

Measurement and Density

OBJECTIVES

- Learn about different types of commonly used laboratory equipment and glassware in chemistry
- Understand how to use laboratory equipment to make measurements with the correct number of significant figures
- Practice organizing and analyzing data

INTRODUCTION

This laboratory activity is designed to introduce some basic chemistry glassware and equipment, including balances, beakers, graduated cylinders, and pipets. You will practice organizing and analyzing data that has been collected, skills that are the hallmark of any good scientist. You will also learn about the importance of reproducibility in measurement and how to analyze a set of data to determine the precision and accuracy of your results.

In this activity, you will use several methods to analyze data. The following definitions should help you with your calculations and data analysis.

Estimated Digit: The estimated digit is the last number appearing in any measurement (even if that number is a zero). The estimated digit is determined based on the scale of the measuring device used. For digital instruments (such as balances), the instrument gives you the estimated digit. It is the *last number shown in the measurement and must be recorded even if that number is zero*. For analog instruments (such as rulers, graduated cylinders, beakers, etc.) the estimated digit must be determined by the scientist (you)! This is done by finding the scale of the instrument (the distance between the two smallest markings) and *estimating one decimal place past that scale*.

Significant Figures (Sig Figs): Significant figures include all known numbers in a measurement (those that are certain based on the scale of the measuring device) and one estimated digit. All measurements and calculations done in science must show the correct number of sig figs. This is how another scientist can look at your data and see the level of precision of the instruments you used to make measurements.

Average: The average is the sum of all individual measurements, divided by the total number of individual measurements.

Deviation: The deviation is the absolute value of the difference between a measurement and the average. For example, if you measured the mass of a sample as 0.5400 grams and the average mass is 0.5500 grams. The deviation of that measurement would be 0.0100 grams.

Average Deviation: The average deviation is the sum of all individual deviations (for each measurement), divided by the total number of deviations.

Percent Error (% error): Percent error is the absolute value of the difference between your calculated value and the actual or accepted value, divided by the accepted value, then multiplied by 100 to convert to a percentage.

Accuracy: Accuracy is a measure of how close your calculated value is to the actual or accepted value. Percent error is a measure of accuracy.

Precision: Precision can be discussed in two contexts. Average deviation is a measure of precision.

1. *Precision of an instrument:* This is determined by the number of sig figs an instrument gives you. The more sig figs the instrument gives (the smaller the scale of the measuring device), the more precise that instrument is.
2. *Precision of a measurement:* This is determined by how close a group of measurements are to each other. When an identical measurement is repeated multiple times, the closer the values are, the more precise the measurement is.

Before continuing with this activity, you will need to watch the video corresponding with this lab! The video (approximately 10 minutes) contains images and explanations for how the data was collected in this experiment: <https://screencast-o-matic.com/watch/cYjfoWGbZ>

CALCULATIONS AND DATA ANALYSIS

Part 1 - Mass Measurements

The mass of a plastic weigh boat was measured 9 times on a top-loading balance and 9 times with an analytical balance. The mass data was used in the following calculations:

- Average mass of weigh boat for each balance
- Deviation for each mass measurement
- Average deviation of mass for each balance

The results of the experiment are summarized in the table below. All calculations for this part of the experiment have been completed for you.

Top-Loading Balances		Analytical Balances	
Weighboat mass (g)	Mass Deviation (g)	Weighboat mass (g)	Mass Deviation (g)
2.59	0.01	2.6036	0.0001
2.62	0.02	2.6038	0.0001
2.61	0.01	2.6039	0.0002
2.61	0.01	2.6033	0.0004
2.6	0	2.6036	0.0001
2.61	0.01	2.6041	0.0004
2.6	0	2.6034	0.0003
2.6	0	2.6038	0.0001
2.59	0.01	2.6037	0.0000
Average = 2.60 g	Average = 0.01 g	Average = 2.6037 g	Average = 0.0002 g

1. The average masses and average deviations for each type of balance are in the last row of the table, in **bold** font. Which type of balance is more precise? Does this make sense? Why?

Part 2 – Volume Measurements

The temperature of the water was measured in °C using a thermometer: **22.6 °C**

The estimated density of water (in units g/mL) at the above temperature was found using a standard reference table from the Handbook of Chemistry and Physics: **0.997608 g/mL**

The mass of 25 mL of water was measured on the analytical balance using three different types of glassware. The data collected is summarized in the table below.

Glassware used to deliver 25 mL of water	Mass of water (g)	Volume of Water (mL)	Percent Error
50 mL beaker	23.3032		
50 mL graduated cylinder	24.6507		
25 mL volumetric pipette	24.8841		

Calculations

- Using the mass of water delivered by each method (i.e., beaker, graduated cylinder, pipette) AND the density of water estimated from the temperature, calculate the volume of water using the formula $D = m/V$. Fill in your calculated volumes in the table above. *Make sure you use the correct number of sig figs!*
- For each type of glassware, calculate the percent error by comparing the *calculated* volume to an accepted value of 25.00 mL. Record your percent error in the final column of the table above.

2. Why did you calculate the volume of water the using the density equation? In other words, why is the *calculated* volume more accurate than the *measured* volume?

3. In 2-3 sentences, discuss the accuracy of each type of glassware by comparing the percent errors.

Part 3 – Density of a Solid Cylinder

The mass of an unknown solid cylinder (in g) was measured using the top-loading balance:

Mass = 11.04 g

Next, the volume of the same cylinder was measured using two different methods:

- **Caliper Method** – measurements of the diameter and height (in units mm) of the solid cylinder were obtained using digital calipers:

Height = 38.68 mm **Diameter = 16.24 mm**

- **Water Displacement Method** – A graduated cylinder was filled to about half of its total volume. The measurement was recorded as the initial volume (V_i) in units mL. Next, the graduated cylinder was tilted without spilling any of the water and the solid cylinder was carefully placed inside of the graduated cylinder to avoid any splashing of water. The graduated cylinder was then placed upright, and the final volume (V_f) was recorded in units mL:

$V_i = 26.9$ mL

$V_f = 35.0$ mL

Calculations

NOTE: All calculations must contain the correct number of sig figs!!!

- Calculate the volume of the cylinder based on the measurements made with the digital calipers. Recall the Volume of a cylinder (V_{cyl}) is determined by the formula $V_{cyl} = \pi r^2 h$ where r is the radius of the cylinder (note that the radius is half the diameter) and h is the height of the cylinder. Pay careful attention to the units here! If you measured in mm, you are squaring the radius, resulting in mm^2 then multiplying by the height in mm, so your final answer should have units mm^3 ! Enter your value into the data table provided below in order to organize your calculations.
- Calculate the volume of the cylinder obtained using the water displacement method. This calculation is much more simple, where $V_{cyl} = V_f - V_i$. In other words, the amount of water displaced by the cylinder is equal to the cylinder's volume. Enter this value into the data table as well.
- In order to compare the measurements obtained from the two methods, you will need to have your calculated volumes in the same units. We will convert the volume from the digital caliper method into units mL in order to match the units of volume from the water displacement method. The following conversion factors will be useful in performing this calculation: $1\text{ cm}^3 = 1000\text{ mm}^3$ and $1\text{ cm}^3 = 1\text{ mL}$.
- Using the mass of the solid cylinder measured for you and the volumes you calculated above, calculate the **density** of the solid cylinder found by each method and enter the values in the data table. Recall: *Density = mass/Volume*.
- If the **accepted value** for the density of the solid cylinder is: **1.37 g/mL**, Calculate the percent error of each method (digital caliper and water displacement), based on your **calculated value** for density. Enter these values into the data table.

Method	Mass (g)	V _{cylinder}	V _{cylinder} (mL)	D _{cylinder} (g/mL)	% error
Digital Calipers					
Water Displacement					

4. Explain why $1 \text{ cm}^3 = 1000 \text{ mm}^3$. You can use words and/or equations/math in your explanation!

5. Based on your data, which method – digital calipers or water displacement – gave more **precise** results? How do you know?

6. Based on your data, which method – digital calipers or water displacement – gave more **accurate** results? How do you know?

7. Based on your results, which method do you think is better to measure the density of a cylinder? Why?