Densities of Solids and Liquids: Mass/Volume Measurements

Objective: To acquaint the student with various measuring devices in the laboratory and to develop good techniques for making accurate measurements with them and to calculate the density of several materials from measured values of volume and mass. Use significant figures to report data.

Concept to be Tested: Density of a material is a characteristic property of a given substance and is a constant relationship of the ratio of mass per unit of volume.

Text References: McMurray and Fay: Chapter 1.5-1.11

Techniques: ***General Lab Procedures and Pipetting***

Introduction

During your study of chemistry you will be required to make observations and measurements and use these measurements in calculations. The most common measurements in the laboratory are mass and volume. This experiment is designed for you to determine the mass and volume of several liquids and solids and to use significant figures to report data in the calculation of density. You will also evaluate the precision and accuracy of a volumetric pipet, a graduated cylinder, and a flask or beaker. These three pieces of scientific glassware are commonly used in the laboratory; however they vary dramatically in their accuracy and precision.

Density is the ratio of mass to a unit of volume and is constant for a given substance (at a given temperature). Density is an intensive property of a substance. Intensive properties depend upon the identity of the material and are constant regardless of the source of this material. Mass and volume are extensive properties and change depending upon the quantity of material that is present.

$$\text{density} = \frac{\text{mass}}{\text{volume}} \qquad \text{or} \qquad D = \frac{M}{V}$$

Measurement of Mass

In the laboratory, you will determine the mass of your sample using an analytical balance. These instruments are calibrated each year and can be depended upon to give accurate and precise measurements for the mass of samples weighed upon them. Your instructor will demonstrate the proper usage of the analytical balance. You will notice that the last digit of the display will vary with time. This last digit will vary due to air currents, students leaning on the bench, and even to moisture evaporating from the surface of the object being weighed. You will need to wait to record your reading until the balance stabilizes. Realize that this last digit is the limit of significant figures available from the balance.

You will determine the actual volume of liquid in your container by determining its mass and then dividing this mass by the density of water at that temperature. The analytical balance is accurate and reasonably precise to four (4) decimal places. The density of water has been determined very accurately to at least 6 decimal places. Using the mass of your sample of water and the density of water at that temperature, you can accurately determine the volume of water in that sample to 4 significant figures. This is how you will “calibrate” your volumetric pipet.

> The accuracy and precision of any instrument is dependent upon the skill of the operator using the device. With appropriate care, these devices should provide reliable data. A careless user can offset the accuracy and precision of any instrument.

Density of Water at Various Temperatures

Temp (ºC)	Den (g/mL)	Temp (ºC)	Den (g/mL)
17.0	0.998774	24.0	0.997296
17.5	0.998686	24.5	0.997171
18.0	0.998595	25.0	0.997044
18.5	0.9985.1	25.5	0.996914
19.0	0.998405	26.0	0.996783
19.5	0.998305	26.5	0.996649
20.0	0.998203	27.0	0.996512
20.5	0.998099	27.5	0.996373
21.0	0.997992	28.0	0.996232
21.5	0.997882	28.5	0.996089
22.0	0.997770	29.0	0.995944
22.5	0.997655	29.5	0.995796
23.0	0.997538	30.0	0.995646
23.5	0.997418	30.5	0.995494

Measurements of Volume

Depending upon the task at hand, you have the option of using several different devices for measuring volume. For a regularly shaped solid, you might be able to measure the volume by taking measurements of its dimensions and then using a formula to calculate the volume of that cube, cylinder, or cone. If it is an irregularly shaped object – one with irregular features that prevent easy calculation of its volume, its volume could be indirectly measured by its displacement of water.

When determining the volume of a liquid, there are three general types of devices to choose from: burets, volumetric pipets, and volumetric flasks; graduated cylinders; and flasks and beakers. Each of these devices has a preferred use. The accuracy and precision of the measurement obtained varies depending upon the device chosen.

The most accurate and precise measurements of the volume of a liquid is made with burets, a volumetric flasks, and volumetric pipets. These provide highly accurate and precise measurements of specific volumes. These devices are calibrated at a specific temperature and their precision at a specified level is guaranteed. This accuracy and precision comes at a cost. Typically the more accurate and precise the device is, the higher its cost. As such these items are used only when the accuracy and precision is required.

A graduated cylinder is less accurate but reasonably precise device. These devices are commonly used to measure and deliver quantities of liquid where the accuracy is not as essential to the experiment. You will routinely use graduated cylinders in the laboratory. Graduated cylinders are much less expensive than the calibrated burets, volumetric flasks and pipets are. They also require much less skill to use correctly. The household equivalent of a graduated cylinder is a measuring cup with which most students have at least some limited experience.

> While graduated cylinders (and thermometers) may be a bit lacking in the accuracy department when it comes to measuring absolute values, they do a remarkably good job when measuring differences in two volumes (especially measuring displacement of volumes).

Laboratory beakers and flasks frequently have volume marking upon them. While this may imply that these can be used to measure volumes of liquids, they are neither accurate nor precise. Beakers and flasks are designed to contain liquids, make mixtures and solutions, and perhaps even to run reactions in. The volume listed on the side of the flask or beaker is an approximate volume that it will contain, the markings are primarily for estimations as to how much more can be safely contained. Unfortunately, because the general shape of a beaker tends to remind one of a measuring cup at home, many students will routinely use a beaker to measure volumes. These are the least expensive, the least accurate, and the least precise glassware you will use.

Experimental Procedure

A. Calibration of a Volumetric Pipet, a Graduated Cylinder, and a Beaker

You will obtain a small beaker, 200 mL beaker, a 10.0 mL volumetric pipet, a 10.0 mL graduated cylinder and a pipet pump. You will be calibrating the pipet, the graduated cylinder, and the small beaker. Pour approximately 100 mL of distilled water into the 200 mL beaker and determine its temperature to the nearest 0.5 °C using a laboratory thermometer. Record this temperature on your data sheet for use in the laboratory report. You will use the water from this beaker for your calibration experiments.

> The volumetric pipet, and the graduated cylinder you are using each list their volumes as 10.0 mL. In the experiment today you will be determining the ***actual*** volume that each actually delivers to the beaker when you measure out exactly 10.0 mL. You will also observe how your skill at using the devices in the lab impact the accuracy and precision of the data you obtain.

Calibration of Pipet
Determine the weight of the small beaker to 0.0001 g and record this reading. *Once you have weighed the beaker, you cannot touch it with your hands or you will transfer fingerprints to it and alter its weight.* Use a paper towel, tongs, or a piece of weighing paper to grab and carry the beaker while protecting it from your fingerprints. Accurately transfer exactly 10.0 mL of distilled water to the beaker using the volumetric pipet. (Read the Techniques section called Pipetting to review correct pipet use.) Allow the liquid to drain from the tip of the pipet (*do not blow it out*) and then touch the tip to the side of the beaker to drain the last bit of liquid from the tip of the buret (some liquid **should** be left in the pipet). Weigh the beaker and the 10 mL aliquot of water and record its weight to 0.0001 g. Pour out the water, dry the beaker, and repeat the procedure twice again for a total of 3 trials. (Weigh the beaker immediately before each trial because residual water left from the previous trial will cause its weight to change slightly.)

You will use the mass of the water and its density to accurately determine the actual volume of water delivered by your volumetric pipet at the current temperature.

Calibration of Graduated Cylinder
This portion of the experiment will follow the same procedure as you used for the calibration of the pipet. Determine the mass of a small dry beaker to 0.0001 g and record this weight. Use a graduated cylinder to exactly measure 10.0 mL of water. You may need to adjust the volume with a micropipette until the volume reads exactly 10.0 mL. Pour the water into your dry beaker and record its weight to 0.0001 g. Discard the water, dry the cylinder, and repeat the procedure twice again for a total of three trials. (As before, you will need to re-weigh the "dry" beaker before each trial since traces of water will significantly alter its mass.)

As before, you will use the mass of water and its density to accurately determine the volume of water present at this temperature.

Calibration of the Small Beaker
This portion of the experiment will follow the same procedure as you used for the calibration of the pipet and graduated cylinder. Determine the mass of a small dry beaker to 0.0001 g and record this weight. Use the graduations on the side of the beaker to exactly measure 10.0 mL of water. You may need to adjust the volume with a micropipette until the volume reads exactly 10.0 mL. Weigh the beaker with the water record its weight to 0.0001 g. Discard the water, dry the cylinder, and repeat the procedure twice again for a total of three trials. (As before, you will need to re-weigh the "dry" beaker before each trial since traces of water will significantly alter its mass.)

As before, you will use the mass of water and its density to accurately determine the volume of water present at this temperature.

You will compare your results to determine which of the three pieces of glassware (volumetric pipet, graduated cylinder, or beaker) is more accurate and more precise.

B. Determination of the Density of an Unknown Liquid

You will have just determined the actual volume delivered by your volumetric pipet (first part of this experiment), you will use this volume along with the mass of the unknown liquid to determine its density at the current laboratory temperature.

Dry the small beaker you used during the calibration of your volumetric pipet and graduated cylinder. Again weigh this beaker and record its weight to 0.0001 g. (Remember prevent fingerprints after you have determined this weight.) Now use the volumetric pipet that you have just calibrated to transfer “10.0 mL” of one of the unknown liquids to the beaker. Record the letter identifying your Unknown Liquid. Follow appropriate pipetting technique for this transfer. Determine the weight of the beaker and the unknown liquid to 0.0001 g and record this weight.

C. Determination of the Density of a Regularly Shaped Solid

Obtain a small regularly shaped object (one which has a volume that can easily be calculated from its measurements). Record the identity of the solid (e.g. brass colored cylinder, silver bar, etc.) Determine its mass to 0.0001 g and record this value. Determine its measurements and determine its volume by calculation. (vol. cylinder = $\pi r^2 h$; dia. = 2 r; vol. = $l \times w \times h$). Determine its density from its calculated volume.

D. Determination of the Density of an Irregularly Shaped Solid

Irregularly shaped objects (coins, nuts, bolts, etc.) have a shape that requires a much more detailed set of measurements and more complex calculations. However there is a trick used often by cooks, determination of volume by displacement (discovered by Archimedes just before he cried “Eureka” and became the earliest recorded streakers). Obtain a 25 to 50 mL-graduated cylinder and an irregularly shaped object from those available. Make certain that your object will fit inside the graduated cylinder. Carefully weigh and record the weight of your object (to 0.0001 g). Record its identity (e.g. penny, nail, bolt, etc.) Fill your graduated cylinder approximately half-full with water and adjust the volume until it exactly lines up with one of the graduation marks on your cylinder. Now tilt the graduated cylinder and carefully **slide** your object into the cylinder. Record the new volume of water. Determine the volume of your object by the amount of water that was ‘displaced.’ Use this and the mass of the irregular object to determine its density.

Safety

You must always wear departmentally approved eye protection when performing and experiment. **You cannot remove your safety goggles when you finish your experiment your fellow students are still performing their experiment!** You may remove your goggles when you **leave** the lab. All of the liquids used in today’s experiment may safely be disposed of down the drain. Much of this glassware is fragile and may shatter. Handle it with care. Dry and replace your glassware in the appropriate storage cabinet before you leave the laboratory.