5.3: Lab 2 Density of sweet drinks

Lab 2 Density of sweet drinks

Objectives

- Explore density of solids, liquids and gases
- Explore how density is related to floating in water (buoyancy)
- Determine the density of a sweet drink (two choices, different colors)
- Evaluate sources of error in measurements and their effect on an experiment.

Safety and Notes

We will not generate any hazardous waste today. Once the sweet drinks enter the lab, they are no longer for human consumption, and we will discard them at the end of the week. In one task, we will heat up a metal strip to high temperature. Do not touch the strip until you cooled it down with cold water.

Introduction

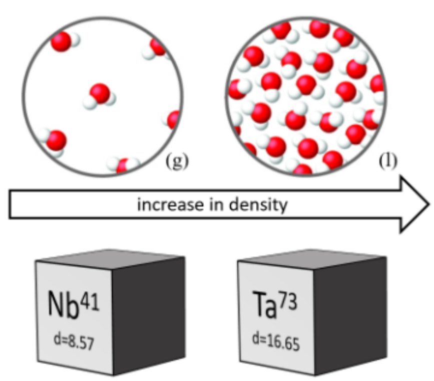
Density

The density of an object is defined as the ratio of its mass to its volume:

$$\text{Density } = \frac{\text{Mass}}{\text{Volume}}$$

For an example of density, consider the following: Imagine a brick that is made of Styrofoam. Imagine a second brick that is made of lead. Note that even though the bricks take up the same amount of space - that is, they have the same volume - there is a major difference in their mass. We would say that the lead is denser, that is it has more mass in the same volume.

How can we explain density at the atomic level? The closer atoms are to each other, the higher the density. For example, the density of liquid water is higher than that of water vapor (steam) because the water molecules are much closer together in the liquid (see image on the right). The heavier the atoms are, the higher the density. For example, the density of metallic tantalum is about twice that of niobium, even though they have similar chemical properties and are in the same group of the periodic table (which is why they are sometimes called twins).



Density of (liquid) water

It is important to note that liquid water has a density of approximately 1.0 g/mL. So at room temperature, 50.0 mL of water has a mass of almost exactly 50.0 g.

Two factors have an effect on the density of water:

1. Temperature will have a small effect on the density. For water, density increases as temperature decreases. For example, a 10.000 mL volume of water will increase by 0.016 mL when the temperature is raised from $18^{\circ}C$ to $25^{\circ}C$. See Table 1 for the density of water at different temperatures.

2. When solids are dissolved in the water, the solution will typically have a higher density than pure water. We might see this effect in today’s lab when we compare the density of sweet drinks (aqueous solutions) with the density of water.

Temp (°C)	d_{H_2O}(g/mL)	Temp(°C)	d_{H_2O}(g/mL)
18.0	0.99860	22.0	0.99777
18.5	0.99850	22.5	0.99765
19.0	0.99841	23.0	0.99754
19.5	0.99830	23.5	0.99742
20.0	0.99820	24.0	0.99730
20.5	0.99809	24.5	0.99716
21.0	0.99799	25.0	0.99704
21.5	0.99788	25.5	0.99690

Table 1. Density of water at different temperatures

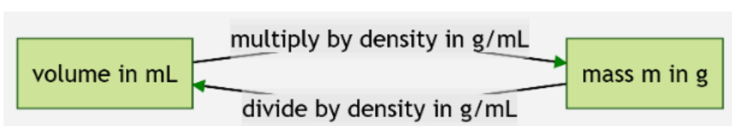
A table of the theoretical values of density for sucrose (table sugar) solutions of various (*w*/*w*)% is included in Table 2 below.

Mass %	Density (**g/mL**)	Mass %	Density (**g/mL**)
0.00	1.000	12.50	1.051
2.50	1.011	15.00	1.062
5.00	1.021	17.50	1.073
7.50	1.030	20.00	1.084
10.00	1.042	22.50	1.102

Table 2: Theoretical Density Values of Sucrose Solutions with Known Mass Percent

Calculating with density

If you know the density of a sample (in g/mL), you can determine the volume from the mass of the sample, and vice versa.



Buoyancy

The concept of buoyancy (a physics concept) is relevant to the interpretation of some of the tasks below. Buoyancy is an upward force of objects submerged in a liquid that explains why some objects sink and others float in a given liquid. The buoyancy is equal to the gravitational force on the displaced liquid, i.e. it depends on the volume of the floating object (or, if it is not fully submerged, the volume that is under the surface) and on the density of the liquid.

Objects that have a density less than water, that is, less than 1.0 g/mL, will float on the surface of the water, with more or less of the object submerged. Those that have a density greater than 1.0 g/mL will sink. Consider our two bricks again. The brick of Styrofoam will float if we toss it into water. The lead will sink "like a rock".

Relative error

In this experiment, we will discuss the relative error, expressed in percent, of our measurements. The equation for finding relative error (or percent error) is:

$$\text{Relative error } = \frac{\text{(Experimental Value-Theoretical Value)}}{\text{Theoretical Value}} \times 100\%$$

If we want to decide whether to use a 100 mL or a 10 mL graduated cylinder for our density measurements, the relative error will be the deciding factor. If the 100 mL cylinder has a tolerance of 0.4 mL and the 10 mL cylinder has a tolerance of 0.05 mL, which one has the smaller absolute volume error? Which one has the smaller relative error? Assuming you have a balance that has a relative error of 0.01%, which volume is better for a density determination?

Graphing Data

In one of the tasks, you will use a graphical method to determine density. It is recommended that you use a spreadsheet for this task (tutorial for Google sheets, MS Excel, IOS Numbers). Make a scatter plot of your data and fit a straight line to it. Then, jot down the formula of the line, given as y = m x + b. You might chose to set b (y-intercept) to zero, but you don't have to. If you do, the formula is simply y = m x. In either case, m is the slope you need for the analysis.

Experimental Procedure

To have less crowding at the balances, you either start with task 1 or with task 2. Do task 3 only when you are done with the two other tasks. Record your observations and calculations in your lab notebook, and use the lab summary sheet to hand in your results and reflections.

Part 1: Density of sweet drink

The protocol below is a bit weird. We are filling a graduated cylinder (which is designed "to contain") from a beaker, whose mass we monitor. We could have measured the mass of the graduated cylinder instead; however, the graduated cylinder has a higher mass (getting close to the maximum of the analytical balance) and an awkward shape for use in the balance.

1. Pour about 60 mL of sweet drink (there are two choices, with different colors) into a 100 mL beaker and measure the total mass (beaker + drink).
2. At your bench, pour 10 mL from the beaker into a 100 mL graduated cylinder. Go slow and steady, and use a transfer pipet for the last milliliter. Observe the meniscus carefully. Any leftover solution in the transfer pipet goes back into the beaker.
3. Measure the total mass of the sweet drink in the beaker again (the mass should be less because you removed 10 mL from it).
4. Repeat steps 2 and 3, adding drink to the same graduated cylinder (so it will be filled with 10 mL, 20 mL, 30 mL, 40 mL and finally 50 mL. Make sure the balance is zeroed before you place the beaker on the weighing dish.
5. Graph the removed volume against the removed mass. The x axis should be the volume in mL and the y axis the mass in g.
6. Fit a line to the data. The slope of the line will have units g/mL and is a measure of the density of the drink.
7. In a different way of analyzing the data, subtract the final mass from the initial mass and divide by the difference in volume to get the density.
8. When you are down, pour the drink into the appropriate one of the two provided containers (we will use it again, and monitor whether the density changes over the week due to evaporation or contamination).

Part 2: Density changes with temperature, pressure, and physical state

Walk through the exhibit (any order), explore the objects and answer the questions on the summary sheet

Part 3: Alternative density determination

Choose **one** of the alternative density determination methods below. Choice 1 can be done at your bench, the others at separate stations. Not all stations might be available.

1. Graduated cylinder

Taking a clean and dry graduated cylinder, measure the mass, and then fill to 10, 20, 30, 40, and 50 mL with the drink you used for task 1, measuring the mass at each step. Use the same graphical analysis as in task 1 to determine the density. When you are done, pour the drink into the appropriate one of the two provided containers (we will use it again, and monitor whether the density changes over the week due to evaporation or contamination).

2. Volumetric flask

Taking a clean and dry 50 mL volumetric flask, measure the mass, and then carefully fill to the line with the drink you used for task 1. If you have a drink that likes to make bubbles, a funnel will be helpful. Measure about 45 mL of the drink in a beaker, and slowly pour it into the funnel whose outlet is at the bottom of the volumetric flask. Use a transfer pipet for the last bit, making sure the liquid does not wet the volumetric flask above the line, and measure the mass. Calculate the density from your data and compare it with that from task 1. When you are done, pour the drink into the appropriate one of the two provided containers (we will use it again, and monitor whether the density changes over the week due to evaporation or contamination).

3. Potato and egg

See whether a potato and a hard-boiled egg float or sink in your drink. Each object has a volume of 60-80 mL, so choose a beaker that the object fits in, place it in the beaker, and fill with the sweet drink until submerged. If they float, estimate which fraction of the object is above the surface of the liquid. From your observations, estimate the density of the liquid. When you are down, rinse and dry the potato and the egg. Pour the drink into the appropriate one of the two provided containers (we will use it again, and monitor whether the density changes over the week due to evaporation or contamination).

4. Below balance measurement

Zero the balance and attach the “sinker” (a large marble on a string) to the hook, zeroing the balance. Submerge the sinker in pure water at room temperature and record the mass difference (which will be negative). Then, dry the sinker and submerge it in your sweet drink, recording the mass difference (which will be negative). The ratio of the mass differences is equal to the ratio of densities. Look up the density of pure water and calculate the density of your sweet drink. When you are done, pour the drink into the appropriate one of the two provided containers (we will use it again, and monitor whether the density changes over the week due to evaporation or contamination).

5. Above balance measurement

Place a beaker with water on the balance and zero the balance. Submerge a “sinker” in the water and record the mass. It represents the buoyancy of the sinker (and you can determine the volume of the sinker if you know the density of the water). Repeat with your sweet drink. If it has a higher density than water, the buoyancy will be larger. The ratio of the masses measured is equal to the ratio of densities. Look up the density of pure water and calculate the density of your sweet drink. When you are done, pour the drink into the appropriate one of the two provided containers (we will use it again, and monitor whether the density changes over the week due to evaporation or contamination).

Acknowledgement

Parts of this lab were adopted from Gerber-Morales's density lab.