LAB 1 - INTRODUCTION TO MEASUREMENT

Goals:

- Understand the difference between the *precision of a device* and the *uncertainty of a measurement*
- Identify proper measuring device for given task
- Properly measure an object with different devices
- Estimate uncertainty for different measurements
- Identify propagation of error in calculations

Introduction -

The basis for any scientific investigation is measurement. The ability to measure accurately the quantities of the experiment is crucial to the success of the experiment. This lab will allow you to practice your skill in using various measurement devices.

You will also learn how to find the overall error that propagates through the calculations. We will use a cylindrical rod to illustrate the measuring and calculating techniques:

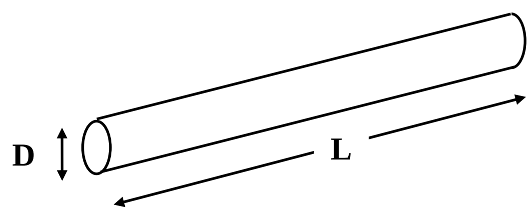

Figure 1 - Cylindrical rod and measurements to be made

Precision - Precision is the term related to the accuracy of the device itself. It is generally considered to be *1/10th of the smallest division of the instrument*. For example, centimeter-type rulers generally have marks for each millimeter--one millimeter (mm) would be the smallest division, so the precision of that ruler would be 1/10th of a mm, or 0.1 mm, or 0.01 cm. An experienced person, under the right conditions, *should* be able to estimate to the precision of the device.

Uncertainty - Uncertainty is the term used to describe how good a measurement is. The uncertainty of a measurement may be larger than the precision *but not smaller* - the smallest uncertainty can't be "better" than the precision! You will have to estimate the uncertainty for each measurement made. Depending on the tools available, you may have to "eyeball" a measurement, thus creating a larger uncertainty. For example, to measure the diameter of a ball with a ruler, you cannot be expected to estimate to the precision of the ruler--your measurement would have a larger uncertainty, maybe ± a few millimeters. The uncertainty of the measurement is based on your reasonable judgment of how accurate your value is--therefore, *the uncertainty is ≥ the precision of the device*. The word ***tolerance*** is also used interchangeably with *uncertainty*.

Accuracy - Accuracy generally means the uncertainty of the measurement itself. Percentage uncertainty (parts per hundred) or parts per thousand, etc. is the best way to express accuracy for comparisons of unrelated measurements.

Part 1 - Measuring with the *Ruler*

1. Precision of the Ruler. The precision of the ruler will be 1/10th of the smallest division. For the meter sticks that we use, that smallest increment is 1 mm (= 0.1 cm or 0.001 m). This means that the precision of the ruler is 0.1 mm = 0.01 cm = 0.0001 m. A careful measurement, made under optimal conditions, should be within $\pm$ 0.1 mm. See the diagram below:

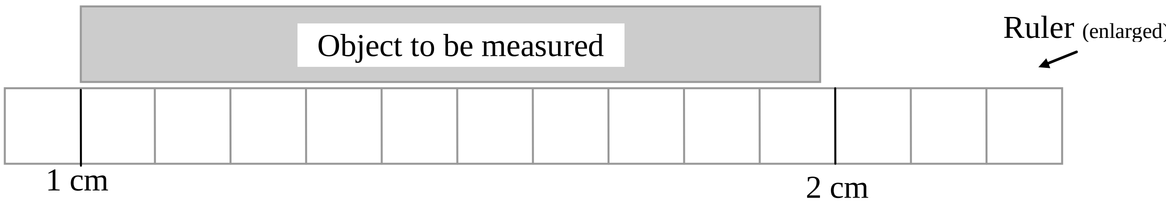

Figure 2 - Ruler and how to read it

Example: For the object above, using a ruler that has 1 mm divisions, we would say the object is more than 9 mm, but less than 10 mm (notice we are measuring relative to the starting 1 cm mark on the ruler – for rulers with "age-rounded" ends … start inward at some other measuring tick – like 1 cm). This is a measurement made under good conditions, so we will estimate to the 1/10 of a mm, and read that measurement as 9.8 mm or 0.98 cm. The uncertainty of the measurement (in this case) can be the precision of the device, thus the final measurement would be $L = 9.8$ mm and $\Delta L = 0.1$ mm so $L = 9.8 \pm 0.1$ mm or $L = 0.98$ cm $\pm$ 0.01 cm. [If you are really confident with the measurement, it is reasonable to use the precision of the device - but, suppose you had to measure the diameter of a pipe, but couldn't saw it to get the cross section ... you would have to "estimate" the measurement - you should NOT use the precision of the meter stick in that case, your uncertainty would be a little larger than the precision!]

2. Measuring with the ruler and Uncertainty. In general, the symbol (Δ) or the symbol (δ) is used to show the uncertainty of a particular measurement. If X is the measurement, then ΔX is considered the uncertainty. Measure the length (L) of the metal rod. (Make sure you don't start the measurement at the end of the ruler, since it might have been worn away.) Try to measure the length of the rod to the precision of the ruler [this may not be possible, for example, if the end of the rod is not a "clean" cut]. Estimate the uncertainty of the measurement and record them below:

L = ________ cm (= ________ m) ΔL = ________ cm (= _________ m)

Thus, using the form $L \pm \Delta L$,
the complete measurement would be L = _______ $\pm$ _______ cm

[Note, you should be able to measure to the tenth of the millimeter.]

The ruler is not as precise as some of the later devices we will use, but if the object is too large for a precision device, it may be the only thing we can use!

Part 2 - Measuring with the Digital Caliper (aka "Vernier Caliper")

1. Precision of the Digital Caliper. The caliper is a higher precision device that has one more decimal point in precision - thus the precision is 1/100th of a millimeter or 0.01 mm = 0.001 cm = 0.00001 m. But, since this is a digital meter – the uncertainty will just be ½ the smallest division – thus 0.005 mm = 0.0005 cm = 0.00005 m. So, we take the LCD reading, and then just express it with ± 0.005 mm.

2. Reading the Digital Caliper. For this device, our job is much easier! We just have to read the number from the screen! Turn on the caliper with the appropriately titled "Off/On" button. Close down the caliper (don't apply a great deal of pressure – just gently, but completely, close it). [When at all possible, try to use the thumb knob on the bottom when opening/closing the caliper – this ensures the proper motion for the measuring system inside.] Then press and hold the zero button. Make sure the units are set to **mm** with the blue button on top. The reading (in mm) is shown in the LCD panel. [*When finished, please make sure you turn OFF the digital caliper!*]

Figure 3 – Image of the Digital Caliber and the various parts

3. Measurement. Measure the diameter of the rod with the Digital Caliper (we will express the answer in centimeters, so remember to divide the reading by 10 to get the answer in cm):

Diameter = __________ cm ± 0.0005 cm

Part 3 - Measuring with the Micrometer Caliper

1. Precision of the Micrometer. This is an analog measuring device, so we need to be careful about the precision of the device (as we did with the ruler). The micrometer has 0.5 mm around a dial that is split into 50 divisions. So, the smallest division of the micrometer is 0.01 mm or 0.001 cm (another factor of 10 more precise than the digital caliper). This scale can be estimated to 1/10th of the smallest division (under optimal conditions), so the precision of the micrometer is 0.001 mm = 0.0001 cm.

2. Reading the Micrometer. There is a rotating cylinder that lets open or close the micrometer. It is very important to use the “thumb knob” on the far end to close the “jaws” of the micrometer. When using the thumb knob, there will be a “clicking” sound when it has reached the maximum allowed pressure for the device (“cranking” the micrometer beyond that will strip the micrometer and affect the calibration). Usually, when the knob on the micrometer is rotated 360 degrees (1 turn = 50 divisions on the handle), the caliper opens by 0.5 mm. [Some micrometers have 100 divisions for a full millimeter - giving the same precision as listed above.] The full millimeter marks are on the top side of the scale on the non-moving part (to the left of the rotating sleeve), and the half-millimeter marks are on the bottom side of the scale. So, reading the micrometer is a two step process: A) Figure out how many whole millimeters in the measurement, and B) Decide if it is over the 1/2 mm mark (this may be hard to see ... sometimes it helps to look at the dial reading ... if you can't quite see the 1/2 mm mark, but the dial reading says 10 ... you probably are just over the half mm mark, so you would add 50 to the dial reading. Finally, C) estimate to 1/10th of the division on the dial to get the remainder of the dial reading. See the example below:

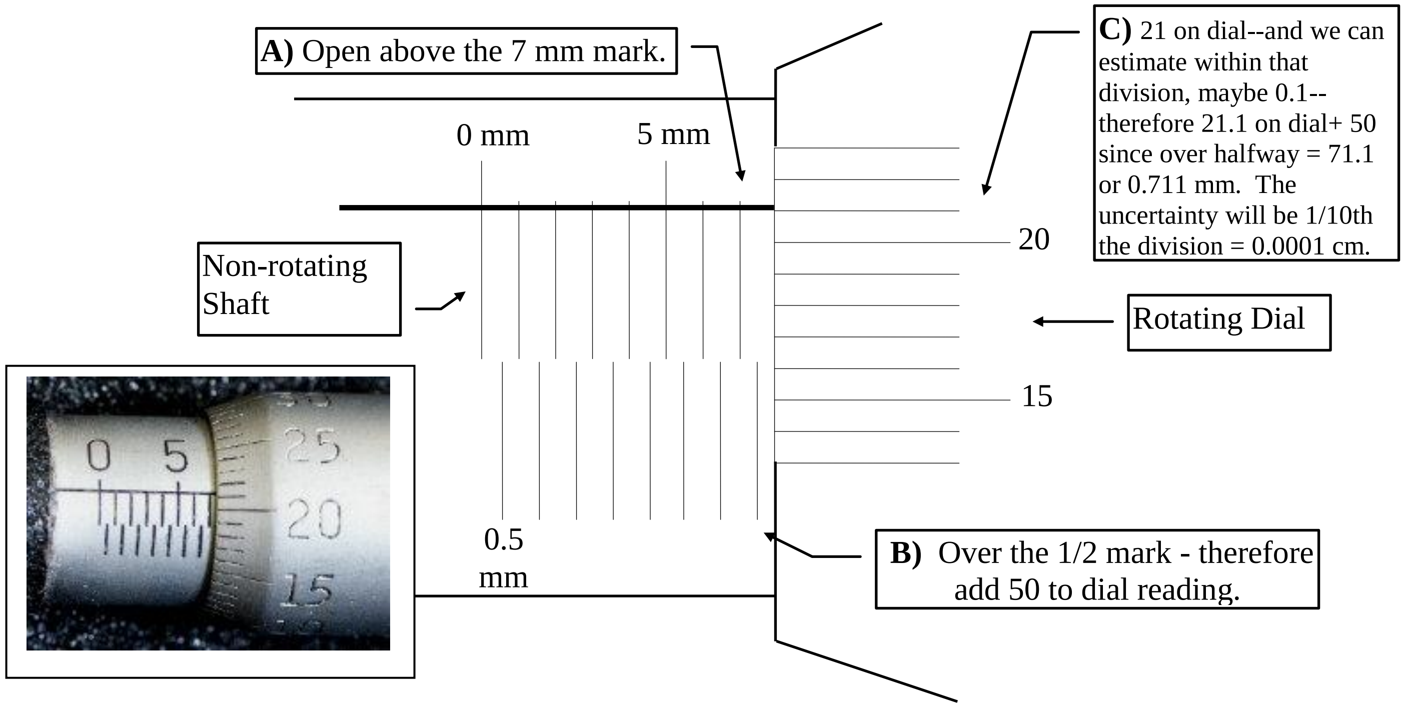

Figure 4 – Micrometer diagram and how to read it [inset actually shows LESS than the ½ mark]).

In this example, the micrometer is open past the 7 mm mark, and also past the half-millimeter mark. So, when we figure out the dial value (0-50), we add another 50 to it since it is over the halfway mark. The dial reading appears to be 21.1, so the total from the 7 mm mark is 21.1+50=71.1, which is 0.711 mm. Thus the final reading is 7.711 mm or 0.7711 cm ± 0.0001 cm.

Now, these micrometers might not be completely zeroed. We should take a reading on the micrometer when it is closed to find the "zero reading" and then we can adjust any other reading by that offset.

3. Finding Zero. Close the micrometer, and take a reading from the dial. Be sure to record whether it is a positive or negative reading:

"Zero reading" or "offset" = X_0 =__________ cm ± _______ cm (keep track of sign!)

[Note: Suppose the offset is positive … that means you already have, say 3 on the dial before you open the micrometer ... thus if you measured something has 24 on the dial, that's really "21 worth" of rotation … so we would take our main measurement and subtract the offset. Now, suppose the offset was -2 (this means you have to "open" the micrometer 2 ticks until you got to the zero … if you had a reading of 24 on the dial ... you really had to open it 26 ticks on the scale ... thus we can still say "subtract the offset" since 24 - (-2) = 26!]

4. Measurement. Measure the diameter of the rod with the micrometer:

Diameter reading X_d = __________ cm ± _______ cm

Therefore $X_d - X_0$ = actual diameter = __________ cm ± _______ cm

Part 4 - Measuring with the *Digital Mass Scale*

1. Precision of the Mass scale. The mass scale has 1 gram as its lowest division. As we did with the digital caliper, the precision of the mass scale would be 0.5 grams or 0.0005 kg (1000 grams in 1 kg).

2. Using the scale. There is an ON button (which doubles as the ZERO button ... once turned on, you can zero the mass scale by holding down the Zero button). There is a MODE button that switches between grams, ounces, pounds, etc. (and it also doubles as the OFF button if you hold it down).

3. Reading the scale. With nothing on the balance pan, the balance should read "zero" (if not, hold down the ZERO button for a moment).

3. Measurement. Measure the mass of the rod with the mass scale:

Mass = __________ grams ± 0.5 grams

= __________ kg ± _______ kg (divide by 1000 to get kg)

Part 5 - Percent Uncertainty (PU), Percent Error (PE) and Percent Difference (PD)

1. Percent uncertainty. When making a measurement of an object, there is often no exact "book value" (or "accepted" value) to compare it to. The height of a particular person has no "known" value, but the acceleration of gravity has an "accepted" value to compare it to (generally considered 9.81 m/s^2). There is still a need to see how well the measurement was made--the percent uncertainty is used to compare measurements in the absence of "accepted" values-- it is a measure of the accuracy:

$$\boxed{\%\text{ uncertainty in X} = \frac{\delta X}{X} \times 100\%}$$

For example, the measurement of 7.4 $\pm$0.2 cm has a percent uncertainty of:

$$\%\text{ uncertainty} = \frac{0.2}{7.4} \times 100\% = 2.7\%$$

That PU can be considered "better" than the measurement of 4.2 ± 0.3 cm with a PU of:

$$\%\text{ uncertainty} = \frac{0.3}{4.2} \times 100\% = 7.1\%$$

2. Percent Error. If there is an exact measurement against which to compare, use the percent error method:

$$\boxed{\%\text{ error of X compared to X}_{\text{standard}} = \frac{|X - X_{\text{standard}}|}{X_{\text{standard}}} \times 100\%}$$

The % error is always positive (notice the "absolute value" symbol in the numerator). This calculation ignores the uncertainty in the X measurement--the purpose of the % error is to see how far off the measurement is from the known value.

3. Percent Difference. Sometimes there is a need to compare to similar measurements (such as two measurements of the same object by two different members of the group). In this situation, use the percent difference calculation:

$$\%\text{ difference of X}_1\text{ compared to X}_2 = \frac{|X_1 - X_2|}{X_{avg}} \times 100 = \frac{|X_1 - X_2|}{\left(\frac{X_1 + X_2}{2}\right)} \times 100$$

The % difference is always positive (notice the "absolute value" symbol). This calculation ignores the uncertainty in either of the X measurements--the purpose of the % difference is to see the relative separation of two similar measurements from the average measurement.

[**Note: We will be using the above definitions often throughout your physics lab experience!!**]

Part 6 - Comparing measurements and the measuring devices

IMPORTANT: In this and future lab experiments - there are often "prediction" sections - it is very important to make reasonable predictions, and to write them down so you can refer to them later … then we perform some task and compare the results with the predictions to see if there are differences - the differences can lead to strong conceptual gains in understanding!

This prediction technique will be used in future labs – make a prediction, and often write it down on the Data/Question sheets – then go back and write down the final observations, and finally discuss any differences.

Prediction Which of the devices (ruler, digital caliper, micrometer) do you expect to be the most accurate? Go to the Data/Question Sheets and rank the devices in the order you think them to be the most accurate.

We have made three measurements of the rod, with three different measuring devices. Which of the measurements was most accurate? The measurement from which of the devices will have the lowest percent uncertainty? Let's find out!

1. Uncertainty calculation. Calculate the percent uncertainties for the measurements from each of the three devices and record them on the Data/Question Sheets.

Question: Move to the Data/Question Sheets and answer the following questions:
According to the percent uncertainties, which measurement seems to be the most accurate? If the answer above differs from your prediction, how do you explain that difference? (Write a full sentence or two as explanation - discuss with your lab partners if necessary.)

Class Discussion - There will be a general class discussion about the above questions once all the groups are finished. Until the lab instructor starts to lead that ... continue with the rest of the lab.

Part 7 - Using "uncertain" numbers in a calculation

1. Error propagation theory. When manipulating numbers with uncertainties, there are certain rules to follow, depending on whether you are using multiplication/division or addition/subtraction. Suppose you consider a simple case of W=X*Y*Z, where X and Y and Z are all measurements with uncertainties. The first thing is to make sure the numbers are in the appropriate units (to make the units of the answer more meaningful – for example, you wouldn't multiply cm by mm in a calculation). The answer W can be found easily from the multiplication of the three products, but what about its uncertainty? You should use the following formula for multiplication/division calculations:

$$\text{If } \mathrm{W} = \mathrm{XYZ} \text{ or } \mathrm{W} = \frac{\mathrm{XY}}{\mathrm{Z}},\ \text{etc,}\quad \text{then } \frac{\delta W}{W} = \sqrt{\left(\frac{\delta X}{X}\right)^2 + \left(\frac{\delta Y}{Y}\right)^2 + \left(\frac{\delta Z}{Z}\right)^2 + \ldots}$$

[Notice that the final PU is just the square root of the sum of the squares of the individual PU's of the products.]

For example: if X = 10.5 ± 0.4 cm and Y = 2.6 ± 0.2 cm and Z = 6.3 ± 0.1 cm, then our final answer will be expressed as $W = \bar{W} + \Delta W$ in the following steps:

ΔX = 0.4, ΔY = 0.2, and ΔZ = 0.1 ... and $\bar{W}$ =(10.5)(2.6)(6.3)=171.99 cm^3 ... then,

$$\frac{\Delta W}{\bar{W}} = \sqrt{\left(\frac{\Delta X}{X}\right)^2 + \left(\frac{\Delta Y}{Y}\right)^2 + \left(\frac{\Delta Z}{Z}\right)^2}$$

$$\frac{\Delta W}{171.99} = \sqrt{\left(\frac{0.4}{10.5}\right)^2 + \left(\frac{0.2}{2.6}\right)^2 + \left(\frac{0.1}{6.3}\right)^2} = 0.0873$$

uncertainty of W = $\Delta W = (0.0873)(171.99) = 15.01\ cm^3$

So, we have two numbers from our calculation: $\bar{W}$ = 171.99 cm^3 and ΔW=15.01 cm^3.
But, we are not finished - we have to express the final answer in the correct number of significant digits. For these types of calculations the procedure is as follows:

- Express the uncertainty in scientific notation
- If the most significant digit is either 1, 2, or 3 then keep 2 significant digits in uncertainty
- If the most significant digit is 4-9 then keep 1 significant digit in uncertainty
- Then, round the calculated measurement to the same decimal place as the uncertainty

For example, in this case, ΔW=15.01 = 1.501x10^1 cm^3 and so the most significant digit is 1 (that's the 10's place - the "1" in front of the 5), and we will keep two (2) significant digits in final answer => 15 cm^3. Thus we will round the original measurement to the "ones place" => 172 cm^3. Our final answer becomes $W = \bar{W} + \Delta W$ =172 ± 15 cm^3.

We will use this technique in the final section.

Part 8 - Statistics and measurements

When making large sets of measurements, it is sometimes useful to make use of statistical functions to help determine the uncertainty in the measurements. Under the right conditions, large sets of measurements on the same object can obey what is known as the normal distribution. This is a bell-shaped curve around the average (or "mean") value of the measurement. The measure of how far the curve spreads on either side is known as the standard deviation, and is thus a measure of the uncertainty of the measurement. [If it is a very narrow bell curve, then the data would appear to be very accurate--the more spread out the curve is, the higher the standard deviation, and the less accurate the measurements are.] It should be pointed out that this statistical calculation is meant to be used with relatively large numbers of data points, and is independent of the individual uncertainties of a given measurement--it is a way to look at the distribution of the measurement values themselves. For this measurement, we will need at least 10 readings of the same "object" to calculate the statistics. The calculation of the standard deviation involves finding the average (or "mean") value ($\bar{x}$) of the data set and calculating the differences between that average and the individual values ($\Delta x_1 = \bar{x} - x_1$). {Note: the Δ here is used for "difference between two values" – not uncertainty.}

The standard deviation is calculated as follows:

$$\text{Mean} = \bar{x} = \frac{\sum x_i}{n} = \frac{x_1 + x_2 + x_3 + x_4 + \dots x_n}{n}$$

$$\Delta x_i = \bar{x} - x_i$$

$$\text{Standard deviation} = \sigma = \sqrt{\frac{(\Delta x_1)^2 + (\Delta x_2)^2 + \dots + (\Delta x_n)^2}{n-1}}$$

$$\text{Standard uncertainty of mean} = \frac{\sigma}{\sqrt{n}}$$

A graphical representation of a possible normal distribution is shown below. This set of measurements is clustered around the average of 3, with a standard deviation of 1. By definition, 68.3% of the data falls within one standard deviation of the average (for a perfect normal distribution), and 95.5% falls within 2 standard deviations.

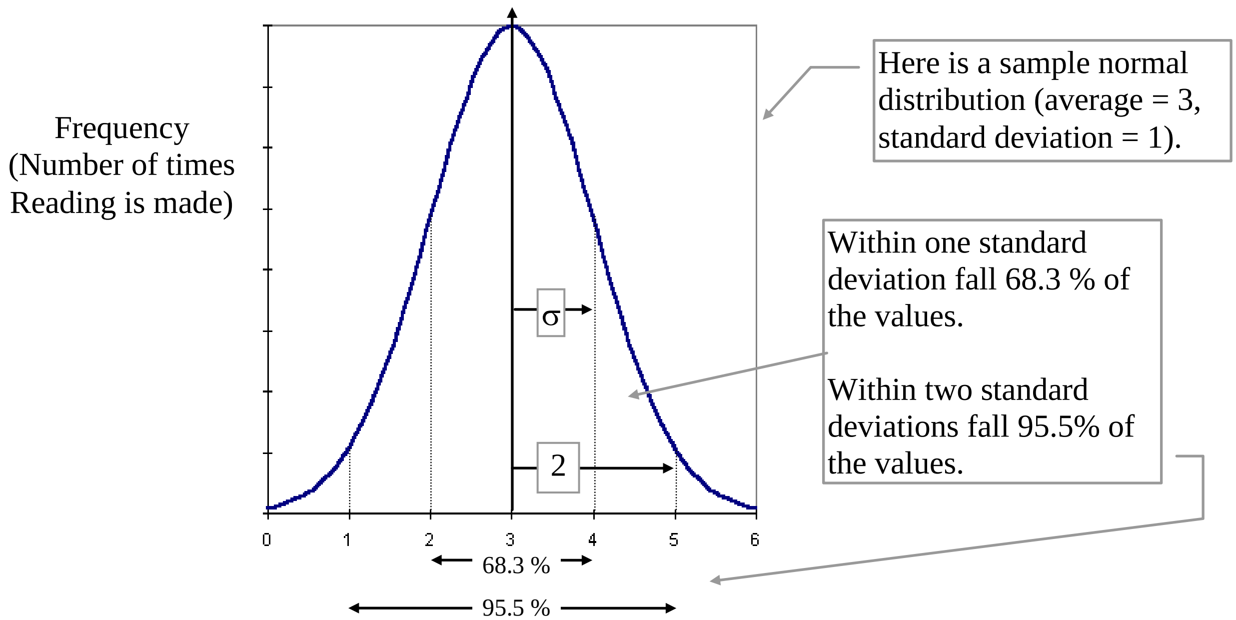

Figure 5 - Normal distribution and standard deviations.

1. Measuring the diameter of the rod at different places. Have each member in the lab group measure, with the micrometer, the diameter of the rod at several different places along the length. This should yield roughly the same numbers, but with manufacturing anomalies or "wear and tear" on the rods, there should be some fluctuations. Make enough measurements so that you have at least 16 values. (We don't need to worry about the uncertainties of each measurement.) Remember to subtract the "zero reading" to get the actual diameters, if necessary. Make sure you use all three decimal places in the mm reading – then convert your answers to cm (by dividing by 10) and record these data values on the data/question sheet.

2. Mean and deviations. We now want to calculate the mean value for the data you collected, and the deviations from the mean (the Δx's as shown in the equations previously). From those values, calculate the standard deviation. Use the formulas above, and record your calculations on the Data/Question sheet.

3. Standard deviation. Record your calculations on the Data/Question sheet.

Question Is the value of the standard deviation that you calculated reasonable for the data? (That is, count how many of the data points out of the total number will lie within one standard deviation from the mean value – is that roughly 68% of the total number of points? ... {11/16 ~ 68%}) Explain.

Part 9 - Calculating the Density of the rod

Refer to the Data/Question Sheets for the calculations in this section.

DATA/QUESTION SHEETS - LAB 1 - INTRODUCTION TO MEASUREMENT

Part 4 - Measuring with the *Digital Mass Scale*

3. Measurement. Measure the mass of the rod with the mass scale:

Mass = __________ grams ± 0.5 grams

= __________ kg ± _______ kg (divide by 1000 to get kg)

Part 6 - Comparing measurements and the measuring devices

Prediction Rate the devices in the order you expect them to be the most accurate:

____

We have made three measurements of the rod, with three different measuring devices. Which of the measurements was most accurate? The measurement from which of the devices will have the lowest percent uncertainty? Let's find out!

List the values you have already found from your measurements:

L = ___________ ± ___________ cm (Ruler)

D = ___________ ± ___________ cm (Digital Caliper)

D = ___________ ± ___________ cm (Micrometer)

1. Uncertainty calculation. Calculate the percent uncertainties for the measurements from each of the three devices:

Example: suppose H = 201.2 ± 3.2 cm then:

$$\% \text{ uncertainty } = \frac{\delta H}{H} \times 100 = \left(\frac{3.2}{201.2}\right) x100 = 1.6\%$$

% Uncertainty in length measurement (ruler) = ________ %

% Uncertainty in diameter measurement (caliper) = ________ %

% Uncertainty in diameter measurement (micrometer) = ________ %

Question: According to the percent uncertainties, which is the actual accuracy ranking?

____

How does your previous answer compare to the prediction? What is an explanation for any possible discrepancies, and give an explanation of why you made this judgment. (Write a full sentence or two as explanation - discuss with your lab partners if necessary.)

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____

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____

Follow-up Measurement – Make a measurement of the ***diameter*** of the rod with the ***ruler*** and calculate the % uncertainty of that measurement.

How does this new % uncertainty for the ruler fit with the % uncertainties for the caliper and the micrometer (and how does it fit with your prediction, and what you actually saw)?

____

____

Part 8 - Statistics and measurements

1. Measuring the diameter of the rod at different places. Record them (in cm) in the spaces below:

______ ______ ______ ______ ______ ______ ______ ______

______ ______ ______ ______ ______ ______ ______ ______

2. Mean and deviations. We now want to calculate the mean value for the data you collected, and the deviations from the mean (the Δx's as shown in the equations previously). From those values, calculate the standard deviation.

Number of data points (n) = ____

$$\text{mean value} = \bar{x} = \frac{\sum x_i}{n} = \frac{x_1 + x_2 + x_3 + x_4 + \ldots x_n}{n} = = \_\_\_\_\_\_ \text{ cm}$$

Deviations : $\Delta x_i = \bar{x} - x_i$:

______ ______ ______ ______ ______ ______ ______ ______

______ ______ ______ ______ ______ ______ ______ ______

Sum of squares of deviations $= (\Delta x_1)^2 + (\Delta x_2)^2 + \ldots + (\Delta x_n)^2 =$ _________

3. Standard deviation. Using the following formula, calculate the standard deviation for your data:

$$\sigma = \sqrt{\frac{(\Delta x_1)^2 + (\Delta x_2)^2 + \ldots + (\Delta x_n)^2}{n-1}} = \_\_\_\_\_\_\_$$

δx = stand uncert of mean = $\frac{\sigma}{\sqrt{n}}$ = ________

You would refer to the data as having a mean value of ________ with a standard deviation of ______.

(This implies that roughly 68 % of the data points should be within one standard deviation from the mean--the larger the number of data points, the better the agreement to the normal distribution). (You should use this value for the diameter in the next section!)

Question Is the value of the standard deviation that you calculated reasonable for the data? (That is, count how many of the data points out of the total number will lie within one standard deviation from the mean value – is that roughly 68% of the total number of points? ... {11/16 ~ 68%}) Explain.

____

____

____

Part 9 - Calculating the Density of the rod

We have enough information about the rod to calculate its density, and then figure out the composition of the rod (the substance of which it is made) (a "non-destructive" testing of the object).

1. Volume calculation. Using the dimension measurements for the rod, calculate the volume using the following cylindrical volume equation (Use the mean diameter from part 8!):

$$V = L \times A = L \times (\pi r^2) = \frac{\pi L D^2}{4} = \_\_\_\_\_\_\_\_\_\_\_\_ \ cm^3$$

2. Volume uncertainty calculation. Using the dimension measurements for the rod, calculate the uncertainty (ΔV) in the volume using the following equation:

$$\delta V = (V)\sqrt{\left(\frac{\delta L}{L}\right)^2 + \left(2\frac{\delta D}{D}\right)^2} = \_\_\_\_\_\_\_\_\_\_\_\_ \ cm^3$$

(Hey, is that factor of 2 in the wrong place – should it be outside the ()?
… No, it is inside to account for the exponent of D in the volume equation.)

Leave the answer with several decimal places--we don't apply the significant figure rule until the last number we calculate, which will be the density.

3. Density calculation. Using the mass found earlier, find the density of the rod (use units of grams and cm^3):

$$\rho = \frac{M}{V} = \_\_\_\_\_\_ \ gm/cm^3$$

4. Calculate the density uncertainty. Using the dimension measurements for the rod, calculate the density uncertainty using the following equation:

$$\delta\rho = (\rho)\sqrt{\left(\frac{\delta V}{V}\right)^2 + \left(\frac{\delta M}{M}\right)^2} = \_\_\_\_\_\_ \ gm/cm^3$$

5. Calculating significant digits. Following the rules in Part 7, determine the significant digits of the answer, and express the final answer to the correct places:

$$\rho = \_\_\_\_\_\_\_\_\_\_\_\_ \pm \_\_\_\_\_\_\_\_\_\_ \ gm/cm^3$$

6. Determine substance. Using the density above and the density table shown, determine the composition of the rod:

Rod material = ____________

(This is the only list you need for the metal rods we have in the lab room – if your density doesn't fit this list, double-check your calculations!)

Densities of the rods used in the lab:

Aluminum ("light")	2.70 g/cm^3
Brass (yellowish)	8.4 - 8.7 g/cm^3 **
Copper (brownish)	8.96 g/cm^3
Iron (tarnished)	7.88 g/cm^3
Nickel (N on end)	8.88 g/cm^3
Steel (shiny)	7.83 g/cm^3

** Varies due to composition of the brass

How do I write up this lab? … **What is required for this lab report?**

Consult the Rubric for this experiment and the “Lab Report Instructions” document (both found on the Lab Schedule page).

Questions/Suggestions -> Dr. Scott Schneider - S_SCHNEIDER@LTU.EDU

Portions of this laboratory manual have been adapted from materials originally developed by Priscilla Laws, David Sokoloff and Ronald Thornton for the Tools for Scientific Thinking, RealTime Physics and Workshop Physics curricula. You are free to use (and modify) this laboratory manual only for non-commercial educational uses.