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#09 Investigating the Relationship between the Mass of a Liquid and its Volume

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INTRODUCTION

Description

In this activity, the students fill a buret with one of five liquids, note the initial volume, and mass an empty beaker. They then deliver a portion of the liquid into the beaker, note the buret reading, and mass the beaker with the liquid. This process is repeated nine more times, adding the liquid to that which is already in the beaker. The data for all five liquids is then shared amongst all the students. Using a spreadsheet program, the students enter the data for each liquid, plot a graph of mass vs. volume for each liquid, and obtain the slope, y-intercept, and R^2 regression value for each line. The students then draw conclusions, answer questions, and form hypotheses based on the data and spreadsheet analysis.

Student Audience

This experiment is suitable for high school and first-year college chemistry classes. Students with little or no lab experience can successfully perform this experiment and, with guidance, carry out the analysis.

Goals for the Experiment/Activity

- Students will develop skills involved in making measurements of volume and mass of a liquid accurately, using a titration buret and a balance.
- Students will develop skills involved in analyzing data using a spreadsheet program.
- From the data and the computer analysis of the data, students will draw conclusions, derive equations, make predictions, and form hypotheses.

Recommended Placement in the Curriculum

This activity is a good way to introduce buret use and the use of a spreadsheet program. The skills learned in using the spreadsheet program can be practiced again and again with future experiments that involve the display of data through graphs. This experiment may also be used as a "first lab" activity, getting the students involved in using analysis equipment immediately.

STUDENT HANDOUT

Investigating the Relationship between the Mass of a Liquid and its Volume

Two very important quantities about matter used in chemistry are the mass and volume of the substance. **Mass** is the amount of matter present. It gives us some idea as to the total number of atoms or molecules present in the sample of the substance: the more atoms or molecules present in a sample of the substance, the more mass it will have. **Volume** is the amount of space taken up by the substance. Again, it gives us some idea as to the total number of atoms or molecules present in a sample. The more atoms or molecules present in a sample, the more volume the sample will occupy. Since atoms and molecules are extremely difficult to observe directly, it is important that we understand the relationship between mass and volume of a substance and how it relates to the number of atoms or molecules present in a sample.

In this experiment, you are going to investigate the relationship between mass and volume of various pure liquids and **solutions** (mixtures of one substance evenly dispersed in another substance). You will display your results graphically, with the aid of a computer spreadsheet program, and use the "shape" of the curve to determine the relationship. You will also learn to properly use two important pieces of analytical equipment, the balance and the buret.

Materials and Equipment

- one of the following liquids:
  - distilled water
  - ethyl alcohol
  - calcium chloride solution
  - 50/50 mixture of water/ethyl alcohol
  - isopropyl alcohol
- buret (preferably with Teflon stopcock)
- buret clamp
- ring stand
- 50-mL beaker
- balance

Safety

- Wear goggles and apron while you or others are conducting the investigation and are in the lab area. If protective gloves are available, wear them if you are working with a liquid other than distilled water.
- Ethyl alcohol and isopropyl alcohol are toxic. Avoid ingestion or inhalation of the fumes. They are also flammable. Be sure there are no open flames in the area.
- Place the used alcohol and the alcohol/water mixture in the containers designated. The distilled water and the calcium chloride solution may be safely poured down the drain when you are finished with the experiment.
- Wash your hands prior to leaving the lab.

Procedure

Part I: Preliminary Reading

Read the following section about the proper use of a buret and the section in the lab manual entitled “Graphs” prior to conducting this experiment.

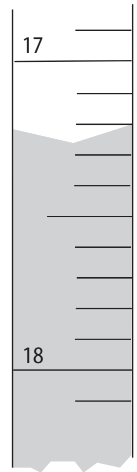
The Buret

A buret is a long, cylindrical, uniform-bore glass tube that has been calibrated. A Teflon stopcock is located at the end of the tube to control the outflow of solution. The buret allows one to deliver variable amounts of solution.

Before use, the buret should be rinsed with several portions of the solution to be used. (To do this, add a small portion of solution with the stopcock closed, remove the buret from its clamp and tip and rotate the buret so that the solution rinses the entire inside surface. Discard this rinse solution and repeat once or twice.) Two new factors arise in using the buret. First, it is necessary to remove air bubbles from the tip. This can usually be done by opening the stopcock fully and letting the flow of liquid wash out the bubble. The second is that the liquid level must be read very carefully, and this must be done twice.

To use the buret, fill it near the top and adjust the liquid level to be below the top mark. It is **not** necessary to set it to 0.00! After the tip is clear of bubbles, it is necessary to read the buret level. For almost all liquids (mercury is a well-known exception) the bottom portion of the meniscus can most reliably be located and this is the part you should use to determine the liquid level. The apparent level of the meniscus depends on the position of your eye and to avoid parallax errors, your eye needs to be on the same level as the meniscus. To help you find this correct eye position, calibration marks on pipets and volumetric flasks go completely around the circumference of the tube. Your eye is at the correct level when this circle appears to be a line. Burets have only a few calibration marks which go completely around the circumference, and you adjust the level of your eye to be in between these marks. Normally a buret is graduated in 0.1 mL steps, and you will need to estimate the reading to the nearest 0.01 mL by visually interpolating between the marks. This job is a little easier if you make a black mark on a small card or piece of paper and hold it behind the buret with the black mark just under the meniscus. If a calibration mark seems to flatten the bottom of the meniscus, the meniscus should be considered to be 0.01 mL below that calibration. Likewise, if the bottom just shows below the calibration the meniscus should be considered to be 0.02 mL below the mark.

Note carefully how the buret is calibrated. Normally zero is at the top and the buret reads down. It is easy to get confused on this point, and it is important to keep this straight. For example, the buret in the figure on the next page reads 17.24 mL (not 18.76 mL because you are reading from the top down).



Part II. Investigating the Relationship Between Mass and Volume of a Liquid

(Each table will be assigned one of the five liquids/solutions to investigate. The results of each table are to be shared with the groups at the other tables. Construct a table showing the identity of the substance and the masses and volumes determined.)

Rinse the buret and fill the buret with the liquid/solution assigned. Note and record the initial buret reading. Using a centigram balance, mass and record a clean, dry, 50-mL beaker. Drain a few milliliters of the liquid into the beaker, note the new buret reading, and mass the beaker with the liquid. Drain a few more milliliters into the buret, again note the buret reading and the mass of the beaker with the liquid. Repeat several more times so that you have 10 sets of measurements. By subtracting the mass of the empty beaker from the mass of the beaker with liquid calculate the mass of the liquid for each measurement. By subtracting the initial buret reading from the buret reading after adding some liquid calculate the volume of the liquid for each measurement. On the board write the name of the substance you used and the masses with their corresponding volumes. Clean up. (The buret should be drained, rinsed several times with distilled water, and turned upside down in the clamp with the stopcock open.)

Analysis of Data

Support each of your answers to the following questions with observations made in this investigation.

1. In general, as the volume of the substance increased what happened to the mass of that substance?
2. Construct a graph of mass vs. volume for each substance. Plot each substance on the same graph. Be sure to identify each substance on the graph. Remember, you controlled the volume of the liquid (independent variable) and then measured the mass of that volume (dependent variable). If you use the computer to make your graph you want a regression line drawn and the statistics to be displayed.
3. Is it a reasonable assumption that for this graph one point will be the origin (0,0)? Explain your answer.
4. Based on the general "shape" of the curves drawn on the graph, what type of relationship exists between a substance's mass and its volume?

5. By choosing two points on each line (not data points) calculate the slope of each line. Be sure to include units of measure. (If you used the computer, the "m" value given is the slope.) Write the equation for each line using "mass" in place of the y variable and "volume" in place of the x variable.
6. What would be the approximate mass of 200 mL of each of these liquids? What would be the approximate volume of 200 g of each of these liquids? (Be sure to show your work.)
7. The slope represents a physical constant known as **density**. Density is defined as the mass per unit volume of a substance. Rank the five solutions in order of **increasing** density.
8. Compare the density of pure water to that of the calcium chloride solution. What happened to the density when calcium chloride was dissolved in the water?
9. Compare the density of pure water, pure ethyl alcohol, and the 50/50 mixture of the two. Is the density of the mixture the simple average of the two? Make a hypothesis as to why or why not.
10. Write a general equation relating mass of a substance to its volume and density.
11. The measures we took were all done at room temperature. It is important when determining densities that the temperature be noted. How would changing the temperature of a sample of substance affect its density? Explain.
12. If a plot of the volume of liquid versus the mass of beaker with liquid was made how would the graph "appear?" What would the slope represent? What would the y-intercept represent? Test your answers by making a graph using the data <u>your</u> group collected.
13. What are potential sources of error in this experiment and how would these errors affect the density value?
14. (optional) Determine the 95% confidence limit for the density value.

INVESTIGATION #1 DATA

Substance Tested:

GROUP 1:

Mass of empty beaker:_________________________	
Mass of beaker and liquid (g)	Volume of liquid in beaker (mL)

GROUP 2:

Mass of empty beaker:_________________________	
Mass of beaker and liquid (g)	Volume of liquid in beaker (mL)

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INSTRUCTOR NOTES

Investigating the Relationship Between Mass of a Liquid and its Volume

In this investigation, students learn how to use a buret and a balance to obtain measures of volume and mass of a liquid. From these measures they will draw conclusions, supporting their conclusions with their results. They will generate mass-volume graphs to establish a relationship between the mass and volume of a liquid and to generate equations for the lines. From the equations they will make predictions. Hypotheses will be made about several aspects of their observations. The lab produces accurate measures of the densities of the liquids, but that is not the primary goal of this investigation.

Time Required

15 minutes for pre-lab discussion
45 minutes for set-up, performing the experiment, and sharing data with other groups
90 minutes to perform computer analysis
45 minutes for discussion of analysis

Students who are not familiar with burets may require additional time during the pre-lab discussion and the experiment.

Group Size

20-30 students divided into pairs: The pairs of students should be distributed so that all five liquids can be tested.

Materials Needed

(class of 30, working in pairs)

- 15 50-mL titration burets (25-mL burets will also work)
- 15 ring stands
- 15 buret clamps
- 15 centigram balances (ideally, at least 5 with three groups per balance)
- 15 50-mL beakers
- 30 other small beakers (used to fill buret and to collect waste liquid)
- 200 mL of each of the following:
    - distilled water
    - ethyl alcohol
    - isopropyl alcohol
    - 50/50 mixture of ethyl alcohol and water (see below)
    - saturated calcium chloride solution (see below)

To prepare the 50/50 mixture of ethyl alcohol and water, measure 100 mL of each in **separate** containers and then combine together.

To prepare the saturated calcium chloride solution, add solid calcium chloride to 200 mL of distilled water with stirring until no more dissolves. Filter the solution into a clean storage bottle.

Safety, Handling, and Disposal

Students should wear goggles and aprons while conducting this investigation and while they are in the lab area. Students working with the calcium chloride solution and the alcohols may wish to wear protective gloves, if available.

The alcohols and the alcohol mixture are flammable and there should be no open flames in the area. Students should also avoid ingestion of any of the chemicals.

Students should avoid contact with the calcium chloride solution.

The used distilled water and calcium chloride solution may be disposed of in the sink.

Have separate containers for the used alcohols and alcohol mixture for students to put their waste. If uncontaminated, the waste can be reused in this experiment or used for other applications where purity is not required. Dispose of used reagents according to local ordinances.

Students should wash their hands prior to leaving the lab.

Points to Cover in the Pre-Lab Discussion

Model how to rinse and fill the buret. Review how to properly read the buret and to record the measurements. Model how the data is to be collected and recorded. Stress the importance of taking their time and obtaining accurate measurements; the entire class will be using these measurements. The students are to determine what volumes of liquid to drain into the beaker and mass. Remind them that the buret only holds 50 mL and that anything more than that can not be measured accurately. Remind students to wear goggles and aprons and to avoid contact with any of the chemicals. Go over disposal procedures for waste chemicals.

Procedural Tips and Suggestions

Prior to class, have the solutions to be tested in labeled bottles and placed on the lab counters. Each lab counter tests one of the five liquids. Have a balance at each lab counter. Depending on your layout you may wish to get out the other equipment and have it ready for the students to use when they come to class to save time. Also have labeled waste containers for the used alcohols.

After the students have collected their data, have them complete a sheet with the entire table's results. Gather up these sheets and make photocopies for each student.

You may want to discuss the statistical significance of a least squares linear regression fit of the data points.

Plausible Answers to the Analysis Questions

1. As the volume of the liquid placed in the beaker increases, the mass increases. For example, with 4.00 mL of ethyl alcohol the mass was 3.20 g and with 12.00 mL the mass was 9.81 g. A similar pattern occurs for all the liquids tested. (Numbers will vary.)
2. Sample graph is attached. See later discussion for generation of graphs using a spreadsheet program.

3. It is reasonable that one point be at the origin (0,0). This represents that there is no liquid in the beaker. If there is no liquid, there is no mass or volume. (This is an important point to stress. Whenever graphs of “real world” information are made, one must consider whether or not it is logical to have a point at the origin. One can also do the linear regression without the origin and see how close the “best” line intercepts the origin.)

4. The mass vs. volume graph is a straight line through the origin. This corresponds to that of a direct relationship, therefore, the mass of a liquid is directly proportional to its volume.

5. The equations for the lines are as follows:
   ethyl alcohol: mass = (0.808 g/mL)volume
   distilled water: mass = (0.997 g/mL)volume
   calcium chloride: mass = (1.20 g/mL)volume
   isopropanol: mass = (0.775 g/mL)volume
   50:50 mixture of ethanol and water: mass = (0.925 g/mL)volume

   (The numbers should be the density of the solutions but will vary because they are student generated.)

6. Answers depend on the value of the slope:
   mass = (0.808 g/mL)(200 mL) = 162 g
   200 g = (0.808 g/mL)volume
   volume = 248 mL

   (Illustrate and encourage proper use of significant figures.)

7. The solutions, ranked in order of increasing density, are as follows: isopropanol (0.775 g/mL), ethyl alcohol (0.808 g/mL), 50/50 mixture of ethanol and water (0.925 g/mL), distilled water (0.997 g/mL), and calcium chloride (1.20 g/mL). (Numbers will vary, but the order should be the same.)

8. The density of calcium chloride solution (1.20 g/mL) is greater than that of distilled water (0.997 g/mL). Adding calcium chloride to water increases the density. You can demonstrate why by noting the original mass and volume of water and then massing the calcium chloride as you add it to the water. Note the final volume of the solution. The mass increases to a greater degree than the volume, thus more mass in relatively the same amount of space yielding a greater density.

9. The density of the 50/50 mixture of ethanol and water (0.925 g/mL) is less than that of distilled water (0.997 g/mL) but more than that of pure ethanol (0.808 g/mL). It is also more than the simple average of the densities of pure water and ethanol (0.903 g/mL). This is because when combining equal volumes of the two liquids the molecules attract one another and draw closer together, reducing the volume, resulting in an increase in the density (same mass but smaller volume). This can be easily demonstrated. Obtain a glass tube about 3/4 inch in diameter and about 3 feet long. Stopper one end of the glass tube with a rubber stopper. Fill the tube half-way with water. Carefully layer ethanol on top of the water until the tube is completely full. Allow just enough room for another stopper to be inserted snugly. Note the amount of air left in the tube. Placing your hands on both stoppers, turn the tube over several times, allowing the alcohol to mix with the water. Note that the size of the air bubble gets larger and larger. You are not generating vapor. A slight vacuum is created as the molecules move closer together reducing the volume. Even though we cannot see them there are spaces between the molecules in a liquid.

10. The equation relating mass of a substance to its volume and density is:
    Mass = Density x Volume or $m = rV$.

11. Changing the temperature results in a change in the density. Heating usually causes the material to expand, raising the volume and lowering the density. Cooling usually has the opposite effect. Changes in state may also occur. Solids are usually more dense than their liquid form (ice is an exception) and gases are much less dense than either their liquid or solid form.

12. The graph would appear as a straight line but it would not go through the origin. The y-intercept would represent the mass of the empty beaker and the slope would still represent the density of the liquid. (See attached student work.)

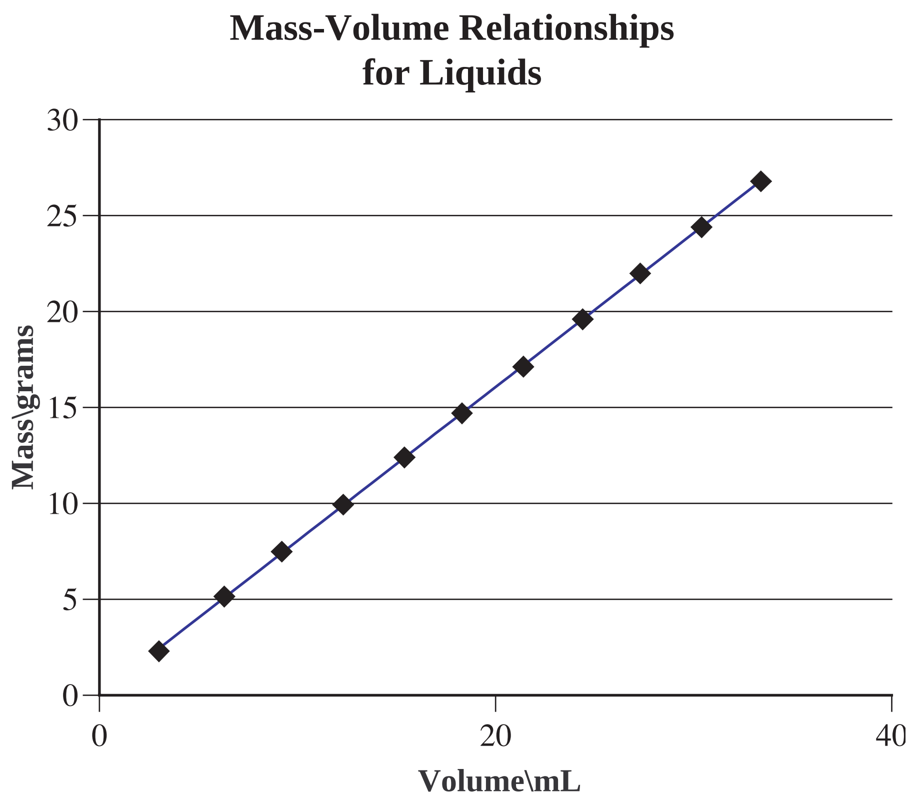
13. Potential sources of error include the following:

- Misreading the liquid level of the buret: This may give higher or lower volume measurements, depending on the way it is misread, which would result in lower or higher densities. Of course, there is an inherent error of ±0.02 mL for each reading.
- Since the buret is a "To Deliver" (TD) volumetric device, if the tip isn't filled with liquid, the actual volume delivered will be less than what is read, leading to a lower calculated density.
- If the buret is not clean and dry and the buret is not properly rinsed, the liquid may be contaminated and the resulting density will be higher or lower depending on the density of the contaminating liquid.

14. There are two ways to determine the 95% confidence limit for the density. One is to calculate the mean and standard deviation (S.D.) of the individual student's densities. The 95% confidence limits are the mean ±2 x S.D. The other way is to report the 95% confidence limits for the slope of the least squares straight line fit to the data. These values are given in the regression statistics output using the Excel software. It might be of interest to compare the two ways.

Sample Student Work

Ethyl Alcohol			
Mass B & L	Bur. Rdg.	Volume L	Mass L
31.46	3.9	3.0	2.29
33.75	6.9	6.3	5.14
36.60	10.2	9.2	7.48
38.94	13.1	12.3	9.93
41.39	16.2	15.4	12.39
43.85	19.3	18.3	14.69
46.15	22.2	21.4	17.12
48.58	25.3	24.4	19.59
51.05	28.3	27.3	21.98
53.44	31.2	30.4	24.39
55.85	34.3	33.4	26.78
58.24	37.3	-3.9	-31.46
Regress 0.804487	Slope 0.61793	Intercept 9.162662	



Extensions

Compare student densities with literature values and discuss possible reasons for discrepancies.

Resources

This lab was based on an experiment used at Rice University, Houston, Texas, in their Chemistry 105 course. Philip R. Brooks, Robert F. Curl, and R. Bruce Weisman, *Introductory Quantitative Chemistry*, 1992, pages 16-19.