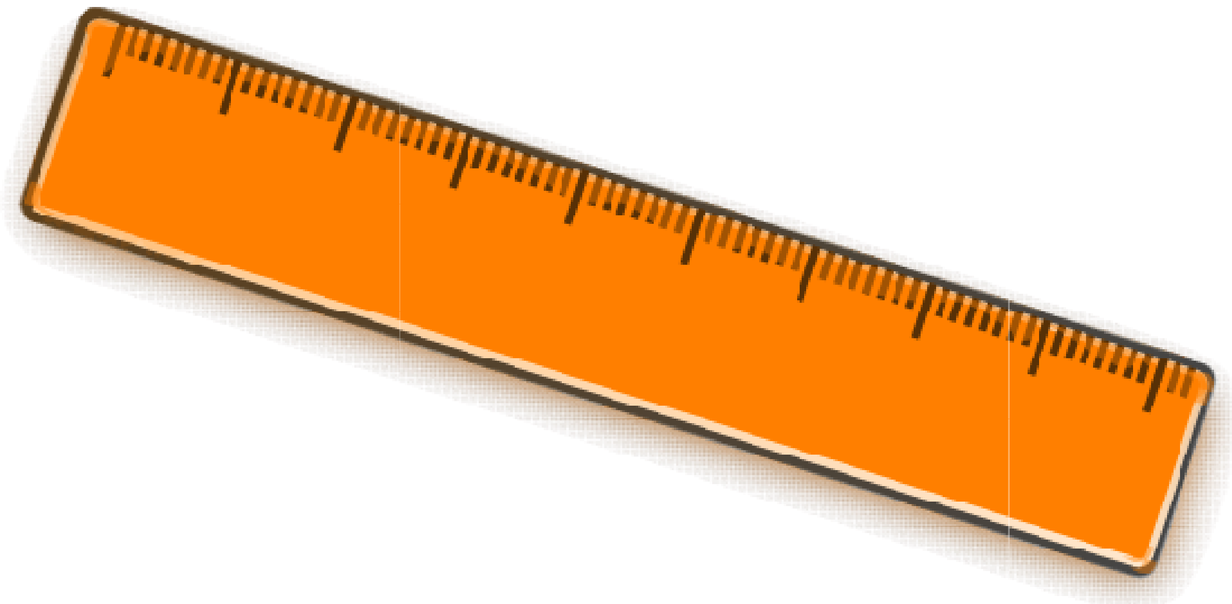
$$[\text{Average value}] \pm [\text{Uncertainty}] \text{ units}$$

The uncertainty tells you the precision with which you can write the average. So to decide how many digits to include for the average, you must first calculate and round the uncertainty. ***Then write the average in the same units, with the same number of decimal places and power of 10 as your uncertainty.***

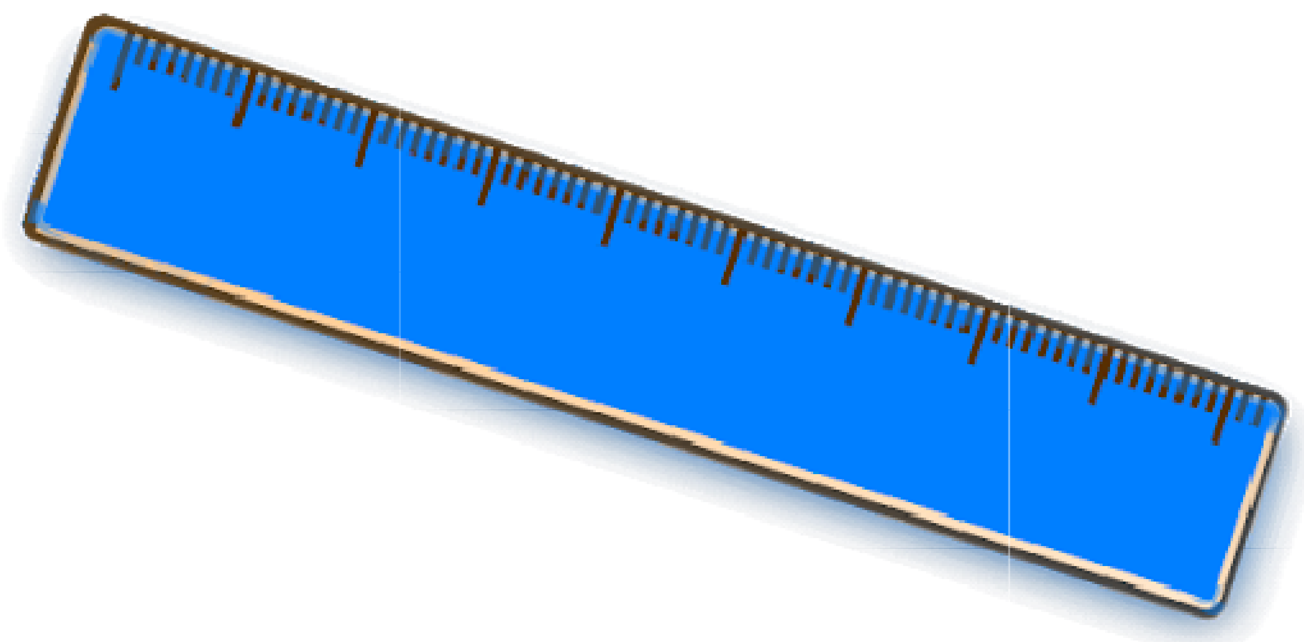
Systematic Error

Accuracy of measurement is the quality of nearness of the average to the true value. Sometimes you may also find that your measurements are systematically too high or too low compared to the true value, which affects the accuracy of your measurements, independent of their precision. For example, forgetting to add on the distance between the end of a ruler and the 0 point on its scale will yield length measurements that are inaccurate, always less than the true value. Systematic error is usually evident if you have some other source against which to compare your measurements (such as a textbook value, or the result from someone else’s experiment, or the result using a different measuring apparatus).

Special Ruler



Normal Ruler



Equipment & Procedure

1. Length Measurement

Each person in your group should get a small piece of fruit or vegetable (apple, tomato, etc.) and will use the rulers shown in this manual to measure the maximum length of their object. The ruler scales use a unit of length called the "Dalley" (symbol Da). One Dalley is the distance between two successive long marks on the ruler. Note: there are 8 smaller marks between each Dalley. To use the scales, put this manual in full screen and place your object so it is touching the screen next to one of the ruler scales.

Using the special ruler (orange), measure the longest length of your object three times independently. To make each measurement independent, rotate the object in various ways (end to end, sideways). Make the table shown and fill it out for your own data in the first row; don't round the average yet!

Special Ruler table

Object	Length 1 (Da)	Length 2 (Da)	Length 3 (Da)	Average Length (Da)	Uncertainty (Da)	Final result (Da)

Next, use the normal ruler (blue) to repeat all the previous steps.

Normal Ruler Table

Instrument Precision (Da):						
Object	Length 1 (Da)	Length 2 (Da)	Length 3 (Da)	Average Length (Da)	Uncertainty (Da)	Final result (Da)

For each kind of ruler, estimate the uncertainty (see introduction).

For each kind of ruler, write your final result for the length of the object in the form

(average ± uncertainty)

to an “appropriate” number of decimal places and significant digits. “Appropriate” means round the uncertainty to one significant digit and then round the average to the same number of decimal places and power of 10 as the uncertainty.

Share your results with your partner(s) and complete the tables so that all data are submitted with the lab report.

Congratulations! You have made your first measurement like a physicist! It was a trivial measurement, of course, but every time you measure in the physics lab, you should take several measurements and express the final result as “(average ± uncertainty) units” with appropriate numbers of digits. And the best part is that, for this particular measurement, you now get to eat the apparatus!

2. Time measurement.

Your reaction time is the time that passes between some external stimulus and your first action. Each person in your group should use the stop light simulator

https://faculty.washington.edu/chudler/java/redgreen.html

to measure their reaction time five times. Make and fill out the table and quote the final result with an uncertainty to an appropriate number of decimal places and significant figures.

Person Name			
Time 1 (s)			
Time 2 (s)			
Time 3 (s)			
Time 4 (s)			
Time 5 (s)			
Average (s)			
Uncertainty (s)			
Final result (s)			
Group Final result			

Group partners should then share their data (complete the table) and then calculate and record in the last line the reaction time of the group as a whole (average ± uncertainty) using each person’s average time.

Conclusions

A conclusion is one or two paragraphs that discuss the main things you learnt from the data you collected and analyzed in this lab. Always quote actual data to support your conclusions.

A conclusion is NOT vague, like … the ball fell really fast

A conclusion is NOT the procedure, like…we measured this then did that

A conclusion is not personal, like… I learnt how to measure the length of a tomato

You could discuss: All possible sources of error that you can think of in the length and time measurements. What kind of error was it, random or systematic? What caused this error? (It is never sufficient to write "Human Error", what exactly caused the error?). Why were some errors bigger than others; for example, uncertainty for the group compared to that for one individual? Was the accuracy of the normal and special rulers the same?