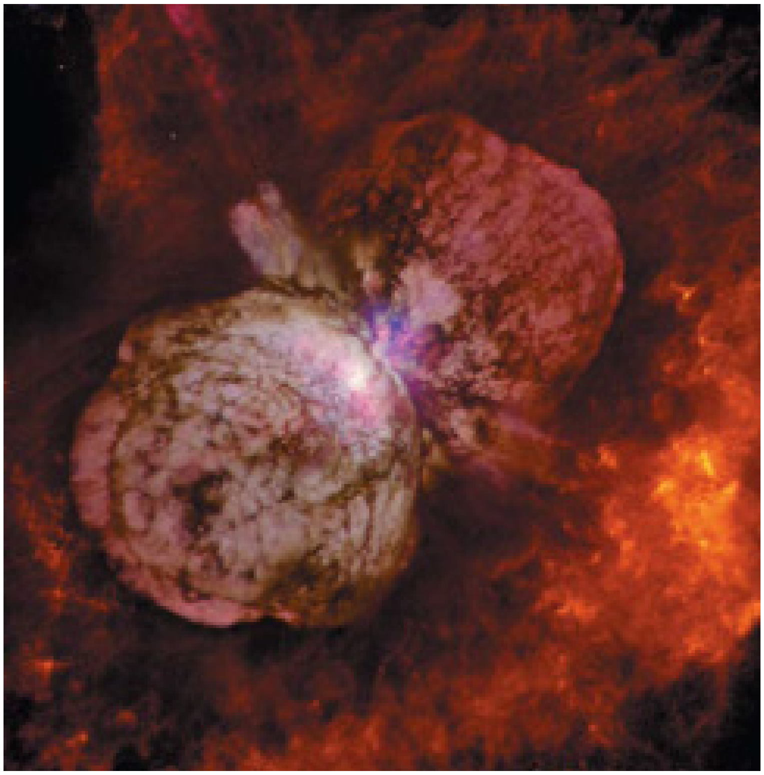


Chapter 2

Particles of Matter

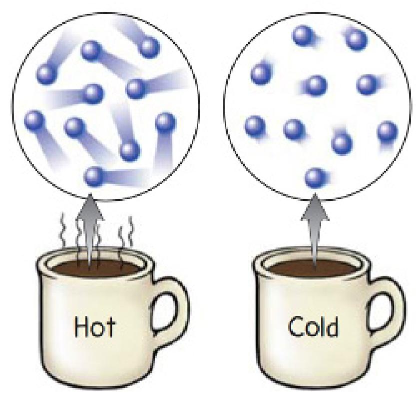
THE MAIN IDEA

Matter is made of particles called atoms

2.6 Temperature and Heat

Atoms and molecules are in constant motion, jiggling to and fro or bouncing from one position to another. By virtue of their motion, these particles possess kinetic energy. Their average kinetic energy is directly related to a property you can sense: how hot something is. Whenever something becomes warmer, the kinetic energy of its submicroscopic particles increases. For example, strike a penny with a hammer and the penny becomes warm because the hammer's blow causes its atoms to jostle faster, increasing their kinetic energy. (The hammer becomes warm for the same reason.) Put a flame to a liquid and the liquid becomes warmer because the energy of the flame causes the particles of the liquid to move faster, increasing their kinetic energy. For example, the molecules in the hot coffee in **Figure 2.19** are moving faster on average than those in the cold coffee.

Temperature tells us how warm or cold an object is relative to some standard. We express temperature by a number that corresponds to the degree of hotness on some chosen scale. Just touching an object certainly isn't a good way of measuring its temperature, as **Figure 2.20** illustrates. To measure temperature, therefore, we take advantage of the fact that nearly all materials expand when their temperature is raised and contract when it is lowered.



Λ Figure 2.19
The difference between hot coffee and cold coffee is the average speed of the molecules. In the hot coffee, the molecules are moving faster on average than they are in the cold coffee. (The "motion trails" on the molecules of hot coffee indicate their higher speed.)

With increasing temperature, the particles move faster and are on average farther apart—the material expands. With decreasing temperature, the particles move more slowly and are on average closer together—the material contracts. A thermometer exploits this characteristic of matter, measuring temperature by means of the expansion and contraction of a liquid, usually mercury or colored alcohol.

CONCEPT **CHECK**

You may have noticed telephone wires sagging on a hot day. This happens because the wires are longer in hot weather than in cold. What is happening on the atomic level to cause such changes in wire length?

CHECK YOUR ANSWER On a hot day, the atoms in the wire are moving faster, and as a result the wire expands. On a cold day, those same atoms are moving more slowly, which causes the wire to contract.

Figure 2.20
Can we trust our sense of hot and cold? Will both fingers feel the same temperature when they are put in the warm water? Try this yourself, and you will see why we use a thermometer for an objective measurement.

The most common thermometer in the world is the Celsius thermometer, named in honor of the Swedish astronomer Anders Celsius (1701–1744), who first suggested the scale of 100 degrees between the freezing point and boiling point of fresh water. In a Celsius thermometer, the number 0 is assigned to the temperature at which pure water freezes and the number 100 is assigned to the temperature at which it boils (at standard atmospheric pressure), with 100 equal divisions called degrees between these two points.

In the United States, we use the Fahrenheit thermometer, named after its originator, the German scientist G. D. Fahrenheit (1686–1736), who chose to assign 0 to the temperature of a mixture containing equal weights of snow and common salt and to assign 100 to the body temperature of a human. Because these reference points are not dependable, the Fahrenheit scale has since been modified such that the freezing point of pure water is designated 32°F and the boiling point of pure water is designated 212°F. On this recalibrated scale, the average human body temperature taken orally is around 98.2°F.

A temperature scale favored by scientists is the Kelvin scale, named after the British physicist Lord Kelvin (1824–1907). This scale is calibrated not in terms of the freezing and boiling points of water but rather in terms of the motion of atoms and molecules. On the Kelvin scale, zero is the temperature at which there is no atomic or molecular motion. This is a theoretical limit called absolute zero, which is the temperature at which the particles of a substance have absolutely no kinetic energy to give up. Absolute zero corresponds to –459.7°F on the Fahrenheit scale and to –273.15°C on the Celsius scale. On the Kelvin scale, this temperature is simply 0 K, which is read "zero kelvin" or "zero K." Marks on the Kelvin scale are the same distance apart as those on the Celsius scale, so the temperature of freezing water is 273 kelvin. (Note that the word degree is not used with the Kelvin scale. To say "273 degrees kelvin" is incorrect. To say "273 kelvin" is correct.) The three scales are compared in **Figure 2.21**.

It is important to understand that temperature is a measure of the *average* amount of energy in a substance, not the total amount of energy, as **Figure 2.22** shows. The total energy in a swimming pool full of boiling water is much more than the total energy in a cupful of boiling water even though both are at the same temperature. Your utility bill after heating the swimming pool water to 100°C would show this. Whereas the total amount of energy in the pool is much more than in the cup, the average molecular motion is the same in both water samples. The water molecules in the swimming pool are moving on average just as fast as the water molecules in the cup. The only difference is that the swimming pool contains more water molecules and hence a greater total amount of energy.

Heat is energy that flows from a higher-temperature object to a lower temperature object. If you touch a hot stove, heat enters your hand because the stove is at a higher temperature than your hand. When you touch a piece of ice, energy passes out of your hand and into the ice because the ice is at a lower temperature than your hand. From a human perspective, if you are absorbing heat, you experience warmth; if you are losing heat, you experience cooling. The next time you touch the hot forehead of a sick, feverish friend, ask him or her whether your hand feels hot or cold. Whereas temperature is absolute, hot and cold are relative.

READING CHECK

What does temperature measure?

FOR YOUR INFORMATION

Most atoms are ancient. They have existed through imponderable ages, recycling through the universe in innumerable forms, both nonliving and living. In this sense, you don't "own" the atoms that make up your body–you are simply their present caretaker. There will be many caretakers to follow.

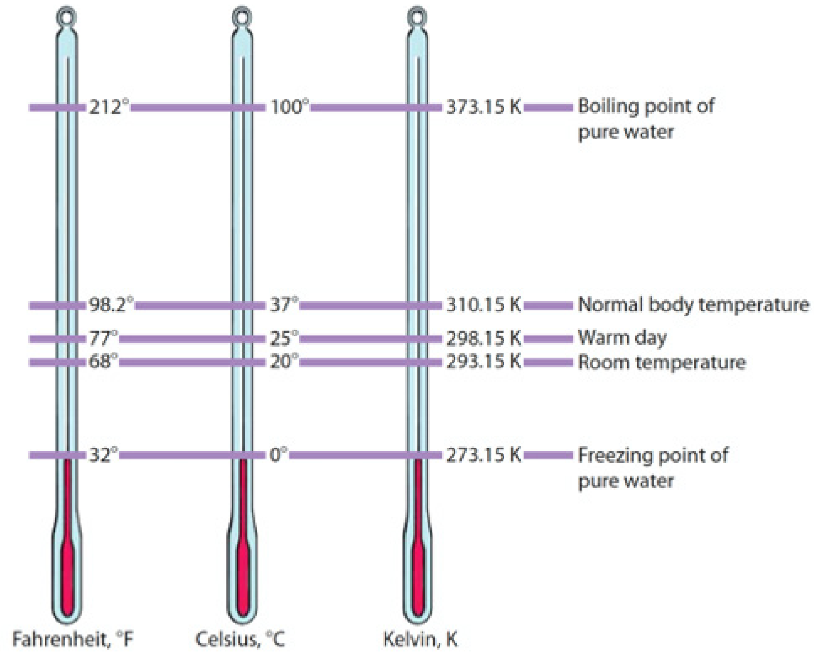


Figure 2.5 >
Some familiar temperatures measured on the Fahrenheit, Celsius, and Kelvin scales.

In general, the greater the temperature difference between two bodies in contact with each other, the greater the rate of heat flow. This is why a hot stove can cause much more damage to your skin than a warm stove. Because heat is a form of energy, its unit is the joule.

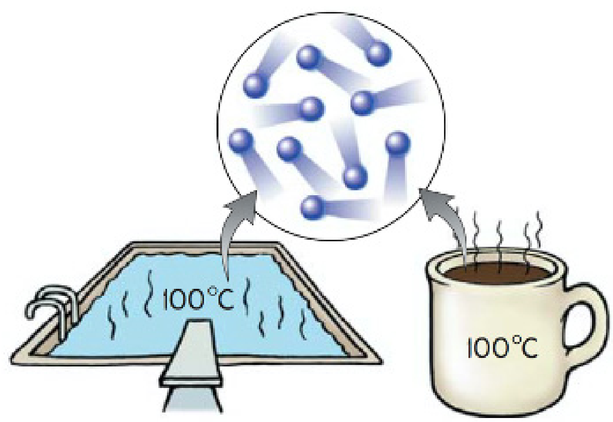


Figure 2.22 >
Bodies of water at the same temperature have the same average molecular kinetic energies. The total energy, however, depends upon how much water you have. For example, a swimming pool of water has much more total energy than a cupful of water, even when at the same temperature. Consider what your electric bill would look like after heating a swimming pool full of water to 100°C.

CONCEPT **CHECK**

When you enter a swimming pool, the water may feel quite cold. After a while, though, your body "gets used to it," and the water no longer feels so cold. Use the concept of heat to explain what is going on.

CHECK YOUR ANSWER Heat flows because of a temperature difference. When you enter the water, your skin temperature is much higher than the water temperature. The result is a signify can't flow of heat from your body to the water, which you experience as cold. Once you have been in the water awhile, your skin temperature is much closer to the water temperature (due to the cooling effects of the water and your body's ability to conserve heat), so the flow of heat from your body is less. With less heat fl owing from your body, the water no longer feels so cold.