Experiment 2:
Mass vs. Volume Relationships

In this exercise, you will graphically represent the relationship between mass and volume. The graphical relationship will be used to predict the volume of an unknown sample based on its mass.

Prelaboratory Assignment

The pre-lab assignment for this experiment is a TRQ on significant digits. You must complete the quiz TWICE in order to receive full credit. You must wait 6 hours between the two sets.

You must also complete the safety TRQ in Chem21 before your lab meeting. You will not be allowed to attend lab until this quiz has been completed.

2.1 Introduction

A graph is a diagram used to show a numerical relationship between two variables or measured quantities. Typically the vertical axis is referred to as the $y$-axis and the horizontal axis is called the $x$-axis. The relationship between the variable plotted on the $y$-axis and the variable plotted on the $x$-axis can be determined by the shape of the graph.

2.1.1 Independent Relationship

The first type of relationship we will discuss is an independent relationship. The graph in Figure 2.1 shows how the speed (velocity) of a car changes as a function of time. The data points given are approximately in a horizontal line, indicating that the variable on the $y$-axis (velocity) has no relationship to (is independent of) the variable on the $x$-axis (time). In other words, the car traveled approximately 60 mph for the entire 10 minutes, and its speed did not depend on how long the car was traveling. Notice that the trendline drawn on the graph does not go through every data point. Instead it represents a general trend in the data.

![Car Velocity vs. Time](image)

Figure 2.1: Car velocity vs. time. This graph shows an independent relationship between the car’s velocity and the time it has been traveling.
2.1.2 Nonlinear Relationship

Sometimes a graph will not have a straight trendline. In this instance, we say the relationship is non-linear. For example, Figure 2.2 is a plot of the temperature of hot water cooling as a function of time which follows a non-linear relationship.

![Cooling Water Curve](image)

Figure 2.2: Water cooling over time. This graph shows that the temperature of water is NOT linearly related to the amount of time it's allowed to cool.

2.1.3 Linear Relationship

If two variables are plotted against each other and the graph is a straight line that either increases or decreases, the relationship between the variables is said to be a direct proportionality or linear. The graph in Figure 2.3 shows the distance that a man walked versus time. Notice that an increasing straight trendline can be drawn through the data points. Therefore, we can say that distance in miles is directly proportional to time in minutes. Again notice that the line drawn does not go through all of the data points but rather represents a general trend in the data.

![Distanced Walked vs. Time](image)

Figure 2.3: Walked distance vs. Time. This graph shows that the distance you walk depends directly (or linearly) on how much time you walk.
If two variables are directly proportional to each other, then as one increases, the other increases. Since the distance traveled increases as the amount of time he walks increases, then we say that distance \( d \) is directly proportional to time \( t \). This direct proportionality is written mathematically as

\[
d \propto t
\]  

(2.1)

where the \( \propto \) symbol means "proportional to."

A direct proportionality can be written mathematically as a linear expression. For the proportionality in Equation 2.1, the mathematical equation relating distance and time is

\[
d = mt + b
\]  

(2.2)

where \( m \) is the slope of the trendline that most closely approximates the data points, and \( b \) is the \( y \)-intercept, the point where the straight line crosses the \( y \)-axis. In Figure 2.3, a computer was used to determine values for the slope and the intercept. In our example, \( b = 0 \) mi. and \( m = 0.5 \) mph so Equation 2.2 may be rewritten as

\[
d = (0.5 \text{ mph}) t
\]  

(2.3)

Notice that the equation includes units for the slope. The units for any slope are units for the \( y \)-axis divided by units for the \( x \)-axis, miles per hour in this case.

It’s important to realize that the slope is not just a number. It has a physical meaning. If you rearrange Equation 2.3 to solve for the slope, you get the expression

\[
m = \frac{d}{t} = 0.5 \text{ mph}
\]  

(2.4)

You should recognize that \( d/t \) is the rate or the speed that the man is walking. Since \( m = 0.5 \) mph, the man is walking a half mile every hour.

### 2.2 Mass vs. Volume

Before beginning your experiment, set up your lab notebook with a title, objective, procedure, and observations as described in the Lab Guide for Experiment 1.

#### 2.2.1 Obtain Mass and Volume Data for Graph

Record all your measurements in a table in your lab notebook. Remember to put units in the column headings and record the correct number of significant figures! (Column headings should be as follows: Trial Number, Mass \( (m) \), Initial Volume \( (V_i) \), Final Volume \( (V_f) \), and BB Volume \( (V_{BB}) \).)

- Obtain a 25 mL graduated cylinder, and add 10 - 15 mL of water to it. Record the EXACT initial volume, \( V_i \), in your notebook. Don’t forget to read from the bottom of the meniscus. Watch sigfigs!!
• Measure the mass of 7 DRY BBs as follows:
  o Place an empty plastic weigh boat on the balance pan.
  o Press the “TARE” or ZERO” button on the balance.
  o Remove the weigh boat from the balance.
  o Add your sample of BBs to the weigh boat.
  o Return the weigh boat (which now contains your BBs) to the balance pan.
  o Record ALL of the digits on the display (even if the last one is a zero) directly
    into your lab notebook.

• To measure the volume of the BBs, you will observe how much water they
  displace. Carefully transfer all of the BBs from the weigh boat into your graduated
  cylinder. Record the final volume of water for trial 1, \( V_f \), in your notebook.

• Retrieve the BBs from the graduated cylinder by pouring the contents into a funnel
  lined with filter paper. DO NOT POUR BBs DOWN THE DRAIN PLEASE!!

• For trial 2 find the volume and mass of 18 DRY BBs using the same procedure as
  trial 1.

• Repeat the process 3 more times using 30, 50 and 65 DRY BBs.

Now, use a computer to prepare a graph of mass on the y-axis vs. volume of BBs on
the x-axis. Add a trendline, showing the equation on the graph. For this experiment, the
y-intercept should be set equal to zero. By clicking twice on the equation, you can type in
appropriate variables (instead of x an y) and add units to your slope. Be sure to include a
title, axis labels and units on your graph. Sketch your graph in your lab notebook and
record the equation for the line.

In your lab notebook, answer the following question using a complete sentence.
Which physical property of a substance corresponds to the slope of your graph? (Hint:
Look at your units for the slope.)

2.2.2 Use Graph to Calculate Volume from Mass

You should now be able to determine the volume of a sample of BBs just by
measuring its mass.

Obtain a random sample of dry BBs. DO NOT COUNT THE NUMBER OF BBs!!
Measure the mass of this sample.

Use the equation for the line on your graph to calculate the volume of this sample of
BBs. This will be referred to as \( V_{calculated} \).

Next, measure the volume of this sample of BBs in the same way you measured the
volumes of the previous samples. Record this measured volume, \( V_{measured} \).

In your notebook, quantitatively compare the calculated and measured volumes by
calculating the percent difference (remember NOT to hit the percent key on your
calculator!):

\[
\frac{|V_{measured} - V_{calculated}|}{V_{calculated}} \times 100 = \text{% difference}
\]
2.3 Wrap-Up

2.3.1 Hazardous Waste

There is no hazardous waste generated in this lab. You can pour the water you used down the drain.

2.3.2 Clean-up

Make sure all of your glassware is clean and dry. Wipe down your work area with a wet paper towel and then dry the area. Have your lab instructor check your station and sign your lab notebook.

BEFORE YOU LEAVE LAB: Tear out the carbon-copy pages of your notebook. Make sure your name, your partner’s name and your section number are on each page. Staple these pages together and turn them in to your instructor.

2.3.3 Work Assignment

Enter all of your data, calculations and answers to questions in the Experiment 2 Assignment in Chem21. You will need to refer to your notebook for this. The Assignment is due 48 hours after your lab ends.