Measurements are a basic necessity in science. Scientists have designed thousands of different tools to help in the vital process of measuring. In this image of the control panel of the space shuttle Atlantis, we see dozens of readouts from measuring systems.

Measurement

We already know that observations are an important part of the scientific method. Hypotheses are accepted or rejected based on how well they explain observations. Some observations, such as "the plant turned brown" are qualitative; these observations have no associated numbers. A quantitative observation includes numbers, and is also called a measurement. A measurement is obtained by comparing an object to some standard. Any observation is useful to a scientist, but quantitative observations are commonly considered more useful. Even if the measurement is an estimate, scientists usually make quantitative measurements in every experiment.

Consider the following pair of observations.

1. When the volume of a gas is decreased, its pressure is increased.
2. When the volume of a gas is reduced from 2.0 liters to 1.0 liter, the pressure increases from 3.0 atm to 6.0 atm.

A great deal more information, and more useful information, is available in the second observation.
Since accurate measurement is a vital tool for doing science, a consistent set of units for measurement is necessary. Physicists throughout the world use the **International System of Units** (also called the SI system). The SI system is basically the metric system, which is convenient because units of different size are related by powers of 10. The system has physical standards for length, mass, and time. These are called **fundamental** units because they have an actual physical standard.

The standard SI unit for length is the **meter**, and is denoted by "m". Originally, the meter was defined as the length between two scratches on a piece of metal which was stored in a secure vault under controlled conditions. The meter’s definition has changed over time, but it is now accepted to be the distance light travels in a vacuum over 1/299792458 of a second.

The standard unit of time, the **second**, was once defined as a fraction of the time it takes the earth to complete an orbit around the sun, but has now been redefined in terms of the frequency of one type of radiation emitted by a cesium-133 atom. Seconds are denoted by "s" or, less commonly, "sec."

The standard unit for mass is the **kilogram**. The kilogram’s standard is a block of platinum-iridium metal kept near Paris, France. Other countries, of course, keep copies. A kilogram is denoted "kg" and is a multiple of the smaller unit of mass, the gram ("g").

Meters, seconds, and kilograms are not the only unit entities. Take, for example, speed. Speed is a **derived** unit, measured in meters per second (m/s). Derived units are units that are expressed using combinations of the fundamental units.

As mentioned earlier, the SI system is a decimal system. Prefixes are used to change SI units by powers of ten. Thus, one hundredth of a meter is a centimeter and one thousandth of a gram is a milligram. The metric units for all quantities use the same prefixes. One thousand meters is a kilometer and one thousand grams is a kilogram. The common prefixes are shown in the **Table 1.1**.

**Table 1.1**: Common Prefixes Used with SI Units

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Symbol</th>
<th>Fractions</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>pico</td>
<td>p</td>
<td>$1 \times 10^{-12}$</td>
<td>picometer (pm)</td>
</tr>
<tr>
<td>nano</td>
<td>n</td>
<td>$1 \times 10^{-9}$</td>
<td>nanometer (nm)</td>
</tr>
<tr>
<td>micro</td>
<td>µ</td>
<td>$1 \times 10^{-6}$</td>
<td>microgram (µg)</td>
</tr>
<tr>
<td>milli</td>
<td>m</td>
<td>$1 \times 10^{-3}$</td>
<td>milligram (mg)</td>
</tr>
<tr>
<td>centi</td>
<td>c</td>
<td>$1 \times 10^{-2}$</td>
<td>centimeter (cm)</td>
</tr>
<tr>
<td>deci</td>
<td>d</td>
<td>$1 \times 10^{-1}$</td>
<td>decimeter (dm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>Multiples</strong></td>
</tr>
<tr>
<td>tera</td>
<td>T</td>
<td>$1 \times 10^{12}$</td>
<td>terameter (Tm)</td>
</tr>
<tr>
<td>giga</td>
<td>G</td>
<td>$1 \times 10^9$</td>
<td>gigameter (Gm)</td>
</tr>
<tr>
<td>mega</td>
<td>M</td>
<td>$1 \times 10^6$</td>
<td>megagram (Mg)</td>
</tr>
<tr>
<td>kilo</td>
<td>k</td>
<td>$1 \times 10^3$</td>
<td>kilogram (kg)</td>
</tr>
<tr>
<td>hecto</td>
<td>h</td>
<td>$1 \times 10^2$</td>
<td>hectogram (hg)</td>
</tr>
<tr>
<td>deca</td>
<td>da</td>
<td>$1 \times 10^1$</td>
<td>decagram (dag)</td>
</tr>
</tbody>
</table>

These prefixes are defined using scientific notation. Numbers with different prefixes can be shown as equalities when they are equivalent measurements. For example, 1 meter = 100 centimeters. Similarly, 0.01 meters = 1 centimeter. These equivalencies are used as **conversion factors** when units need to be converted.
Examples

Example 1

Convert 500 millimeters to meters.

The equivalency statement for millimeters and meters is $1000 \text{ mm} = 1 \text{ m}$.

To convert 500 mm to m, we multiply 500 mm by a conversion factor that will cancel the millimeter units and generate the meter units. This requires that the conversion factor has meters in the numerator and millimeters in the denominator.

$$\frac{500 \text{ mm}}{1000 \text{ mm}} = 0.500 \text{ m}$$

500 mm is equivalent to 0.5 m.

Example 2

Convert $11 \mu g$ to mg.

When converting from one prefix to another, such as in this problem, it is usually easiest to convert through the base unit. In this case, the base unit is grams, so we use the two following equivalency statements:

$$1 \times 10^6 \mu g = 1 \text{ g} \text{ and } 1000 \text{ mg} = 1 \text{ g}$$

The first conversion factor converts from micrograms to grams and the second conversion factor converts from grams to milligrams.

$$\left(11 \mu g\right) \left(\frac{1 \text{ g}}{1 \times 10^6 \mu g}\right) \left(\frac{1000 \text{ mg}}{1 \text{ g}}\right) = 1.1 \times 10^{-2} \text{ mg}$$

$11 \mu g$ is $1.1 \times 10^{-2} \text{ mg}$.

The key to converting units is to think of these equivalency statements as a creative way of multiplying by one. You can multiply any number by one at any time because it does not change the number. Play around with converting between different measuring systems using equivalencies and the creative multiplication of one strategy in the following simulation:

**SIMULATION**

Learn about making conversions between different types of units by negotiating with a trader at the crossroads.

URL: [http://www.ck12.org/physics/unit-conversions/simulationint/At-The-Crossroads](http://www.ck12.org/physics/unit-conversions/simulationint/At-The-Crossroads)

Further Reading

- Metric Units
- Unit Conversions
Summary

- Measurements (quantitative observations) are often more useful than qualitative observations.
- The system of units for measurements in physics is the SI system.
- The fundamental quantities in the SI system are length, mass, and time.
- The SI unit for length is the meter, for time is the second, and for mass is the kilogram.
- Prefixes are used to change SI units by powers of ten.
- Equivalencies are used as conversion factors when units need to be converted.

Review

1. Which of the following are quantitative observations?
   a. The sky is blue.
   b. The toy car is about 3 inches long.
   c. It is 250,000 miles from the earth to the moon.
   d. The wooden cart has a mass of 18.654 g.
   e. When at rest, the pendulum points toward the center of the earth.

2. Convert 76.2 kilometers to meters.
3. Convert 76.2 picograms to kilograms.
4. Convert 1 day into seconds.

Explore More

Use the resource below to answer the questions that follow.

[URL: http://www.ck12.org/flx/render/embeddedobject/70079]

1. Draw for yourself the conversion base used in this video.
2. Convert 6.6 meters to centimeters using the process shown.
3. Convert 1 mile to feet. Then convert to inches. Then convert to centimeters. How many centimeters are in a mile?
4. At 2:29 in the video, he motions across and then down in solving the problem. What is the mathematical process he is doing?

- **measurement**: The process or the result of determining the ratio of a physical quantity, such as a length, time, temperature etc., to a unit of measurement, such as the meter, second or degree Celsius.
- **the SI system of units**: A complete metric system of units of measurement for scientists; fundamental quantities are length (meter) and mass (kilogram) and time (second) and electric current (ampere) and temperature (kelvin) and amount of matter (mole) and luminous intensity (candela).
- **fundamental quantity vs derived quantity**: In the language of measurement, *quantities* are quantifiable aspects of the world, such as time, distance, velocity, mass, temperature, energy, and weight, and *units* are used to describe their measure. Many of these quantities are related to each other by various physical laws, and as a result the units of some of the quantities can be expressed as products (or ratios) of powers of other units (e.g., momentum is mass times velocity and velocity is measured in distance divided by time). Those
quantities whose units are expressed in terms of other units are regarded as derived quantities. Those that cannot be so expressed in terms of other units are regarded as “fundamental” quantities.

- **conversion factor:** A numerical factor used to multiply or divide a quantity when converting from one system of units to another.

References

