# 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 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 |

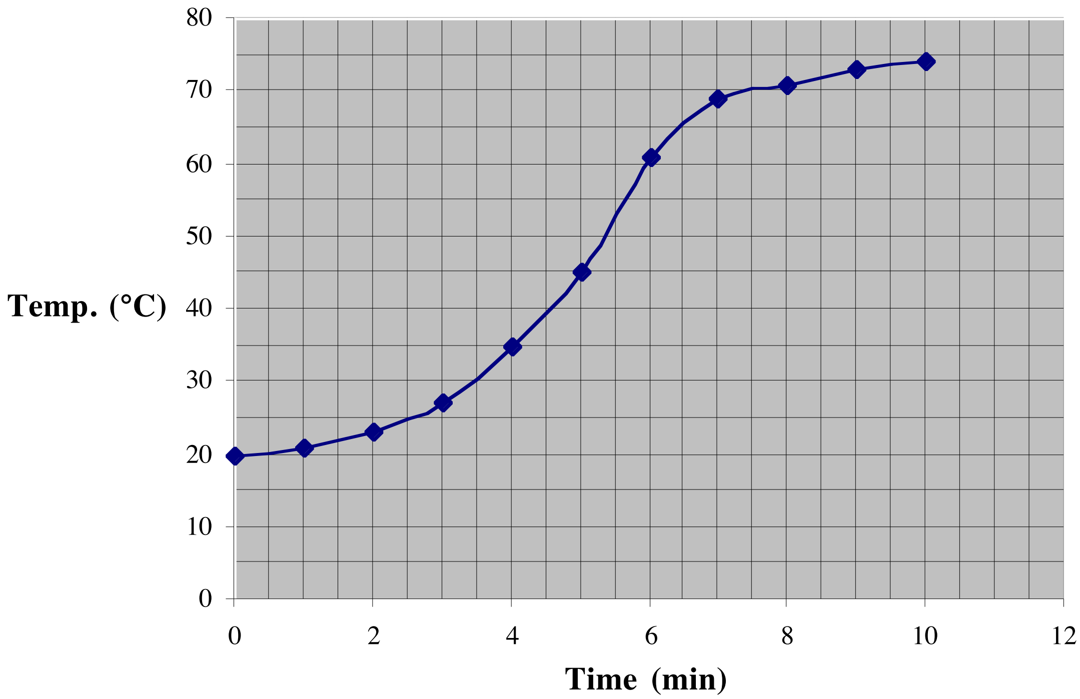
Notice the title, headings, and units.

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>**

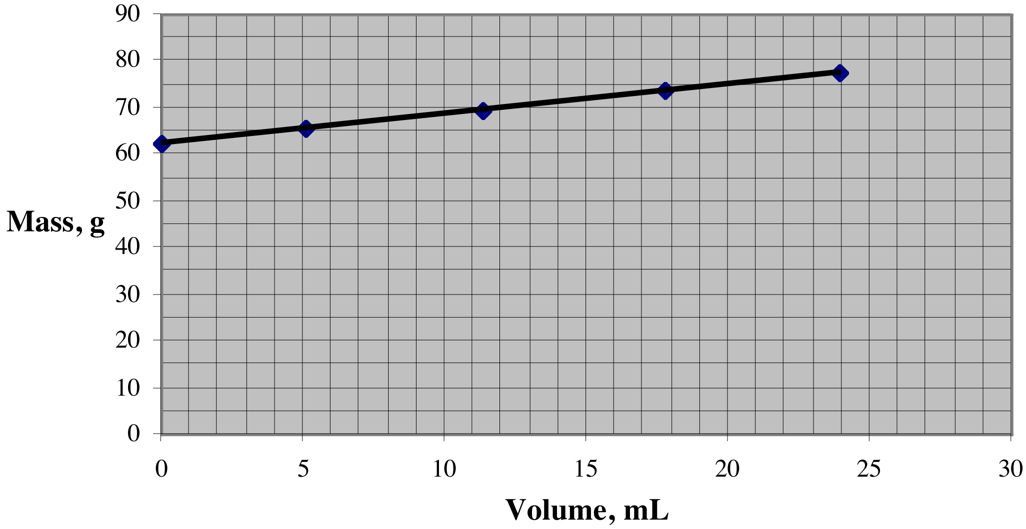
**Note: an example of a correctly prepared graph is shown at the end of this section.**

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.

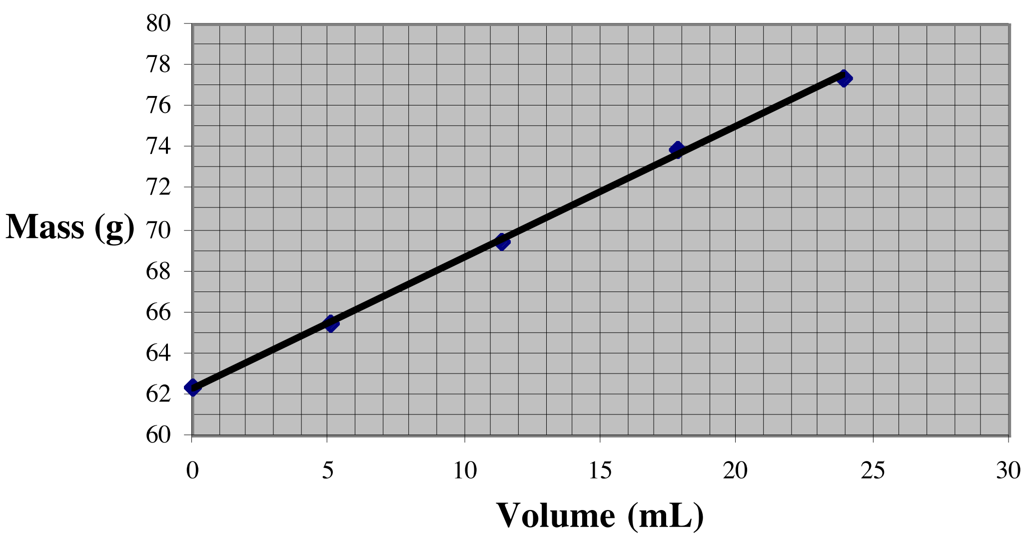
## Mass of Beaker Plus Liquid vs. Volume of Liquid




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

## Mass of Beaker Plus Liquid vs. Volume of Liquid



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 $1 \times 10^n$, $2 \times 10^n$, or $5 \times 10^n$ 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).

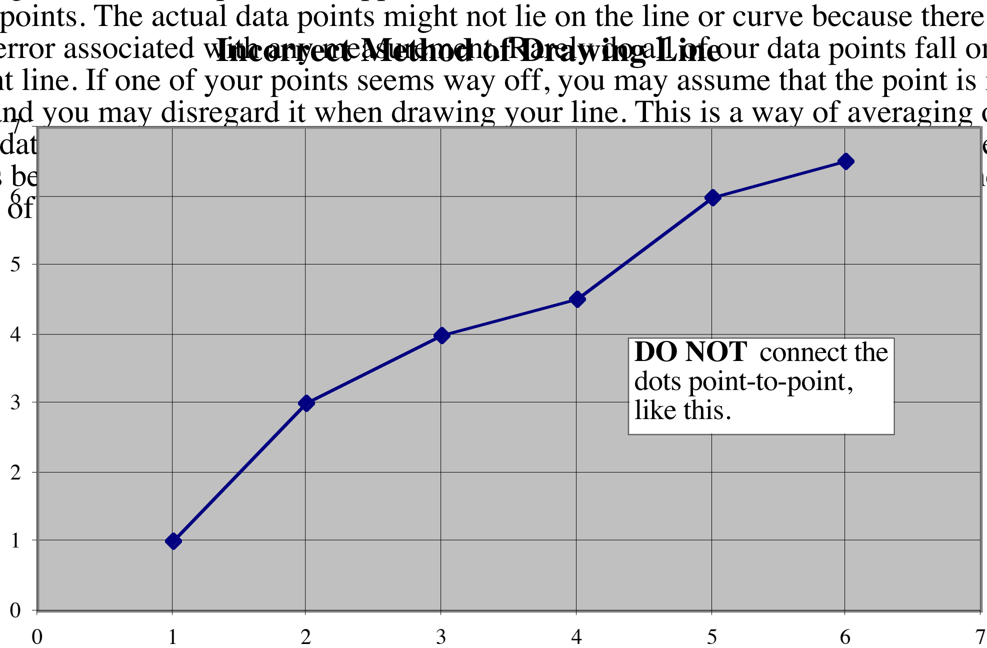
As an example, if the lowest data point is 348 and the highest data point is 551, the range of values is the difference: 551-348 = 203. If your paper has 18 major divisions along this axis, the first estimate for the number of units per division is 203/18 = 11.3 units/division. This must then be increased 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.

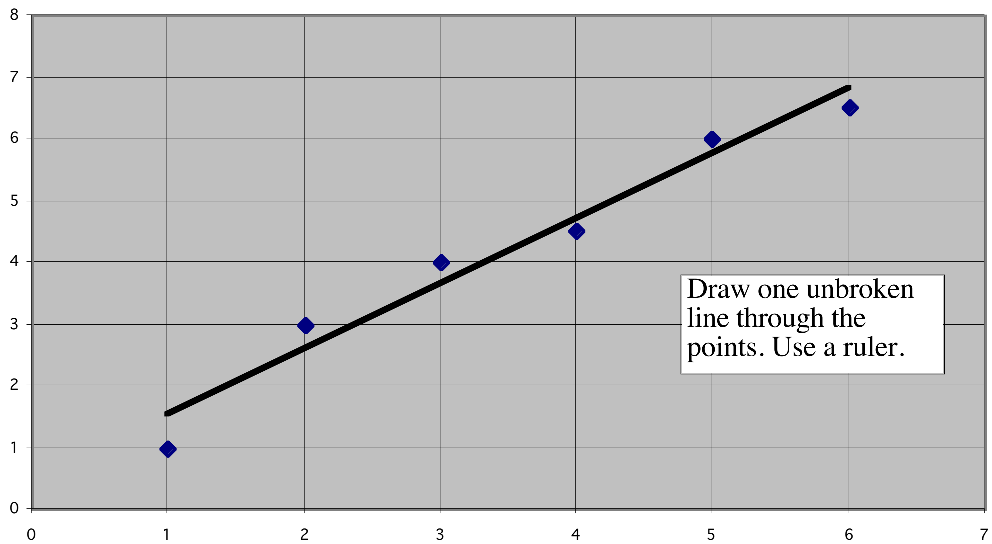
If your numbers are very small or very large, sometimes it can be convenient to express the numbers a little differently. For example, if your data ranged from $5.0 \times 10^{-4}$ to $13.0 \times 10^{-4}$ m, you could just include the numbers 5.0 through 13.0 on the scale, and on the label for the axis, 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 because there is some error associated with any measurement. Rarely do all of your 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 all of the dat ee the graphs be e values of



## Correct Method of Drawing Line




**Example**

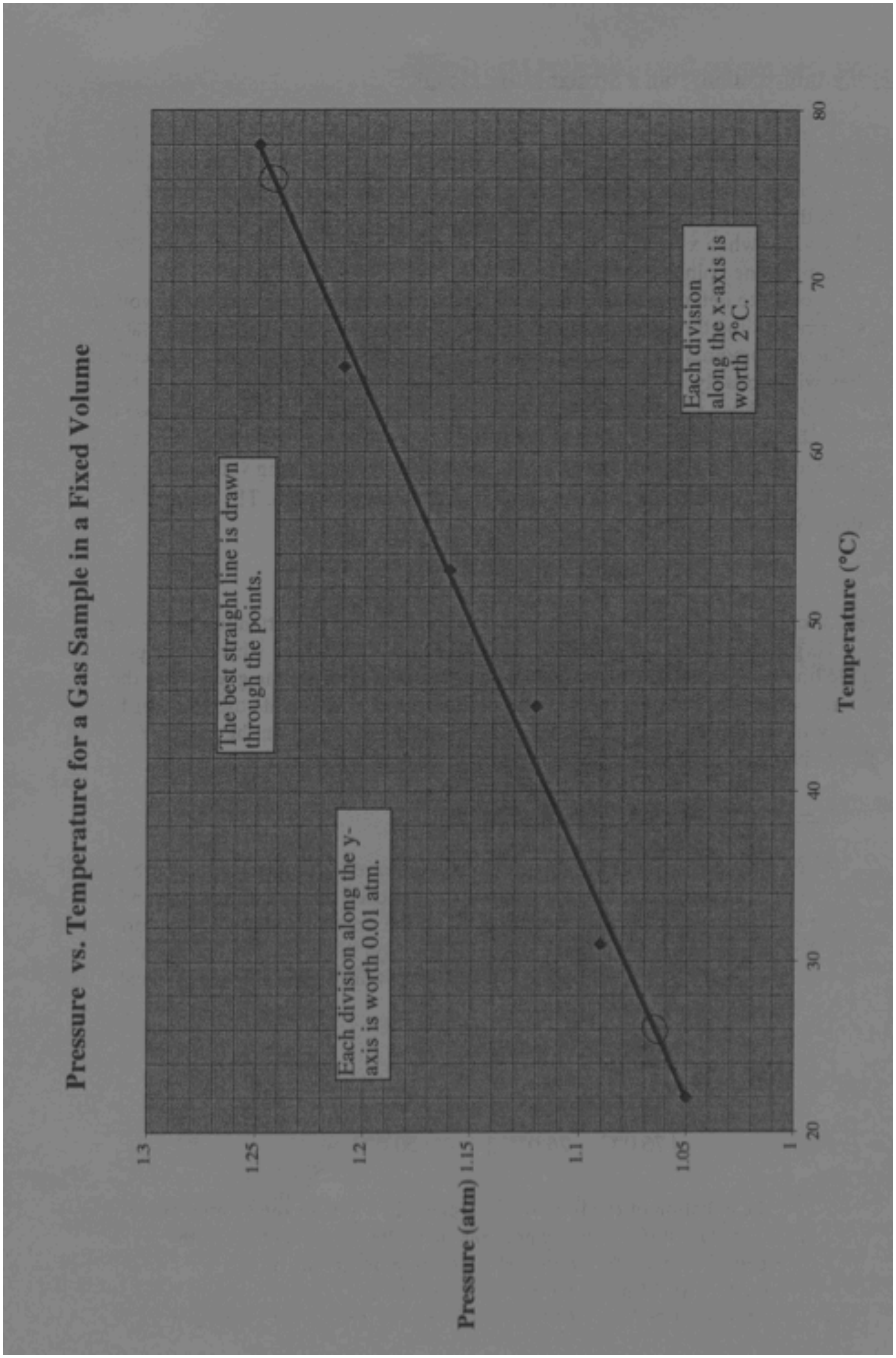
Shown here is some sample data for an experiment. In this experiment, the pressure of a sample of gas with a constant volume was measured at different temperatures. You are to make a graph of pressure vs. temperature for the gas sample.

| **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
Pressure (atm)
Temperature (°C)
1.3
1.25
1.2
1.15
1.1
1.05
1
20
30
40
50
60
70
80
Each division along the y-axis is worth 0.01 atm.
The best straight line is drawn through the points.
Each division along the x-axis is worth 2°C.

## Getting Information from a Straight Line Graph

Sometimes the slope of a line contains information that is useful to you. The equation of a straight line is often expressed in the form $y = mx + b$. In this equation, m is the value of the slope, and b is the value of the y-intercept (this is where the line intersects the y axis if the graph starts with the x value of 0. Its coordinates are (0, b), so it is the y value when $x = 0$). In the equation $y = mx + b$, x and y correspond to the coordinates of one point on the line.

In order to determine the slope, you first need to make the graph. After you draw the best straight line through the points, choose two points that are on the line that you drew. These two points should be far apart from each other (to minimize the uncertainty), and they will probably not correspond to actual data points. Sometimes it is helpful to choose points whose values are easy to estimate from the graph. After you choose the two points on the line, assign one of them the value $(x_1, y_1)$ and the other the value $(x_2, y_2)$. You need to determine the values of $x_1$, $y_1$, $x_2$, and $y_2$ by estimating values off of the graph, and you must include both the number and the unit for each. The slope m is calculated as follows:

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

It doesn't matter which point is which, just be consistent and pay attention to the sign.

To get the y-intercept, you first need the value of the slope. Choose one point that is on the line and get the x and y values by estimating them from the graph. Use the equation $y = mx + b$, and plug in the values of y, m, and x. Calculate the value of b. (Why find the y-intercept this way? Often, the y-intercept is not shown on the graph. You won't be able to just read it off of the graph if your x-axis does not start at 0.)

## Example – Determining the Slope of a Graph

As an example, we will use the previously prepared example graph of pressure vs. temperature. To determine the slope, two points are chosen that are on the line and far apart from one another. The points are indicated on the graph, and they do not correspond to actual data points (since few, if any, data points are on the line). The coordinates of these points are (26.0°C, 1.065 atm) and (76.0°C, 1.244 atm). The slope is then calculated as:

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

$$m = \frac{(1.244 \text{ atm} \ - 1.065 \text{ atm})}{(76.0℃ \ - 26.0°\text{C})} = \frac{0.179 \text{ atm}}{50.0℃} = 3.58 \times 10^{-3} \frac{\text{atm}}{℃}$$

To get the equation of the line, we also need the value of the y-intercept. Since our graph does not start at (0, 0), we cannot just read the y-intercept off of the graph. To find the y-intercept, you need the coordinates of one point that is on the line and you also need the slope of the line. Plug the values into the equation $y = mx + b$, and solve for b. If you use the coordinates (26.0°C, 1.065 atm) and the previously determined slope of $3.58 \times 10^{-3}$ atm/°C, the y-intercept is calculated as follows.

$$y = mx + b$$

$$1.065 \text{ atm} = (3.58 \times 10^{-3} \text{ atm/°C})(26.0°\text{C}) + b$$

$$1.065 \text{ atm} = 0.09308 \text{ atm} + b$$
$$1.065 \text{ atm} - 0.09308 \text{ atm} = b$$
$$b = 0.972 \text{ atm}$$

The equation of the line is thus:

$$y = (3.58 \times 10^{-3} \text{ atm/°C})\, x + 0.972 \text{ atm}$$