3. Graphing Mass versus Volume to Determine Density

Driving Questions

Graphs are more than just dots on a piece of paper. Properly constructed graphs can reveal hidden relationships between data that a list of numbers could not provide. For example, plotting mass and volume data for a particular substance leads to a mathematical relationship tied to a material's density that can only be discovered using a graph. How can a graph of mass versus volume reveal the density of a substance?

Background

Graphing data is an important skill that makes finding relationships between data easier. The relationship between data can be linear or non-linear. In a linear relationship as one variable increases the other variable increases or decreases at a constant rate and looks like a straight line. In a non-linear relationship as one variable increases the other variable increases or decreases at a changing rate and looks curved. How one variable responds to the other depends upon their influences.

If a variable changes value as a result of a change in a different variable, it is said to be a dependent variable. If a variable is free to change on its own, without influence from other factors, it is said to be an independent variable. Independent variables are usually increased or decreased by the scientist performing the experiment. In a controlled experiment, only one independent variable is adjusted and studied at a time.

Independent variables are graphed on the x-axis (horizontal axis), while dependent variables are graphed on the y-axis (vertical axis). These axes are labeled with a short description of their values and given proper units of measure. The scale of each axis is chosen to allow the data to be spread over the entire graph. The title of the graph is a description of the purpose of the comparison of the two variables.

After the data are plotted on the graph, a mathematical relationship is found between the variables. Data often shows a linear relationship and is fit using the equation of a straight line: $y = mx + b$, where m is the slope (rise over run) and b is the y-intercept (where the line crosses the y-axis at $x = 0$). Linear relationships that have a y-intercept of zero are called directly proportional relationships ($y = mx$). In the experiment, the slope and the y-intercept often provide specific information about the system.

Materials and Equipment

For each student or group:

- Four different-sized rectangular aluminum pieces (part of PASCO's Discover Density Set)
- Four different-sized rectangular plastic pieces of the same composition (part of PASCO's Discover Density Set)
- Balance (2 to 3 per class)
- Metric ruler (or calipers)

Safety

Follow all standard laboratory procedures.

Sequencing Challenge

The steps below are part of the Procedure for this lab activity. They are not in the right order. Determine the proper order and write numbers in the circles that put the steps in the correct sequence.

○	○	○	○	○
Use the slope of the best fit line to determine the density of the substance making up the set of objects.	Plot Mass versus Volume on a graph.	After measuring length, width, and height of each object, measure the mass of each object in the set.	Measure the length, width, and height of the objects in a set.	Once all the data has been collected, calculate the volume of the objects in the set.

Procedure

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

Collect Data

Part 1 – Aluminum Objects

1. ☐ Look at Table 1 below. Which values can you measure directly, and which values will you need to calculate?

_____

2. ☐ Predict the effect of volume on the mass of aluminum metal.

_____

3. ☐ Measure the length, width, height, and mass of the four aluminum metal pieces. Be sure to record the values using the correct number of significant figures in Table 1 below.

Table 1: Aluminum objects

Aluminum Object	Length (cm)	Width (cm)	Height (cm)	Mass (g)	Volume (cm^3)
1					
2					
3					
4					

4. ☐ Calculate the volume for each of the four aluminum objects and enter them in Table 1 above.

_____

_____

Part 2 – Plastic Objects

5. ☐ Predict the effect of volume on the mass of the plastic objects.

_____

_____

6. ☐ Measure the length, width, height, and mass of the four plastic objects. Be sure to record the values using the correct number of significant figures in Table 2 below.

Table 2: Plastic objects

Plastic Object	Length (cm)	Width (cm)	Height (cm)	Mass (g)	Volume (cm^3)
1					
2					
3					
4					

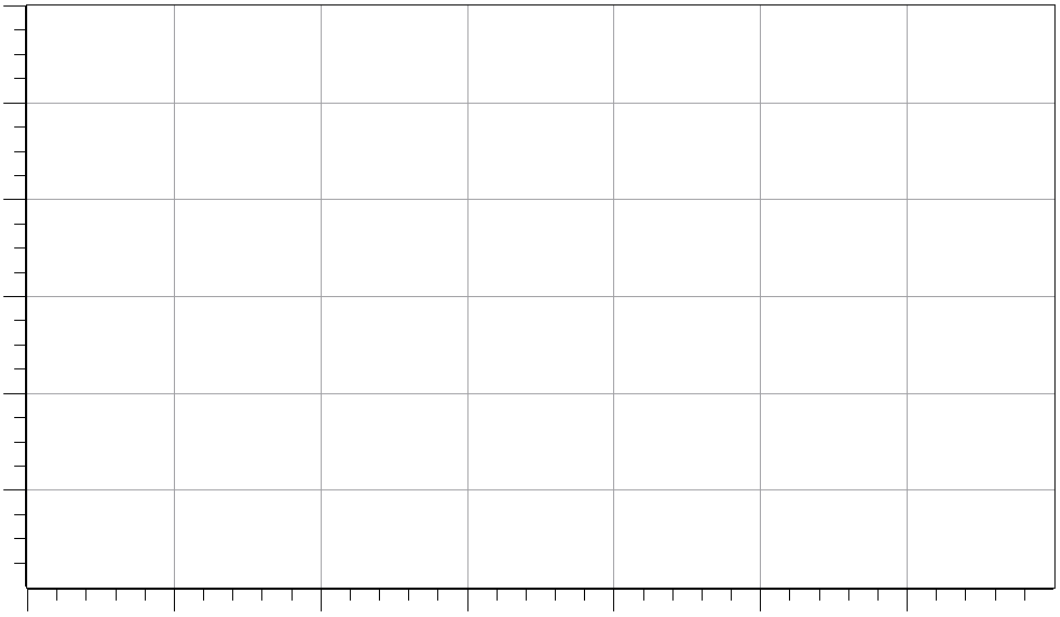
7. ☐ Calculate the volumes for each of the four plastic objects and enter the values in the Table 2 above.

8. ☐ Clean up your lab station according to the teacher's instructions.

Data Analysis

Part 1 – Aluminum Objects

1. ☐ Plot Mass (g) versus Volume (cm^3). Consider the volume to be the independent variable (graphed on the x-axis) and the mass to be the dependent variable (graphed on the y-axis). Label the overall graph, the x-axis, the y-axis, and include units on the axes.



2. ☐ Is the relationship between mass and volume linear or non-linear? How do you know?

3. ☐ On the graph, add a line of best fit. In this case, the line of best fit should be a straight line. The data points might or might not fall exactly on the line, but there should be approximately the same number of data points above the line as below the line.

4. ☐ Find the equation of the line of best fit $y = mx + b$ by determining the slope m of the line. Note that the y-intercept b should be zero because when the volume x equals zero, the mass y is also zero. The slope m of the line is found by marking two points on the line, then dividing the difference in y-coordinates (called the rise) by the difference in x-coordinates (the run).

5. ☐ Calculate the individual densities of each aluminum object and the average value for the density of aluminum. Record the densities in Table 3 below.

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

Table 3: Density of aluminum objects

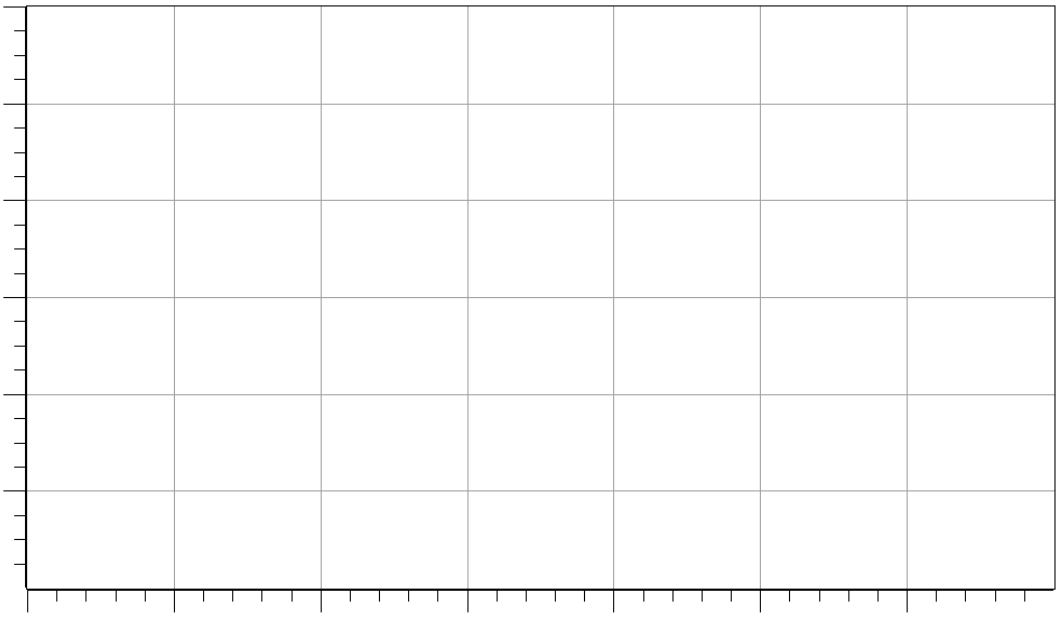
Aluminum Object	**Mass (g)**	**Volume (cm^3)**	**Density (g/cm^3)**
1			
2			
3			
4			
Average (g/cm^3)			

6. ☐ How does the slope of the line compare to the average density calculated from the individual densities above?

7. ☐ The accepted value for the density of aluminum is 2.70 g/cm^3. How does this compare with your experimentally determined value?

Part 2 – Plastic Objects

8. ☐ Plot Mass (g) versus Volume (cm^3) for the plastic objects on the graph below. Label the overall graph, the x-axis, the y-axis, and include units on the axes.



9. ☐ Is the relationship between mass and volume for plastic object linear or non-linear? How do you know?

_____

_____

10. ☐ On the graph, add a line of best fit. In this case, the line of best fit should be a straight line. The data points might or might not fall exactly on the line, but there should be approximately the same number of data points above the line as below the line.

11. ☐ Find the equation of the line of best fit $y = mx + b$ by determining the slope m of the line. Note that the y-intercept b should be zero because when the volume x equals zero, the mass y is also zero. The slope m of the line is found by marking two points on the line, then dividing the difference in y coordinates (called the rise) by the difference in x-coordinates (the run).

_____

_____

_____

12. ☐ Calculate the individual densities of each plastic object and the average value for the density of aluminum. Record the densities in Table 4 below.

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

Table 4: Density of plastic objects

Plastic Object	Mass (g)	Volume (cm^3)	Density (g/cm^3)
1			
2			
3			
4			
Average (g/cm^3)			

13. ☐ How does the slope of the line compare to the average density calculated from the individual densities above?

_____

14. ☐ The accepted value for the density of this particular type of plastic (polyvinyl chloride) is 1.39 g/cm^3. How does this compare with your experimentally determined value?

_____

_____

_____

Analysis Questions

1. **Explain the relationship between mass and volume (directly proportional, linear, or non-linear). Are mass and volume always related this way?**

_____

_____

2. **Identify the dependent and independent variables in this experiment.**

3. **If the axes upon which the variables are plotted were accidentally switched, would the slope of the line still equal the substance's density? How would you know?**

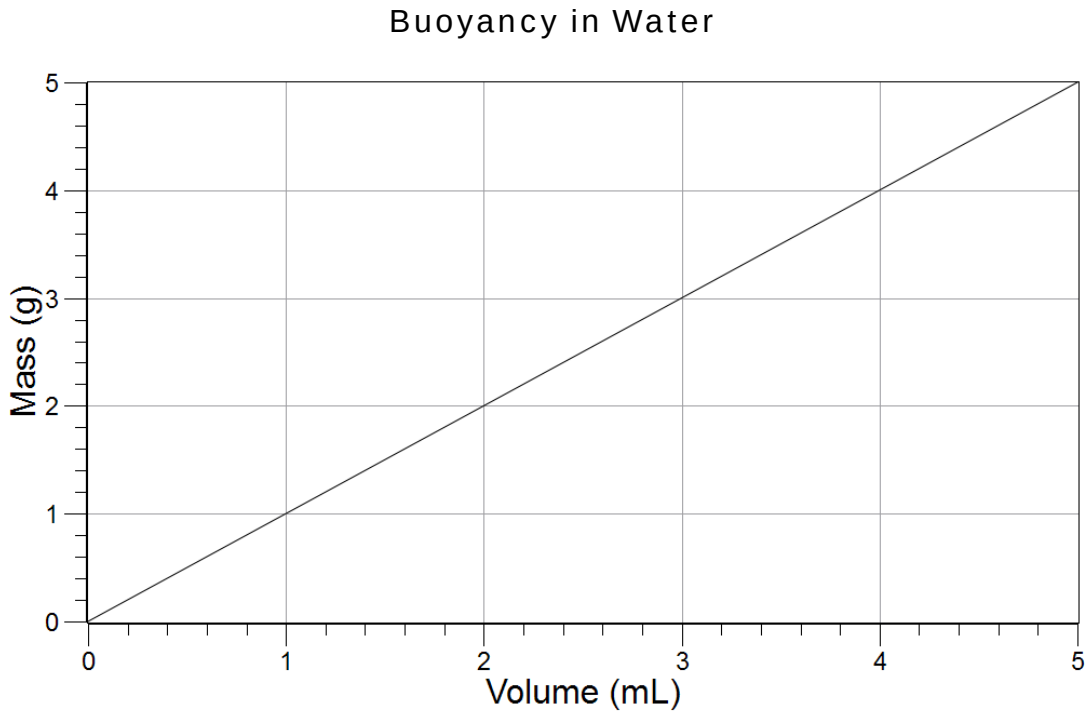
4. **The y-intercept is not included in the formula to calculate density. Explain.**

5. **The values for the slopes of both the aluminum and the plastic were different. Explain how slope allows for the comparison of the densities of different materials.**

Synthesis Questions

Use available resources to help you answer the following questions.

1. **Below is a graph with the density of water (ρ_{water} = 1.0 g/mL) plotted. Label the area where the data points representing objects that sink will be found. Also, label the area for objects that will float. Give an example for each.**



2. **A beaker of water is placed on a hot plate and allowed to boil. After 10 minutes of boiling, the volume in the beaker was measured every five minutes over the course of 30 minutes to produce the data shown in Table 5 below.**

Table 5: Volume of water as water is allowed to boil

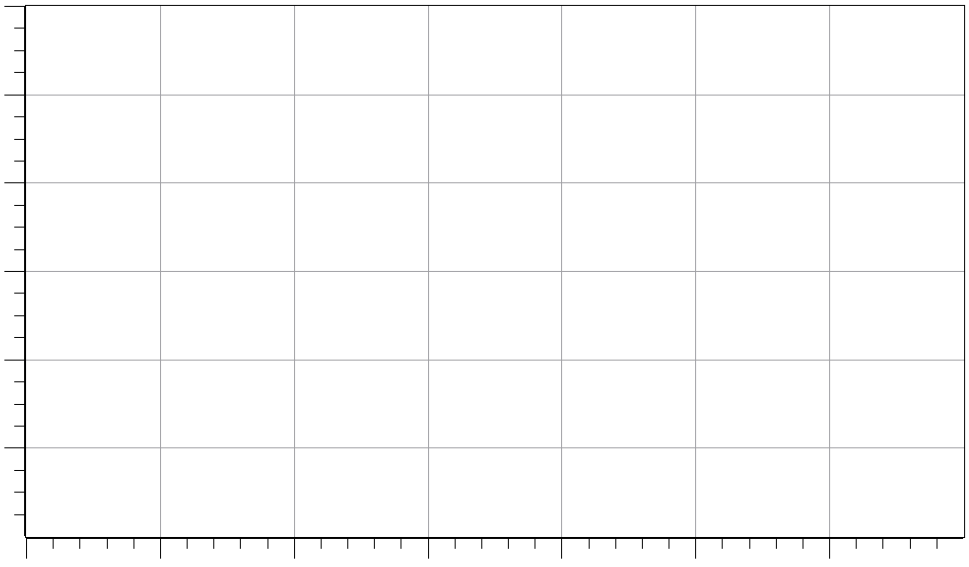
Time (minutes)	Volume (mL)
10	595
15	465
20	335
25	205
30	75

a. **Identify the independent and dependent variables. Explain each choice.**

_____

_____

b. **Use the grid below to construct a graph of the data. Be sure to descriptively title the figure and properly label each axis. Include a straight line to show the line of best fit.**



c. **Give the equation for the line of best fit.**

d. **Describe the relationship that exists between the volume of water in the beaker and the time the water is allowed to boil. Hint is there a directly proportional, linear, or non-linear relationship?**

e. **What does the value of the slope mean in this particular experiment? Use the units on the slope to help identify its meaning.**

f. **What is the value for the y-intercept? What does the value of the y-intercept mean in this particular experiment?**

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. **Which statement about mass and volume data is always true?**

   A. They are directly related
   B. They are indirectly related
   C. They are both dependent variables
   D. They are both independent variables

2. **A plot of mass and volume data that produces a steep slope is from a substance**

   A. With a density greater than one with a shallow slope
   B. With a density less than one with a shallow slope
   C. That sinks in water
   D. That floats in water

3. **A plot of mass and volume data that produces a slope less than 1**

   A. Is very dense
   B. Is not dense
   C. Floats in water
   D. Sinks in water

4. **The y-intercept is:**

   A. The change in y-values over the change in x-values
   B. The change in x-values over the change in y-values
   C. The y-value at the point where x = 0
   D. The x-value at the point where y = 0

5. **The slope is:**

   A. The change in y-values over the change in x-values
   B. The change in x-values over the change in y-values
   C. The y-value at the point where x = 0
   D. The x-value at the point where y = 0

Key Term Challenge

Fill in the blanks from the list of words in the Key Term Challenge Word Bank.

1. The purpose of an _____ is to produce data that will prove or disprove a hypothesis. A good experiment is one that studies the most relevant variables. _____ variables are those whose conditions are set by the experimenter. _____ variables are those whose values depend upon other variables. Variables that change in value at a constant rate and can be fit using a straight line are said to have a _____ relationship. Linear relationships that do not have a y-intercept (and therefore pass through the origin) are called _____ relationships. Variables that change at varying rates and are fit using a curved line are _____. In _____ experiments, only one independent variable is changed at a time.

2. A good graph has a title that is a description of the _____ of the experiment. The _____ of each axis contain the data's proper units of measure. The _____ variable is plotted on the x-axis and the _____ variable is plotted on the y-axis. The _____ of each axis depends on the range of data, and is set such that the data fills the entire graph. After the data is plotted, a line is added that mathematically relates the variables to each other. The equation of a straight line is in the form of _____. The _____ of the line *m* is calculated by finding the change in the _____ over the change in the _____.

Key Term Challenge Word Bank

Paragraph 1

controlled
dependent
directly proportional
experiment
independent
linear
non-linear
short
variable

Paragraph 2

dependent
independent
labels
length
purpose
scale
slope
units
x-values
y = mx + b
y-intercept
y-values