**Unit 1 – Fundamental of Science & Astronomy**

**Parts II - Measurements & Metric Systems**

Scientists present their [evidence](https://www.teachastronomy.com/textbook/How-Science-Works/Measurements/) in the form of a measurement. People make many statements in everyday life. Some are qualitative and some are quantitative. A friend might say "This music is great!" or "It was colder yesterday than today," or, "There are only four forces of nature." There is no reliable way to quantify the first statement, even though your friend may feel it is true. However, the next two statements can be quantified, and they can be subjected to actual measurements that will either support or refute the assertions. In science, we try to deal only with statements that can be quantified. Otherwise, we would have no way to compare results.  
  
Scientists use measurements to arrive at precise and quantitative statements. A [measurement](https://www.teachastronomy.com/textbook/How-Science-Works/Measurements/) must have two components: a number and a unit, which specifies the type of the quantity that is being counted. Notice that numbers alone are not that useful. Units must be in a system that is well defined. The statement "It was cold yesterday" can be quantified by saying that "It was 15 degrees yesterday," but you still need to know whether this is on the Celsius or Fahrenheit system of units. The statement "The stock market fell 50 points" is quantified, but to understand it, you need to know what a point on the Dow Jones average actually represents.  
  
Astronomers need to handle very large and very small numbers. Scientific notation is useful shorthand for writing numbers of any size (it is also often called exponential notation). For example, instead of saying that the nearest [star](https://www.teachastronomy.com/textbook/How-Science-Works/Measurements/) is about 40,000,000,000,000 kilometers away, we can say it is 4 x 1013 kilometers away. (The exponent "13" represents the number of zeros following the significant figure "4.")  
  
The system of units in physical science is amazingly simple. All the diverse measurements we can make in the physical world — speed and [force](https://www.teachastronomy.com/textbook/How-Science-Works/Measurements/) and [temperature](https://www.teachastronomy.com/textbook/How-Science-Works/Measurements/) and electric charge and [energy](https://www.teachastronomy.com/textbook/How-Science-Works/Measurements/) and so on — are derived from only three fundamental properties: mass, length, and time. To these properties we attach the familiar units in the metric system: kilograms to measure mass, meters to measure length, and seconds to measure time. Almost every other type of [measurement](https://www.teachastronomy.com/textbook/How-Science-Works/Measurements/) is just some combination of these units. For example, area is just [length](https://www.teachastronomy.com/textbook/How-Science-Works/Measurements/) multiplied by length, and [momentum](https://www.teachastronomy.com/textbook/How-Science-Works/Measurements/) is just [mass](https://www.teachastronomy.com/textbook/How-Science-Works/Measurements/) multiplied by velocity — which is the same as mass multiplied by length divided by time. Even concepts such as energy or temperature can be expressed as combinations of the same three quantities. A simple system of units helps scientists make sense of a complicated world.  
  
Why do scientists generally use units in the metric system? The [metric system](https://www.teachastronomy.com/textbook/How-Science-Works/Measurements/) was first put into widespread use after the French Revolution of 1789. The architects of the French Revolution wanted to make a break with the culture defined by royalty and hereditary power and usher in an Age of Reason. As part of this sweeping set of social changes, they introduced a set of units based on a decimal counting system. The metric system was designed to replace the [English system](https://www.teachastronomy.com/textbook/How-Science-Works/Measurements/) where a gallon is 8 pints, a foot is 12 inches, a pound [weight](https://www.teachastronomy.com/textbook/How-Science-Works/Measurements/) is 16 ounces, a pound Sterling is 20 shillings, and so on. These units have their origins in medieval European history! At a [time](https://www.teachastronomy.com/textbook/How-Science-Works/Measurements/) when few people were literate or numerate, it was easier to have measurements that could be easily subdivided. The numbers 8, 12, 16, and 20 all have three or more factors, while 10 only has two factors.  
  
However, the [metric system](https://www.teachastronomy.com/textbook/How-Science-Works/Measurements/) is much simpler. For example, a meter (which is roughly a yard) is 100 centimeters, and a kilometer is 1000 meters. Thomas Jefferson was very impressed by the metric system and pushed for it to be adopted in the United States. He would be very disappointed if he knew that nearly 230 years later his country was the world's last holdout against adopting the metric system. It is ironic that the world’s most advanced technological society still clings to inches, miles, acres, gallons, pints, pounds, and even horsepower ratings! These anachronistic units are awkward to deal with and the result is a subtle but profound disconnect between scientists and the general public.  
  
Astronomy deals with [temperature](https://www.teachastronomy.com/textbook/How-Science-Works/Measurements/) extremes from the coldness of intergalactic space at 3 degrees above absolute cold to the shock wave of a [supernova](https://www.teachastronomy.com/textbook/How-Science-Works/Measurements/) at a billion (109) degrees. It spans objects that range in size from microscopic cosmic dust grains (10-6 meters) to the distance that light has traveled in the age of the [universe](https://www.teachastronomy.com/textbook/How-Science-Works/Measurements/) (1023kilometers). Discussions range from the sparseness of the space between galaxies at a density of 10-19 kilograms per cubic meter, to the density inside a [black hole](https://www.teachastronomy.com/textbook/How-Science-Works/Measurements/) at 1018 kilograms per cubic meter. The difference between these last measurements is a factor of 1037, or 10 followed by 37 zeros! With such factors, it is not surprising that astronomers use scientific notation.  
  
Notice the number of significant figures, or non-zero digits, in a scientific measurement. For example, look at the numbers 13,000 kilometers and 12,756 kilometers. In scientific notation, we would write these numbers 1.3 x 104kilometers and 1.2756 x 104 kilometers. The first number implies quite a rough measurement; changing the least significant figure would give you 12,000 or 14,000, which is a difference of 15 percent. But the second number implies a very fine measurement; changing the least significant figure would give you 12,755 or 12,757, which is a difference of a tiny fraction of a percent. So the number of [significant figures](https://www.teachastronomy.com/textbook/How-Science-Works/Measurements/) is a measure of precision. Note that a calculator will often return a large number of significant figures, but that doesn't mean you should infer a high [precision](https://www.teachastronomy.com/textbook/How-Science-Works/Measurements/) to the number. The precision of a number in science depends on how the [measurement](https://www.teachastronomy.com/textbook/How-Science-Works/Measurements/) was made.  
  
However, we should point out that precise numbers are not always required in science and are sometimes not even possible to measure. Some measurements of atomic phenomena are precise to twelve significant figures (one part in a trillion) while some numbers in [cosmology](https://www.teachastronomy.com/textbook/How-Science-Works/Measurements/) are only precise to one significant figure. You can understand most of the material in [astronomy](https://www.teachastronomy.com/textbook/How-Science-Works/Measurements/) without having to deal with very precise numbers. In the example just given, it is more important to remember that the Earth is roughly 13,000 kilometers across than to try to memorize that it is exactly 12,756 kilometers across. Few numbers in astronomy are known with a [precision](https://www.teachastronomy.com/textbook/How-Science-Works/Measurements/) of more than three significant figures. Sometimes the uncertainty is a factor of ten, which is called an order of magnitude. Knowing an approximate value allows you to estimate many effects without extensive calculations or looking things up in books. This basic scientific skill is called estimation. Estimation saves [time](https://www.teachastronomy.com/textbook/How-Science-Works/Measurements/) and allows scientists to distinguish promising hypotheses from foolish ones.

**Units and the Metric System**

The subject of [measurement](https://www.teachastronomy.com/textbook/How-Science-Works/Units-and-the-Metric-System/) has a rich and fascinating history. Ever since humans have traded goods, they have needed a standard system of weights and measures. Many of our familiar units are part of the English system, which dates back to the Middle Ages. For example, [length](https://www.teachastronomy.com/textbook/How-Science-Works/Units-and-the-Metric-System/) units were based on the human body: an inch is the length of the end joint of a thumb, a foot is of course the length of a foot, a yard is the distance from the tip of the nose to the end of an outstretched arm, and a fathom is the distance between the fingertips of two arms held straight out. However, these units are variable, since people are different sizes! As early as 1215, King John of England recognized the need for standardization in the Magna Carta, "There shall be standard measures of wine, corn, and ale throughout the kingdom."

Even after standardization, the [English system](https://www.teachastronomy.com/textbook/How-Science-Works/Units-and-the-Metric-System/) of units is a mess. It consists of a welter of different units, many of which are divided by different amounts. There are 8 pints in a gallon, 12 inches in a foot, and 16 ounces in a pound. Many units are accidents of history, but the use of these multiples came about because very few people have ever been numerate. It is easy to divide up objects when they are contained in groups of 8 (= 2 × 2 × 2) or 12 (= 2 × 2 × 3) or 16 (= 2 × 2 × 2 × 2).  
  
The [metric system](https://www.teachastronomy.com/textbook/How-Science-Works/Units-and-the-Metric-System/) was established by the French Academy of Sciences in 1791. It grew out of the French Revolution and a desire to rationalize many aspects of human affairs. The goal was to create a [measurement](https://www.teachastronomy.com/textbook/How-Science-Works/Units-and-the-Metric-System/) system based on invariable quantities in nature, rather than on parts of the human body. Thus, the meter was defined to be 1 ten-millionth of the distance from the Earth’s equator to the North Pole, the gram was defined to be the [mass](https://www.teachastronomy.com/textbook/How-Science-Works/Units-and-the-Metric-System/) of a cubic centimeter of water at 4º C, and the second was defined to be 1/86,400 of a solar day (1/60 × 1/60 × 1/24). The metric system makes a lot of sense. There is only one basic [unit](https://www.teachastronomy.com/textbook/How-Science-Works/Units-and-the-Metric-System/) for each quantity and all subdivisions and multiples are powers of ten. Thomas Jefferson was impressed by the [metric system](https://www.teachastronomy.com/textbook/How-Science-Works/Units-and-the-Metric-System/) and pushed for its adoption in the United States. Finally, the United States and sixteen other countries signed the Treaty of the Meter in 1879. But as you look around, you will see that we are not metric in everyday life. In this regard, the United States is almost a lone holdout — not even the English use the [English system](https://www.teachastronomy.com/textbook/How-Science-Works/Units-and-the-Metric-System/) any more!  
  
Scientists have embraced the metric system completely. Here are the conversion factors between some familiar quantities in the English system and their counterparts in the metric system:  
  
• 1 m = 39.37 in and the reverse 1 in = 0.0254 m = 25.4 mm  
  
• 1 m = 1.094 yd and the reverse 1 yd = 0.914 m = 914 mm  
  
• 1 km = 0.621 mi and the reverse 1 mi = 1.609 km = 8/5 km  
  
• 1 g = 0.0353 oz and the reverse 1 oz = 28.3 g = 0.0283 kg  
  
• 1 kg = 2.205 lb and the reverse 1 lb = 0.454 kg = 454 g  
  
• 1 liter = 1.06 qt and the reverse 1 qt = 0.94 liters = 940 cm3  
  
• 1 liter = 0.264 gal and the reverse 1 gal = 3.79 liters = 3790 cm3  
  
• 1 W = 0.00134 hp and the reverse 1 horsepower = 745.7 W  
  
• 1 J = 0.00024 cal and the reverse 1 calorie = 4186 J  
  
These are just a few of the most common units from the English system. There are many more. You can be glad you do not have to remember the distinctions between cubits and furlongs and pecks and pottles and bushels and jacks and jills! Here are other important quantities that can all be derived from the fundamental units of mass, length, and time:  
  
• Frequency: measured in cycles/s or Hertz (Hz)  
  
• Force: measured in kg m/s2 or Newton (N)  
  
• Energy: measured in kg m2/s2 or Joules (J)  
  
• Power: measured in J/s or Watts (W)  
  
• Temperature: measured in K or Kelvin (K)  
  
In science, [temperature](https://www.teachastronomy.com/textbook/How-Science-Works/Units-and-the-Metric-System/) is given on the Kelvin scale, named after the Scottish physicist William Thomson, Lord Kelvin. The Kelvin scale is measured with reference to absolute zero — the temperature at which an object contains no [heat](https://www.teachastronomy.com/textbook/How-Science-Works/Units-and-the-Metric-System/) and all atomic motions are frozen. Some scientists also use the Celsius scale, named after the Swedish astronomer Anders Celsius. The Celsius scale is also called the centigrade scale, since it is based on the division of the range from the freezing to the boiling points of water into 100 equal degrees. A third temperature scale was named after German physicist Gabriel Fahrenheit, who made the first successful mercury thermometer in 1720. The Fahrenheit scale is not used by scientists, and it is only used in the United States.  
  
The information below gives some important [temperature](https://www.teachastronomy.com/textbook/How-Science-Works/Units-and-the-Metric-System/) markers and tells you how to convert from one temperature scale to another.

• Absolute zero: 0 K = -273 °C = -459 °F  
  
• Water freezes: 273 K = 0 °C = 32 °F  
  
• Water boils: 373 K = 100°C = 212 °F  
  
• Surface of the Sun: 5700 K = 5427 °C = 9797 °F  
  
• Any level: °C + 273 = 5/9(°F-32) = (9/5)°C+32  
  
Despite the variety of measurements we can make in the natural world, there are three fundamental properties that cannot be described in any simpler terms. These fundamental properties are mass, length, and time. Every quantity you see in basic [astronomy](https://www.teachastronomy.com/textbook/How-Science-Works/Units-and-the-Metric-System/) can be expressed as some combination of these three. For example, velocity is distance (or length) divided by time, and density is [mass](https://www.teachastronomy.com/textbook/How-Science-Works/Units-and-the-Metric-System/) divided by [volume](https://www.teachastronomy.com/textbook/How-Science-Works/Units-and-the-Metric-System/) (or [length](https://www.teachastronomy.com/textbook/How-Science-Works/Units-and-the-Metric-System/) cubed).  
  
The [metric system](https://www.teachastronomy.com/textbook/How-Science-Works/Units-and-the-Metric-System/) has been refined over time. The modern version of the metric system was agreed on in 1960; it is called the International System of Units (SI). We now have fundamental and extremely precise definitions of the units of mass, length, and time. The standard [unit](https://www.teachastronomy.com/textbook/How-Science-Works/Units-and-the-Metric-System/) for mass is the kilogram (kg). The "true" kilogram is a metal cylinder kept at the International Bureau of Weights and Measures in Paris. The standard unit of length is the meter (m). The meter is defined to be the distance that light travels in 1/299,792,458 seconds; this definition is precise because we have measured the [speed of light](https://www.teachastronomy.com/textbook/How-Science-Works/Units-and-the-Metric-System/) very accurately. The standard unit of [time](https://www.teachastronomy.com/textbook/How-Science-Works/Units-and-the-Metric-System/) is the second (s). One second is defined as the [length](https://www.teachastronomy.com/textbook/How-Science-Works/Units-and-the-Metric-System/) of time required for 9,192,631,770 vibrations of the cesium-133 atom. These exact definitions are not important — scales and rulers and clocks work well enough in everyday life. But it is important to know that metric units have precise definitions.

Author: Chris Impey