

Experiment 3

Density of an Unknown

Pre-Lab Assignment

Before coming to lab:

- Read the lab thoroughly.
- Read the sections on Volumetric Flasks and Volumetric Pipettes in Introduction 1: Instrumentation in Lab.
- Answer the pre-lab questions that appear at the end of this lab exercise.

Purpose

The density of an unknown seed will be determined using the displacement of water. A thermometer and volumetric pipette will be calibrated and be used to experimentally determine the density of liquid water, which will be compared to the literature value with appropriate error analysis.

Background

Density is a physical characteristic unique to each pure substance. As a result, its value can be used to identify unknowns. The density of an object is defined in Eqn. 1.

$$\text{density} = \frac{\text{mass}}{\text{volume}} \qquad \text{Eqn. 1}$$

Knowing the density of an object also provides a conversion between an object's mass and its volume, or vice versa. In the laboratory it is often easier to measure a substance's mass instead of its volume, or volume instead of mass.

Example Problem: Calculating the Density of an Unknown Solid

A 50.00 mL volumetric flask weighs 26.7500 g. The entirety of an unknown solid is added to the flask and reweighed at 30.1150 g. Deionized water is added to the calibration mark and the flask, sample, and water is reweighed at 74.9950 g. Calculate the density of the unknown solid, assuming the density of water is 0.998203 g/mL.

Step 1: Find the mass of the unknown

$$30.1150 \text{ g} - 26.7500 \text{ g} = 3.3650 \text{ g unknown}$$

Step 2: Find the mass of water added

$$74.9950 \text{ g} - 30.1150 \text{ g} = 44.8800 \text{ g water}$$

Step 3: Find the volume of water added

$$44.8800 \text{ g} \times \frac{1 \text{ mL}}{0.998203 \text{ g}} = 44.9608 \text{ mL}$$

Step 4: Find the volume of the unknown

$$50.00 \text{ mL} - 44.961 \text{ mL} = 5.04 \text{ mL}$$

Step 5: Find the density of the unknown

$$\frac{3.3650 \text{ g}}{5.04 \text{ mL}} = 0.668 \text{ g/mL}$$

Density is also dependent on temperature. In the lab, the most common devices used to measure temperature are the glass thermometers and the electronic Vernier temperature probes. Instruments contain some amount of uncertainty and error that must be determined by calibration and finding a correction factor, as seen in Eqn. 2. Much like density, the freezing and boiling point are also unique to a substance. The freezing and boiling point of water will be used to calibrate the glass thermometer as their true values are tabulated and well-known. The boiling point of water is dependent on the surrounding atmospheric pressure, so that will need to be measured on the day of the experiment with the classroom barometer.

$$T_C = \frac{(0^\circ\text{C} - T_s(\text{freezing point})) + (T_A(\text{boiling point}) - T_s(\text{boiling point}))}{2} \quad \text{Eqn. 2}$$

Here, the correction factor (T_C) is the error of the electronic temperature sensor. T_s is the temperature recorded by the sensor and T_A is the actual tabulated boiling point at that day's atmospheric pressure. Any temperature recorded by the temperature sensor should be corrected by adding the T_C .

Example Problem: Finding T_c

A temperature sensor was used to record the freezing point of water as 0.112°C and the boiling point as 100.102°C . The actual boiling point of water on that day was tabulated at 99.982°C . The same sensor was then used to record the temperature of another substance at 72.355°C . Find the actual temperature of the second substance.

Step 1: Find T_c

$$T_c = \frac{(0^\circ\text{C} - 0.112^\circ\text{C}) + (99.982^\circ\text{C} - 100.102^\circ\text{C})}{2} = \frac{-0.232^\circ\text{C}}{2} = -0.116^\circ\text{C}$$

Step 2: Add $T_s + T_c$ to find T_A

$$72.355^\circ\text{C} + (-0.116^\circ\text{C}) = 72.239^\circ\text{C}$$

Plotting the actual temperature after correction (T_A) versus thermometer reading (T_R) for a set of temperatures will yield a linear equation that relates the two. This equation can continue to be used throughout the lab to convert any temperature taken by the thermometer to its actual, accurate temperature. Refer to Exercise 1 in this lab manual for instructions for graphing.

In the lab volume is typically measured either with a graduated cylinder or with volumetric glassware, such as a volumetric flask or pipette. Volumetric glassware has been previously calibrated for high precision and accuracy which can be tested by calibrating it with water as well.

Recall that measurements in lab can be accurate, precise, both, or neither. These can be analyzed by determining percent error, standard deviation, and other error analysis on the numbers taken. Review Experiment 1 in this lab manual for more information.

Example Problem: Finding T_A

A graph of thermometer reading versus actual temperature had a linear trendline equation of $y = 1.0382x - 0.6525$. The same thermometer was used to record a temperature of a sample as 20.4°C . Find the actual temperature of the sample.

Step 1: Use the trendline to find the actual temperature (y).

$$y = 1.0382(20.4) - 0.6525 = 21.2 - 0.6525 = 20.5^\circ\text{C}$$

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Procedure

Part I: Density of a Solid Unknown

1. Obtain a 50.00 mL volumetric flask from your instructor. Ensure that it is clean and dry and then weigh it empty. Record this mass in your data sheet.
2. Obtain a solid unknown from your instructor. Add the entire unknown to the volumetric flask and reweigh. Record this mass in your data sheet.
3. Fill the volumetric flask approximately halfway with deionized water with your wash bottle. Ensure that there are no solid pieces stuck in the neck of the flask.
4. Swirl and tap the flask and contents to remove any large air bubbles that may be trapped between the solid pieces. Tiny bubbles on the surface of the unknown may not be able to be removed.
5. With your wash bottle, add deionized water to reach the neck of the flask. Switch to a dropper and carefully add deionized water drop by drop until just below the flask's calibration mark.
6. Use a piece of rolled paper towel to remove any drops from the neck of the flask that are above the calibration mark.
7. Use your dropper to very carefully add deionized water until the bottom of the meniscus is touching the calibration mark. Do not allow any water drops to remain in the neck of the flask above the calibration mark.
8. Weigh the volumetric flask, sample, and water. Record the mass in your data sheet.
9. Empty the flask's contents in the appropriate container (not the sink). Rinse the flask three times with deionized water and then leave on the assigned rack.
10. Use a glass thermometer and record the temperature of the deionized water in your wash bottle.
11. Calculate the density of your unknown. Assume that the density of water is 1.00000 g/mL.

Part II: Thermometer Calibration

1. With a partner, obtain a Vernier GoDirect temperature probe and either a lab computer or a LabQuest 2 interface. If using a lab computer, make sure that the Graphical Analysis 4 program is already open. Connect the sensor to computer or interface using the USB cord. The current temperature of the probe in degrees C will be shown on the screen automatically (Fig. 1).



Fig. 1: Temperature Sensor with LabQuest 2

Wrap the temperature probe's wire with aluminum foil to prevent damage. Slide a slit stopper onto the temperature probe from the bottom.

2. Set up a Bunsen burner beneath an iron ring and wire gauze.
3. In a 250 mL beaker, place approximately 125 mL of ice and 75 mL of tap water. Put this beaker on top of the wire gauze and use a second iron ring around it to avoid tipping.
4. Lower the temperature sensor into the ice water. If using a two-holed stopper, slide a glass thermometer into the second hole. Otherwise, use more split stoppers to hold each partner's glass thermometer. Clamp the sensor and the thermometers about 1 cm from the bottom of the beaker (not touching).
5. Gently stir the mixture with a glass stirring rod. When the temperature on the computer or LabQuest 2 stabilizes at or near 0°C, read each thermometer (T_R) to the nearest 0.1°C and record these and the temperature sensor (T_S) reading on your data sheet.
6. Raise the temperature sensor and thermometers. Empty the beaker and add approximately 200 mL of room temperature tap water (about 20°C) to it.
7. If the water is not at 20°C, use the Bunsen burner to heat it. Turn off the burner and return the temperature sensor and thermometers to 1 cm from the bottom of the beaker. Let the temperature stabilize for at least one minute and then read and record the temperature on the sensor and thermometers. Record the temperatures on your data sheet.

- Repeat Step 8, this time heating the water to approximately 40°C before turning off the burner, letting it stabilize, and recording the temperatures. Repeat Step 8 again to approximately 60°C, 80°C, and then finally when the water reaches a gentle boil. Record the temperatures on both sensor and thermometer each time.
- Record the atmospheric pressure from the classroom barometer for the day. Use this to look up the true value for the boiling point of water at this pressure.
- Calculate the correction factor (T_c) for the temperature sensor and then use it to find the actual temperature (T_A) at the recorded 20, 40, 60, and 80°C (not ice or boiling).
- Graph thermometer reading (x-axis) versus actual temperature (y-axis), add a linear trendline, and record the trendline equation.

Part III: Pipette Calibration

- Fill a 250 mL beaker approximately half full with deionized water. Take the temperature of the water with a glass thermometer and record this in your data sheet.
- Weigh a clean, dry 125 mL Erlenmeyer flask with cork stopper. Record this mass in your data sheet.
- Fill the 5 mL volumetric pipette completely with deionized water, being sure to not get any liquid into the rubber bulb. Allow the pipette to drain into the sink. It should drain completely, leaving only a drop or two in the very tip of the pipette. If so, move on to Step 5.
- If the pipette does not drain completely (droplets are left along the inside of the glass), clean it with a hot soap solution. Heat approximately 50 mL of deionized water to boiling and then add a few drops of dish soap and stir. Using the rubber bulb, pull the soap solution up and down the pipette vigorously for at least a minute. Then use the bulb to fill the pipette with tap water and drain, then deionized water and drain, to rinse. If drops still cling to the inside of the pipette, see your instructor for a replacement.
- Using the rubber bulb, measure 5.00 mL of deionized water from the beaker you prepared in Step 1 with your volumetric pipette and transfer it to the Erlenmeyer flask in Step 2.
- Stopper the flask and reweigh, recording the mass in your data sheet.
- Repeat Steps 5-6 four more times, for a total of five portions of 5.00 mL water added to the Erlenmeyer. Do **not** empty the flask in between portions; there should be 25.00 mL total inside the Erlenmeyer flask when finished.
- Find the individual masses of each 5.00 mL portion of water added.
- Use the trendline equation from Part II to convert the temperature you recorded in Step 1 to the actual temperature.
- Look up the density of water at this actual temperature in Step 9.
- Use the density of water found in Step 10 to convert the masses in Step 8 to volume.
- Calculate the average volume and standard deviation.

Part IV: Density of a Solid Unknown Correction

1. With the temperature recorded in Part I Step 10 (Part I Line #4 on the Data Sheet), use the trendline from Part II to convert the temperature to actual temperature.
2. Look up the density of water at this actual temperature in Step 1.
3. Recalculate the density of the unknown, this time using the actual density of water found in Step 2.
4. Calculate the percent error between the density originally found in Part I and the new corrected density in Step 3, using Part I's density as the experimental value and Part IV's as the theoretical.

Experiment 3—Data Sheet

Name: _____

Unknown #: _____

Thermometer #: _____

Part I: Density of a Solid Unknown

1. Mass of volumetric flask (g) _____

2. Mass of flask and sample (g) _____

3. Mass of flask, sample, and water (g) _____

4. Water temperature (°C) _____

5. Mass of sample (g) _____

show calculation:

6. Mass of water (g) _____

show calculation:

7. Density of H₂O (g/mL) 1.00000 g/mL

8. Volume of water added (mL) _____

show calculation:

9. Volume of sample (mL) _____

show calculation:

10. Density of sample (g/mL) _____

show calculation:

Part II: Thermometer Calibration

Thermometer Reading (T_R °C)	Sensor Reading (T_S °C)	Actual Temperature (T_A °C)
		0°C (ice)
		T_A (boiling) =

1. Atmospheric Pressure (inHg) _____

2. Temperature Correction (T_c , °C)
show calculation: _____

3. Trendline equation (from graph) _____

Part III: Pipette Calibration

1. Temperature of water ($^{\circ}\text{C}$) _____

2. Mass of flask (g) _____

3. Mass of flask + first 5.00 mL H_2O (g) _____

4. Mass of flask + second 5.00 mL H_2O (g) _____

5. Mass of flask + third 5.00 mL H_2O (g) _____

6. Mass of flask + fourth 5.00 mL H_2O (g) _____

7. Mass of flask + fifth 5.00 mL H_2O (g) _____

8. Mass of first 5.00 mL H_2O (g) _____

show calculation:

9. Mass of second 5.00 mL H_2O (g) _____

show calculation:

10. Mass of third 5.00 mL H_2O (g) _____

show calculation:

11. Mass of fourth 5.00 mL H_2O (g) _____

show calculation:

12. Mass of fifth 5.00 mL H_2O (g) _____

show calculation:

13. Actual temperature of H₂O (°C)

show calculation:

14. Density of H₂O (g/mL)

15. Volume of first 5.00 mL H₂O (mL)

show calculation:

16. Volume of second 5.00 mL H₂O (mL)

show calculation:

17. Volume of third 5.00 mL H₂O (mL)

show calculation:

18. Volume of fourth 5.00 mL H₂O (mL)

show calculation:

19. Volume of fifth 5.00 mL H₂O (mL)

show calculation:

20. Average volume pipetted (mL)
show calculation:

21. Standard deviation (σ)
show calculation:

22. Result ($\bar{x} \pm \sigma$)

Part IV: Density of a Solid Unknown Correction

1. Actual temperature from Part I ($^{\circ}\text{C}$) _____
show calculation:

2. Density of water (g/mL) _____

3. Corrected density of sample (g/mL) _____
show calculation:

4. Percent Error (%) _____
show calculation:

4. Convert the corrected density of your sample from Part IV into the following units. Show all your work.

12 inches = 1 foot

3 feet = 1 yard

2000 pounds = 1 ton

a. pounds/ft³

b. tons/yard³

c. kilograms/liter

Experiment 3—Pre-Lab Assignment

Name: _____

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

1. A 100.00 mL volumetric flask weighs 35.9325 g. When an unknown solid is added to it, the flask and sample weigh 48.8565 g. Deionized water is added to the calibration mark. The flask, sample, and water together weigh 140.8321 g. Calculate the density of the unknown, assuming the density of water is 0.998203 g/mL.

2. What two measuring devices are being calibrated in this experiment?

_____ and _____

3. The following volumes were obtained during the calibration of a 10.00 mL pipette: 10.15 mL, 9.95 mL, and 10.02 mL. Calculate the average and the standard deviation of these three measurements. Report your answer as $\bar{x} \pm \sigma$. Round the average and standard deviation to 2 decimal places.

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