4.1: Matter

Describe properties of matter.

Everything in the world is made of matter—everything you can touch, the air you breathe, the food you eat. We are going to begin our study of matter by looking at some of the properties of matter. Specifically, we will be looking at the mass, volume, density, and temperature of matter.

Mass

Mass is a measurement of the amount of “stuff” an object is made of. This “stuff” is matter. Therefore, mass is a measure of the amount of matter. You learned a little bit about mass in lesson 2. You discovered that forces acting on mass will cause acceleration or a change in motion. Mass can also be considered a measure of inertia. *Inertia is the tendency of a moving object to stay in motion until acted upon by another force.* The more mass an object has, the more inertia it has. Thus, for a given amount of force, a larger mass will experience less acceleration than a smaller mass. For example, it is a lot easier to change the motion of a ping pong ball than changing the motion of a bowling ball. This is because the bowling ball is made of a lot more matter than the ping pong ball.

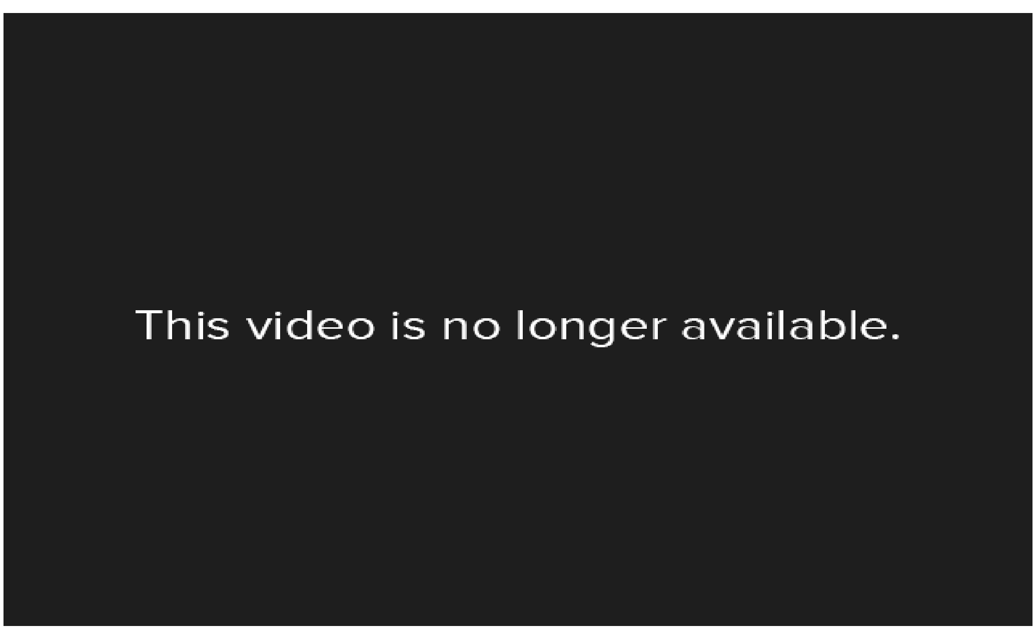

Fig. 4.1: The more mass an object has, the harder it is to change its motion.

Many people confuse the mass of an object with its weight. Weight is another name for the force of gravity acting on an object and is equal to the mass times the gravitational field. A typical student might have a mass of 60 kg. This student weighs 600 N on Earth. The same student would still have a mass of 60 kg on the moon but would weigh only about 100 N on the moon. This is because the gravitational field on the moon is about one-sixth as large as the gravitational field on the earth. The amount of matter that makes up the student doesn't change just because she is on the moon, but the force of gravity acting on that mass does.

The newton is the unit for weight in the SI (metric) system. However, throughout the world people use the kilogram for metric weight. This is technically not correct because mass and weight are two different quantities! People found it convenient to use kilograms to describe the weight of objects. So bear in mind that while the kilogram is really supposed to be a unit of mass, most people think of it as a unit of weight. For this course, we will stick strictly to measuring mass in kilograms and weight in newtons. We will also use the symbols kg for kilograms and N for newtons.

Volume

You may have learned about volume in a math class. The volume of an object can be defined as the amount of space that the object takes up. Some symmetrical shapes have formulas for finding the volume. In the figure below you can see three such formulas. The symbol π (the Greek letter pi) is a number equal to about 3.14. For odd-shaped objects, one way you could find the volume is to submerge the object in water and find the volume of water that it displaces. An example of this is when you get in the tub—the water level in the tub rises. If you were to completely submerge yourself, then measure how high the water rose, the volume of the risen water would be the volume of your body.

The units for measuring volume can be expressed in different ways. One common way is to use the formulas, which would end up giving you units of cm^3 or m^3, depending on what length units you put into the formulas. Another way to express volume is through liters (L) or milliliters (mL). One cubic centimeter (cm^3) is equal to one milliliter. One cubic meter is equal to 1 million cubic centimeters. (There are 100 cm in 1 m, so if you cube both numbers, you find $1{,}000{,}000\ cm^3 = 1\ m^3$.)

Here are the equations for finding the volume of a box, sphere, and cylinder:

$$Box \rightarrow V = length \cdot width \cdot height$$

$$Sphere \rightarrow V = \frac{4}{3}\pi \cdot radius^3$$

$$Cylinder \rightarrow V = \pi \cdot radius^2 \cdot height$$

Equation 4.1: Volume for a box, sphere, and cylinder

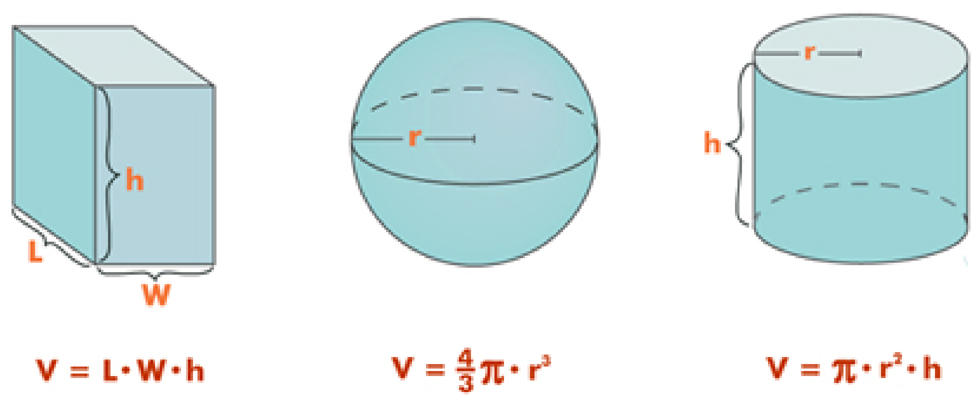

Fig. 4.2: Volume for a box, sphere, and cylinder

Example 4.1:

Find the volume of a box that measures 10 cm by 15 cm by 20 cm.

Hide Answer

$V = l \cdot w \cdot h$

$V = (10\text{ cm})(15\text{ cm})(20\text{ cm})$

$V = 3{,}000\text{ cm}^3$ (Note the units— $cm \cdot cm \cdot cm = cm^3$)

Example 4.2:

Find the volume of a sphere that has a radius of 5 cm.

Hide Answer

$V = (4/3)\ \pi\ r^3$

$V = (4/3)\ (\pi)\ (5cm)^3$

$V = (4/3)\ (3.14)\ (125\text{ cm}^3)$ (Note the units— $cm \cdot cm \cdot cm = cm^3$)

$V = 523\text{ cm}^3$

Example 4.3:

Find the volume of a cylinder that has a radius of 8 cm and a height of 12 cm.

Hide Answer

$V = \pi \cdot r^2 \cdot h$

$V = (3.14) \cdot (8\ cm)^2 \cdot (12cm)$

$V = (3.14) \cdot (64\ cm^2) \cdot (12cm)$

$V = 2{,}412\ cm^3$ (Note the units— $cm^2 \cdot cm = cm^3$)

Density

Another property of matter is related to both mass and volume. This property is called density. There is a simple formula for finding the density of an object. The symbol used to represent density is ρ (the Greek letter rho). Take the mass divided by the volume and you will have density. Therefore, density is the mass of an object or substance per unit of volume.

Density is unique because for a given substance, the size does not matter. The ratio (or fraction) of mass to volume is in direct proportion. Let's look at an example to see what this means.

$$density = \frac{mass}{volume}$$

Equation 4.2: Formula for finding the density of an object

Suppose we take a teaspoon of water and measure its mass and volume. We also take a swimming pool full of water and measure its mass and volume. When we calculate the density of water for both sample sizes, we find the exact same number for the density. It does not matter if we had a teaspoon full or a swimming pool full of water! Look at the following example, where the density of a spoonful of water is compared with the density of a bucketful of water. Even though the bucket of water has more mass and volume, both have the same density.

A spoon full of water	A bucket full of water
ex: mass: **5g** volume: **5 cm³**	ex: mass: **2600g** volume: **2600 cm³**
$\frac{5g}{5\ cm^3} = 1.0g / cm^3$	$\frac{2600g}{2600\ cm^3} = 1.0g / cm^3$

Table 4.1: Density of a spoon full of water vs. density of a bucket full of water

Notice that the mass and volume both depend on how large an object is—a larger sample would have a larger mass and a larger volume—but when we divide to find density, we see that the sample size makes no difference. So density is a very important property of matter.

One interesting effect of density is that we can determine whether objects will float or sink just by looking at their densities. For example, oil will float in water because it has a lower density than water. Hot air rises in the atmosphere because it has a smaller density than cooler air. The density of pure water is 1 g / cm³.

Example 4.4:

Find the density of an object that has a mass of 20 grams and a volume of 10 cm³. Would it float or sink in pure water? (remember the density of water is 1g/cm³).

Hide Answer

$\rho = m/v$

$\rho = 20\ g / 10\ cm^3$

$\rho = 2\ g/cm^3$ (This is greater than the density of water, so it would sink.)

Example 4.5:

Find the density of a solid cube that measures 2 cm by 4 cm by 10 cm, and has a mass of 40 g. Would it float or sink in pure water? (remember the density of water is 1g/cm³).

Hide Answer

$\rho = m/v$

$\rho = 40\ g$ / volume

$V = l \cdot w \cdot h$

$V = (2\ cm)(4\ cm)(10\ cm) = 80\ cm^3$

$\rho = 40\ g / 80\ cm^3$

$\rho = 0.5\ g / cm^3$ (This is less than the density of water, so it would float.)

Temperature

Another property of matter is its temperature. Temperature measures the average kinetic energy of the molecules of a substance. Many people think that temperature is a measure of the heat in an object, but this is not true. Heat in its true scientific meaning is a form of energy. As you add heat to a substance, its temperature will rise. So temperature could be described as a degree of hotness. A teaspoon of boiling water will have the same temperature as five gallons of boiling water, but the five gallons of water contains much more energy than the teaspoon. A cup of boiling water certainly has a higher temperature than a tubful of warm water, yet the cup does not have more heat energy. The quantity of heat depends on the mass of an object, the temperature does not. With temperature it does not matter if there are five molecules or five billion molecules. Heat, on the other hand, does take into account the number of molecules.

All forms of matter are composed of atoms or molecules that are in constant motion. Because of this motion, all matter is said to have thermal (or heat) energy. Whenever a substance is heated, its atoms move faster and faster. This results in an increase in thermal energy. It is the average motion of the atoms or molecules that we sense when we determine how hot or cold it is. We often describe this as the temperature. Temperature is really a measure of the average motion of atoms or molecules in a substance.

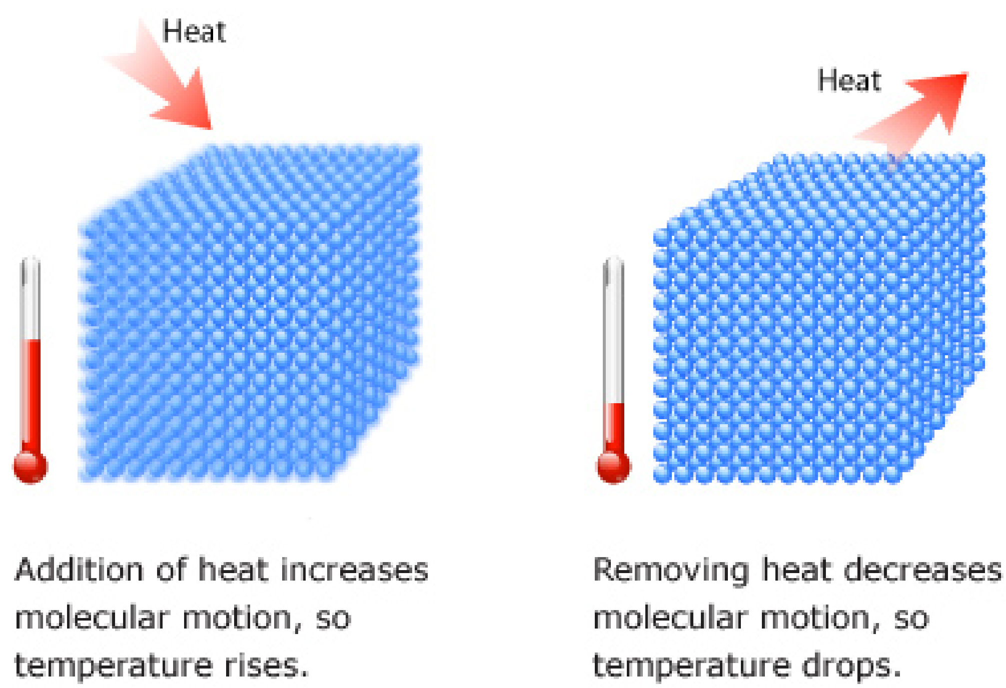

Fig. 4.3: Temperature is the measure of the average motion of the atoms or molecules in a substance

There are three temperature scales in common use today. The first scale, called the Fahrenheit scale, was developed by Gabriel Fahrenheit in 1714. There are many stories told about how he came up with his system, I’ll just explain one here. Some historians say he assigned zero to the lowest temperature he could get by mixing salt with ice. Then he assigned 98 to the temperature of the human body. According to this scale, pure water froze at 32 degrees and boiled at 212 degrees. The Fahrenheit scale is used today only in the United States.

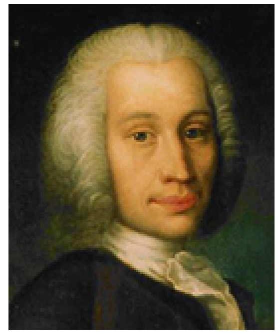
Fig. 4.4: Andres Celsius

The second temperature scale, called the Celsius scale, was developed in 1742 by a Swedish astronomer named Andres Celsius. He originally called this scale the Centigrade scale because he based it upon 100 degrees between the freezing and boiling points of water. Water freezes at 0 degrees and boils at 100 degrees Centigrade. Today we call this the Celsius scale. It is used in nearly every country in the world as part of the metric system.

Lord Kelvin of England developed the third temperature scale called the Kelvin scale. The Kelvin scale is based upon the expansion and contraction of gases. He observed that for every 1°C change, volumes would change by 1/273. He theorized that at -273°C gas would have zero volume! This temperature is called absolute zero, and it is the temperature at which all molecular motion stops. Lord Kelvin based his temperature scale on this absolute zero. On this scale, water freezes at 273 K and boils at 373 K. The increments, or degrees, are equivalent to those of the Celsius scale, but merely start with zero at a different location. The Kelvin temperature scale is used primarily by scientists.

Converting between Temperature Scales

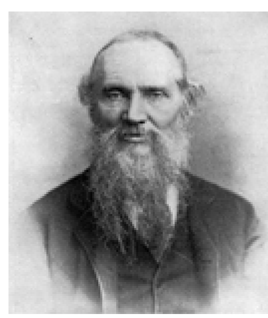
Figure 4.5: Lord Kelvin

Temperatures can be converted from one scale to another (and because each system of measurement is not used universally, it becomes necessary). Look at the formulas below. They are organized by a “convert from → convert to” format. So C → F means you are converting from Celsius to Fahrenheit. All you need to do is substitute the known Celsius temperature into the formula and you will find the equivalent Fahrenheit temperature.

$$
\begin{array}{ll}
C \rightarrow F & F = 1.8 \cdot C + 32 \\
F \rightarrow C & C = (F - 32) \div 1.8 \\
K \rightarrow C & C = K - 273 \\
C \rightarrow K & K = C + 273 \\
K \rightarrow F & F = 1.8 \cdot K - 459 \\
F \rightarrow K & K = (F + 459) \div 1.8
\end{array}
$$

Equation 4.3: Formulas for converting between temperature scale

Example 4.6:

Normal body temperature is 98.6 degrees Fahrenheit. Find this temperature in degrees Celsius. (Note that this is a conversion of F→C because we are given F and are looking to find C.)

Hide Answer

C = (F - 32) ÷ 1.8

C = (98.6 - 32) ÷ 1.8

C = (66.6) ÷ 1.8

C = 37 so 98.6 °F = 37°C