1.7: Measuring Mass, Length, and Volume

Learning Objective

- Describe the units (and abbreviations) that go with various quantities.
- Derive new units by combining numerical prefixes with units.

Mass vs. Weight

One of the many interesting things about travel in outer space is the idea of weightlessness. If something is not fastened down, it will float in mid-air. Early astronauts learned that weightlessness had bad effects on bone structure. If there was no pressure on the legs, those bones would begin to lose mass. Weight provided by gravity is needed to maintain healthy bones. Specially designed equipment is now a part of every space mission so the astronauts can maintain good body fitness.

Mass is a measure of the amount of matter that an object contains. The mass of an object is made in comparison to the standard mass of 1 kilogram. The kilogram was originally defined as the mass of $1 \mathrm{~L}$ of liquid water at $4^{\circ} \mathrm{C}$ (volume of a liquid changes slightly with temperature). In the laboratory, mass is measured with a balance (see below), which must be calibrated with a standard mass so that its measurements are accurate.

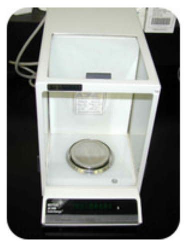

Figure 1.7.1: An analytical balance makes very sensitive mass measurements in a laboratory, usually in grams.

Other common units of mass are the gram and the milligram. A gram is 1/1000th of a kilogram, meaning that there are $1000 \mathrm{~g}$ in $1 \mathrm{~kg}$. A milligram is 1/1000th of a gram, so there are $1000 \mathrm{~mg}$ in $1 \mathrm{~g}$.

The Difference Between Mass and Weight

The mass of a body is a measure of its inertial property or how much matter it contains. The weight of a body is a measure of the force exerted on it by gravity or the force needed to support it. Gravity on earth gives a body a downward acceleration of about 9.8 $\mathrm{m/s^2}$. In common parlance, weight is often used as a synonym for mass in weights and measures. For instance, the verb “to weigh” means “to determine the mass of” or “to have a mass of.” The incorrect use of weight in place of mass should be phased out, and the term mass used when mass is meant. The SI unit of mass is the kilogram (kg). In science and technology, the weight of a body in a particular reference frame is defined as the force that gives the body an acceleration equal to the local acceleration of free fall in that reference frame. Thus, the SI unit of the quantity weight defined in this way (force) is the newton (N).

Length

Length is the measurement of the extent of something along its greatest dimension. The SI basic unit of length, or linear measure, is the **meter** (m). All measurements of length may be made in meters, though the prefixes listed in various tables will often be more convenient. The width of a room may be expressed as about 5 meters (m), whereas a large distance, such as the distance between New York City and Chicago, is better expressed as 1150 kilometers (km). Very small distances can be expressed in units such as the millimeter or the micrometer. The width of a typical human hair is about 10 micrometers $(\mu \mathrm{m})$.

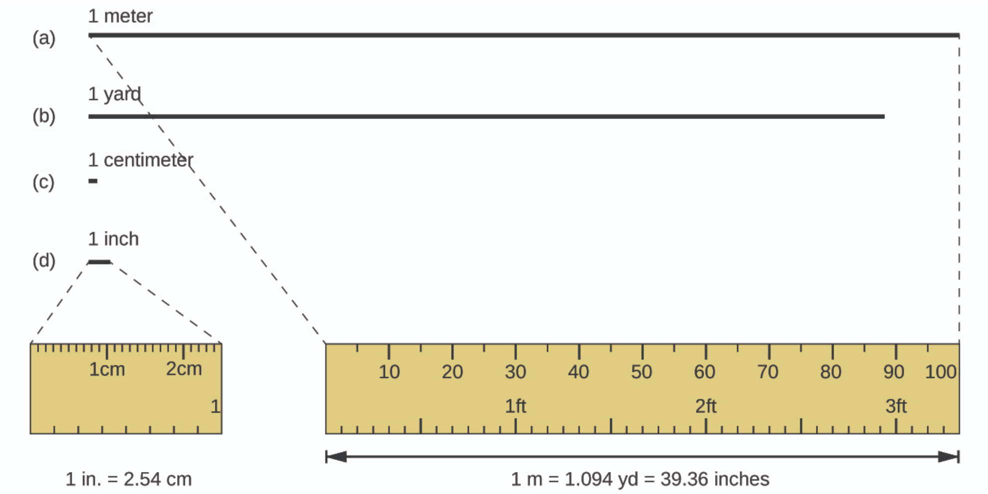

Figure $1.7.2$: The relative lengths of 1 m, 1 yd, 1 cm, and 1 in. are shown (not actual size), as well as comparisons of 2.54 cm and 1 in., and of 1 m and 1.094 yd. (CC BY 4.0; OpenStax)

Volume

In addition to the fundamental units, SI also allows for **derived** units based on a fundamental unit or units. There are many derived units used in science. For example, the derived unit for *area* comes from the idea that area is defined as width times height. Because both width and height are lengths, they both have the fundamental unit of meter, so the unit of area is meter × meter, or meter^2 (m^2). This is sometimes spoken as "square meters." A unit with a prefix can also be used to derive a unit for area, so we can also have cm^2, mm^2, or km^2 as acceptable units for area.

Volume is the amount of space occupied by a sample of matter. The volume of a regular object can be calculated by multiplying its length by its width and its height. Since each of those is a linear measurement, we say that units of volume are derived from units of length. One unit of volume is the cubic meter $\left(\text{m}^3\right)$, which is the volume occupied by a cube that measures 1 m on each side. This very large volume is not very convenient for typical use in a chemistry laboratory. A liter $\left(\text{L}\right)$ is the volume of a cube that measures 10 cm $\left(1 \text{ dm}\right)$ on each side. A liter is thus equal to both 1000 cm^3 $\left(10 \text{ cm} \times 10 \text{ cm} \times 10 \text{ cm}\right)$ and to 1 dm^3. A smaller unit of volume that is commonly used is the milliliter (mL - note the capital L which is a standard practice). A milliliter is the volume of a cube that measures 1 cm on each side. Therefore, a milliliter is equal to a cubic centimeter $\left(\text{cm}^3\right)$. There are 1000 mL in 1 L, which is the same as saying that there are 1000 cm^3 in 1 dm^3.

Another definition of a liter is one-tenth of a meter cubed. Because one-tenth of a meter is 10 cm, then a liter is equal to 1,000 cm^3 (Figure $1.7.3$). Because 1 L equals 1,000 mL, we conclude that 1 mL equals 1 cm^3; thus, these units are interchangeable.

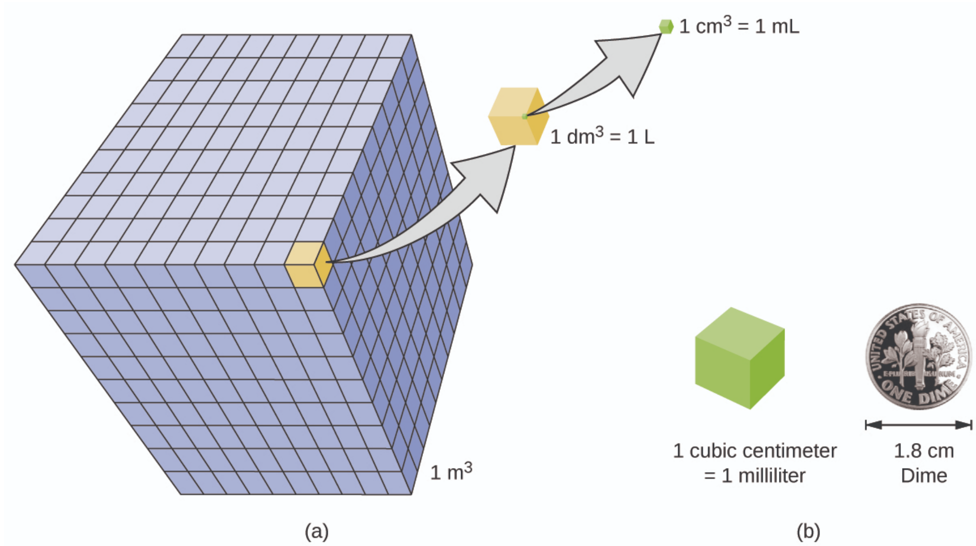

Figure 1.7.3: Units of Volume. (a) The relative volumes are shown for cubes of 1 m^3, 1 dm^3 (1 L), and 1 cm^3 (1 mL) (not to scale). A liter (L) is defined as a cube 1 dm (1/10th of a meter) on a side. A milliliter (mL), 1/1,000th of a liter, is equal to 1 cubic centimeter. (b) The diameter of a dime is compared relative to the edge length of a 1-cm^3 (1-mL) cube. (CC BY 4.0; OpenStax)

Units not only are multiplied together but also can be divided. For example, if you are traveling at one meter for every second of time elapsed, your velocity is 1 meter per second, or 1 m/s. The word *per* implies division, so velocity is determined by dividing a distance quantity by a time quantity. Other units for velocity include kilometers per hour (km/h) or even micrometers per nanosecond (μm/ns). Later, we will see other derived units that can be expressed as fractions.

Key Takeaways

- Mass is a measure of the amount of matter that an object contains. Mass is independent of location.
- Weight is a measure of force that is equal to the gravitational pull on an object. Weight depends on location.
- Units can be multiplied and divided to generate new units for quantities like the liter for volume.