Calorimetry sometimes involves a change of state, as the following Examples show. Indeed, latent heats are often measured using calorimetry.

EXAMPLE 14–7 **Making ice.** How much energy does a freezer have to remove from 1.5 kg of water at 20°C to make ice at −12°C?

APPROACH We need to calculate the total energy removed by adding the heat outflow (1) to reduce the water from 20°C to 0°C, (2) to change it to ice at 0°C, and (3) to lower the ice from 0°C to −12°C.

SOLUTION The heat Q that needs to be removed from the 1.5 kg of water is

$$\begin{aligned} Q &= mc_{\mathrm{w}}(20^\circ\mathrm{C} - 0^\circ\mathrm{C}) + mL_{\mathrm{F}} + mc_{\mathrm{ice}}[0^\circ - (-12^\circ\mathrm{C})] \\ &= (1.5\,\mathrm{kg})(4186\,\mathrm{J/kg\cdot C^\circ})(20\,\mathrm{C^\circ}) + (1.5\,\mathrm{kg})(3.33\times10^5\,\mathrm{J/kg}) \\ &\quad + (1.5\,\mathrm{kg})(2100\,\mathrm{J/kg\cdot C^\circ})(12\,\mathrm{C^\circ}) \\ &= 6.6\times10^5\,\mathrm{J} = 660\,\mathrm{kJ}. \end{aligned}$$

EXAMPLE 14–8 **ESTIMATE** **Will all the ice melt?** At a reception, a 0.50-kg chunk of ice at −10°C is placed in 3.0 kg of "iced" tea at 20°C. At what temperature and in what phase will the final mixture be? The tea can be considered as water. Ignore any heat flow to the surroundings, including the container.

APPROACH Before we can write down an equation applying conservation of energy, we must first check to see if the final state will be all ice, a mixture of ice and water at 0°C, or all water. To bring the 3.0 kg of water at 20°C down to 0°C would require an energy release of

PROBLEM SOLVING
First determine (or estimate) the final state

$$m_{\mathrm{w}}c_{\mathrm{w}}(20^\circ\mathrm{C} - 0^\circ\mathrm{C}) = (3.0\,\mathrm{kg})(4186\,\mathrm{J/kg\cdot C^\circ})(20\,\mathrm{C^\circ}) = 250\,\mathrm{kJ}.$$

On the other hand, to raise the ice from −10°C to 0°C would require

$$m_{\mathrm{ice}}c_{\mathrm{ice}}[0^\circ\mathrm{C} - (-10^\circ\mathrm{C})] = (0.50\,\mathrm{kg})(2100\,\mathrm{J/kg\cdot C^\circ})(10\,\mathrm{C^\circ}) = 10.5\,\mathrm{kJ},$$

and to change the ice to water at 0°C would require

$$m_{\mathrm{ice}}L_{\mathrm{F}} = (0.50\,\mathrm{kg})(333\,\mathrm{kJ/kg}) = 167\,\mathrm{kJ},$$

for a total of 10.5 kJ + 167 kJ = 177 kJ. This is not enough energy to bring the 3.0 kg of water at 20°C down to 0°C, so we know that the mixture must end up all water, somewhere between 0°C and 20°C.

SOLUTION To determine the final temperature T, we apply conservation of energy and write

Then determine the final temperature

heat gain = heat loss

$$\begin{pmatrix}\text{heat to raise}\\ \text{0.50 kg of ice}\\ \text{from } -10^\circ\text{C}\\ \text{to } 0^\circ\text{C}\end{pmatrix} + \begin{pmatrix}\text{heat to change}\\ \text{0.50 kg}\\ \text{of ice}\\ \text{to water}\end{pmatrix} + \begin{pmatrix}\text{heat to raise}\\ \text{0.50 kg of water}\\ \text{from } 0^\circ\text{C}\\ \text{to } T\end{pmatrix} = \begin{pmatrix}\text{heat lost by}\\ \text{3.0 kg of}\\ \text{water cooling}\\ \text{from } 20^\circ\text{C to } T\end{pmatrix}.$$

Using some of the results from above, we obtain

$$\begin{aligned} 10.5\,\mathrm{kJ} + 167\,\mathrm{kJ} + (0.50\,\mathrm{kg})(4186\,\mathrm{J/kg\cdot C^\circ})(T - 0^\circ\mathrm{C}) \\ = (3.0\,\mathrm{kg})(4186\,\mathrm{J/kg\cdot C^\circ})(20^\circ\mathrm{C} - T). \end{aligned}$$

Solving for T we obtain

$$T = 5.0^\circ\mathrm{C}.$$

EXERCISE A How much more ice at −10°C would be needed in Example 14–8 to bring the tea down to 0°C, while just melting all the ice?