8.2 Temperature

You have probably used a thermometer. Did you ever stop to think about how it works? In this section, you will learn what temperature is, how it is measured, and how the devices we use to measure temperature work.

VOCABULARY

Fahrenheit - a temperature scale in which water freezes at 32 degrees and boils at 212 degrees.

Celsius - a temperature scale in which water freezes at 0 degrees and boils at 100 degrees.

Temperature scales

Fahrenheit There are two common temperature scales. On the **Fahrenheit** scale, water freezes at 32 degrees and boils at 212 degrees (Figure 8.6). There are 180 Fahrenheit degrees between the freezing point and the boiling point of water. Temperature in the United States is commonly measured in Fahrenheit; 68°F (68 degrees Fahrenheit) is a comfortable room temperature.

Celsius The **Celsius** scale divides the interval between the freezing and boiling points of water into 100 degrees (instead of 180). Water freezes at 0°C (0 degrees Celsius) and boils at 100°C. Most scientists and engineers use Celsius because 0 and 100 are easier to work with than 32 and 212.

Converting between the scales A weather report of 21°C in London, England predicts a pleasant day, good for shorts and a T-shirt. A weather report of 21°F in Minneapolis, Minnesota means a heavy winter coat, gloves, and a hat will be needed. Because the U.S. is one of only a few countries that use the Fahrenheit scale, it is useful to know how to convert between Fahrenheit and Celsius.

CONVERTING BETWEEN FAHRENHEIT AND CELSIUS

$$T_{Fahrenheit} = \frac{9}{5} T_{Celsius} + 32 \qquad T_{Celsius} = \frac{5}{9}(T_{Fahrenheit} - 32)$$

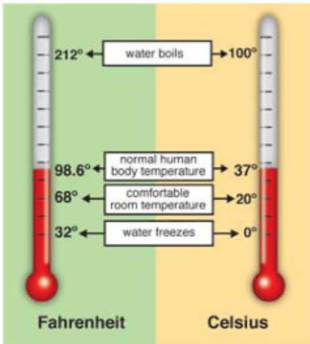


Figure 8.6: *The Fahrenheit and Celsius temperature scales.*

Next

Solving Problems: Temperature Conversions

A friend in Paris sends you a recipe for a cake. The French recipe says to bake the cake at a temperature of 200°C for 45 minutes. At what temperature should you set your oven, which uses the Fahrenheit scale (Figure 8.7)?

1. Looking for: You are asked for the temperature in degrees Fahrenheit.

2. Given: You are given the temperature in degrees Celsius.

3. Relationships: Use the conversion formula: $T_F = {}^9/_5\, T_C + 32$.

4. Solution: $T_F = ({}^9/_5)(200) + 32 = 392°F$

Figure 8.7: *A French recipe says to bake a cake at 200°C. At what temperature would you set the oven in degrees Fahrenheit?*

Your turn...

a. You are planning a trip to Iceland where the average July temperature is 11.2°C. What is this temperature in Fahrenheit?

b. You are doing a science experiment with a Fahrenheit thermometer. Your data must be in degrees Celsius. If you measure a temperature of 125°F, what is this temperature in degrees Celsius?

c. The temperature on the Moon varies from –230°C at night to 120°C during the day. What is the range in temperatures on the Moon in degrees Fahrenheit?

Photo courtesy of the Image Science & Analysis Laboratory, NASA Johnson Space Center

SOLVE FIRST LOOK LATER

a. 52.2°F

b. 51.7°C

c. –382°F to 248°F

Defining temperature

Atoms are always in motion Imagine you had a microscope powerful enough to see individual molecules in a compound (or atoms in the case of an element). You would see that the molecules are in constant motion, even in a solid object. In a solid, the molecules are not fixed in place, but act like they are connected by springs (Figure 8.8). Each molecule stays in the same average place, but constantly jiggles back and forth in all directions. The "jiggling" is motion and motion means *energy*. The back-and-forth jiggling of molecules is caused by **thermal energy**, which is a kind of kinetic energy.

Temperature and energy Thermal energy is proportional to temperature. When the temperature goes up, the energy of motion increases. This means the molecules jiggle around more vigorously. The higher the temperature, the more thermal energy molecules have and the faster they move around. **Temperature** measures a particular kind of kinetic energy per molecule.

Temperature measures the kinetic energy per molecule due to random motion.

Random versus average motion If you throw a rock, the rock gets more kinetic energy, but the temperature of the rock does *not* go up. How can temperature measure kinetic energy then? The answer is the difference between *random motion* of the molecules, and *average motion* of the object. For a collection of many molecules (like a rock), the kinetic energy has two parts. The kinetic energy of the thrown rock comes from the average motion of the whole collection, or the whole rock. This kinetic energy is *not* what temperature measures.

Random motion Each molecule in the rock is also jiggling back and forth independently of the other molecules in the rock. This jiggling motion is random motion. Random motion is motion that is scattered equally in all directions. On average, there are as many molecules moving one way as there are moving the opposite way. *Temperature measures the kinetic energy of the random motion*. Temperature is not affected by any kinetic energy associated with average motion. This is why throwing a rock does not make it hotter (Figure 8.9).

VOCABULARY

thermal energy - energy due to temperature.

temperature - a quantity that measures the kinetic energy per molecule due to random motion.

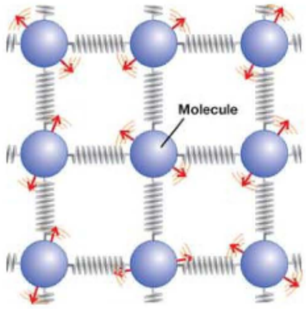


Figure 8.8: *Molecules in a solid are connected by bonds that act like springs.*

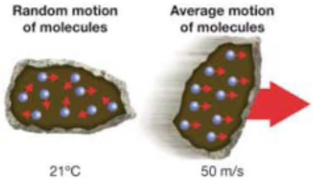


Figure 8.9: *A collection of molecules can have both average motion and random motion. That is why a rock has both a velocity and a temperature.*

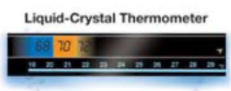
Thermometers

Thermometers If you touch an object, you can sense whether it is hot or cold but you cannot tell the exact temperature. A **thermometer** is an instrument that measures exact temperature. The most common thermometers contain either a red fluid, which is alcohol containing a small amount of red dye; or a silvery fluid, which is mercury. You may have also used a thermometer with a digital readout.

Using a liquid to sense the temperature Thermometers can detect the physical changes in materials caused by change in temperature. Different types of thermometers measure different physical changes. In a thermometer that uses a liquid to sense temperature, the expansion of the liquid is directly proportional to increase in temperature. As the temperature increases, the liquid expands and rises up a long, thin tube (Figure 8.10). The height that the liquid rises indicates the temperature. The tube is long and thin so a small change in volume makes a large change in the height of the liquid.

Digital thermometers Another physical property that changes with temperature is electrical resistance. The resistance of a metal wire will increase as temperature increases. Since the metal is hotter and the metal atoms are shaking more, there is more resistance to electrons passing through the wire. A *thermistor* is a device that changes its electrical resistance as the temperature changes. Some digital thermometers sense temperature by measuring the resistance of a thermistor.

Liquid-crystal thermometers Some thermometers, often used on the outside of aquariums, contain liquid crystals that change color based on temperature. As temperature increases, the molecules of the liquid crystal bump into each other more and more. This causes a change in the structure of the crystals, which in turn affects their color. These thermometers are able to accurately determine the temperature between 65°F and 85°F.



VOCABULARY

thermometer - an instrument that measures temperature.

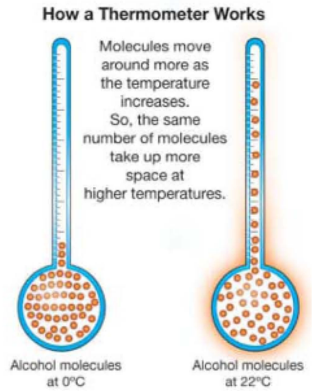


Figure 8.10: *How a thermometer works.*

Absolute zero and the Kelvin temperature scale

Absolute zero There is a limit to how cold matter can get. As the temperature is reduced, molecules move more and more slowly. When the temperature gets down to **absolute zero**, molecules have the lowest energy they can have and the temperature cannot get any lower. You can think of absolute zero as the temperature at which molecules are completely frozen, with no motion. Technically, molecules never become absolutely motionless, but the amount of kinetic energy is so small it might as well be zero. Absolute zero occurs at –273°C (–459°F).

You cannot have a temperature lower than absolute zero.

The Kelvin scale A temperature in Celsius measures only *relative* thermal energy, relative to zero Celsius. The **Kelvin scale** is useful in science because it starts at absolute zero. A temperature in Kelvins measures the actual energy of molecules relative to zero energy.

Converting to Kelvin The Kelvin (K) unit of temperature is the same size as the Celsius degree. If a room's temperature increases by 2°C, it also increases by 2K. Water freezes at 273K and boils at 373K. Most of the outer planets and moons have temperatures closer to absolute zero than to the freezing point of water (Figure 8.11). To convert from Celsius to Kelvins you add 273 to the temperature in Celsius. For example, a temperature of 21°C is equal to 294K (21 + 273).

High temperatures While absolute zero is the lower limit for temperature, there is no practical upper limit. Temperature can go up almost indefinitely. As the temperature increases, exotic forms of matter appear. For example, at 10,000°C, atoms start to come apart and become a *plasma*. In a plasma, atoms are broken apart into separate positive ions and negative electrons. Plasma conducts electricity and is formed in lightning and inside stars. You'll read more about plasma in the next section.

VOCABULARY

absolute zero - the lowest possible temperature, at which thermal energy is as close to zero as it can be, approximately –273°C.

Kelvin scale - a temperature scale that starts at absolute zero and has units the same size as Celsius degrees.

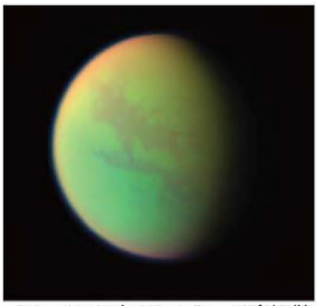


Photo courtesy of the Cassini Imaging Team and NASA/JPL/SSI

Figure 8.11: *The average surface temperature of Saturn's largest moon, Titan, is 93K.*

Section 8.2 Review

1. People in the United States know that water boils at 212°F. In Europe, people know that water boils at 100°C. Is the water in the United States different than the water in Europe? What explains the two different temperatures?
2. A comfortable room temperature is 20°C. What is this temperature in degrees Fahrenheit?
3. Which is colder, 0°C or 20°F?
4. Explain the scientific meaning of the word *random*.
5. Temperature measures:
   a. The kinetic energy of the random motion of molecules in an object.
   b. The kinetic energy of the average motion of molecules in an object.
   c. The potential energy of an object.
   d. The motion of an object.
6. A thermometer that uses a liquid to measure temperature works because:
   a. The electrical resistance in the liquid changes with temperature.
   b. The liquid changes color as temperature changes.
   c. The expansion of the liquid is directly proportional to the increase in temperature.
7. Which statement best describes the relationship between temperature and thermal energy?
   a. Temperature and thermal energy mean the same thing.
   b. As temperature increases, thermal energy increases.
   c. As temperature increases, thermal energy decreases.
   d. Thermal energy is not related to temperature.
8. Would thermal energy be greater at 0°C or 48°F? Explain your answer.
9. Why can't there be a temperature lower than absolute zero?

SOLVE IT!

What is absolute zero in degrees Fahrenheit?