EXAMPLE 13–5 **Ring on a rod.** An iron ring is to fit snugly on a cylindrical iron rod. At 20°C, the diameter of the rod is 6.445 cm and the inside diameter of the ring is 6.420 cm. To slip over the rod, the ring must be slightly larger than the rod diameter by about 0.008 cm. To what temperature must the ring be brought if its hole is to be large enough so it will slip over the rod?

APPROACH The hole in the ring must be increased from a diameter of 6.420 cm to 6.445 cm + 0.008 cm = 6.453 cm. The ring must be heated since the hole diameter will increase linearly with temperature (as in Example 13–4).

SOLUTION We solve for ΔT in Eq. 13–1a and find

$$\Delta T = \frac{\Delta L}{\alpha L_0} = \frac{6.453\text{ cm} - 6.420\text{ cm}}{(12 \times 10^{-6}/\text{C}^\circ)(6.420\text{ cm})} = 430\,\text{C}^\circ.$$

So it must be raised at least to $T = (20^\circ\text{C} + 430\,\text{C}^\circ) = 450^\circ\text{C}$.

NOTE In doing Problems, don't forget the last step, adding in the initial temperature (20°C here).

CONCEPTUAL EXAMPLE 13–6 **Opening a tight jar lid.** When the lid of a glass jar is tight, holding the lid under hot water for a short time will often make it easier to open. Why?

PHYSICS APPLIED
Opening a tight lid

RESPONSE The lid may be struck by the hot water more directly than the glass and so expand sooner. But even if not, metals generally expand more than glass for the same temperature change (α is greater—see Table 13–1).

Volume Expansion

The change in *volume* of a material which undergoes a temperature change is given by a relation similar to Eq. 13–1a, namely,

$$\Delta V = \beta V_0\,\Delta T, \tag{13–2}$$

Volume expansion

where ΔT is the change in temperature, V_0 is the original volume, ΔV is the change in volume, and β is the *coefficient of volume expansion*. The units of β are $(\text{C}^\circ)^{-1}$.

Values of β for various materials are given in Table 13–1. Notice that for solids, β is normally equal to approximately 3α (work Problem 19 to see why). For solids that are not isotropic (that is, not having the same properties in all directions), the relation $\beta \approx 3\alpha$ is not valid. (Note that linear expansion has no meaning for liquids and gases since they do not have fixed shapes.)

$\beta \approx 3\alpha$

EXAMPLE 13–7 **Gas tank in the sun.** The 70-L steel gas tank of a car is filled to the top with gasoline at 20°C. The car sits in the sun and the tank reaches a temperature of 40°C (104°F). How much gasoline do you expect to overflow from the tank?

PHYSICS APPLIED
Gas tank overflow

APPROACH Both the gasoline and the tank expand as the temperature increases, and we assume they do so linearly as described by Eq. 13–2. The volume of overflowing gasoline equals the volume increase of the gasoline minus the increase in volume of the tank.

SOLUTION The gasoline expands by

$$\Delta V = \beta V_0\,\Delta T = (950 \times 10^{-6}\,\text{C}^{\circ -1})(70\text{ L})(40^\circ\text{C} - 20^\circ\text{C}) = 1.3\text{ L}.$$

The tank also expands. We can think of it as a steel shell that undergoes volume expansion ($\beta \approx 3\alpha = 36 \times 10^{-6}\,\text{C}^{\circ -1}$). If the tank were solid, the surface layer (the shell) would expand just the same. Thus the tank increases in volume by

$$\Delta V = (36 \times 10^{-6}\,\text{C}^{\circ -1})(70\text{ L})(40^\circ\text{C} - 20^\circ\text{C}) = 0.050\text{ L},$$

so the tank expansion has little effect. More than a liter of gas could spill out.

NOTE Want to save a few pennies? Fill your gas tank when it is cool and the gas is denser—more molecules for the same price. But don't fill the tank all the way.