PHYSICS APPLIED
Refrigerator

A perfect **refrigerator**—one in which no work is required to take heat from the low-temperature region to the high-temperature region—is not possible. This is the **Clausius statement of the second law of thermodynamics**, already mentioned in Section 15–4: it can be stated formally as

SECOND LAW OF THERMODYNAMICS (Clausius statement)

no device is possible whose sole effect is to transfer heat from one system at a temperature T_L into a second system at a higher temperature T_H.

To make heat flow from a low-temperature object (or system) to one at a higher temperature, work must be done. Thus, *there can be no perfect refrigerator.*

The **coefficient of performance** (COP) of a refrigerator is defined as the heat Q_L removed from the low-temperature area (inside a refrigerator) divided by the work W done to remove the heat (Fig. 15–16):

$$\text{COP} = \frac{Q_L}{W}. \qquad \begin{bmatrix}\text{refrigerator and}\\ \text{air conditioner}\end{bmatrix} \quad \textbf{(15–6a)}$$

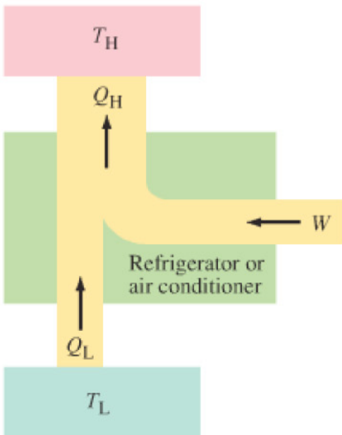

FIGURE 15–16 (repeated) Schematic diagram of energy transfers for a refrigerator or air conditioner.

This makes sense since the more heat, Q_L, that can be removed from inside the refrigerator for a given amount of work, the better (more efficient) the refrigerator is. Energy is conserved, so from the first law of thermodynamics we can write $Q_L + W = Q_H$, or $W = Q_H - Q_L$ (see Fig. 15–16). Then Eq. 15–6a becomes

$$\text{COP} = \frac{Q_L}{W} = \frac{Q_L}{Q_H - Q_L}. \qquad \begin{bmatrix}\text{refrigerator and}\\ \text{air conditioner}\end{bmatrix} \quad \textbf{(15–6b)}$$

For an ideal refrigerator (not a perfect one, which is impossible), the best one could do would be

$$\text{COP}_{\text{ideal}} = \frac{T_L}{T_H - T_L}, \qquad \begin{bmatrix}\text{refrigerator and}\\ \text{air conditioner}\end{bmatrix} \quad \textbf{(15–6c)}$$

analagous to an ideal (Carnot) engine (Eq. 15–5).

PHYSICS APPLIED
Air conditioner

An **air conditioner** works very much like a refrigerator, although the actual construction details are different: an air conditioner takes heat Q_L from inside a room or building at a low temperature, and deposits heat Q_H outside to the environment at a higher temperature. Equations 15–6 also describe the coefficient of performance for an air conditioner.

EXAMPLE 15–12 **Making ice.** A freezer has a COP of 3.8 and uses 200 W of power. How long would it take to freeze an ice-cube tray that contains 600 g of water at 0°C?

APPROACH In Eq. 15–6b, Q_L is the heat that must be transferred out of the water so it will become ice. To determine Q_L, we use the latent heat of fusion of water and Eq. 14–3, $Q = mL$.

SOLUTION From Table 14–3, $L = 333\,\text{kJ/kg}$. Hence $Q = mL = (0.600\,\text{kg})(3.33 \times 10^5\,\text{J/kg}) = 2.0 \times 10^5\,\text{J}$ is the total energy that needs to be removed from the water. The freezer does work at the rate of $200\,\text{W} = 200\,\text{J/s} = W/t$, which is the work W it can do in t seconds. We solve for t: $t = W/(200\,\text{J/s})$. For W, we use Eq. 15–6b: $W = Q_L/\text{COP}$. Thus

$$t = \frac{W}{200\,\text{J/s}} = \frac{Q_L/\text{COP}}{200\,\text{J/s}} = \frac{2.0 \times 10^5\,\text{J}}{(3.8)(200\,\text{J/s})} = 260\,\text{s},$$

or about $4\frac{1}{2}$ min.

Heat naturally flows from high temperature to low temperature. Refrigerators and air conditioners do work to accomplish the opposite: to make heat flow from cold to hot. We might say they "pump" heat from cold areas to hotter areas, against the natural tendency of heat to flow from hot to cold, just as water can be pumped uphill, against the natural tendency to flow downhill. The term