Physics 02, Fall 2019

MEASUREMENTS

Learning Goals. In this lab, we

- *evaluate instrumental uncertainties;*
- *report and propogate uncertainties (estimate the uncertainty in the final answer);*
- *make estimates.*

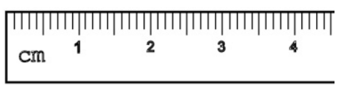
PART 0. BACKGROUND

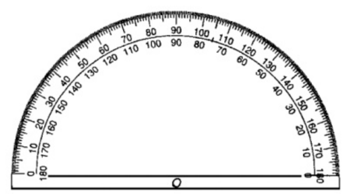
Read text *"Experimental Uncertainties"*

PART 1. EXERCISES

1. Carpenter Chris reported the measurements of the height of a doorway by stating a best estimate of 210 cm and that the height was certainly between 205 and 215 cm.
   Write this result in the form $x_{best} \pm \delta x$.

2. What are the absolute instrumental uncertainties δx for the following instruments?

a. Ruler


b. Protractor


c. Watch


100 50 20 10 5 2 1

d. Scale (measures in grams)

3. Write the following values in their most appropriate forms: round the uncertainty to one significant digit, round the value to the same decimal position as the uncertainty, then use scientific notation.

   Example: $L = 35689 \pm 132$ m $= 35700 \pm 100$ m $= (3.57 \pm 0.01) \times 10^4$ m

   a) x = 23.323 ± 1.12 mm
   b) t = 1,234,567 ± 54,321 s
   c) r = 0.000,000,538 ± 0.000,000,03 mm

4. After a hike in Yosemite valley, a friend asks how fast you walked. You recall that the trail was about 8 miles long, and you took 2 to 3 hours.

   a. What is your average speed if you assume the average time of 2½ hours?
   b. Assume that absolute uncertainty in your distance measurement is 0.1 mile. Estimate the fractional (percentage) uncertainty in your distance measurement.
   c. What is the absolute uncertainty in your time measurement? What is its fractional uncertainty?
   d. The simplest way to determine the uncertainty in the speed is to assume that its fractional uncertainty is *equal to the fractional uncertainty of the least precise measurement*.
      Compare the fractional uncertainties for time and distance. Which is least accurate?
      Therefore, what is the fractional uncertainty in the speed? Write speed as $v_{best} \pm \delta v$, where δv is a percentage. (for example, 80mph ± 4%)
   e. Determine the absolute uncertainty in your speed. Write your speed as $v_{best} \pm \delta v$, where δv is an absolute value (for example, 85 ± 3 mph).

PART 2. MEASURING Π (PI)

Here, we test experimentally that the ratio of a circle's circumference to its diameter is equal to $\boldsymbol{\pi}$ (pi), approximately 3.141592654.

1. Choose one circular object from the spheres and cylinders available in the laboratory. Measure the diameter and circumference of this object. Measure the circumference directly. *Don't determine C using $C = \pi D$.* Our goal is to test this.

2. Write your measurement uncertainties.
   a) For the diameter, write the absolute value for the instrumental uncertainty. Write the corresponding fractional uncertainty.
   b) Repeat for the circumference.

3. Calculate $\boldsymbol{\pi}$. Use the ratio of the measured circumference to measured diameter ($\pi_{meas} = C/D$).

4. Estimate the fractional uncertainty $\delta\boldsymbol{\pi}$. Write your final result as $\boldsymbol{\pi}_{\text{meas}} \pm \delta\boldsymbol{\pi}$.
   Estimate the absolute uncertainty in $\boldsymbol{\pi}_{\text{meas}}$

5. Compare your experimental result with the expected value.
   Is the experimental result consistent with the expected value?
   If there's a discrepancy, can you claim that it's insignificant? (Consider the uncertainty.)
   What are possible reasons for the discrepancy? That is, list possible sources of error, other than instrumental uncertainty.

PART 3. ESTIMATES

Some problems in physics and engineering call for precise numerical answers. We need to know exactly how long to fire a rocket to put a space probe on course toward a distant planet, or exactly what size to cut the tiny quartz crystal whose vibrations set the pulse of a digital watch. But for many other purposes, we need only a rough idea of the size of the physical effect. And rough estimates help check to see the results of more difficult calculations make sense.[1]

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[1] From Wolfson, *Essential University Physics* 3rd ed, Vol 1. (Pearson, 2016) Pg 8.

Estimates rely on your already existing knowledge of the length, mass, or duration of common objects or events. Estimates get better if you're able to take a single, simple measurement of a small piece of the problem. Often, estimates are good to within an order of magnitude (power of 10); in this case, for example, 5000 and 2000 are comparable answers.

1. Breaths.[2] Estimate the number of breaths taken in an average human lifetime. First, estimate the number of breaths you take in a minute (count it if you like). Second, estimate the average number of years a person lives. Then calculate the number of minutes there are in a lifetime (there are about 6×10^5 minutes/year). Finally, calculate the number of breaths in a lifetime.
   Discuss the range, or uncertainty, in your answer. That is, how does your answer change if we say that 90 years or 50 years is the average lifetime?

2. Paper thickness. Estimate the thickness of a single paper sheet in your textbook, without directly measuring the thickness of a single sheet of paper. Explain how you did this estimate.
   Discuss the range, or uncertainty, in your answer. That is, how does your answer change if one of your assumed values, for example the number of sheets, went up or down?

3. Small items. Without actually counting them, estimate the total number of items in the container. You're welcome to take one or two simple measurements if you think that's helpful. Explain how you did this estimate. Discuss the range, or uncertainty, in your answer.

4. Saint Mary's chapel. Estimate its height. Explain how you did this estimate. Include an uncertainty in your estimate.

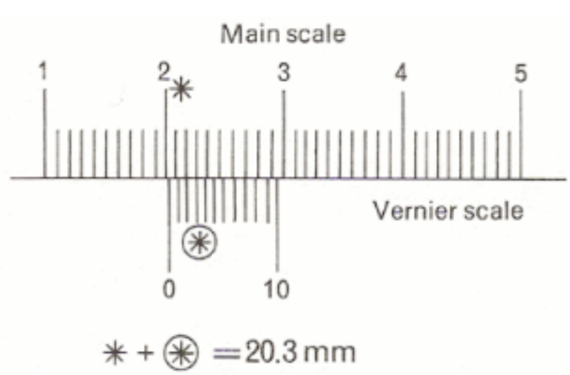
APPENDIX: HOW TO USE AND READ A VERNIER CALIPER.

A *vernier caliper* has jaws that you can place around an object, and on the other side it has jaws made to fit inside an object. The secondary jaws are for measuring the inner diameter of an object. Also, a stiff bar extends from the caliper as you open it that can be used to measure depth.

Vernier calipers have two graduated scales. The main (top) scale is like a ruler. The second (bottom) scale, called the vernier scale, slides parallel to the main scale and enables reading to be made to a fraction of a division on the main scale.

Most vernier scales have 10 divisions in the same length as 9 divisions on the main scale. That means that the divisions on the vernier scale are shorter than those on the main scale by 1/10 of a division on the main scale.

How to read a vernier caliper: First, look at the main scale (the top scale) and determine where "0" of the vernier (bottom) scale lies. In the example below, "0" of the bottom scale is between 2.0 and 2.1 on the main scale, so the true reading is somewhere between 2.0 cm and 2.1 cm. Then, for more accuracy, look at the main scale and the vernier scale at the same time, and determine where the two scales line up (when a line from the top scale and a line from the bottom scale meet end-to-end). In this case, they seem to line up at the third line **(line 3 on the vernier scale)**. The final reading is then 2.03 cm (or 20.3 mm), which is between 2.0 cm and 2.1 cm as was initially determined.



[2] This is Example 1.4 from Serway and Jewett, Physics for Scientists and Engineers 8th edition (Brooks/Cole 2010)