0.2: The Metric System

Learning Objectives

- Students will know the units of distance, time, mass, and temperature in the metric (SI) system.
- Students will understand the prefixes that may modify these units.

In order to have a standard system for measurements, scientists usually use the metric system (the International System of Units, or SI). Unless you live in the United States, you probably already use meters to measure length and kilograms to measure mass.

If the quantities to be measured are too big or too small, then a more suitable unit can be devised simply by adding a Greek prefix. The prefix “centi” means “one-hundredth,” so a centimeter is one-hundredth of a meter. For smaller objects, the millimeter can be used, with “milli” indicating “one-thousandth.” Going in the other direction, kilometers can be used to measure larger things. The prefix “kilo” means “one thousand,” so a kilometer is 1,000 meters. Other Greek prefixes are used to indicate other multipliers of the basic unit. Table 0.1 is included to help you understand some of the prefixes we will be using.

Table 0.1 Prefixes and Their Meanings

PREFIX	MEANING (IN USA)	EXPONENT	SYMBOL
Tera	trillion	10^{12}	T
Giga	billion	10^{9}	G
Mega	million	10^{6}	M
kilo	thousand	10^{3}	k
centi	one-hundredth	10^{-2}	c
milli	one-thousandth	10^{-3}	m
micro	one-millionth	10^{-6}	μ
nano	one-billionth	10^{-9}	n
pico	one-trillionth	10^{-12}	p

The distances we encounter while studying the Universe are much bigger (or smaller) than those we typically encounter on Earth. For example, we might measure distances in our daily lives using meters or kilometers. Meters, which are about the same as a yard, are suitable to measure the size of a person or a house, each of which has dimensions of a few meters. If we want to describe the size of a town or the distance between towns, then the meter is too small. A town might be 10,000 m across, so using kilometers would be more natural: It is much easier to describe the size of a town as 5 km across than to say it is 5,000 m across! Going smaller, centimeters can be used to measure things with sizes comparable to the width of a finger, and nanometers can be used to describe microscopic things.

All metric units work this way, so a kilogram (kg) is 1,000 grams. A gram is a small mass; a sugar cube has a mass of about one gram. A textbook has a mass of about a kilogram, and a human has a mass of about 80 kilograms. It is important to distinguish the mass and the size of an object scientifically. In everyday life, we might describe an object as “massive” and “large” and mean the same thing, but scientifically, “massive” means something has a large mass and “large” means it has a large size.

Mass and size are related to each other through an object’s density. Density is an object’s mass per unit volume and is a measure of how tightly packed the atoms of a substance are. If the substance is less dense, like cotton candy, it is fluffier, and if a substance is more dense, like lead, there is more mass squeezed into a smaller volume. The SI units for density are kg/m^3. Density can also be measured in g/cm^3.

While the Fahrenheit or Celsius temperature scales are most often used in everyday life, the Kelvin temperature scale is used by astronomers and physicists. This is because the Kelvin scale is more natural in terms of what temperature is really measuring, the random internal motions of the particles making up a material. Zero Kelvin, or absolute zero , is defined to be the point at which random motions in a substance would cease. As the motions become more energetic, the temperature would go up accordingly. We say “motions would cease,” not “motions cease,” because in real materials, the motions never actually cease; according to quantum mechanics, it is impossible for atoms to reach zero energy. Even if we could cool them to arbitrarily low temperatures, there would always be some small but nonzero residual energy left in the system.

Table 0.2 below provides the temperatures of some familiar phenomena in Kelvin, Celsius, and Fahrenheit to give you a sense of how these temperature scales relate. For example, zero Kelvin corresponds to −273.15 °C and −459.67 °F. Kelvin units are defined to have the same size as Celsius degrees; they just have different zero-points. Since water freezes at 0 °C and boils at 100 °C, the corresponding temperatures in Kelvin (K) are 273.15 K and 373.15 K. We often do not concern ourselves with the "0.15" and just say that water freezes at 273 K and boils at 373 K. The SI unit of temperature is the Kelvin (K) not the degree Kelvin (°K); since it is an absolute scale, there is no such thing as a "degree Kelvin."

You can probably already guess why Kelvin temperatures are not used in most daily weather reports. We tend to live out our lives within the temperatures between the freezing and boiling points of water (for the most part) and so Celsius is a much more convenient scale. But when we want to easily understand how the temperature of an object is related to its internal energy state, then we have to use Kelvin to measure temperature. Many of the temperatures we will encounter in astronomy are quite high or low by earthly standards. For instance, even a "cool" star

still has a surface temperature of several thousand Kelvin and an interior temperature of several million Kelvin. On the other hand, when we talk about the average temperature of the Universe as a whole, it is only about 3K.

Table 0.2 Temperature Scales

	KELVIN (K)	CELSIUS (°C)	FAHRENHEIT (°F)
Absolute Zero	0	−273	−459
Water Freezes	273	0	32
Room Temperature	300	23	81
Water Boils	373	100	212