Experiment 4 - Graphing

In many instances the goal of making measurements is to discover or study the relationship that exists between two variables. The pressure and the volume of a gas, the volume and the temperature of a substance, or the concentration of a colored solution and the intensity of that color are examples of sets of variables that are related. As one variable changes, so does the other.

A graph is a pictorial representation of the relationship between two variables. When making a graph, the first step is to organize the data into a data table. The next step is to plot the data points and draw a line through the points. You might then want to predict values of the variables from the graph.

Data Table

The data that you measure must be organized into a neat table. It must include a descriptive title, and each row or column must have a heading indicating the quantity being measured and the units of each type of measurement. It can be arranged horizontally or vertically. Here is an example of a data table:

Heating of Compound X											
Time, min.	0	1	2	3	4	5	6	7	8	9	10
Temp, °C	20	21	23	27	35	45	61	69	71	73	74

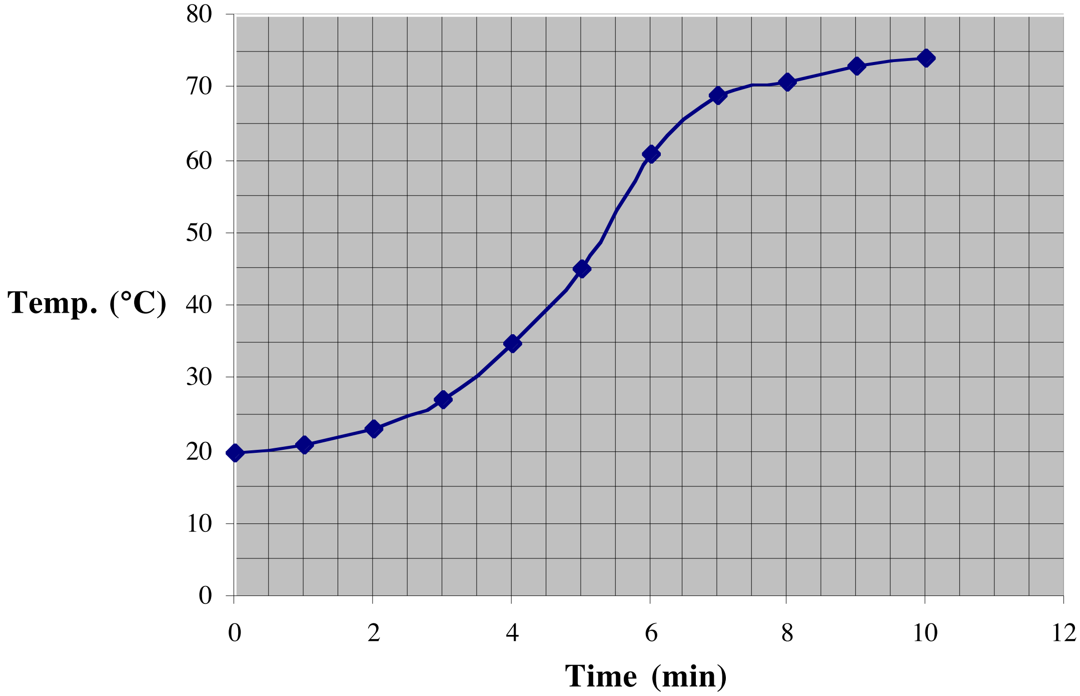
Notice the title, headings, and units.

In the experiment that generated the above data table, the temperature of substance X was taken at eleven different times. Each of the eleven sets of data corresponds to one point on a graph that we could make from this data. Each can be thought of as an ordered pair: for example, the first would be (0 min., 20°C). The second would be (1 min., 21°C), and so on. Each of the ordered pairs gives an x value and a y value to be plotted on a graph.

Graphs

Graphs, like data tables, must include a descriptive title. Along their axes, they must include labels of what was measured and the units of each type of measurement. The graph is usually a line or a curve that shows the relationship between all of the numbers on the data table. It includes all of the information on the data table, but by putting it in the form of a graph, it is easier to see how the data changes with each measurement. The graph of the above data is shown below. It is shown smaller than it should be because of space considerations. (If you were to draw this graph, it should take up most of the page.)

Temperature vs. Time for the Heating of Compound X



Features of a graph:

1. A Title: The title on a graph should be a brief but clear description of the relationship under study. Titles like "Lab Number 1" or "Volume and Temperature" are not acceptable because their meaning is clear only to those familiar with the experiment and the meaning will be lost as memory fades with the passage of time. Examples of clear titles are "Absorbance at 447 nm vs. Concentration of $FeSCN^{2+}$" or "The vapor pressure of water vs. Temperature".

2. Labeled Axes: On a graph, the horizontal axis is called the x-axis and the vertical axis is the y-axis. Ordered pairs are represented as (x, y). Usually, the variable that varies consistently is placed along the x-axis. (Often, both will vary consistently. In that case, follow the conventional format for that type of graph. You may be told which axis to use for which variable.) If you are told to make a graph of "temperature vs. time", that means temperature is on the y-axis and time is on the x-axis. Similarly, if you are told to make a graph of "absorbance vs. concentration", then absorbance is on the y-axis and concentration is on the x-axis.

Each axis of the graph should be clearly labeled to show the quantity it represents and the units that have been used to measure the quantity. You should recognize the distinction between the quantity measured (pressure, volume, temperature, time, etc.) and the units that have been used to measure that quantity (atmospheres, liters, degrees Celsius, seconds, etc.).

It is convenient to label each axis with the name of the measured quantity followed by the unit. You can separate the unit (usually abbreviated) from the quantity by a comma or a slash mark, or you can include the unit in parentheses, for example, "volume, mL", “volume/mL”, or “volume (mL)”. This way, only numbers need to appear beside each axis, and the axes are not cluttered up with the units for each number written on the scale.

3. Scales: Each axis has a scale. These numbers on the graph increase from left to right on the x-axis and from bottom to top along the y-axis. These numbers increase in uniform increments, and the scales do not have to start at zero.

The scale on each axis should be chosen carefully so that the entire range of values can be plotted on the graph. For practical reasons, 2, 5, or 10 divisions on the graph paper should represent a decimal unit in the variable. This equivalence will make it easy to estimate values that lie between the scale divisions. For greatest accuracy, the scales selected should be chosen so that the graph nearly fills the page. Be sure, however, that no plotted points fall outside the borders of the graph.

4. Data Points: Each data point on the graph should be clearly marked.

5. The Curve: A smooth curve or a straight line should be drawn through the points. The curve should pass as close as possible to each of the points but should not be connected point-to-point with short lines.

<u>Preparing the Graph</u>

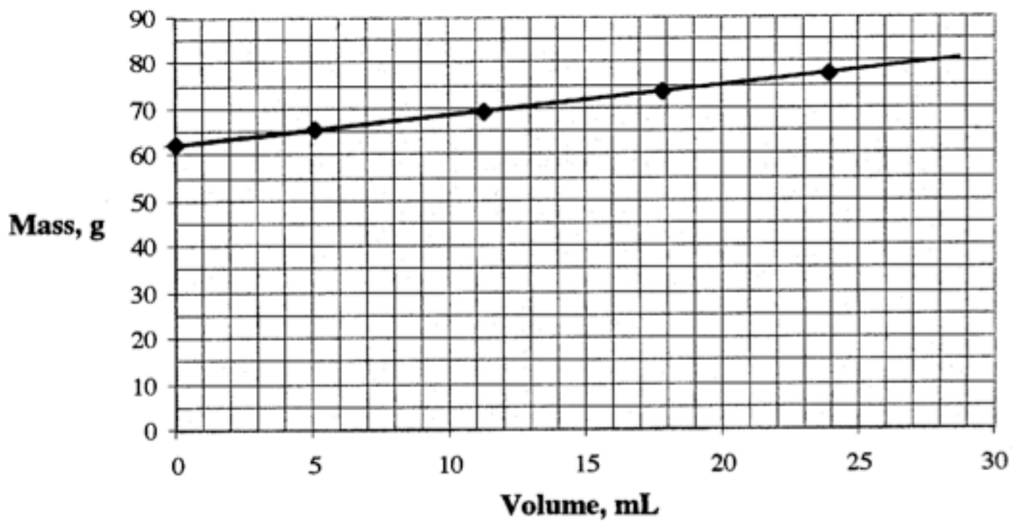
Note: an example of a correctly prepared graph is shown at the end of this section.

1. Draw vertical and horizontal axes on the graph paper. These should leave enough room to label the axes, but the graph should take up most of the page. Give the graph a descriptive title (derived from the data) and write it at the top of the page.

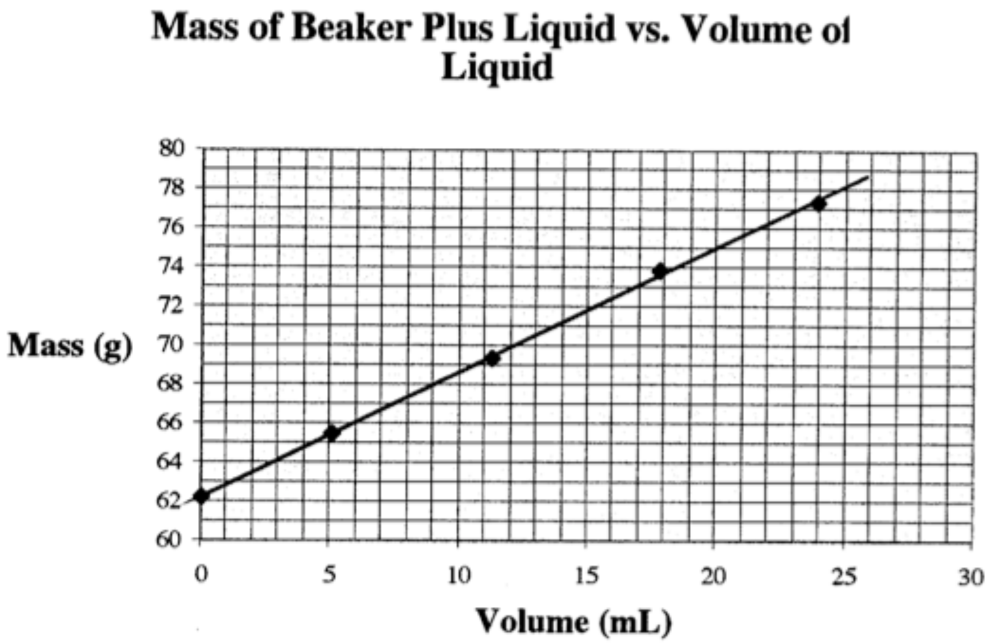
2. Label each of the axes with the quantity measured and the units used. For example: “distance (km)” and “time (hr)”.

3. Look at your range of data and choose the scale that you will use. You can get the most precise information from a graph if the area in which the points are plotted takes up most of the page (leaving enough room so that the title and the labels of the axes are not crowded). Therefore, it is often not convenient to start the scale at (0, 0), because often that would make the plotted points scrunched into one small section of the page, and you wouldn't be able to get very precise information from it. (See the graph below. The axes start at (0,0), but the y-axis data starts at around 60 g. This makes the y-axis values too close together. The y-axis should start at around 60 g so that it can be expanded to spread out the data.) The size of the intervals on an axis must be uniform but they do not need to match the size of the intervals on the other axis.

Mass of Beaker Plus Liquid vs. Volume of Liquid



Above is a graph with incorrect scales. The x-axis is spread out sufficiently, but the points are too close together on the y-axis. Since the y-axis data ranges from a little over 60 g to a little under 80 g, the y-axis should start at 60 g and end at 80 g. This will spread out the data well, so that the plotted points cover most of the page. Below, the graph is shown with a more appropriate scale for the y-axis. When the data points are spread out to cover most of the page, it is possible to make more precise determinations and estimations from the graph. (Again, if you were to draw these graphs, they should take up the whole page. They are shown smaller here for space considerations.)



To determine your scale, take the difference of your highest and lowest x values to get the range of x values. Do the same for the y values. Look at your graph paper, and count the number of squares you have along each axis. If your graph paper has major and minor divisions, count the number of major divisions. Get a tentative range for each axis by dividing the difference between the high and low values of the data by the number of squares (or major divisions) along that axis. This will tell you about how many units there will be per each division. However, on the actual graph, you will use numbers that are easily divisible (such as: every division worth 1 unit, or 2 units, or 5, 10, 20, 50, etc.) in order to make the graph easy to plot and to read. You will need to estimate between the lines, and if each square represents something awkward such as 3 units or 7 units, it is very difficult to make an accurate estimate. Therefore, each major division should be either 1×10^n, 2×10^n, or 5×10^n units (This is called the 1-2-5 rule). From your calculated approximate number of units per division, choose an actual number of units per division that is slightly larger and which is easily divisible (preferably, one that follows the 1-2-5 rule).

As an example, if the lowest data point is 348 and the highest data point is 551, the range of values is the difference: 551-348 = 203. If your paper has 18 major divisions along this axis, the first estimate for the number of units per division is 203/18 = 11.3 units/division. This must then be increased to the nearest number that follows the 1-2-5 rule. In this case, the next highest 1-2-5 rule number is 20, so each division will represent 20 units. On your axis, begin with the nearest round number that is just smaller than the smallest data point. In this case, the lowest number along the axis will be 340. (A specific example is given at the end of this section.)

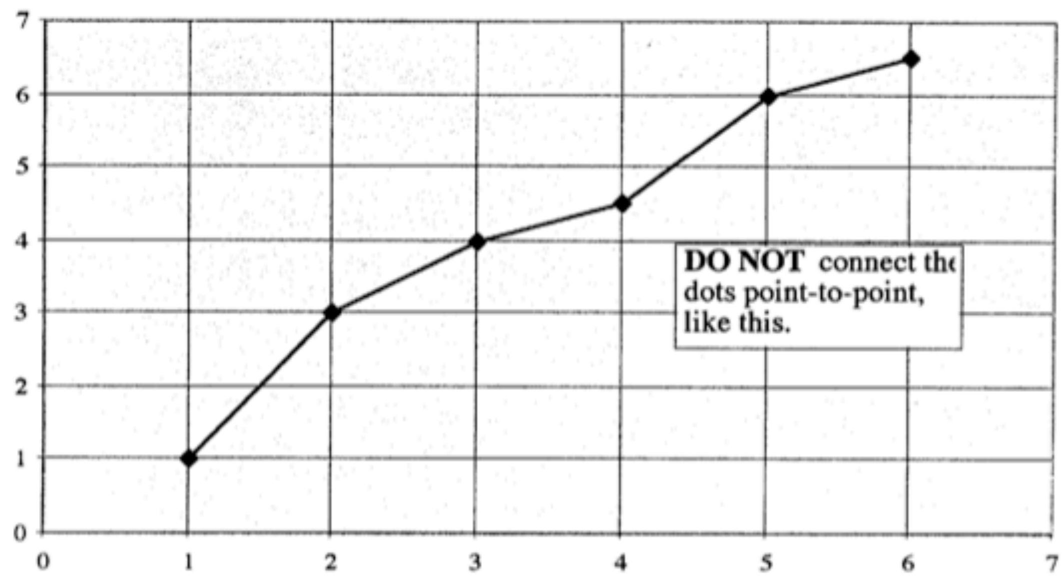
The numbers written on the scale should be round numbers, such as 10, 20, 30, and not 23, 33, 43. The numbers along the scale must be evenly spaced. Do not write a number at each division- that makes the scale too crowded.

If your numbers are very small or very large, sometimes it can be convenient to express the numbers a little differently. For example, if your data ranged from 5.0×10^{-4} to 13.0×10^{-4} m, you could just include the numbers 5.0 through 13.0 on the scale, and on the label for the axis, you would specify "length (10^{-4} m)". Another option is to express the numbers in more convenient units. In the above case, if you expressed the numbers in millimeters, your data would range from 0.5 to 1.3 mm.

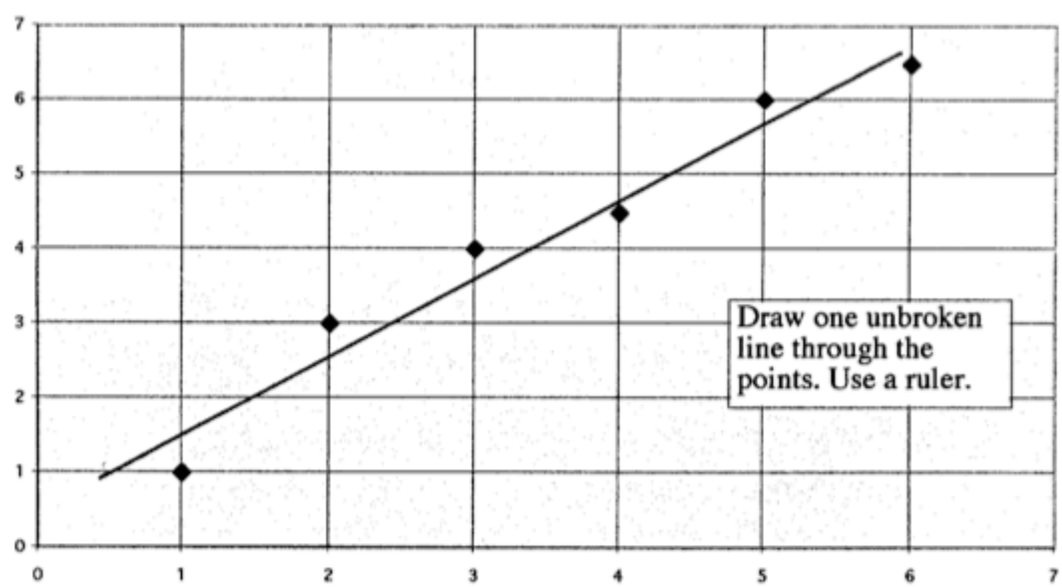
4. Plot the points on the graph. Each set of measurements is one point. Find the intersection of the two values, and draw a point on the graph. Do this for all the data.

5. Draw a straight line or a smooth curve through the points. If the relationship is supposed to be linear, draw the best straight line (using a ruler) that comes closest to showing the relationship. If it is supposed to be a curve, draw a smooth curve among all of the points. The actual data points might not lie on the line or curve line because there is some error associated with any measurement. Rarely do all of our data points fall on a straight line. If one of your points seems way off, you may assume that the point is in error and you may disregard it when drawing your line. This is a way of averaging out <u>all</u> of the data, and yes, there is some estimation involved! **Do not** connect the dots. (See the graphs on the next page.) Once you have the line or curve drawn, you can use it to estimate the values of other points along the graph.

Incorrect Method of Drawing Line



Correct Method of Drawing Line



Example

Shown here is some sample data for an experiment. In this experiment, the pressure of a sample of gas with a constant volume was measured at different temperatures. You are to make a graph of pressure vs. temperature for the gas sample.

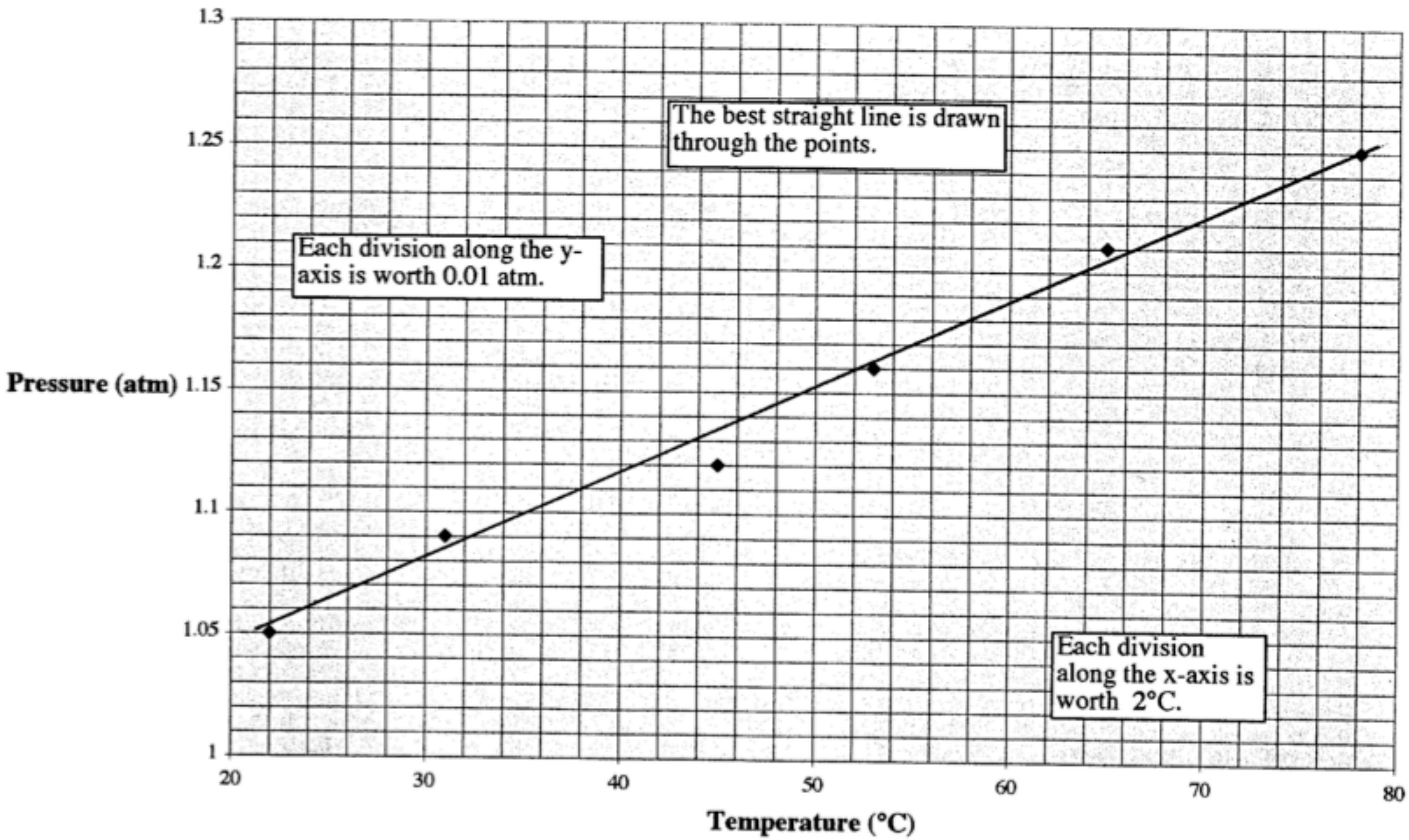
Pressure and temperature of a gas sample in a fixed volume	
Pressure of gas (atm)	Temperature of gas (°C)
1.05	22
1.09	31
1.12	45
1.16	53
1.21	65
1.25	78

Since the instructions specified a graph of "pressure vs. temperature," pressure must be on the y-axis and temperature must be on the x-axis. Looking at the data, we can see that the pressure range goes from 1.05 to 1.25 atm. Therefore, the y-axis should go from 1.0 to 1.3 atm, or 1.02 to 1.26 atm (or some other range that includes the data and consists of "round" numbers). The temperature values range from 22 to 78°C, so the x-axis should range from 20 to 80°C. This range will include all of the data, and the points will be spread out well. The graph is shown on the next page (so that it can take up the whole page).

Notice the following on the graph:

1. It has a descriptive title.
2. The axes are labeled with the quantities and the units.
3. The numbers along the axes are "round" numbers and are evenly spaced.
4. Each division follows the "1-2-5 rule".
5. The axes have the correct scales in order to spread out the data points.
6. The best straight line is drawn through the points.

Pressure vs. Temperature for a Gas Sample in a Fixed Volume



The Experiment

In this experiment, we will show the relationship between the mass and volume of a liquid. The volumes and masses of five different samples of the same substance will be measured. After the data for the samples are collected, the mass and volume of each sample will be used to prepare a graph. The density (in g/mL) will be visually represented on the graph.

Procedure

1. Weigh a clean, dry 50-mL or 100-mL beaker and record its mass.
2. In another small beaker, obtain about 60 mL of water or another liquid assigned by your instructor. Using a 10-mL graduated cylinder or a 10-mL pipet, carefully measure out a 10 mL sample of the liquid. If you use a graduated cylinder, the volume does not have to be exactly 10.0 mL, but you must record the volume to the nearest 0.1 mL (for example: 9.7 mL) If you use a volumetric pipet, the volume will be 10.0 mL. (Ask the instructor for a demonstration of the correct procedure for using a pipet.) Record the actual volume used.
3. Transfer the 10 mL sample to the weighed beaker. Weigh the beaker and liquid. Record the mass.
4. Measure out another 10 mL sample of the same liquid (again recording the volume to the nearest 0.1 mL) and add it to the weighed beaker of liquid. Weigh the beaker again with this added liquid.
5. Continue to increase the total volume of liquid by adding 10 mL each time (measuring the volume to the nearest 0.1 mL each time) and weighing the beaker plus liquid. You may take the last set of measurements when the total volume of liquid in the beaker reaches about 50 mL.

Calculations

1. Calculate the mass of each sample of liquid by subtracting the mass of the beaker from the total mass of the beaker plus liquid.
2. Make a data table of your data (mass of liquid and volume of liquid).
3. Set up a graph of your data. Make a graph of mass vs. volume: plot mass on the vertical (y) axis and volume on the horizontal (x) axis.
4. Using a ruler, draw the best straight line through the data. If some of the points fall off of the line, run the line between them so you have as many points above the line as you do below the line.

Follow-up

1. Use the graph to predict the mass of 8.0 mL of the liquid you used.
2. Measure out 8.0 mL of the liquid you used. Using a pre-weighed beaker, determine the actual mass of the 8.0 mL of liquid.
3. Compare the predicted mass of the liquid to its actual mass, and comment on how close they are.

Questions

1. An IV pump delivers the following volume of saline solution over five hours.

Volume (mL)	Time (hours)

0	0
50	1.0
75	1.5
100	2.0
150	3.0
175	3.5
200	4.0
250	5.0

Prepare a graph to represent the above data.

2. Use the graph to answer the following questions. Show your reasoning.
   a. What volume of solution has been delivered after 1.2 hours?
   b. How long will it take to deliver 130 mL of the IV solution?
   c. What volume of solution will be delivered in 2.7 hours?
   d. How much time will it take for 183 mL of solution to be delivered?

3. From the graph that you made in the experiment (the mass vs. volume graph), calculate the slope of the line. The slope is equal to the "rise" divided by the "run" – in other words, the change in the y value divided by the change in the x value. This can be determined by choosing two points that are actually on the straight line that you drew (they don't have to be actual data points), determining their coordinates [(x_1, y_1) and (x_2, y_2)], and using the equation:

$$slope = \frac{(y_2 - y_1)}{(x_2 - x_1)}$$

The slope should have units and a sign (+ or -), so make sure to include the units in the x and y values. In this case, the slope of the line is equal to the density of the liquid, if you have drawn the graph correctly.