# Measurement

Ck12 Science

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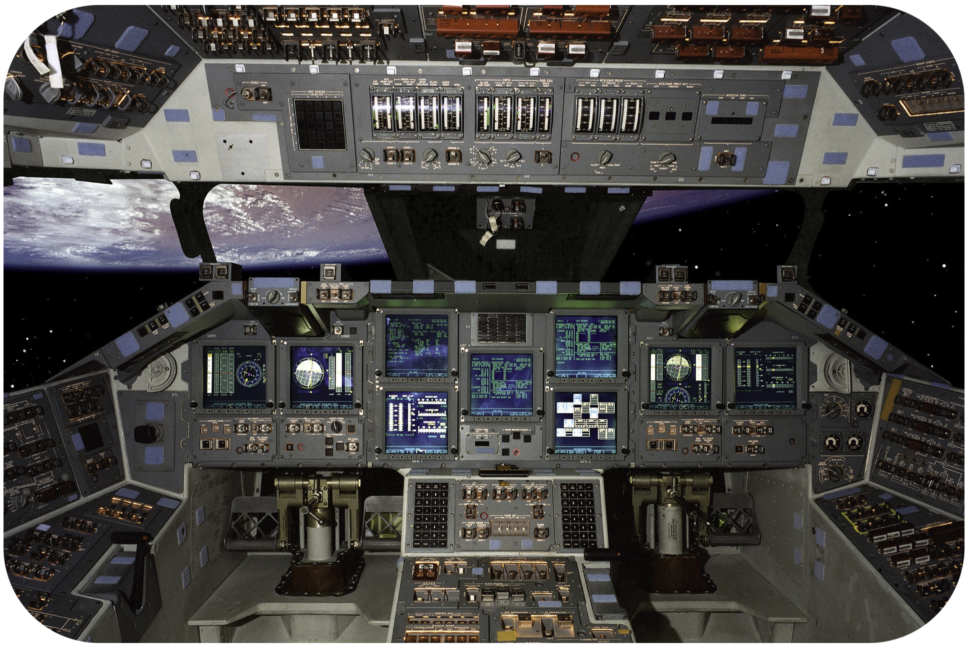
# CONCEPT 1 Measurement

- Distinguish between qualitative and quantitative observations.
- Distinguish between fundamental and derived quantities.
- State the SI units for length, mass, and time.
- Make requested unit conversions in the SI system.



Measurements are a basic necessity in science. Scientists have designed thousands of meters and other measuring 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

Observation is an integral part of the scientific method. Hypotheses are accepted or rejected based on how well they explain observations. Some observations have numbers associated with them and some do not. An observation such as "the plant turned brown" is called a qualitative observation because it does not have any numbers associated with it. An observation such as "the object moved 200 meters" is called a quantitative observation because it contains a number. Quantitative observations are also called **measurements.** The numerical component of the observation is obtained by measurement, i.e. comparing the observation to some standard even if the comparison is an estimate. In terms of value to a scientist, all observations are useful but quantitative observations are much more useful. Whenever possible, you should make quantitative rather than qualitative observations, even if the measurement is an estimate.

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.

It should be easy to see that a great deal more information in available in the second observation.

Since accurate measurement if a vital tool in doing science, it becomes obvious that 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 a convenient system 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. There are two other fundamental units that you will earn later.

The standard SI unit for length is the meter. Originally, the definition of the meter was the distance between two scratches on a length of metal. The standard length of metal was stored in a secure vault under controlled conditions of temperature, pressure, and humidity. Most countries had their own copies of the standard meter and many copies were made for actual use. Later, the standard was redefined as one ten-millionth of the distance from the north pole to the equator measured along a line that passed through Lyons, France. In 1960, the standard was redefined again as a multiple of a wavelength of light emitted by krypton-86. In 1982, the standard was redefined yet again as the distance light travels in 1/299792458 second in a vacuum.

The standard unit of time, the second, was once defined as a fraction of the time it takes the earth to complete it 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.

The standard unit for mass is the kilogram. This standard is a mass of platinum-iridium metal cylinder kept near Paris, France. Other countries, of course, keep copies.

Units that are expressed using combinations of fundamental units are called **derived** units. For example, length is a fundamental unit measured in meters, time is a fundamental unit measured in seconds, and speed is a derived unit measured in meters/second.

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: Prefixes Used with SI Units**

| Prefix | Symbol | Fractions | Example |
|---|---|---|---|
| pico | p | $1 \times 10^{-12}$ | picometer (pm) |
| nano | n | $1 \times 10^{-9}$ | nanometer (nm) |
| micro | $\mu$ | $1 \times 10^{-6}$ | micgrogram ($\mu$g) |
| milli | m | $1 \times 10^{-3}$ | milligram (mg) |
| centi | c | $1 \times 10^{-2}$ | centimeter (cm) |
| deci | d | $1 \times 10^{-1}$ | decimeter (dm) |
| | | **Multiples** | |
| tera | T | $1 \times 10^{12}$ | terameter (Tm) |
| giga | G | $1 \times 10^{9}$ | gigameter (Gm) |
| mega | M | $1 \times 10^{6}$ | megagram (Mg) |
| kilo | k | $1 \times 10^{3}$ | kilogram (kg) |
| hecto | h | $1 \times 10^{2}$ | hectogram (hg) |
| deka | da | $1 \times 10^{1}$ | dekagram (dag) |

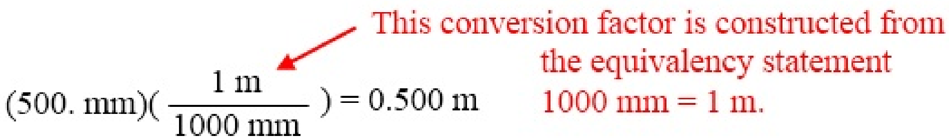
Equivalent measurements with different units can be shown as equalities such as 1 meter = 100 centimeters. Each of the prefixes with each of the quantities has equivalency statements. For example, 1 gigameter = $1 \times 10^9$ meters and 1 kilogram = 1000 grams. These equivalencies are used as **conversion factors** when units need to be converted.

**Example:** Convert 500. millimeters to meters.

**Solution:**

The equivalency statement for millimeters and meters is 1000 mm = 1 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.




**Example:** Convert 11 $\mu$g to mg.

**Solution:**

We need two equivalency statements because we need two conversion factors.

$1 \times 10^9\ \mu\text{g} = 1\ \text{g}$ and $1000\ \text{mg} = 1\ \text{g}$

$(11\ \mu\text{g})\left(\frac{1\ \text{g}}{1\times10^{-9}\ \mu\text{g}}\right)\left(\frac{1000\ \text{mg}}{1\ \text{g}}\right) = 1.1\times10^{-5}\ \text{mg}$

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

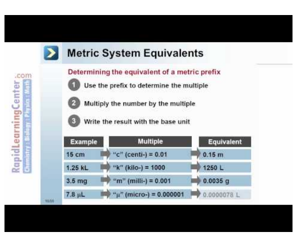
### Summary

- Measurements (quantitative observations) are more useful than qualitative observations.
- You should make measurements, even estimated ones, whenever possible.
- The system of units for measurements in physics is the SI system.
- At this time, the fundamental quantities are length, mass, and time.
- The SI unit for length is the meter and the standard meter is the distance light travels in $\frac{1}{299792458}$ second in a vacuum.
- The SI unit for time is the second and the standard second is based on of the frequency of one type of radiation emitted by a cesium-133 atom.
- The SI unit for mass is the kilogram and is based on a mass stored in France.
- Prefixes are used to change SI units by powers of ten.
- Equivalencies are used as conversion factors when units need to be converted.

### Practice

Use this resource to answer the following questions.

http://www.youtube.com/watch?v=mSxcLzQAbkI




MEDIA

Click image to the left for more content.

1. Name two areas of study within the field of physics.

2. What is the definition of a "base unit" in measurement systems?
3. Name one commonly used non-SI unit.

### 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.

- **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

1. Courtesy of NASA. http://spaceflight.nasa.gov/gallery/images/shuttle/sts-101/html/jsc2000e10522.html. Public Domain
2. CK-12 Foundation - Richard Parsons. . CC-BY-NC-SA 3.0