# Graphs and Graphing

Graphs provide a convenient way to represent the simultaneous behavior of the values of related quantities. In most graphs, this is done by using a grid containing perpendicular $x$ and $y$ axes. By convention, the $x$ axis is horizontal, and the $y$ axis is vertical. A single point on such a grid represents a specific value for each of two related quantities. The graph is formed by connecting the points with a line that can be either curved or straight. These characteristics are shown in Figure A.1.

Some graphs represent experimentally measured relationships between quantities, while others represent the behavior of quantities related by a specific mathematical formula. The abilities to construct graphs and obtain information from them are important in the study of science. The techniques used are illustrated by the following example.

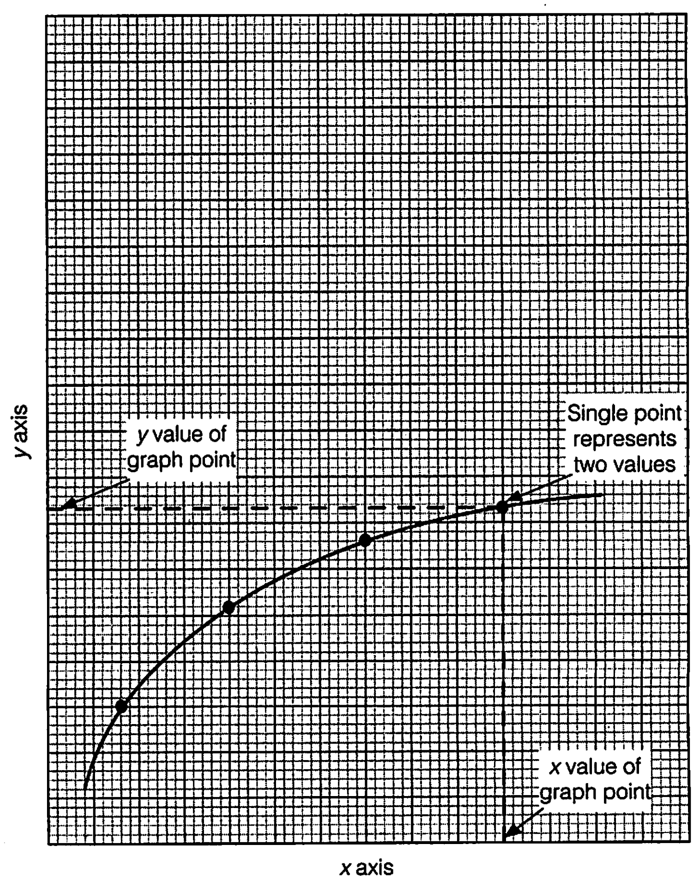


**Figure A.1**
*Graphical representation of values of related quantities*

### *Example A.1*

Some chemistry students were given the assignment of experimentally determining the rate at which acetone, a volatile liquid, evaporates at room temperature. To accomplish the task, they put a dish that contained some acetone on an electronic balance and determined the mass of the dish plus acetone at one minute intervals for a total of 6 minutes. The following data were collected:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Mass of dish + acetone (g): | 51.33 | 51.07 | 50.83 | 50.60 | 50.37 | 50.15 | 49.93 |
| Time (minutes): | 0.0 | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 | 6.0 |

The total mass of acetone evaporated at each time was obtained by subtracting the mass of the dish plus acetone at that time from the mass at zero time. The following values were obtained:

| | | | | | | |
|---|---|---|---|---|---|---|
| Mass of acetone evaporated (g): | 0.26 | 0.50 | 0.73 | 0.96 | 1.18 | 1.40 |
| Time (minutes): | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 | 6.0 |

These values will be graphed and the rate of evaporation determined as the slope of the resulting line.

The mass evaporated will be represented along the $y$ axis (vertical axis) on the grid, and the time along the $x$ axis (horizontal axis), as shown in Figure A.2. When numbers are assigned to the $x$ and $y$ axes, it is important

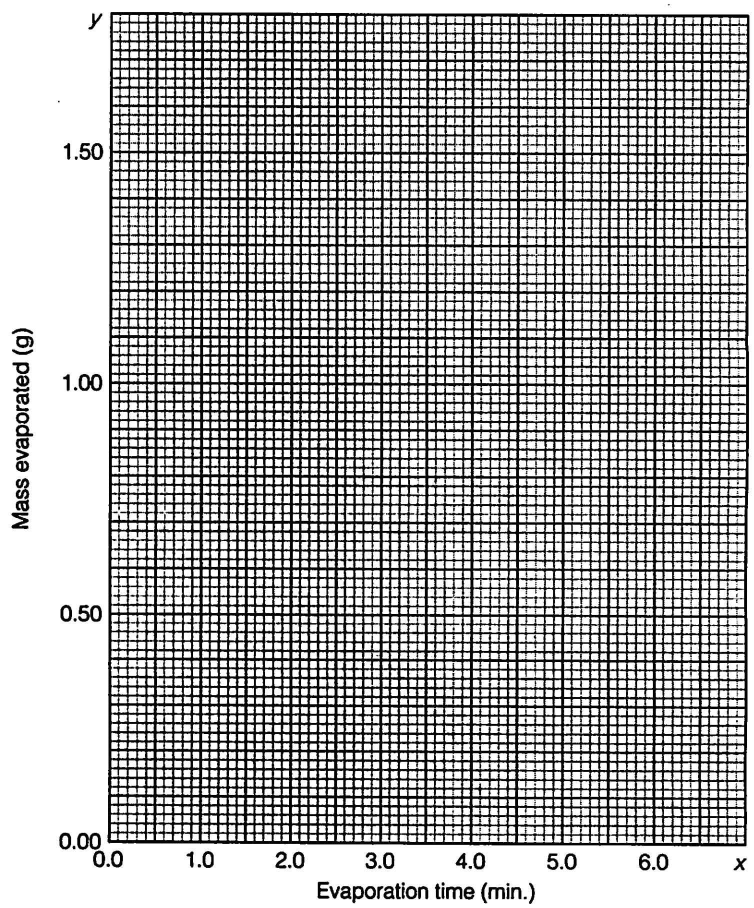


**Figure A.2**
*A numbered and labeled grid*

to assign them such that all the data can be included and most of the available space on the graph is used. A common mistake is to crowd the plotted data into a small corner of the available space. Also, the numbers on the axes should be assigned so that a specific distance along an axis always represents the same change in value. In Figure A.2, for example, two large divisions along the $x$ axis represents 1.0 minute, while each large division along the $y$ axis represents 0.10 gram. The lowest values shown on both axes of this graph is zero. However, this is not always the case. In general, the axes are numbered in such a way that the data will fit on the graph regardless of whether or not the lowest values shown are zero.

After numbers and labels are assigned to the axes, the positions of the points are determined. This is done by taking a time such as 1.0 minute and a corresponding mass that evaporated (0.26 g corresponds to the time of 1.0 min.) and locating their proper positions on the $x$ and $y$ axes. A line is then drawn vertically from the 1.0-min. point on the $x$ axis and horizontally from the 0.26-g point on the $y$ axis. The single graph point that represents both values is located at the intersection of these two lines, as shown in Figure A.3.

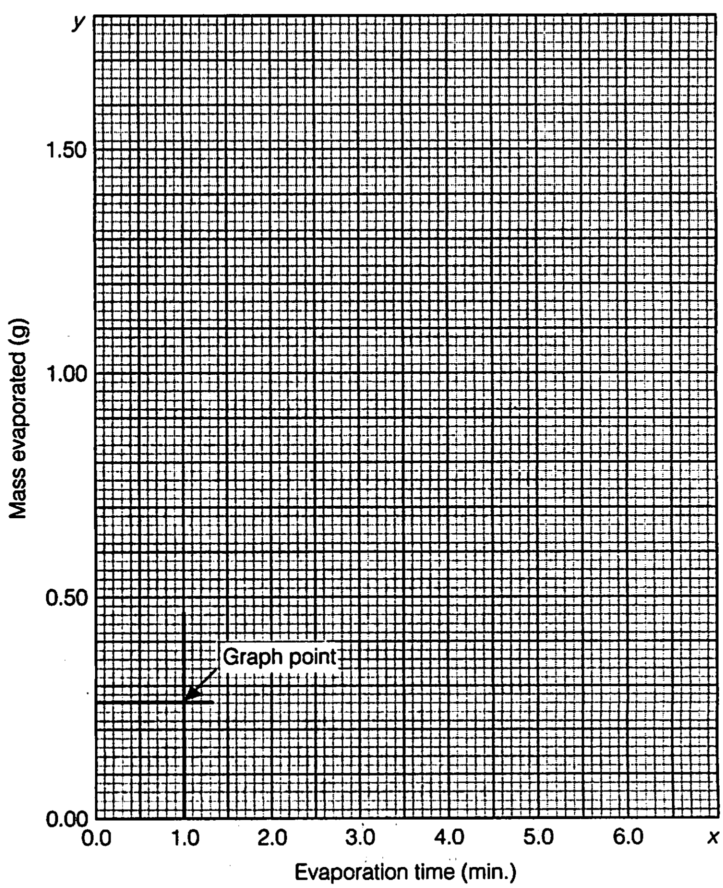


**Figure A.3**
*Locating graph points from data points*

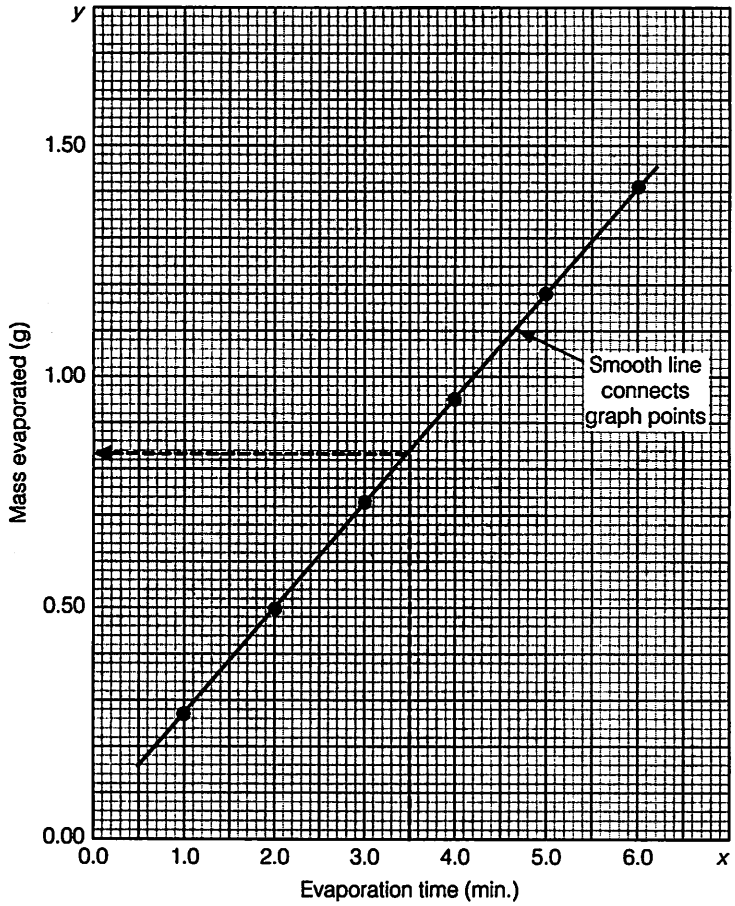


**Figure A.4**
*Determination of mass evaporated from a completed graph*

Graph points corresponding to the remaining pairs of data points (2.0 min. and 0.50 g, and so on) are obtained in the same way. The resulting graph points are connected by a smooth line, and the graph is completed as shown in Figure A.4. Once the graph is drawn, the value of one of the graphed quantities that corresponds to a value of the other quantity can be easily obtained. For example, let's determine the mass of acetone that would have evaporated after a time of 3.5 minutes had passed in the experiment. This is done by drawing a vertical line up from the 3.5-min. point on the $x$ axis until the line intersects the line that connects the graph points. A horizontal line is then drawn to the left from this point of intersection until it meets the $y$ axis. The value at the point of intersection with the $y$ axis gives the mass of acetone that would have been evaporated after 3.5 minutes in the experiment. This process, represented by the dotted lines in Figure A.4, gives a mass of acetone evaporated value of 0.84 g.

Useful information can often be obtained from the slope of a graph. In this example, the slope will give the rate of evaporation of acetone in units of grams per minute. The slope of a graph is the change in the quantity plotted on the $y$ axis that occurs when the quantity plotted on the $x$ axis changes. The slope is calculated by determining the value of the rise of the graph divided by the run of the graph. The rise of a graph is simply the change in the value of the quantity plotted on the $y$ axis, and the run is the corresponding change in the value of the quantity plotted on the $x$ axis.

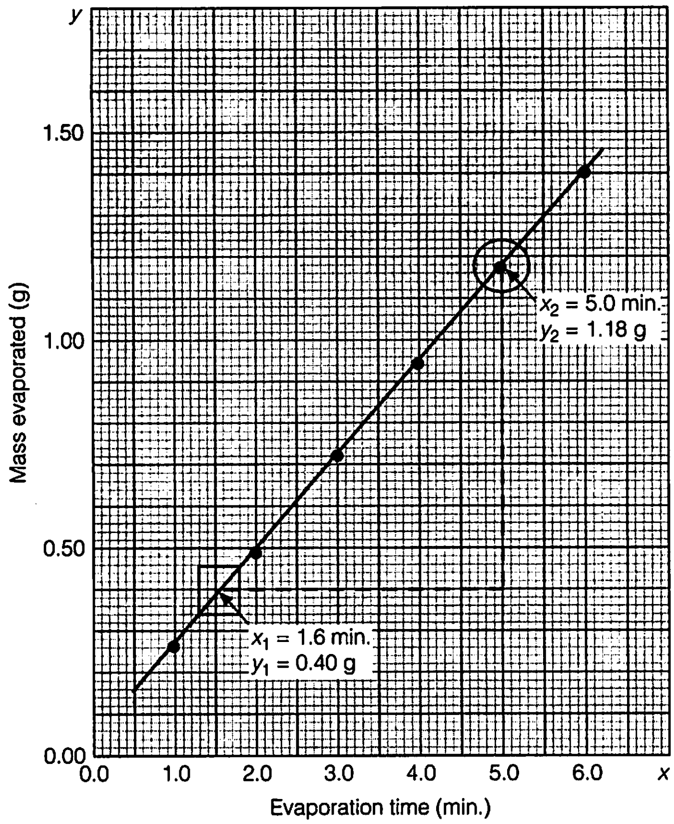


**Figure A.5**
*Determination of the slope of a graph*

The method for determining the slope is illustrated in Figure A.5. A horizontal line and a vertical line are drawn that both intersect the graph and also intersect each other (the dotted lines in Figure A.5). Both the points where the drawn lines intersect the graph correspond to a value of the quantity plotted on the $x$ axis and the quantity plotted on the $y$ axis. In Figure A.5, the values of the $x$ and $y$ quantities at the intersection of the horizontal line with the graph are denoted $x_1$ and $y_1$. This point is enclosed in a small square in Figure A.5, and corresponds to $x_1 = 1.6$ min. and $y_1 = 0.40$ g. The values of the $x$ and $y$ quantities at the intersection of the vertical line with the graph (enclosed in a small circle) are denoted $x_2$ and $y_2$. Their values are $x_2 = 5.0$ min. and $y_2 = 1.18$ g.

The rise of the graph is the change in the value of the $y$ quantity and will always be the value of $y$ corresponding to the vertical dotted line ($y_2$) minus the value of $y$ corresponding to the horizontal dotted line ($y_1$). The run of the graph is the change in the value of the $x$ quantity and will always be the value of $x$ corresponding to the vertical dotted line ($x_2$) minus the value of $x$ corresponding to the horizontal dotted line ($x_1$). Thus, the slope is calculated as follows:

$$\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{y_2 - y_1}{x_2 - x_1} = \frac{1.18\,\text{g} - 0.40\,\text{g}}{5.0\text{ min} - 1.6\text{ min}} = \frac{0.78\,\text{g}}{3.4\text{ min}} = \frac{0.23\,\text{g}}{\text{min}}$$

The slope gives the rate of evaporation of acetone as 0.23 g per minute. This value has a positive sign and is called a positive slope; $y$ increases when $x$ increases. In some cases, $y$ decreases when $x$ increases. In such cases, $y_2$ will have a smaller value than $y_1$, and the quantity $y_2 - y_1$ will have a negative value. This will cause the calculated slope to have a negative value, and the graph is said to have a negative slope. If the data consisting of the mass of dish + acetone had been plotted on the $y$ axis, and the time on the $x$ axis, a graph with a negative slope would have resulted. The slope of this graph would give the rate of change of the mass of the dish + acetone (actually the mass of acetone) with time in units of grams per minute. However, the negative slope indicates that the mass is decreasing with time.