Experiment 1

Significant Figures and Measurement

Pre-Lab Assignment

Before coming to lab:

- Read the lab thoroughly.
- Answer the pre-lab questions that appear at the end of this lab exercise.

Purpose

The concepts of significant figures, error analysis, accuracy, and precision when in a laboratory atmosphere will be introduced and practiced. Methods for using the most commonly seen laboratory equipment will be described and practiced. The density of water will be graphically determined by measuring portions of mass and volume of deionized water.

Background

Measurements in the laboratory typically fall into one of two categories: exact or inexact. Exact measurements are quantities that can be counted, such as 12 eggs being in 1 dozen or the number of people in the classroom. These numbers have no uncertainty as there is no estimation involved in their measurement; there are exactly 12 eggs or exactly the number of people. Inexact quantities are those that required measurement by some sort of experimental equipment, such as a ruler or balance. A length may be "about" 3.5 cm or a mass "about" 10.5 grams. These numbers contain uncertainty since their value had to be estimated by the user. Inexact does not mean incorrect; it simply means that the quantities contain some form of rounding and estimation. In the laboratory setting inexact measurements are far more common than exact.

Significant figures provide a system that accounts for the uncertainty in inexact numbers. It also creates universal rules for rounding to ensure consistency between individuals. Any data recorded on data sheets or in lab reports should always be reported to correct significant figures.

To determine the number of significant figures that a quantity has is dependent on its zero and nonzero integers. Any number that is not zero (1-9) is considered a significant figure. Any zero can be classified as either **leading, interior,** or **trailing**. Leading zeroes are to the left of any nonzero integers and are never significant figures. Interior zeroes are in between any nonzero integers and are always considered significant figures. Trailing zeroes are to the right of any nonzero integers and are significant figures only if a decimal point is explicitly written. If no decimal point is written, then trailing zeroes are considered insignificant. The number of significant figures a quantity has is a measure of its exactness; the more significant figures present, the more exact the number.

Example Problem: Determining Significant Figures

Determine the number of significant figures in: (a) 0.003801 (b) 2300 and (c) 0.0450

Step 1: Count the nonzero integers.

(a) has 3, 8, 1 = 3 (b) has 2, 3 = 2 (c) has 4, 5 = 2

Step 2: Find any leading zeroes. These are NOT significant.

(a) has three leading zeroes: 0.003801
(b) has no leading zeroes
(c) has two leading zeroes: 0.0450

Step 3: Find any interior zeroes. These ARE significant.

(a) has one interior zero: 0.003801
(b) has no interior zeroes
(c) has no interior zeroes

Step 4: Find any trailing zeroes. These are significant ONLY if a decimal point is written.

(a) has no trailing zeroes
(b) has two trailing zeroes and NO decimal point: 2300
(c) has one trailing zero AND a decimal point: 0.0450

Step 5: Add the significant figures in Steps 1, 2, and 4.

(a) 3 from Step 1 + 1 from Step 3 = 4 (0.003801)
(b) 2 from Step 1 = 2 (2300)
(c) 2 from Step 1 + 1 from Step 4 = 3 (0.0450)

When used in calculations, the rules for rounding for significant figures vary based on the mathematical operation being performed. For multiplication and division, the answer is rounded to contain the same number of significant figures as the factor with the fewest. For addition and subtraction, the answer is rounded to the decimal place as the factor with the smallest. For multistep calculations, always follow the order of operations (PEMDAS, or first parentheses/exponent, second multiplication/division, third addition/subtraction). In data sheets and lab reports, numbers should not be rounded until the very final answer, and then reported in correct significant figures.

Example Problem: Using Significant Figures in Calculations

Calculate the following: $2.3 \times 10^2 + 0.821\ (72 - 34.5)$

Step 1: Do the parentheses first

Subtraction keeps to the decimal place: 72 ends in the ones position
$2.3 \times 10^2 + 0.821(3\underline{7}.5)$

Step 2: Do multiplication

Multiplication keeps to the number: 3$\underline{7}$.5 has 2 significant figures from Step 1, though the entire number is used in the calculation
$2.3 \times 10^2 + 3\underline{0}.7875$

Step 3: Do addition last. Round for significant figures in the final answer.

Addition keeps to the decimal place: 2.3×10^2 = 230 which ends in the tens position
$2.3 \times 10^2 + 3\underline{0}.7875 = 2\underline{6}0.7875 \rightarrow 260$

Any measurement made in lab has inherent uncertainty based on the limitations of the device used. The accuracy of different instruments is typically labeled and varies from device to device. As a rule, data should always be recorded to one decimal place beyond the instrument's markings. For example, a ruler marked for 1 cm at each line should be recorded to the 0.1 cm, even if the decimal place is a zero. This is called the estimated digit since it will be in between clear marks. The main exception to this rule are digital scales. All visible digits should be recorded with no estimated digit. Liquids that form a meniscus should be measured to the bottom of the arc.

Experimental results can be accurate, precise, both, or neither (Fig. 1). Accuracy measures how close the experimental result is to the true value. Precision measures how close multiple experimental results are to each other. Good results should strive to be both accurate and precise.

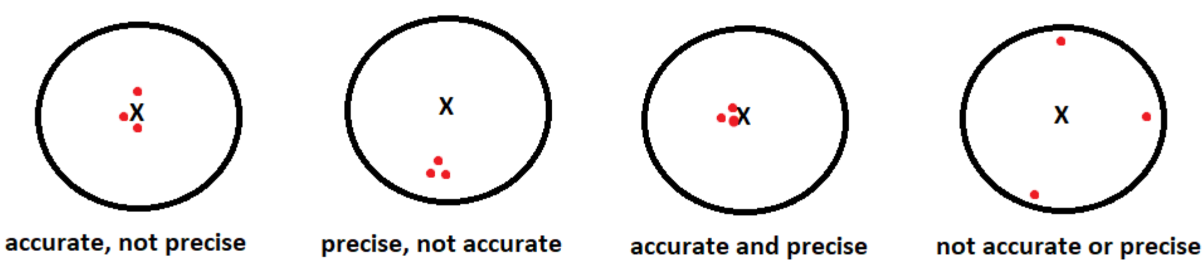


Fig. 1: Accuracy and Precision

The two most common types of error in the laboratory setting are classified as random and systematic. Random error is unpredictable and unpreventable and can cause results to be either too high or too low. Systematic error is predictable and usually due to faulty equipment or poor calibration. It causes results to be incorrect by the same interval each time.

Error analysis measures the accuracy and precision of any experimental results and should always be reported, whenever possible, with one's results. There are many ways the analyze error in measurements, but the most common are percent error in Eqn. 1 and standard deviation in Eqn. 2.

$$\text{percent error} = \left|\frac{\text{theoretical value-experimental value}}{\text{theoretical value}}\right| \times 100 \quad \text{Eqn. 1}$$

Percent error is calculated for a single value when the theoretical value is known. The theoretical value represents the accepted value and the experimental value the calculated result found in lab. The smaller (closer to zero) the percent error, the closer the experimental result is to the accepted value.

Example Problem: Calculating Percent Error

A student determined the boiling point of water to be 99.5°C. The known value is 100.0°C. Calculate the percent error.

Step 1: Use Eqn. 1 to find percent error

$$\text{percent error} = \left|\frac{100.0°\text{C}-99.5°\text{C}}{100.0°\text{C}}\right| \times 100 = 0.5\% \text{ error}$$

$$\text{standard deviation } (\sigma) = \sqrt{\frac{(x_1-\bar{x})^2 + \ldots(x_n-\bar{x})^2}{(n-1)}} \quad \text{Eqn. 2}$$

Standard deviation is calculated for a set of repeated measurements. Here, x_1 represents a single result and $\bar{x}$ represents the average of all results. The value of $(x_1 - \bar{x})$ is known as the deviation and is calculated for each individual measurement (x_n), squared, and then summed. The number of measurements taken is represented as n. The smaller the standard deviation, the closer the set of measurements are to one another. Results are reported as $\bar{x} \pm \sigma$.

Example Problem: Finding Standard Deviation

A student measured the mass of a weight three times and recorded 10.11 g, 9.98 g, and 10.02 g. Find the standard deviation in these measurements.

Step 1: Find the average

$$\frac{10.11\text{ g}+9.98\text{ g}+10.02\text{ g}}{3} = \frac{30.11\text{ g}}{3} = 10.037\text{ g}$$

Step 2: Use Eqn. 2 to find standard deviation

$$\sigma = \sqrt{\frac{(10.11\text{ g}-10.037\text{ g})^2 + (9.98\text{ g}-10.037\text{ g})^2 + (10.02\text{ g}-10.037\text{ g})^2}{3-1}}$$

$$\sigma = \sqrt{\frac{(0.073)^2 - (-0.057)^2 - (-0.017)^2}{2}}$$

$$\sigma = \sqrt{\frac{0.008867}{2}} = 0.067 \text{ so } 10.037\text{ g} \pm 0.067$$

Many times mathematical relationships between experimental data can be expressed or determined graphically. Ordered pairs are used as sets of data and trendline equations can be calculated to find the set's relationship in an equation. Recall that the x-axis is for the independent variable (the one you control) and the y-axis is for the dependent variable (one that changes when x changes). Graphs can be prepared either by hand or with software and will be used frequently throughout this course. For this lab, you will graph the mass versus volume of portions of water. Since density is mass/volume, the relationship between these two variables should be linear and the slope of the trendline created will be equivalent to the density.

Graphs prepared on computer should always include a descriptive title and titles and units on the axes. Data should be plotted as a scatter plot of single points. If a trendline is added, its equation should be included clearly on the graph. Graphs should always be printed on a full page and included with any post-lab assignment or lab report.

Procedure

Part I: Measuring Mass

1. Obtain 10 unpopped corn kernels.

2. Weigh a clean, empty weigh boat on the electronic balance. Make sure that the balance is tared before use (it should read 0.0000 g). Record the mass in your data sheet.

3. Add the 10 kernels to your weigh boat. Record the new mass in your data sheet.

4. Place the kernels into a 400 mL beaker. Using a watch glass over the top as a cover, put the beaker and popcorn on an electronic hotplate and heat just until all 10 kernels are popped. Do **not** burn any of the kernels. If any burn, you will need to restart.

5. Reweigh a clean, empty weigh boat. Record the mass in your data sheet.

6. Place all 10 popped kernels into the weigh boat and reweigh. Record the mass in your data sheet.

7. Calculate the percentage of mass lost per 10 kernels from popping.

8. Get the percent of mass lost per 10 kernels from two other students for Part I. Record their data in your data sheet. Make sure to give them credit.

9. Calculate the standard deviation of the three percent of mass lost for Step 8.

Part II: Measuring Volume

1. Dry your 10 mL graduated cylinder thoroughly. Weigh it and record the mass on your data sheet.

2. Fill a 50 mL beaker with approximately 10 mL of deionized water.

3. Use a glass thermometer to record the temperature of the deionized water in your data sheet.

4. Using your transfer pipette (dropper), transfer 20 drops of deionized water to your graduated cylinder. Record the volume in your data sheet.

5. Weigh the graduated cylinder and water. Record the mass in your data sheet.

6. Without emptying your graduated cylinder, add 20 more drops of deionized water to your graduated cylinder with the same dropper. Record the new volume in your data sheet.

7. Weigh the graduated cylinder and water. Record the mass in your data sheet.

8. Without emptying your graduated cylinder, add 20 more drops of deionized water to your graduated cylinder with the same dropper. You should have a total of 60 drops in your graduated cylinder. Record the new volume in your data sheet.

9. Weigh the graduated cylinder and water. Record the mass in your data sheet.

10. Calculate the average volume of 20 drops.

11. Calculate the standard deviation for the three volumes of 20 drops of water for Steps 4, 6, 9, and 10.

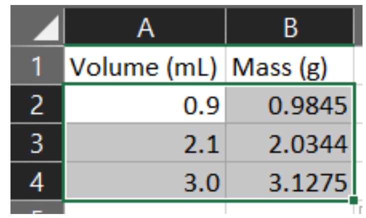
Part III: Graphical Analysis

1. Using your data in Part II, calculate the mass of each 20 drop portion of deionized H_2O.

2. Open Microsoft Excel on the lab computer.

3. In Column A, type your x-axis values, including title and units. In Column B, type your y-axis values, including title and units.

4. Drag and select a box around your numerical values in Column A and B (Fig. 2).



	A	B
1	Volume (mL)	Mass (g)
2	0.9	0.9845
3	2.1	2.0344
4	3.0	3.1275

Fig. 2: Excel data

5. Go to Insert. Under Charts, select Scatter (Fig. 3).

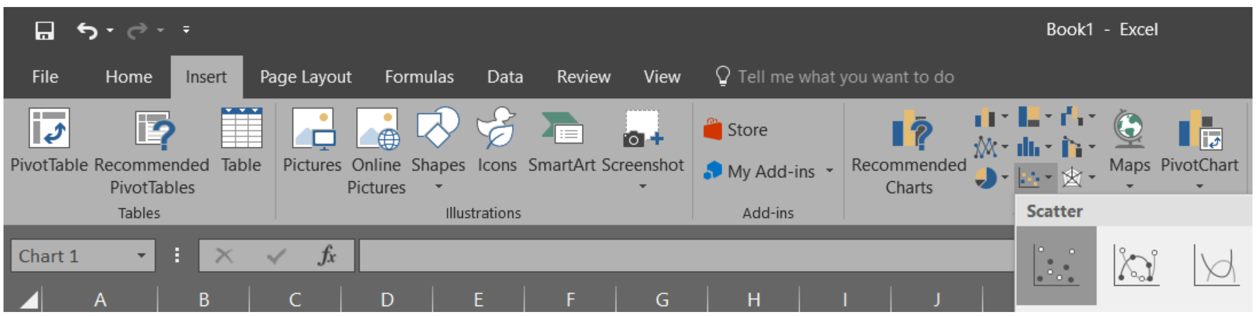


Fig. 3: Insert Scatter Plot

6. Under Chart Tools, Design, click Quick Layout and choose Layout 1 (Fig. 4).

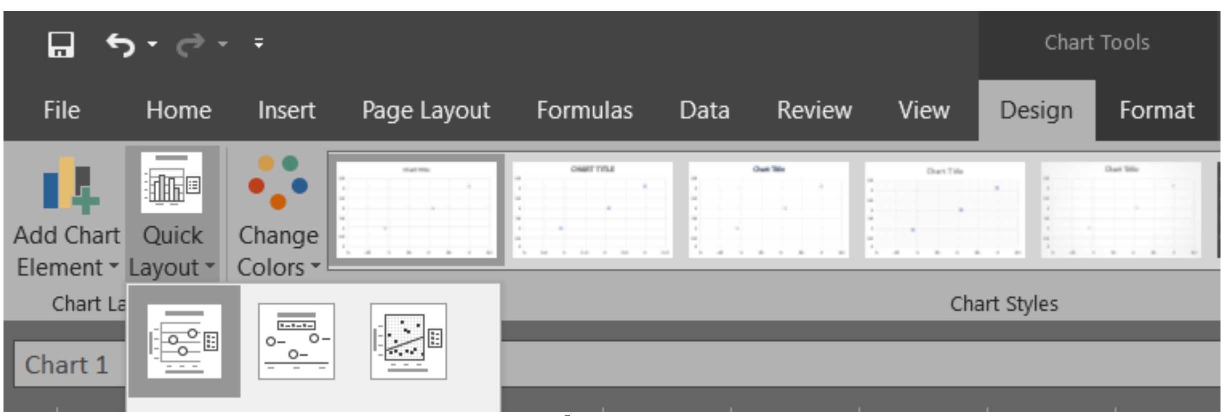


Fig. 4: Layout 1

7. Add a descriptive title for the chart. Label each chart title with the data plotted and units.

8. Right click on any data point on the graph. Select Add Trendline (Fig. 5).

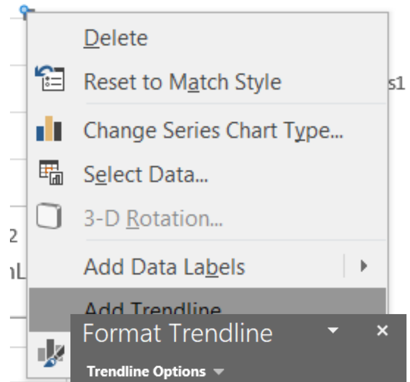


Fig. 5: Add Trendline

9. Under Trendline Options on the right hand menu, ensure that Linear and Display Equation on Chart are selected (Fig 6).

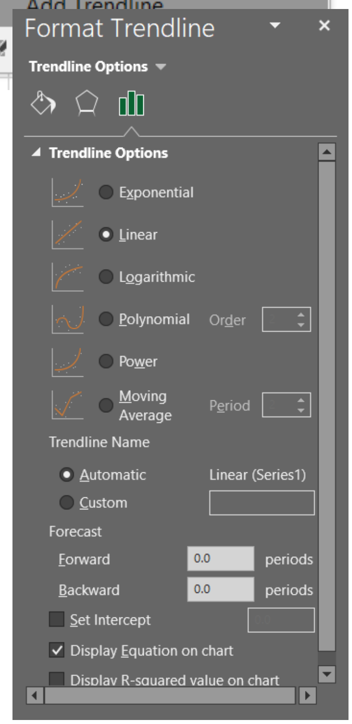


Fig. 6: Trendline Options

10. Make sure that the equation is readable on the chart. Delete the legend on the right hand side. Print the chart as full page (Fig. 7).

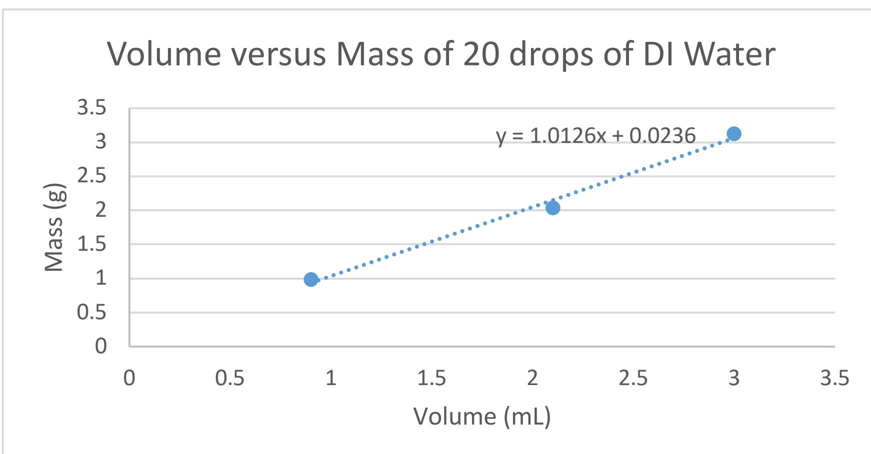


Fig. 7: Graph of Volume versus Mass

11. Look up the tabulated value of the density of water at the temperature you recorded in Part II. Calculate the percent error between this value and your experimentally determined density of water.

Experiment 1—Data Sheet

Name: ____

Part I: Measuring Mass

1. Mass of weigh boat (g) ______________________________

2. Mass of weigh boat + unpopped corn (g) ______________________________

3. Mass of weigh boat (g) ______________________________

4. Mass of weigh boat + popped corn (g) ______________________________

5. Mass of unpopped corn (g) ______________________________
show calculation:

6. Mass of popped corn (g) ______________________________
show calculation:

7. Mass lost after popping (g) ______________________________
show calculation:

8. Percent Mass lost after popping (%) ______________________________
show calculation:

9, Percent Mass lost after popping from other students (%) ____________ ____________

10. Average Percent Mass lost after popping (%) ______________________________
show calculation:

11. Standard Deviation of Percent Mass Lost (σ) ______________________
show calculation:

12. Percent Mass lost after popping (report as $\bar{x} \pm \sigma$): ______________________

Part II: Measuring Volume

1. Mass of graduated cylinder (g) ______________________

2. Temperature of deionized H_2O (°C) ______________________

3. Volume of 20 drops H_2O (mL) ______________________

4. Mass of graduated cylinder + 20 drops H_2O (g) ______________________

5. Volume of 40 drops H_2O (mL) ______________________

6. Mass of graduated cylinder + 40 drops H_2O (g) ______________________

7. Volume of 60 drops H_2O (mL) ______________________

8. Mass of graduated cylinder + 60 drops H_2O (g) ______________________

9. Volume of first 20 drops H_2O (mL) ______________________
show calculation:

10. Volume of second 20 drops H_2O (mL) ______________________
show calculation:

11. Volume of third 20 drops H_2O (mL) ______________________
show calculation:

12. Average volume of 20 drops H_2O (mL) ______________________________
show calculation:

13. Standard Deviation of volume of 20 drops (σ) ______________________________
show calculation:

14. Volume of 20 drops H_2O (report as $\bar{x} \pm \sigma$): ______________________________

Part III: Graphical Analysis

1. Mass of first 20 drops H_2O from Part II (g) ______________________________
show calculation:

2. Mass of second 20 drops H_2O from Part II (g) ______________________________
show calculation:

3. Mass of third 20 drops H_2O from Part II (g) ______________________________
show calculation:

4. Density of H_2O from graph (g/mL) ______________________________

5. Tabulated density of H_2O at Part II's T (g/mL) ______________________________

6. Percent Error of density of H_2O (%) ______________________________
show calculation:

Experiment 1—Post-Lab Assignment

1. Was your standard deviation for Part I large or small? Does this indicate accurate, precise, both, or neither results? Explain.

2. Was your percent error for Part III large or small? Does this indicate accurate, precise, both, or neither results? Explain.

3. Graduated cylinders are typically marked to the 1 mL. Volumetric pipettes are measured to the 0.01 mL. Which glassware is more accurate: the graduated cylinder or volumetric pipette? Which is more precise? Explain.

4. Perform the following calculations. Report your final answer to correct significant figures.

a. $38.2 \times 0.0801 + 4.45$

b. $(6.0 - 3.2)^2 \div 0.8$

c. $9.2 \times 10^3 + 1.42 \times 10^4 - 8.6 \times 10^2$

Experiment 1—Pre-Lab Assignment

Name: ____

For all calculations, show all work and draw a box around the final answers.

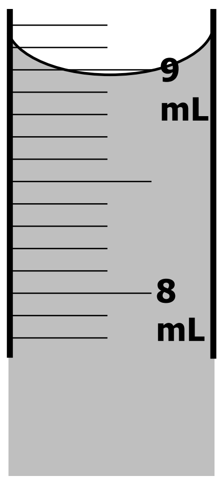
1. Determine the number of significant figures in the following quantities:

   a. 23.40 mL ____________________

   b. 100 grams ____________________

   c. 0.005020 kJ ____________________

2. Record the volume of water in the graduated cylinder below, rounding correctly. Indicate the estimated digit by underlining it.



3. A student used a graduated cylinder to measure out three portions of 5 mL of water three times, recording 4.9 mL, 5.0 mL, and 5.2 mL. Calculate the standard deviation for these measurements. Report your final answer as $\bar{x} \pm \sigma$.