FAU FLORIDA ATLANTIC UNIVERSITY

Lab Manual 1: Measurement & Graphs for Health Science

General Chemistry for Health Sciences Lab

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Introduction

Chemistry is the study of matter and how matter changes. Matter is anything that takes up space. Like in any other science, measurements are a very important part of chemistry – and everyday life. Measurements provide quantitative information that can be represented with numbers.

A measurement has three parts: magnitude, unit, and uncertainty. **Magnitude** is the numerical value obtained with measuring devices. **Unit** is the standard quantity and is used to express a physical amount, which is adopted by law. **Uncertainty** is the expected value within a measurement range, as opposed to a true value of the measurement. Uncertainty can be categorized in the way of accuracy and in the way of precision. Accuracy and precision are important when taking measurements. The ability of an instrument to measure the accurate value is known as accuracy. Precision reflects how reproducible measurements are under the same conditions, that is, the degree of reproducibility. All measurements have uncertainty. In order to compensate for uncertainty, a measurement is represented with significant figures. Significant figures are one of the ways to quantify the precision of a measurement by notating how many digits are present in a number obtained through a measurement.

Many different quantities can be measured. Some examples are mass, volume, temperature, length, and time. Measured numbers are obtained by using measuring tools, such as a ruler, glassware, scale, thermometer, or stopwatch. Units of measured numbers can vary depending on the tools used. Also, it is important to know there are different measuring systems such as the International System of Units (SI), the metric system, the imperial system, and customary units for the United States.

Most of the time, measurements are taken by using different units in order to compare one measurement to another measurement. Dimensional analysis simplifies these calculations. Dimensional analysis is a process to convert a unit of measurement to a different unit of measurement by using equalities of units. Graphical analysis is another technique and is used to derive quantitative relationships between variables, specifically when large quantities of data are produced.

Goal of Lab 1: Measurement & Graphs for Health Science

The goal of this lab is to become familiar with measurement skills used in science labs, perform dimensional analysis, and interpret data produced from the experimentation.

Theory and Background

Measurements provide much of the information that informs the hypotheses, theories, and laws describing the behavior of matter and energy in both the macroscopic and microscopic domains of chemistry. Every measurement provides three kinds of information: the size or magnitude of the measurement (a number); a standard of comparison for the measurement (a unit); and an indication of the uncertainty of the measurement. While the number and unit are explicitly represented when a quantity is written, the uncertainty is an aspect of the measurement result that is more implicitly represented and will be discussed later. The number in the measurement can be represented in different ways, including decimal form and scientific notation. For example, the maximum takeoff weight of a Boeing 777-200ER airliner is 298,000 kilograms, which can also be written as 2.98×10^5 kg. The mass of the average mosquito is about 0.0000025 kilograms, which can be written as 2.5×10^{-6} kg

Units, such as liters, pounds, and centimeters, are standards of comparison for measurements. A 2-liter bottle of a soft drink contains a volume of beverage that is twice that of the accepted volume of 1 liter. The meat used to prepare a 0.25-pound hamburger weighs one-fourth as much as the accepted weight of 1 pound. Without units, a number can be meaningless, confusing, or possibly life threatening. Suppose a doctor prescribes phenobarbital to control a patient's seizures and states a dosage of "100" without specifying units. Not only will this be confusing to the medical professional giving the dose, but the consequences can be dire: 100 mg given three times per day can be effective as an anticonvulsant, but a single dose of 100 g is more than 10 times the lethal amount.

Table 1.1 lists measurement units for seven fundamental properties ("base units"). Standards for these units are fixed by international agreement, called the **International System of Units** or **SI Units**. SI units have been used by the United States National Institute of Standards and Technology (NIST) since 1964. Units for other properties may be derived from these seven base units.

Table 1.1 Basic Units of the SI System

Property Measured	Symbol	Example
length	meter	m
mass	kilogram	kg
time	second	s
temperature	kelvin	K
electric current	ampere	A
amount of substance	mole	mol
luminous intensity	candela	cd

[credit: *Chemistry 2e.* Table 1.2. OpenStax. CC BY.]

Everyday measurement units are often defined as fractions or multiples of other units. Milk is commonly packaged in containers of 1 gallon (4 quarts), 1 quart (0.25 gallon), and one pint (0.5 quart). This same approach is used with SI units, but these fractions or multiples are always powers of 10. Fractional or multiple SI units are named using a prefix and the name of the base unit. For example, a length of 1000 meters is also called a kilometer because the prefix *kilo* means “one thousand,” which in scientific notation is 10^3 (1 kilometer = 1000 m = 10^3 m). Table 1.2 lists the prefixes used and the powers to which 10 are raised are listed in.

Table 1.2 Scientific Notation Units

Prefix	Symbol	Factor	Example
femto	f	10^{-15}	1 femtosecond (fs) = 1×10^{-15} s (0.000000000000001 s)
pico	p	10^{-12}	1 picometer (pm) = 1×10^{-12} m (0.000000000001 m)
nano	n	10^{-9}	4 nanograms (ng) = 4×10^{-9} g (0.000000004 g)
micro	µ	10^{-6}	1 microliter (µL) = 1×10^{-6} L (0.000001 L)
milli	m	10^{-3}	2 millimoles (mmol) = 2×10^{-3} mol (0.002 mol)
centi	c	10^{-2}	7 centimeters (cm) = 7×10^{-2} m (0.07 m)
deci	d	10^{-1}	1 deciliter (dL) = 1×10^{-1} L (0.1 L)
kilo	k	10^{3}	1 kilometer (km) = 1×10^{3} m (1000 m)
mega	M	10^{6}	3 megahertz (MHz) = 3×10^{6} Hz (3,000,000 Hz)
giga	G	10^{9}	8 gigayears (Gyr) = 8×10^{9} yr (8,000,000,000 yr)
tera	T	10^{12}	5 terawatts (TW) = 5×10^{12} W (5,000,000,000,000 W)

[credit: *Chemistry 2e*. Table 1.3. OpenStax. CC BY.]

Need a refresher or more practice with scientific notation? Visit Math Skills Review: Scientific Notation to go over the basics of scientific notation.

SI Base Units

The initial units of the metric system, which eventually evolved into the SI system, were established in France during the French Revolution. The original standards for the meter and the kilogram were adopted there in 1799 and eventually by other countries. This section introduces four of the SI base units commonly used in chemistry. Other SI units will be introduced in subsequent chapters.

Length

The standard unit of **length** in both the SI and original metric systems is the **meter (m)**. A meter was originally specified as 1/10,000,000 of the distance from the North Pole to the equator. It is now defined as the distance light in a vacuum travels in 1/299,792,458 of a second. A meter is about 3 inches longer than a yard (Figure 1.1); one meter is

about 39.37 inches or 1.094 yards. Longer distances are often reported in kilometers (1 km = 1000 m = 103 m), whereas shorter distances can be reported in centimeters (1 cm = 0.01 m = 10^{-2} m) or millimeters (1 mm = 0.001 m = 10^{-3} m).

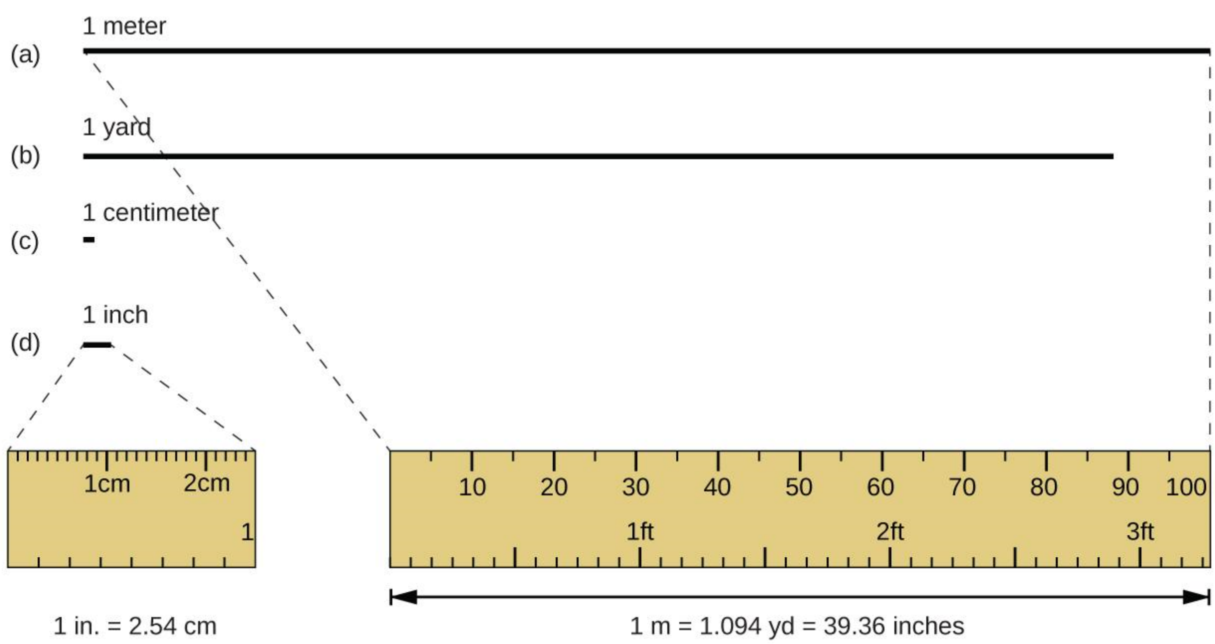


Figure 1.1 The relative lengths of 1 m, 1 yd, 1 cm, and 1 in. are shown (not actual size), as well as comparisons of 2.54 cm and 1 in., and of 1 m and 1.094 yd. [credit: *Chemistry 2e*. Figure 1.23. OpenStax. CC BY.]

Mass

The standard unit of mass in the SI system is the **kilogram (kg)**. The kilogram was previously defined by the International Union of Pure and Applied Chemistry (IUPAC) as the mass of a specific reference object. This object was originally one liter of pure water, and more recently it was a metal cylinder made from a platinum-iridium alloy with a height and diameter of 39 mm. In May 2019, this definition was changed to one that is based instead on precisely measured values of several fundamental physical constants. One kilogram is about 2.2 pounds. The gram (g) is exactly equal to 1/1000 of the mass of the kilogram (10^{-3} kg).

Temperature

Temperature is an intensive property. The SI unit of temperature is the **kelvin (K)**. The IUPAC convention is to use kelvin (all lowercase) for the word, K (uppercase) for the unit symbol, and neither the word "degree" nor the degree symbol (°). The degree **Celsius (°C)** is also allowed in the SI system, with both the word "degree" and the degree symbol used for Celsius measurements. Celsius degrees are the same magnitude as those of kelvin, but the two scales place their zeros in different places. Water freezes at 273.15 K (0 °C) and boils at 373.15 K (100 °C) by definition, and normal human body temperature is approximately 310 K (37 °C). The conversion between these two units and the Fahrenheit scale will be discussed later in this chapter.

Time

The SI base unit of time is the **second (s)**. Small- and large-time intervals can be expressed with the appropriate prefixes; for example, 3 microseconds = 0.000003 s = 3 x 10^{-6} and 5 megaseconds = 5,000,000 s = 5 x 10^{6} s. Alternatively, hours, days, and years can be used.

Derived SI Units

We can derive many units from the seven SI base units. For example, we can use the base unit of length to define a unit of volume, and the base units of mass and length to define a unit of density.

Volume

Volume is the measure of the amount of space occupied by an object. The standard SI unit of volume is defined by the base unit of length (Figure 1.2). The standard volume is a **cubic meter (m^3)**, a cube with an edge length of exactly one meter. To dispense a cubic meter of water, we could build a cubic box with edge lengths of exactly one meter. This box would hold a cubic meter of water or any other substance.

A more commonly used unit of volume is derived from the decimeter (0.1 m, or 10 cm). A cube with edge lengths of exactly one decimeter contains a volume of one cubic decimeter (dm^3). A **liter (L)** is the more common name for the cubic decimeter. One liter is about 1.06 quarts.

A **cubic centimeter (cm^3)** is the volume of a cube with an edge length of exactly one centimeter. The abbreviation **cc** (for **c**ubic **c**entimeter) is often used by health professionals. A cubic centimeter is equivalent to a **milliliter (mL)** and is 1/1000 of a liter.

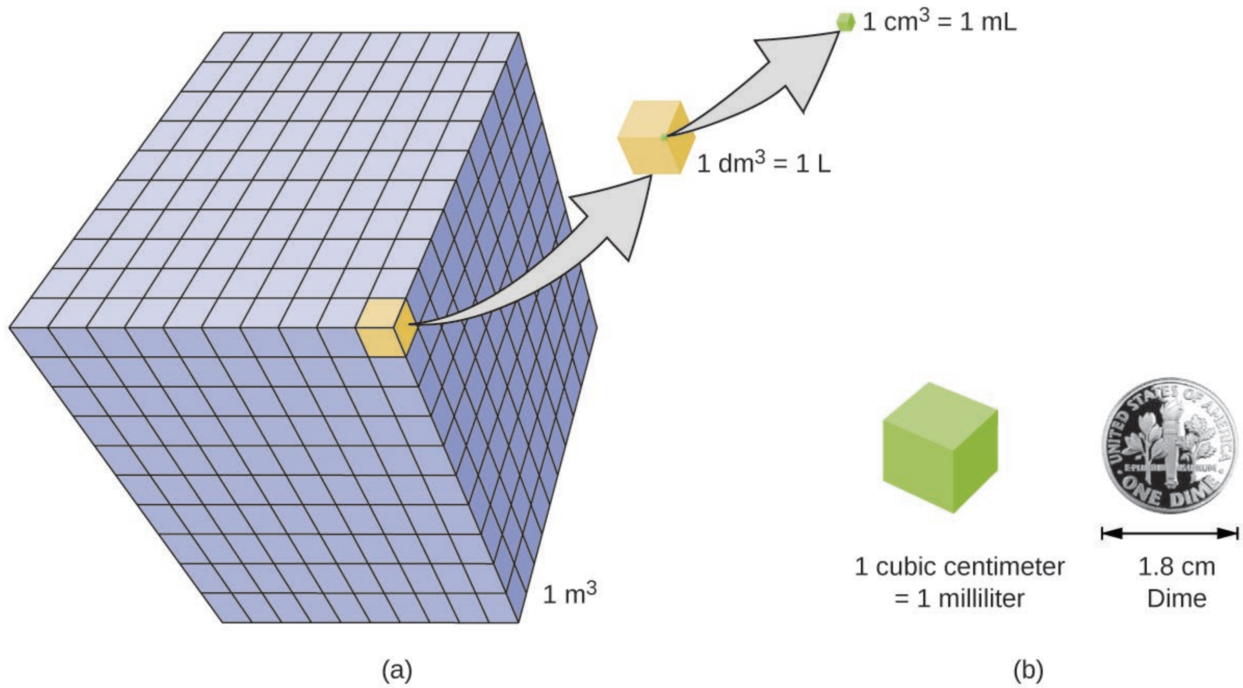


Figure 1.2 (a) The relative volumes are shown for cubes of 1 m^3, 1 dm^3 (1 L), and 1 cm^3 (1 mL) (not to scale). (b) The diameter of a dime is compared relative to the edge length of a 1-cm^3 (1-mL) cube. [credit: *Chemistry 2e*. Figure 1.25. OpenStax. CC BY.]

Counting is the only type of measurement that is free from uncertainty, provided the number of objects being counted does not change while the counting process is underway. The result of such a counting measurement is an example of an **exact number**. By counting the eggs in a carton, one can determine *exactly* how many eggs the carton contains. The numbers of defined quantities are also exact. By definition, 1 foot is exactly 12 inches, 1 inch is exactly 2.54 centimeters, and 1 gram is exactly 0.001 kilogram. Quantities derived from measurements other than counting, however, are uncertain to varying extents due to practical limitations of the measurement process used.

Significant Figures in Measurement

The numbers of measured quantities, unlike defined or directly counted quantities, are not exact. To measure the volume of liquid in a graduated cylinder, you should make a reading at the bottom of the meniscus, the lowest point on the curved surface of the liquid. Refer to Figure 1.3 for an illustration of significant figures in measurement.

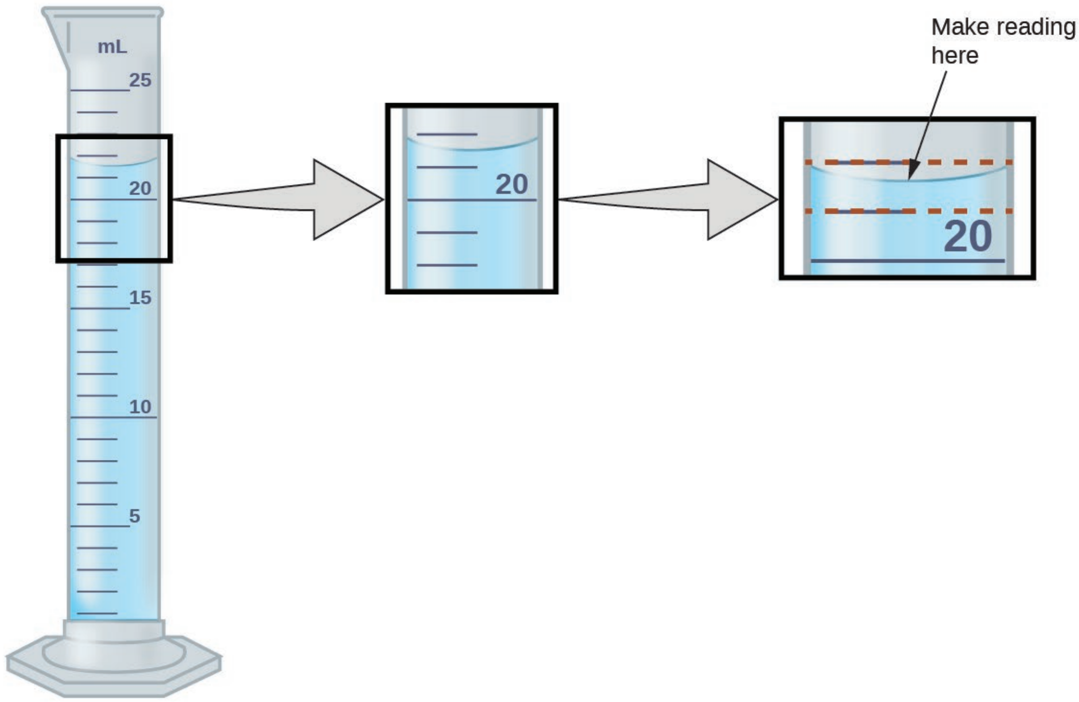


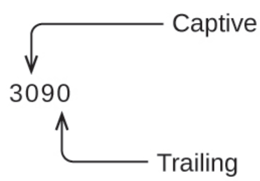
Figure 1.3 To measure the volume of liquid in this graduated cylinder, you must mentally subdivide the distance between the 21 and 22 mL marks into tenths of a milliliter, and then make a reading (estimate) at the bottom of the meniscus. [credit: *Chemistry 2e*. Figure 1.26. OpenStax. CC BY.]

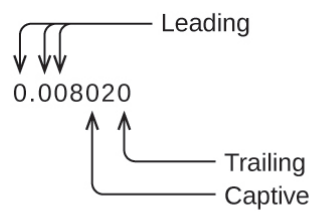
The bottom of the meniscus in this case clearly lies between the 21 and 22 markings, meaning the liquid volume is *certainly* greater than 21 mL but less than 22 mL. The meniscus appears to be a bit closer to the 22-mL mark than to the 21-mL mark, and so a reasonable estimate of the liquid's volume would be 21.6 mL. In the number 21.6, then, the digits 2 and 1 are certain, but the 6 is an estimate. Some people might estimate the meniscus position to be equally distant from each of the markings and estimate the tenth-place digit as 5, while others may think it to be even closer to the 22-mL mark and estimate this digit to be 7. Note that it would be pointless to attempt to estimate a digit for the hundredths place, given that the tenths-place digit is uncertain. In general, numerical scales such as the one on this graduated cylinder will permit measurements to one-tenth of the smallest scale division. The scale in this case has 1-mL divisions, and so volumes may be measured to the nearest 0.1 mL.

This concept holds true for all measurements, even if you do not actively make an estimate. If you place a quarter on a standard electronic balance, you may obtain a reading of 6.72 g. The digits 6 and 7 are certain, and the 2 indicates that the mass of the quarter is likely between 6.71 and 6.73 grams. The quarter weighs *about* 6.72 grams, with a nominal uncertainty in the measurement of ± 0.01 gram. If the coin is weighed on a more sensitive balance, the mass might be 6.723 g. This means its mass lies between 6.722 and 6.724 grams, an uncertainty of 0.001 gram. Every measurement has some **uncertainty**, which depends on the device used (and the user's ability). All the digits in a measurement, including the uncertain last digit, are called **significant**

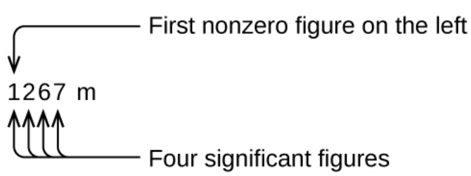
figures or **significant digits**. Note that zero may be a measured value; for example, if you stand on a scale that shows weight to the nearest pound and it shows “120,” then the 1 (hundreds), 2 (tens) and 0 (ones) are all significant (measured) values.

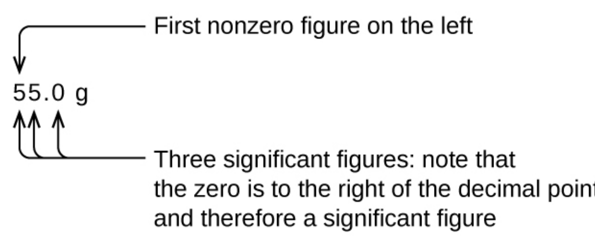
A measurement result is properly reported when its significant digits accurately represent the certainty of the measurement process. But what if you were analyzing a reported value and trying to determine what is significant and what is not? Well, for starters, all nonzero digits are significant, and it is only zeros that require some thought. We will use the terms “leading,” “trailing,” and “captive” for the zeros and will consider how to deal with them.



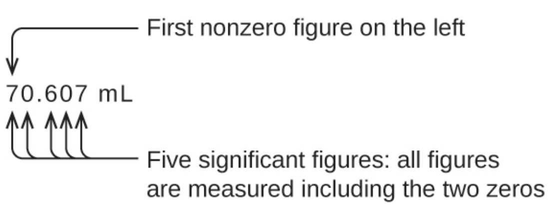


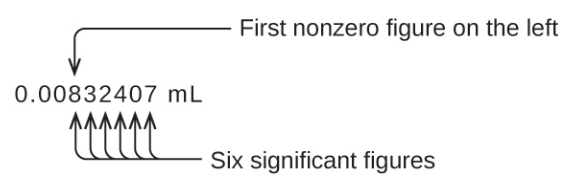
Starting with the first nonzero digit on the left, count this digit and all remaining digits to the right. This is the number of significant figures in the measurement unless the last digit is a trailing zero lying to the left of the decimal point.





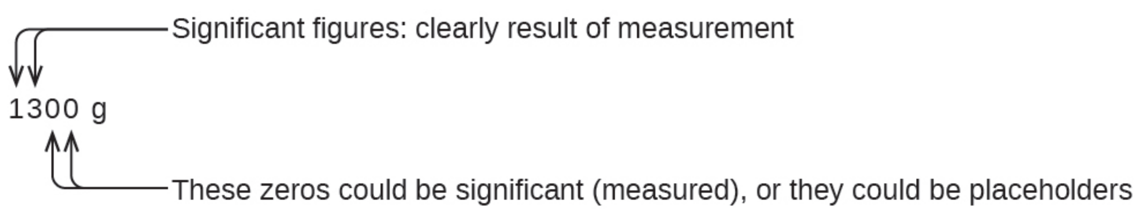
Captive zeros result from measurement and are therefore always significant. Leading zeros, however, are never significant—they merely tell us where the decimal point is located.





The leading zeros in this example are not significant. We could use exponential notation (see OpenStax *Chemistry 2e* Appendix B) and express the number as 8.32407×10^{-3}; then the number 8.32407 contains all of the significant figures, and 10^{-3} locates the decimal point.

The number of significant figures is uncertain in a number that ends with a zero to the left of the decimal point location. The zeros in the measurement 1,300 grams could be significant or they could simply indicate where the decimal point is located. The ambiguity can be resolved with the use of exponential notation: 1.3×10^3 (two significant figures), 1.30×10^3 (three significant figures, if the tens place was measured), or 1.300×10^3 (four significant figures, if the ones place was also measured). In cases where only the decimal-formatted number is available, it is prudent to assume that all trailing zeros are not significant.



When determining significant figures, be sure to pay attention to reported values and think about the measurement and significant figures in terms of what is reasonable or likely when evaluating whether the value makes sense. For example, the official January 2014 census reported the resident population of the US as 317,297,725. Do you think the US population was correctly determined to the reported nine significant figures, that is, to the exact number of people? People are constantly being born, dying, or moving into or out of the country, and assumptions are made to account for the large

number of people who are not actually counted. Because of these uncertainties, it might be more reasonable to expect that we know the population to within perhaps a million or so, in which case the population should be reported as 3.17×10^8 people.

Significant Figures in Calculations

A second important principle of uncertainty is that results calculated from a measurement are at least as uncertain as the measurement itself. Take the uncertainty in measurements into account to avoid misrepresenting the uncertainty in calculated results. One way to do this is to report the result of a calculation with the correct number of significant figures, which is determined by the following three rules for **rounding** numbers:

1. When adding or subtracting numbers, round the result to the same number of decimal places as the number with the least number of decimal places (the least certain value in terms of addition and subtraction).

2. When multiplying or dividing numbers, round the result to the same number of digits as the number with the least number of significant figures (the least certain value in terms of multiplication and division).

3. If the digit to be dropped (the one immediately to the right of the digit to be retained) is less than 5, “round down” and leave the retained digit unchanged; if it is more than 5, “round up” and increase the retained digit by 1. If the dropped digit is 5, and it’s either the last digit in the number or it’s followed only by zeros, round up or down, whichever yields an even value for the retained digit. If any nonzero digits follow the dropped 5, round up. (The last part of this rule may strike you as a bit odd, but it’s based on reliable statistics and is aimed at avoiding any bias when dropping the digit “5,” since it is equally close to both possible values of the retained digit.)

The following examples illustrate the application of this rule in rounding a few different numbers to three significant figures:

- 0.028675 rounds “up” to 0.0287 (the dropped digit, 7, is greater than 5)
- 18.3384 rounds “down” to 18.3 (the dropped digit, 3, is less than 5)
- 6.8752 rounds “up” to 6.88 (the dropped digit is 5, and a nonzero digit follows it)
- 92.85 rounds “down” to 92.8 (the dropped digit is 5, and the retained digit is even)

Accuracy and Precision

Scientists typically make repeated measurements of a quantity to ensure the quality of their findings and to evaluate both the **precision** and the **accuracy** of their results. Measurements are said to be precise if they yield very similar results when repeated in the same manner. A measurement is considered accurate if it yields a result that is very close to the true or accepted value. Precise values agree with each other; accurate values agree with a true value. These characterizations can be extended to other contexts, such as the results of an archery competition (Figure 1.4).

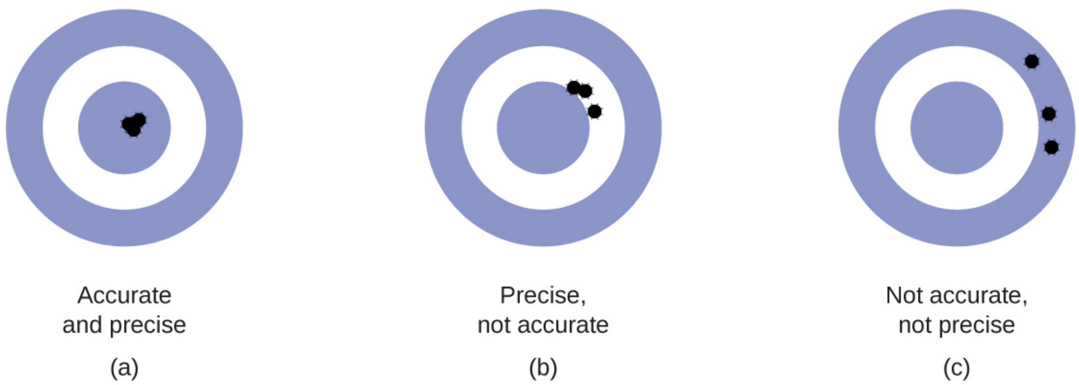


Figure 1.4 (a) These arrows are close to both the bull's eye and one another, so they are both accurate and precise. (b) These arrows are close to one another but not on target, so they are precise but not accurate. (c) These arrows are neither on target nor close to one another, so they are neither accurate nor precise. [credit: *Chemistry 2e*. Figure 1.27. OpenStax. CC BY.]

Suppose a quality control chemist at a pharmaceutical company is tasked with checking the accuracy and precision of three different machines that are meant to dispense 10 ounces (296 mL) of cough syrup into storage bottles. She proceeds to use each machine to fill five bottles and then carefully determines the actual volume dispensed, obtaining the results tabulated in Table 1.3 below.

Table 1.3 Volume (mL) of Cough Medicine Delivered by 10-oz (296 mL) Dispensers

Dispenser #1	Dispenser #2	Dispenser #3
283.3	298.3	296.1
284.1	294.2	295.9
283.9	296.0	296.1
284.0	297.8	296.0
284.1	293.9	296.1

[credit: *Chemistry 2e*. Table 1.5. OpenStax. CC BY.]

Considering these results, she will report that dispenser #1 is precise (values all close to one another, within a few tenths of a milliliter) but not accurate (none of the values are close to the target value of 296 mL, each being more than 10 mL too low). Results for dispenser #2 represent improved accuracy (each volume is less than 3 mL away from 296 mL) but worse precision (volumes vary by more than 4 mL). Finally, she can report that dispenser #3 is working well, dispensing cough syrup both accurately (all volumes within 0.1 mL of the target volume) and precisely (volumes differing from each other by no more than 0.2 mL).

Mathematical Treatment of Measurement Results

It is often the case that a quantity of interest may not be easy (or even possible) to measure directly but instead must be calculated from other directly measured properties and appropriate mathematical relationships. For example, consider measuring the average speed of an athlete running sprints. This is typically accomplished by measuring the *time* required for the athlete to run from the starting line to the finish line, and the *distance* between these two lines, and then computing *speed* from the equation that relates these three properties:

$$speed = \frac{distance}{time}$$

An Olympic-quality sprinter can run 100 m in approximately 10 s, corresponding to an average speed of,

$$\frac{100\ m}{10\ s} = 10\ m/s$$

Note that this simple arithmetic involves dividing the numbers of each measured quantity to yield the number of the computed quantity (100/10 = 10) *and likewise* dividing the units of each measured quantity to yield the unit of the computed quantity (m/s = m/s). Now, consider using this same relation to predict the time required for a person running at this speed to travel a distance of 25 m. The same relation among the three properties is used, but in this case, the two quantities provided are a speed (10 m/s) and a distance (25 m). To yield the sought property, time, the equation must be rearranged appropriately:

$$time = \frac{distance}{speed}$$

The time can then be computed as:

$$\frac{25\ m}{10\ m/s} = 2.5\ s$$

Again, arithmetic on the numbers (25/10 = 2.5) was accompanied by the same arithmetic on the units (m/m/s = s) to yield the number and unit of the result, 2.5 s. Note that, just as for numbers, when a unit is divided by an identical unit (in this case, m/m), the result is “1”—or, as commonly phrased, the units “cancel.”

These calculations are examples of a versatile mathematical approach known as **dimensional analysis** (or the **factor-label method**). Dimensional analysis is based on the below premise.

In dimensional analysis, the units of quantities must be subjected to the same mathematical operations as their associated numbers.

This method can be applied to computations ranging from simple unit conversions to more complex, multi-step calculations involving several different quantities.

Conversion Factors and Dimensional Analysis

A ratio of two equivalent quantities expressed with different measurement units can be used as a **unit conversion factor**. For example, the lengths of 2.54 cm and 1 in. are equivalent (by definition), and so a unit conversion factor may be derived from the ratio,

$$\frac{2.54\ cm}{1\ in.}(2.54\ cm = 1\ in.)\text{ or }2.54\frac{cm}{in.}$$

In Table 1.4, several other commonly used conversion factors are given.

Table 1.4 Common Conversion Factors

Length	Volume	Mass
1 m = 1.0936 yd	1 L = 1.0567 qt	1 kg = 2.2046 lb
1 in. = 2.54 cm (exact)	1 qt = 0.94635 L	1 lb = 453.59 g
1 km = 0.62137 mi	1 ft^3 = 28.317 L	1 (avoirdupois) oz = 28.349 g
1 mi = 1609.3 m	1 tbsp = 14.787 mL	1 (troy) oz = 31.103 g

[credit: *Chemistry 2e*. Table 1.6. OpenStax. CC BY.]

When a quantity (such as distance in inches) is multiplied by an appropriate unit conversion factor, the quantity is converted to an equivalent value with different units (such as distance in centimeters). For example, a basketball player's vertical jump of 34 inches can be converted to centimeters by:

$$34\ \cancel{in.} \times \frac{2.54\ cm}{1\ \cancel{in.}} = 86\ cm$$

Since this simple arithmetic involves quantities, the premise of dimensional analysis requires that we multiply both numbers and units. The numbers of these two quantities are multiplied to yield the number of the product quantity, 86, whereas the units are multiplied to yield $\frac{in.\ x\ cm}{in.}$. Just as for numbers, a ratio of identical units is also numerically equal to one, $\frac{in.}{in.} = 1$, and the unit product thus simplifies to *cm*. (When identical units divide to yield a factor of 1, they are said to "cancel.") Dimensional analysis may be used to confirm the proper application of unit conversion factors as demonstrated in the following example.

Conversion of Temperature Units

We use the word **temperature** to refer to the hotness or coldness of a substance. One way we measure a change in temperature is to use the fact that most substances expand when their temperature increases and contract when their temperature decreases. The mercury or alcohol in a common glass thermometer changes its volume as the temperature changes, and the position of the trapped liquid along a printed scale may be used as a measure of temperature.

Temperature scales are defined relative to selected reference temperatures: Two of the most commonly used are the freezing and boiling temperatures of water at a specified atmospheric pressure. On the Celsius scale, 0 °C is defined as the freezing temperature of water and 100 °C as the boiling temperature of water. The space between the two temperatures is divided into 100 equal intervals, which we call degrees. On the **Fahrenheit** scale, the freezing point of water is defined as 32 °F and the boiling temperature as 212 °F. The space between these two points on a Fahrenheit thermometer is divided into 180 equal parts (degrees).

Defining the Celsius and Fahrenheit temperature scales as described in the previous paragraph results in a slightly more complex relationship between temperature values on these two scales than for different units of measure for other properties. Most measurement units for a given property are directly proportional to one another (y = mx). Using familiar length units as one example:

$$length\ in\ feet = \left(\frac{1\,ft}{12\,in.}\right) \times\ length\ in\ inches$$

where y = length in feet, x = length in inches, and the proportionality constant, m, is the conversion factor. The Celsius and Fahrenheit temperature scales, however, do not share a common zero point, and so the relationship between these two scales is a linear one rather than a proportional one (y = mx + b). Consequently, converting a temperature from one of these scales into the other requires more than simple multiplication by a conversion factor, m, it also must take into account differences in the scales' zero points (b).

The linear equation relating Celsius and Fahrenheit temperatures is easily derived from the two temperatures used to define each scale. Representing the Celsius temperature as *x* and the Fahrenheit temperature as *y*, the slope, *m*, is computed to be:

$$m = \frac{\Delta y}{\Delta x} = \frac{212\ °\text{F} - 32\ °\text{F}}{100\ °\text{C} - 0\ °\text{C}} = \frac{180\ °\text{F}}{100\ °\text{C}} = \frac{9\ °\text{F}}{5\ °\text{C}}$$

The *y*-intercept of the equation, *b*, is then calculated using either of the equivalent temperature pairs, (100 °C, 212 °F) or (0 °C, 32 °F), as:

$$b = y - mx = 32\ °\text{F} - \frac{9\ °\text{F}}{5\ °\text{C}} \times 0\ °\text{C} = 32\ °\text{F}$$

The equation relating the temperature (*T*) scales is then:

$$T_{°\text{F}} = \left(\frac{9\ °\text{F}}{5\ °\text{C}} \times T_{°\text{C}}\right) + 32\ °\text{F}$$

An abbreviated form of this equation that omits the measurement units is:

$$T_{°\text{F}} = \left(\frac{9}{5} \times T_{°\text{C}}\right) + 32 T_{°\text{F}} = \left(\frac{9}{5} \times T_{°\text{C}}\right) + 32$$

Rearrangement of this equation yields the form useful for converting from Fahrenheit to Celsius:

$$T_{°\text{C}} = \frac{5}{9}(T_{°\text{F}} - 32)$$

As mentioned earlier in this chapter, the SI unit of temperature is the kelvin (K). Unlike the Celsius and Fahrenheit scales, the kelvin scale is an absolute temperature scale in which 0 (zero) K corresponds to the lowest temperature that can theoretically be achieved. Since the kelvin temperature scale is absolute, a degree symbol is not included in the unit abbreviation, K. The early 19th-century discovery of the relationship between a gas's volume and temperature suggested that the volume of a gas would be zero at −273.15 °C. In 1848, British physicist William Thompson, who later adopted the title of Lord Kelvin, proposed an absolute temperature scale based on this concept.

The freezing temperature of water on this scale is 273.15 K and its boiling temperature is 373.15 K. Notice the numerical difference in these two reference temperatures is 100, the same as for the Celsius scale, and so the linear relation between these two temperature scales will exhibit a slope of $1\frac{K}{°C}$. Following the same approach, the equations for converting between the kelvin and Celsius temperature scales are derived to be:

$$T_{\text{K}} = T_{°\text{C}} + 273.15$$

$$T_{°\text{C}} = T_{\text{K}} - 273.15$$

The 273.15 in these equations has been determined experimentally, so it is not exact. Figure 1.5 shows the relationship among the three temperature scales.

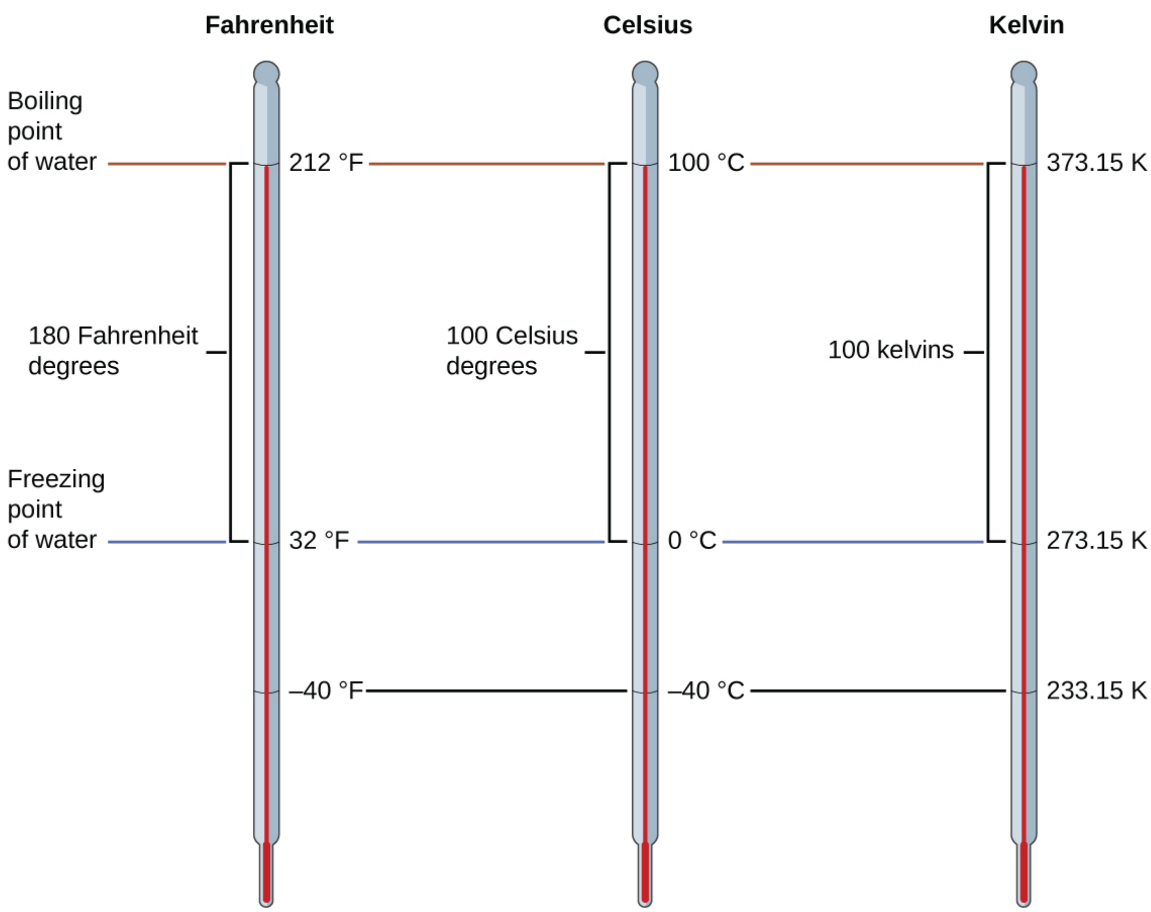


Figure 1.5 The Fahrenheit, Celsius, and kelvin temperature scales are compared. [credit: *Chemistry 2e*. Figure 1.28. OpenStax. CC BY.]

Although the kelvin (absolute) temperature scale is the official SI temperature scale, Celsius is commonly used in many scientific contexts and is the scale of choice for nonscience contexts in almost all areas of the world. Very few countries (the U.S. and its territories, the Bahamas, Belize, Cayman Islands, and Palau) still use Fahrenheit for weather, medicine, and cooking.

Key Graphing Concepts

Math is a tool for understanding relationships that can be expressed mathematically using algebra or graphs. The algebraic equation for a line is,

$$y = b + mx$$

where x is the variable on the horizontal axis and y is the variable on the vertical axis, the b term is the y-intercept and the m term is the slope. An axis is a measurement reference line. The slope of a line is the same at any point on the line and it indicates the relationship (positive, negative, or zero) between two variables.

Graphs allow you to illustrate data visually. They can illustrate patterns, comparisons, trends, and apportionment by condensing the numerical data and providing an intuitive sense of relationships in the data. A line graph shows the relationship between two variables: one is shown on the horizontal axis and one on the vertical axis.

Any graph is a single visual perspective on a subject. The impression it leaves will be based on many choices, such as what data or time frame is included, how data or groups are divided up, the relative size of vertical and horizontal axes, whether the scale used on a vertical starts at zero. Thus, any graph should be regarded somewhat skeptically, remembering that the underlying relationship can be open to different interpretations.

Interpretation of Graphs

There are other ways of representing models, such as text or narrative. But why would you use your fist to bang a nail, if you had a hammer? Math has certain advantages over text. It disciplines your thinking by making you specify exactly what you mean. You can get away with fuzzy thinking in your head, but you cannot when you reduce a model to algebraic equations. At the same time, math also has disadvantages. Mathematical models are necessarily based on simplifying assumptions, so they are not likely to be perfectly realistic. Mathematical models also lack the nuances which can be found in narrative models. The point is that math is one tool, but it is not the only tool or even always the best tool scientists can use. So, what math will you need for this lab manual? The answer is: little more than high school algebra and graphs.

You will need to know:

- What a function is
- How to interpret the equation of a line (i.e., slope and intercept)
- How to manipulate a line (i.e., changing the slope or the intercept)
- How to compute and interpret a growth rate (i.e., percentage change)
- How to read and manipulate a graph

Algebraic Models

Often, parts of models are expressed in terms of mathematical functions. What is a function? A function describes a relationship. Sometimes the relationship is a definition. For example (using words), your professor is Adam Smith. This could be expressed as,

$$\text{Professor} = \text{Adam Smith}$$

As another example (using words), let's say your friends are Margaret, Bob, and Shawn. Mathematically, the relationship with your friends could be expressed as,

$$\text{Friends} = \text{Margaret} + \text{Bob} + \text{Shawn} + \text{Margaret}$$

Functions describe cause and effect. The variable on the left-hand side is what is being explained ("the effect"). On the right-hand side is what is doing the explaining ("the causes"). For example, suppose your GPA was determined as follows:

$$\text{GPA} = 0.25 \times \text{combined\_SAT} + 0.25 \times \text{class\_attendance} + 0.50 \times \text{hours\_spent\_studying}$$

$$\text{GPA} = 0.25 \times \text{combined\_SAT} + 0.25 \times \text{class\_attendance} + 0.50 \times \text{hours\_spent\_studying}$$

This equation states that your GPA depends on three things: your combined SAT score, your class attendance, and the number of hours you spend studying. It also says that study time is twice as important (0.50) as either combined_SAT score (0.25) or class_attendance (0.25). If this relationship is true, how could you raise your GPA? By not skipping class and studying more. Note that you cannot do anything about your SAT score, since if you are in college, you have (presumably) already taken the SATs.

Most relationships we use in general chemistry are expressed as linear equations of the form $y = b + mx$.

Expressing Equations Graphically

Graphs are useful for two purposes. The first is to express equations visually, and the second is to display statistics or data. This section will discuss expressing equations visually.

A variable is the name given to a quantity that may assume a range of values. In the equation of a line presented above, x and y are the variables, with x on the horizontal axis and y on the vertical axis, and b and m representing factors that determine the shape of the line. To see how this equation works, consider a numerical example:

$$y = 9 + 3x$$

In this equation for a specific line, the b term has been set equal to 9 and the m term has been set equal to 3. Table 1.5 shows the values of x and y for this given equation.

Table 1.5 Values for the Slope Intercept Equation

x	y
0	9
1	12
2	15
3	18
4	21
5	24
6	27

[credit: *Principles of Economics 2e.* TableA1. OpenStax. CC BY.]

Figure 1.6 shows this equation, and these values, in a graph. To construct the table, just plug in a series of different values for x, and then calculate what value of y results. In the figure, these points are plotted and a line is drawn through them.

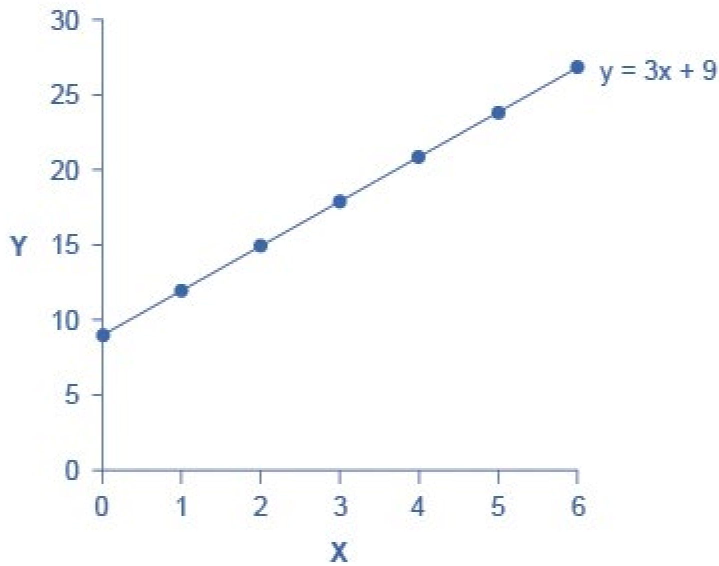


Figure 1.6 Slope and the Algebra of Straight Lines. The line graph has *x* on the horizontal axis and y on the vertical axis. The y-intercept—that is, the point where the line intersects the y-axis—is 9. The slope of the line is 3; that is, there is a rise of 3 on the vertical axis for every increase of 1 on the horizontal axis. The slope is the same all along a straight line. [credit: *Principles of Economics 2e.* Figure A1. OpenStax. CC BY.]

This example illustrates how the b and m terms in an equation for a straight line determine the shape of the line. The b term is called the y-intercept. The reason for this name is that, if x = 0, then the b term will reveal where the line intercepts, or crosses, the y-axis. In this example, the line hits the vertical axis at 9. The m term in the equation for the line is the slope. Remember that slope is defined as rise over run; more specifically, the slope of a line from one point to another is the change in the vertical axis divided by the change in the horizontal axis. In this example, each time the x term increases by one (the run), the y term rises by three. Thus, the slope of this line is three. Specifying a y-intercept and a slope—that is, specifying b and m in the equation for a line—will identify a specific line. Although it is rare for real-world data points to arrange themselves as an exact straight line, it often turns out that a straight line can offer a reasonable approximation of actual data.

Interpreting the Slope

The concept of slope is very useful in all sciences, because it measures the relationship between two variables. A positive slope means that two variables are positively related; that is, when x increases, so does y, or when x decreases, y decreases also. Graphically, a positive slope means that as a line on the line graph moves from left to right, the line rises. The length-weight relationship, shown in Figure 1.7 later in the “Line Graph” section, has a positive slope.

A negative slope means that two variables are negatively related; that is, when x increases, y decreases, or when x decreases, y increases. Graphically, a negative slope means that, as the line on the line graph moves from left to right, the line falls. The altitude-air density relationship, shown in Figure 1.8 later in the "Line Graph" section, has a negative slope. A slope of zero means that there is no relationship between x and y. Graphically, the line is flat; that is, zero rise over the run.

The slope of a straight line between two points can be calculated in numerical terms. To calculate slope, begin by designating one point as the "starting point" and the other point as the "end point" and then calculating the rise over run between these two points. As an example, consider the slope of the air density graph between the points representing an altitude of 4,000 meters and an altitude of 6,000 meters:

Rise: Change in variable on vertical axis (end point minus original point),

$$\text{Rise} = 0.100 - 0.307 = -0.207$$

Run: Change in variable on horizontal axis (end point minus original point)

$$\text{Run} = 6{,}000 - 4{,}000 = 2{,}000$$

Thus, the slope of a straight line between these two points would be that from the altitude of 4,000 meters up to 6,000 meters, the density of the air decreases by approximately 0.1 kilograms/cubic meter for each of the next 1,000 meters.

Suppose the slope of a line were to increase. Graphically, that means it would get steeper. Suppose the slope of a line were to decrease. Then it would get flatter. These conditions are true whether or not the slope was positive or negative to begin with. A higher positive slope means a steeper upward tilt to the line, while a smaller positive slope means a flatter upward tilt to the line. A negative slope that is larger in absolute value (that is, more negative) means a steeper downward tilt to the line. A slope of zero is a horizontal flat line. A vertical line has an infinite slope.

Suppose a line has a larger intercept. Graphically, that means it would shift out (or up) from the old origin, parallel to the old line. If a line has a smaller intercept, it would shift in (or down), parallel to the old line.

Displaying Data Graphically and Interpreting the Graph

Graphs are also used to display data or evidence. Graphs are a method of presenting numerical patterns. They condense detailed numerical information into a visual form in which relationships and numerical patterns can be seen more easily. For example, which countries have larger or smaller populations? A careful reader could examine a long list of numbers representing the populations of many countries, but with over 200 nations in the world, searching through such a list would take concentration and time. Putting these same numbers on a graph can quickly reveal population patterns.

Line Graphs

The graphs we have discussed so far are called line graphs, because they show a relationship between two variables: one measured on the horizontal axis and the other measured on the vertical axis.

Sometimes it is useful to show more than one set of data on the same axes. The data in Table 1.6a and Table 1.6b is displayed in Figure 1.7, which shows the relationship between two variables: length and median weight for American baby boys and girls during the first three years of life. (The median means that half of all babies weigh more than this and half weigh less.) The line graph measures length in inches on the horizontal axis and weight in pounds on the vertical axis. For example, point A on the figure shows that a boy who is 28 inches long will have a median weight of about 19 pounds. One line on the graph shows the length-weight relationship for boys and the other line shows the relationship for girls. This kind of graph is widely used by healthcare providers to check whether a child's physical development is roughly on track.

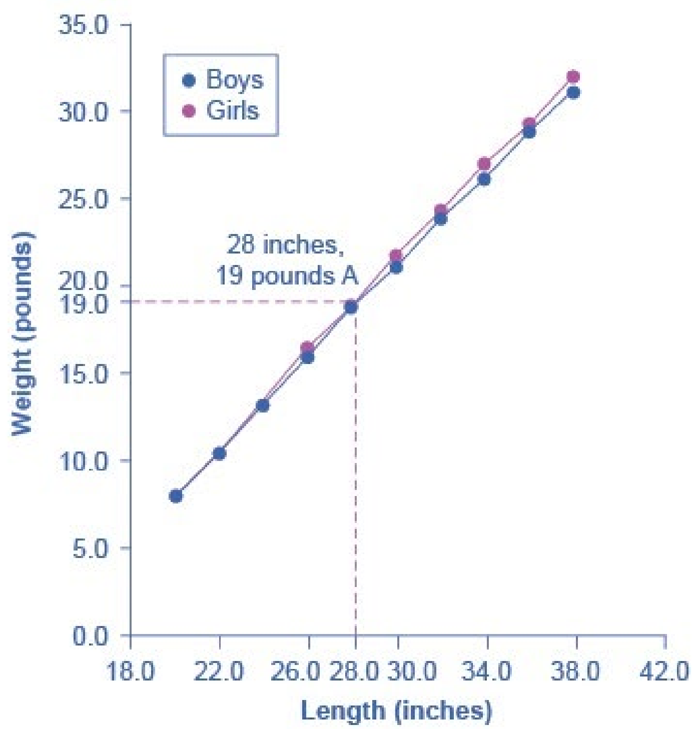


Figure 1.7 The Length-Weight Relationship for American Girls and Boys. The line graph shows the relationship between height and weight for boys and girls from birth to 3 years. Point A, for example, shows that a boy of 28 inches in height (measured on the horizontal axis) is typically 19 pounds in weight (measured on the vertical axis). These data apply only to children in the first three years of life. [credit: *Principles of Economics 2e.* Figure A3. OpenStax. CC BY.]

Table 1.6a Length to Weight Relationship for American Girls from Birth to 36 Months

Girl Length (inches)	Girl Weight (pounds)
20.0	7.9
22.0	10.5
24.0	13.2
26.0	16.0
28.0	18.8
30.0	21.2
32.0	24.0
34.0	26.2
36.0	28.9
38.0	31.3

[credit: *Principles of Economics 2e.* Split from TableA2. OpenStax. CC BY.]

Table 1.6b Length to Weight Relationship for American Boys from Birth to 36 Months

Boy Length (inches)	Boy Weight (pounds)
20.0	8.0
22.0	10.5
24.0	13.5
26.0	16.4
28.0	19.0
30.0	21.8
32.0	24.3
34.0	27.0
36.0	29.3
38.0	32.0

[credit: *Principles of Economics 2e.* Split from TableA2. OpenStax. CC BY.]

Not all relationships are linear. Sometimes they are curves. Figure 1.8 presents another example of a line graph, representing the data from Table 1.7. In this case, the line graph shows how thin the air becomes when you climb a mountain. The horizontal axis of the figure shows altitude, measured in meters above sea level. The vertical axis measures the density of the air at each altitude. Air density is measured by the weight of the air in a cubic meter of space (that is, a box measuring one meter in height, width, and depth). As the graph shows, air pressure is heaviest at ground level and becomes lighter as you climb. Figure 1.8 shows that a cubic meter of air at an altitude of 500 meters weighs approximately one kilogram (about 2.2 pounds). However, as the altitude increases, air density decreases. A cubic meter of air at the top of Mount Everest, at about 8,828 meters, would weigh only 0.023 kilograms. The thin air at high altitudes explains why many mountain climbers need to use oxygen tanks as they reach the top of a mountain.

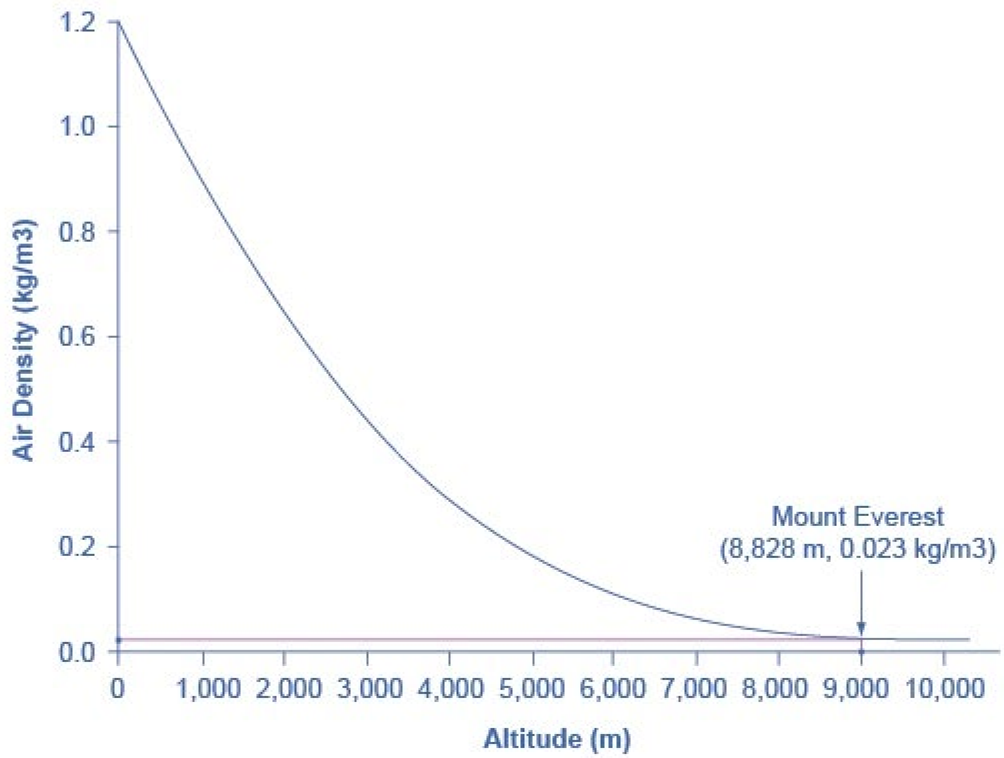


Figure 1.8 Altitude-Air Density Relationship. This line graph shows the relationship between altitude, measured in meters above sea level, and air density, measured in kilograms of air per cubic meter. As altitude rises, air density declines. The point at the top of Mount Everest has an altitude of approximately 8,828 meters above sea level (the horizontal axis) and air density of 0.023 kilograms per cubic meter (the vertical axis). [credit: *Principles of Economics 2e.* Figure A4. OpenStax. CC BY.]

Table 1.7 Altitude to Air Density Relationship

Altitude (meters)	Air Density (kg/cubic meters)
0	1.200
500	1.093
1,000	0.831
1,500	0.678
2,000	0.569
2,500	0.484
3,000	0.415
3,500	0.357
4,000	0.307
4,500	0.231
5,000	0.182
5,500	0.142
6,000	0.100
6,500	0.085
7,000	0.066
7,500	0.051
8,000	0.041
8,500	0.025
9,000	0.022
9,500	0.019
10,000	0.014

[credit: *Principles of Economics 2e.* TableA3. OpenStax. CC BY.]

The length-weight relationship and the altitude-air density relationships in these two figures represent averages. If you were to collect actual data on air pressure at different altitudes, the same altitude in different geographic locations will have slightly different air density, depending on factors like how far you are from the equator, local weather conditions, and the humidity in the air. Similarly, in measuring the height and weight of children for the previous line graph, children of a particular height would have a range of different weights, some above average and some below. In the real world, this sort of variation in data is common. The task of a researcher is to organize that data in a way that helps to understand typical patterns.

Two-Dimensional (*x*-*y*) Graphing

The relationship between any two properties of a system can be represented graphically by a two-dimensional data plot. Such a graph has two axes: a horizontal one corresponding to the independent variable, or the variable whose value is being controlled (*x*), and a vertical axis corresponding to the dependent variable, or the variable whose value is being observed or measured (*y*).

When the value of *y* is changing as a function of *x* (that is, different values of *x* correspond to different values of *y*), a graph of this change can be plotted or sketched. The graph can be produced by using specific values for (*x*, *y*) data pairs.

CONCEPT IN ACTION: GRAPHING THE DEPENDENCE OF Y ON X

Table 1.8 contains the following points: (1,5), (2,10), (3,7), and (4,14).

Table 1.8 Data to Graph Dependence of *y* on *x*

x	y
1	5
2	10
3	7
4	14

Shown in Figure 1.9, each of these points can be plotted on a graph connected to produce a graphical representation of the dependence of y on x.

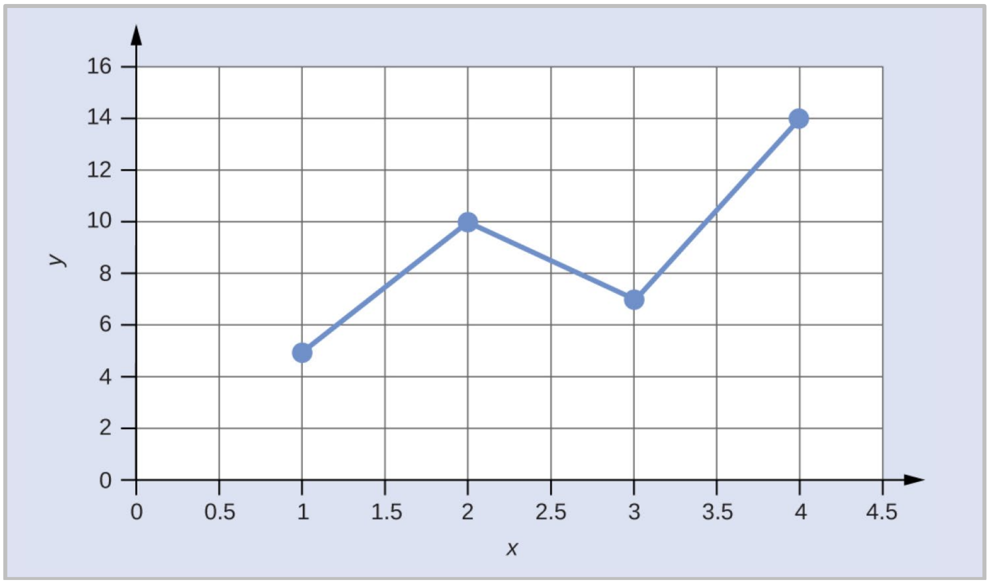


Figure 1.9 Graphical representation of the dependence of y on x. [credit: *Chemistry 2e.* Example B11. OpenStax. CC BY.]

If the function that describes the dependence of *y* on *x* is known, it may be used to compute x, y data pairs that may subsequently be plotted.

Concept in Action: Plotting Data Pairs

If we know that $y = x^2 + 2$, we can produce a table of a few (x, y) values and then plot the line based on the data shown here.

Table 1.9 Data to Plot Pairs

x	$y = x^2 + 2$
1	3
2	6
3	11
4	18

[credit: *Chemistry 2e.* Example B12. OpenStax. CC BY.]

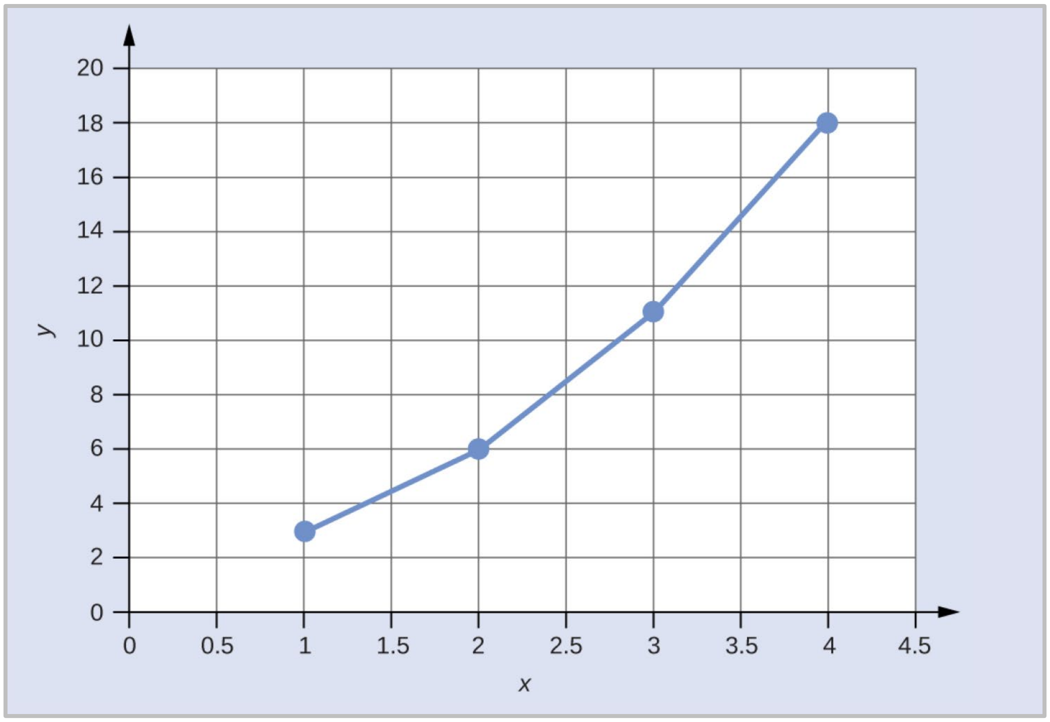


Figure 1.10 Graphical representation of $y = x^2 + 2$. [credit: *Chemistry 2e.* Example B12. OpenStax. CC BY.]

Tools and How We Use Them

Graduated cylinder: A Graduated cylinder (Figure 1.11) has a narrow cylindrical shape with a calibrated scale marked on the outside of the wall representing the amount of liquid that has been measured. Graduated cylinders have different sizes. The scale divisions on a graduated cylinder are determined by its size. The scale is read to one digit beyond the smallest scale and uses the bottom of the meniscus to determine the volume in the graduated cylinder. If you have a 10mL graduated cylinder, if the smallest graduation is tenth of a milliliter (0.1mL), so when you read the volume, you can estimate to the hundredths place (0.01mL).

Figure 1.11 Graduated cylinder. [credit: Florida Atlantic University Center for Online and Continuing Education.]

Volumetric Flask: Volumetric flask (Figure 1.12) is a laboratory glassware that is used to prepare solutions, primarily standard or stock solutions. They are calibrated at a specific volume, reducing the uncertainty for the given volumetric flask. The narrow neck of the volumetric flask will have a thin graduation to show where a specific volume is reached.

Figure 1.12 Volumetric flask. [credit: Florida Atlantic University Center for Online and Continuing Education.]

Pippets or Pipet: Pipets are an essential laboratory tool, and used to dispense a certain amount of liquids. They are calibrated to deliver a specific volume; they measure volume of solution more precisely, marked like graduated cylinders. They are designed to measure specific volume and commonly come in sizes 1 mL, 2 mL, 5 mL, 10 mL, 25 mL, and 50 mL. The best way to measure volumes is to use a volumetric pipette (Figure 1.13) and micropipette.

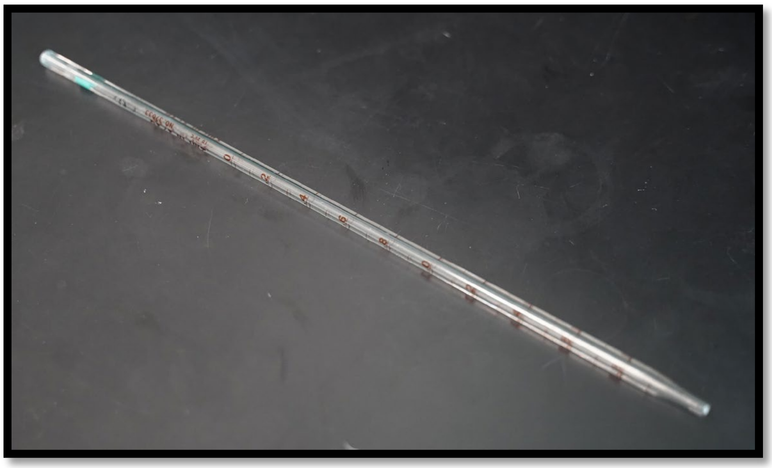


Figure 1.13 Pipet. [credit: Florida Atlantic University Center for Online and Continuing Education.]

Erlenmeyer Flask: An Erlenmeyer flask (Figure 1.14) is a cone-shaped glassware with a neck that allows to hold the flask or attach the clamp, the shape makes the flask very stable. They are used for mixing and storing chemicals and solutions and you can shake or stir the flask without spilling liquid. By using cork or stopper or parafilm, Erlenmeyer can be sealed up to store the solution.

Figure 1.14 Erlenmeyer flask. [credit: Florida Atlantic University Center for Online and Continuing Education.]

Beaker: Beakers are used for measuring and mixing of the reactions mixtures, solutions in the lab. They are used to measure volumes to within 10% accuracy. They are marked on the side with lines indicating the volume contains, beakers should be used for obtaining precise measurement of volume. Figure 1.15 shows an individual beaker.

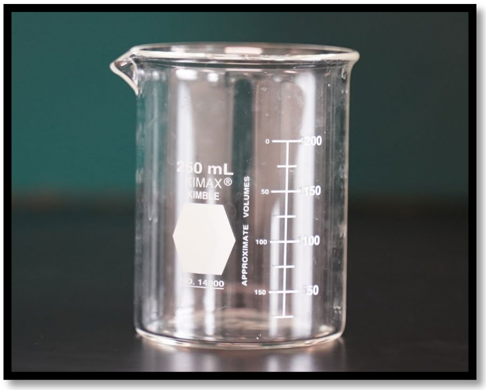


Figure 1.15 Beaker. [credit: Florida Atlantic University Center for Online and Continuing Education.]

Burette or Buret: Another glassware measures liquids precisely is burette. Burette is similar to the graduated cylinder and is easier to measure a required volume of liquid through graduations. They are primarily used when it is necessary to dispense a small measured volume of liquid, mainly for titrations. Figure 1.16 shows a burette apparatus and Figure 1.17 shows a zoomed-in view of a burette.

Figure 1.16 Burette with white attachment, called a stopcock. A stopcock controls the flow of the liquid. When positioned vertically, as shown, the stopcock is open, which allows the liquid to drain. [credit: Florida Atlantic University Center for Online and Continuing Education.]

Figure 1.17 Zoomed-in image of burette and stopcock. [credit: Florida Atlantic University Center for Online and Continuing Education.]

Scale or Balance: Scales (Figure 1.18) are used to measure the mass of the chemicals. There are many different types of balances available to make a mass measurement. In this lab, mass measurement will be done using top loading electronic balance with an 0.01 g or greater accuracy.

Figure 1.18 Images of scales, also known as balances, to measure mass. [credit: Florida Atlantic University Center for Online and Continuing Education.]

Lab Examples

Example 1.1: Rounding Numbers

Round the following to the indicated number of significant figures:

(a) 31.57 (to two significant figures)

(b) 8.1649 (to three significant figures)

(c) 0.051065 (to four significant figures)

(d) 0.90275 (to four significant figures)

Solution

(a) 31.57 rounds "up" to 32 (the dropped digit is 5, and the retained digit is even)

(b) 8.1649 rounds "down" to 8.16 (the dropped digit, 4, is less than 5)

(c) 0.051065 rounds "down" to 0.05106 (the dropped digit is 5, and the retained digit is even)

(d) 0.90275 rounds "up" to 0.9028 (the dropped digit is 5, and the retained digit is even)

Check Your Learning

Round the following to the indicated number of significant figures:

(a) 0.424 (to two significant figures)

(b) 0.0038661 (to three significant figures)

(c) 421.25 (to four significant figures)

(d) 28,683.5 (to five significant figures)

ANSWER

(a) 0.42; (b) 0.00387; (c) 421.2; (d) 28,684

Example 1.2: Addition and Subtraction with Significant Figures

---

Rule: When adding or subtracting numbers, round the result to the same number of decimal places as the number with the fewest decimal places (i.e., the least certain value in terms of addition and subtraction).

(a) Add 1.0023 g and 4.383 g
(b) Subtract 421.23 g from 486 g

Solution
(a)

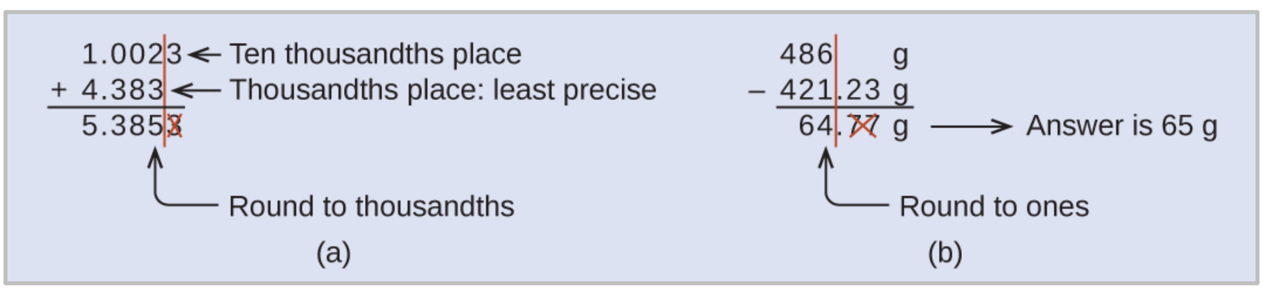
$$\begin{array}{r} 1.0023\text{ g} \\ +\ 4.383\text{ g} \\ \hline 5.3853\text{ g} \end{array}$$

Answer is 5.385 g (rounded to the thousandths place)

(b)

$$\begin{array}{r} 486\text{ g} \\ -421.23\text{ g} \\ \hline 64.77\text{ g} \end{array}$$

The answer is 65 g (rounded to the ones place, that is, no decimal places)



Check Your Learning
(a) Add 2.334 mL and 0.31 mL
(b) Subtract 55.8752 m from 56.533 m

ANSWER
(a) 2.64 mL
(b) 0.658 m

Example 1.3: Multiplication and Division with Significant Figures

Rule: When multiplying or dividing numbers, round the result to the same number of digits as the number with the fewest significant figures (the least certain value in terms of multiplication and division).

(a) Multiply 0.6238 cm by 6.6 cm
(b) Divide 421.23 g by 486 mL

Solution

(a) $0.6238\text{ cm} \times 6.6\text{ cm} = 4.11708\text{ cm}^2$

$$\longrightarrow \text{result is } 4.1\text{ cm}^2 \text{(rounded to two significant figures)}$$

The result in (a) is rounded to two significant figures due to the multiplication of significant figures rule,

$$\text{four significant figures} \times \text{two significant figures} \longrightarrow \text{two significant figures answer}$$

(b) $\dfrac{421.23\text{ g}}{486\text{ mL}} = 0.86728\ldots\text{ g/mL}$

$$\longrightarrow \text{result is } 0.867\text{ g/mL (rounded to three significant figures)}$$

The result in (b) is rounded to three significant figures due to the division of significant figures rule,

$$\frac{\text{five significant figures}}{\text{three significant figures}} \longrightarrow \text{three significant figures answer}$$

Check Your Learning

(a) Multiply 2.334 cm and 0.320 cm
(b) Divide 55.8752 m by 56.53 s

ANSWER

(a) 0.747 cm^2
(b) 0.9884 m/s

In the midst of all these technicalities, it is important to keep in mind the reason for these rules about significant figures and rounding—to correctly represent the certainty of the values reported and to ensure that a calculated result is not represented as being more certain than the least certain value used in the calculation.

Example 1.4: Calculation with Significant Figures

One common bathtub is 13.44 dm long, 5.920 dm wide, and 2.54 dm deep. Assume that the tub is rectangular and calculate its approximate volume in liters.

Solution

$$V = l \times w \times d$$
$$= 13.44\ \text{dm} \times 5.920\ \text{dm} \times 2.54\ \text{dm}$$
$$= 202.09459 \ldots \text{dm}^3\ \text{(value from calculator)}$$
$$= 202\ \text{dm}^3 \text{ or } 202\ \text{L (answer rounded to three significant figures)}$$

Check Your Learning
What is the density of a liquid with a mass of 31.1415 g and a volume of 30.13 cm^3?

ANSWER
1.034 g/mL

Example 1.5: Using a Unit Conversion Factor

The mass of a competition frisbee is 125 g. Convert its mass to ounces using the unit conversion factor derived from the relationship 1 oz = 28.349 g (Table 1.4).

Solution
Given the conversion factor, the mass in ounces may be derived using an equation similar to the one used for converting length from inches to centimeters.

$$x\ \text{oz} = 125\ \text{g} \times \text{unit conversion factor}$$

The unit conversion factor may be represented as:

$$\frac{1\ \text{oz}}{28.349\ \text{g}} \text{ and } \frac{28.349\ \text{g}}{1\ \text{oz}}$$

The correct unit conversion factor is the ratio that cancels the units of grams and leaves ounces.

$$x \text{ oz} = 125 \cancel{\text{g}} \times \frac{1 \text{ oz}}{28.349 \cancel{\text{g}}}$$

$$= \left(\frac{125}{28.349}\right) \text{oz}$$

$$= 4.41 \text{ oz (three significant figures)}$$

Check Your Learning
Convert a volume of 9.345 qt to liters

ANSWER
8.844 L

Beyond simple unit conversions, the factor-label method can be used to solve more complex problems involving computations. Regardless of the details, the basic approach is the same—all the *factors* involved in the calculation must be appropriately oriented to ensure that their *labels* (units) will appropriately cancel and/or combine to yield the desired unit in the result. As your study of chemistry continues, you will encounter many opportunities to apply this approach.

Example 1.6: Computing Quantities from Measurement Results and Known Mathematical Relations

What is the density of common antifreeze in units of g/mL? A 4.00-qt sample of the antifreeze weighs 9.26 lb.

Solution

Since density $= \frac{\text{mass}}{\text{volume}}$, we need to divide the mass in grams by the volume in milliliters. In general: the number of units of B = the number of units of A × unit conversion factor. The necessary conversion factors are given in Table 1.4 are 1 lb = 453.59 g; 1 L = 1.0567 qt; 1 L = 1,000 mL. Mass may be converted from pounds to grams as follows:

$$9.26 \cancel{\text{lb}} \times \frac{453.59 \text{ g}}{1 \cancel{\text{lb}}} = 4.20 \times 10^3 \text{ g}$$

Volume may be converted from quarts to milliliters via two steps:

Step 1. Convert quarts to liters.

$$4.00\ \cancel{\text{qt}} \times \frac{1\ \text{L}}{1.0567\ \cancel{\text{qt}}} = 3.78\ \text{L}$$

Step 2. Convert liters to milliliters.

$$3.78\ \cancel{\text{L}} \times \frac{1000\ \text{mL}}{1\ \cancel{\text{L}}} = 3.78 \times 10^3\ \text{mL}$$

Then,

$$\text{density} = \frac{4.20 \times 10^3\ \text{g}}{3.78 \times 10^3\ \text{mL}} = 1.11\ \text{g/mL}$$

Alternatively, the calculation could be set up in a way that uses three-unit conversion factors sequentially as follows:

$$\frac{9.26\ \cancel{\text{lb}}}{4.00\ \cancel{\text{qt}}} \times \frac{453.59\ \text{g}}{1\ \cancel{\text{lb}}} \times \frac{1.0567\ \cancel{\text{qt}}}{1\ \cancel{\text{L}}} \times \frac{1\ \cancel{\text{L}}}{1000\ \text{mL}} = 1.11\ \text{g/mL}$$

Check Your Learning
What is the volume in liters of 1.000 oz, given that 1 L = 1.0567 qt and 1 qt = 32 oz (exactly)?

ANSWER
2.956×10^{-2} L

EXAMPLE 1.7: COMPUTING QUANTITIES FROM MEASUREMENT RESULTS AND KNOWN MATHEMATICAL RELATIONS

While being driven from Philadelphia to Atlanta, a distance of about 1250 km, a 2014 Lamborghini Aventador Roadster uses 213 L gasoline.

(a) What (average) fuel economy, in miles per gallon, did the Roadster get during this trip?

(b) If gasoline costs $3.80 per gallon, what was the fuel cost for this trip?

Solution

(a) First convert distance from kilometers to miles:

$$1250\ \cancel{\text{km}} \times \frac{0.62137\ \text{mi}}{1\ \cancel{\text{km}}} = 777\ \text{mi}$$

and then convert volume from liters to gallons:

$$213\ \cancel{\text{L}} \times \frac{1.0567\ \cancel{\text{qt}}}{1\ \cancel{\text{L}}} \times \frac{1\ \text{gal}}{4\ \cancel{\text{qt}}} = 56.3\ \text{gal}$$

Finally,

$$\text{(average) mileage} = \frac{777\ \text{mi}}{56.3\ \text{gal}} = 13.8\ \text{mi/gal} = 13.8\ \text{mpg}$$

Alternatively, the calculation could be set up in a way that uses all the conversion factors sequentially, as follows:

$$\frac{1250\ \cancel{\text{km}}}{213\ \cancel{\text{L}}} \times \frac{0.62137\ \text{mi}}{1\ \cancel{\text{km}}} \times \frac{1\ \cancel{\text{L}}}{1.0567\ \cancel{\text{qt}}} \times \frac{4\ \cancel{\text{qt}}}{1\ \text{gal}} = 13.8\ \text{mpg}$$

(b) Using the previously calculated volume in gallons, we find,

$$56.3\ \cancel{\text{gal}} \times \frac{\$3.80}{1\ \cancel{\text{gal}}} = \$214$$

Check Your Learning

A Toyota Prius Hybrid uses 59.7 L gasoline to drive from San Francisco to Seattle, a distance of 1300 km (two significant digits).

(a) What (average) fuel economy, in miles per gallon, did the Prius get during this trip?

(b) If gasoline costs \$3.90 per gallon, what was the fuel cost for this trip?

ANSWER
(a) 51 mpg
(b) \$62

EXAMPLE 1.8: CONVERSION FROM CELSIUS

Normal body temperature has been commonly accepted as 37.0 °C (although it varies depending on time of day and method of measurement, as well as among individuals). What is this temperature on the kelvin scale and on the Fahrenheit scale?

Solution

$$\text{K} = {}^\circ\text{C} + 273.15 = 37.0 + 273.2 = 310.2\ \text{K}$$

$$^\circ\text{F} = \frac{9}{5}\,{}^\circ\text{C} + 32.0 = \left(\frac{9}{5} \times 37.0\right) + 32.0 = 66.6 + 32.0 = 98.6\ {}^\circ\text{F}$$

Check Your Learning
Convert 80.92 °C to K and °F

ANSWER
354.07 K, 177.7 °F

EXAMPLE 1.9: CONVERSION FROM FAHRENHEIT

Baking a ready-made pizza calls for an oven temperature of 450 °F. If you are in Europe, and your oven thermometer uses the Celsius scale, what is the setting? What is the kelvin temperature?

Solution

$$^\circ\text{C} = \frac{5}{9}({}^\circ\text{F} - 32) = \frac{5}{9}(450 - 32) = \frac{5}{9} \times 418 = 232\ {}^\circ\text{C}$$

$$\longrightarrow \text{set oven to } 230\ {}^\circ\text{C} (\text{two significant figures})$$

$$\text{K} = {}^\circ\text{C} + 273.15 = 230 + 273 = 503\ \text{K}$$

$$\longrightarrow 5.0 \times 10^2\ \text{K (two significant figures)}$$

Check Your Learning
Convert 50 °F to °C and K.

ANSWER
10 °C, 280 K

Relations to Health Sciences

Although any health science degree includes services in hospitals, clinics that promote wellness and implement strategies, it also involves statistical skills such as measurements, drawing, and interpreting charts and diagrams to improve the health of individuals or societies. Doctors, nurses or medical assistants must know how to read medical instruments that can give different units of measurements. Most of the time, nurses receive orders from doctors and they have to be able to transfer these medication orders into the right doses such that an anesthesiologist should take a consideration of patients' weight to adjust the drug to correct concentration so, active chemical is not too strong for the patient.

In addition to all sciences, real-life examples we encounter in everyday life include taking blood pressure (Figure 1.19), temperature (Figure 1.20), weighing ourselves (Figure 1.21), and cooking (Figure 1.22).

Figure 1.19 Doctors measuring blood pressure of a patient. People make measurements every day. It is common that healthcare professionals use measurements in providing services. [credit: ernestoeslava. (2018). Pixabay image.]

Figure 1.20 Medic takes the temperature of patients during a training for Ebola treatment. [credit: UK Department of International Development (2014). Taking temperature to check for Ebola. CC BY.]

Figure 1.21 Child being weighed in Honduras by U.S. Air Force Staff Sergeant. [credit: Tech. Sgt. William Farrow. U.S. Air Force photo. Public domain.]

Figure 1.17 The process of cooking requires measurement. [credit: stevepb. (2014). Kitchen scale. Pixabay.]

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