colliding with one another. On the average, the speeds are sufficiently high in a gas that when two molecules collide, the force of attraction is not strong enough to keep them close together and they fly off in new directions.

EXAMPLE 13–1 ESTIMATE **Distance between atoms.** The density of copper is $8.9 \times 10^3\ \mathrm{kg/m^3}$, and each copper atom has a mass of 63 u. Estimate the average distance between neighboring copper atoms.

APPROACH We consider a cube of copper 1 m on a side. From the given density we can calculate the mass of a 1-m^3 cube. We divide this by the mass of one atom (63 u) to obtain the number of atoms in $1\ \mathrm{m}^3$. Let N be the number of atoms in a 1-m length; then $(N)(N)(N) = N^3$ equals this total number of atoms in $1\ \mathrm{m}^3$.

SOLUTION The mass of 1 copper atom is $63\ \mathrm{u} = 63 \times 1.66 \times 10^{-27}\ \mathrm{kg} = 1.05 \times 10^{-25}\ \mathrm{kg}$. This means that in a cube of copper 1 m on a side $(\text{volume} = 1\ \mathrm{m}^3)$, there are

$$\frac{8.9 \times 10^3\ \mathrm{kg/m^3}}{1.05 \times 10^{-25}\ \mathrm{kg/atom}} = 8.5 \times 10^{28}\ \mathrm{atoms/m^3}.$$

The volume of a cube of side l is $V = l^3$, so on one edge of the 1-m-long cube there are $(8.5 \times 10^{28})^{\frac{1}{3}}$ atoms $= 4.4 \times 10^9$ atoms. Hence the distance between neighboring atoms is

$$\frac{1\ \mathrm{m}}{4.4 \times 10^9\ \mathrm{atoms}} = 2.3 \times 10^{-10}\ \mathrm{m}.$$

NOTE Watch out for units. Even though "atoms" is not a unit, it is helpful to include it to make sure you calculate correctly.

13–2 Temperature and Thermometers

In everyday life, **temperature** is a measure of how hot or cold something is. A hot oven is said to have a high temperature, whereas the ice of a frozen lake is said to have a low temperature.

Many properties of matter change with temperature. For example, most materials expand when heated.† An iron beam is longer when hot than when cold. Concrete roads and sidewalks expand and contract slightly according to temperature, which is why compressible spacers or expansion joints (Fig. 13–3) are placed at regular intervals. The electrical resistance of matter changes with temperature (see Chapter 18). So too does the color radiated by objects, at least at high temperatures: you may have noticed that the heating element of an electric stove glows with a red color when hot. At higher temperatures, solids such as iron glow orange or even white. The white light from an ordinary incandescent lightbulb comes from an extremely hot tungsten wire. The surface temperatures of the Sun and other stars can be measured by the predominant color (more precisely, wavelengths) of light they emit.

FIGURE 13–3 Expansion joint on a bridge.

Instruments designed to measure temperature are called **thermometers**. There are many kinds of thermometers, but their operation always depends on some property of matter that changes with temperature. Most common thermometers rely on the expansion of a material with an increase in temperature. The first idea for a thermometer (Fig. 13–4a), by Galileo, made use of the expansion of a gas. Common thermometers today consist of a hollow glass tube filled with mercury or with alcohol colored with a red dye, as were the earliest usable thermometers (Fig. 13–4b). Figure 13–4c shows an early clinical thermometer of a different type, also based on a change in density with temperature.

†Most materials expand when their temperature is raised, but not all. Water, for example, in the range 0°C to 4°C contracts with an increase in temperature (see Section 13–4).