An 8.0 g ice cube at −10°C is put into a Thermos flask containing 100 cm³ of water at 20°C. By how much has the entropy of the cube–water system changed when equilibrium is reached? The specific heat of ice is 2220 J/kg · K.

\[ Q_{\text{lost}} + Q_{\text{gained}} = 0 \]
\[ m_w C_w (T_f - 20) + m_{\text{ice}} C_{\text{ice}} (0-(-10)) + m_{\text{ice}} L_f + m_w C_w (T_f - 0) = 0 \]
\[ 0.008 \times 4186 \times (T_f - 20) + 0.008 \times 2220 \times 10 + 0.008 \times 333 \times 10^3 \]
\[ + 0.008 \times 4186 \times T_f = 0 \]
\[ 452.1 T_f = 5590.4 \implies \boxed{T_f = 12.4^\circ C} \]

\[ \Delta S_{\text{ice}} = m_{\text{ice}} C_{\text{ice}} \ln \left( \frac{T_{\text{fusion}}}{T_i} \right) + m_{\text{ice}} L_f + m_w C_w \ln \left( \frac{T_f}{T_{\text{fusion}}} \right) \]
\[ = 0.008 \times 2220 \ln \left( \frac{273}{263} \right) + \frac{0.008 \times 333 \times 10^3}{273} + 0.008 \times 4186 \ln \left( \frac{285.4}{293} \right) \]
\[ = 0.66 + 9.76 + 1.49 = 11.91 \ J/K \]

\[ \Delta S_{\text{water}} = m_w C_w \ln \left( \frac{T_f}{T_i} \right) = 0.1 \times 4186 \times \ln \left( \frac{285.4}{293} \right) \]
\[ = -11.00 \ J/K \]

\[ \Delta S_{\text{system}} = 0.91 \ J/K \]
A Carnot engine operates between 235°C and 115°C, absorbing $6.30 \times 10^4 \text{ J}$ per cycle at the higher temperature. (a) What is the efficiency of the engine? (b) How much work per cycle is this engine capable of performing?

**Carnot engine (ideal engine)**

$T_H = 235^\circ \text{C} = 508 \text{ K}$

$T_L = 115^\circ \text{C} = 388 \text{ K}$

$Q_H = 6.3 \times 10^4 \text{ J/cycle}$

a) $\eta_c = 1 - \frac{T_L}{T_H} = 1 - \frac{388}{508} = 0.236 = 23.6\%$

b) $\eta_c = \frac{W}{Q_H} \Rightarrow W = \eta_c Q_H = 1.49 \times 10^4 \text{ J/cycle}$
A 500 W Carnot engine operates between constant-temperature reservoirs at 100°C and 60.0°C. What is the rate at which energy is (a) taken in by the engine as heat and (b) exhausted by the engine as heat?

Carnot engine $T_H = 373 K \quad T_L = 333 K$.

a) $P = 500 W = \frac{W}{t}$

$\epsilon_c = 1 - \frac{T_L}{T_H} = 1 - \frac{333}{373} = 0.107 = 10.7\%$

$\epsilon_c = \frac{W}{Q_H} \Rightarrow Q_H = \frac{W}{\epsilon_c}$

$Q_H = \frac{W}{\epsilon_c} = \frac{P}{\epsilon_c} = \frac{500}{0.107} = 4672 J/s$

b) $W = Q_H - |Q_L| \Rightarrow |Q_L| = \frac{Q_H - W}{\epsilon_c} = \frac{4672 - 500}{0.107} = 4172 J/s$
Figure 20-27 shows a reversible cycle through which 1.00 mol of a monatomic ideal gas is taken. Process bc is an adiabatic expansion, with $p_b = 10.0$ atm and $V_b = 1.00 \times 10^{-3}$ m$^3$. For the cycle, find (a) the energy added to the gas as heat, (b) the energy leaving the gas as heat, (c) the net work done by the gas, and (d) the efficiency of the cycle.

Reversible cycle, $n = 1$ mole, monatomic ideal gas $\gamma = 1.67$

$P_b = 10$ atm, $V_b = 1 \times 10^{-3}$ m$^3$

a) Heat added $Q > 0$ or $Q_{ab}$. It is $Q_{a\rightarrow b}$

$$Q_{ab} = n \cdot C_V \cdot \Delta T = n \cdot \frac{3}{2} R \cdot \frac{P_b V_b - P_a V_a}{\gamma R}$$

adiabatic $\Rightarrow P_c V_c^\gamma = P_b V_b^\gamma \Rightarrow P_c = P_b \left( \frac{V_b}{V_c} \right)^\gamma = 10 \left( \frac{1}{8} \right)^{1.67}$

$= 0.31$ atm = $P_a$

$$Q_{ab} = \frac{3}{2} \times (10 \times 1.01 \times 10^5 \times 10^{-3} - 0.31 \times 1.01 \times 10^5 \times 10^3) = \frac{1.47 \times 10^3}{J} \geq 0$$

$$Q_{ab} = Q_{ad}$$
b) \( Q_{bc} = 0 \) and \( Q_{ca} < 0 \) or \( Q_L \)

\[
Q_{ca} = n C_p \Delta T = \frac{5}{2} R \times \frac{P_{aV_a} - P_{cV_c}}{nR}
\]

\[
= \frac{5}{2} \left( 0.31 \times 1.01 \times 10^5 \times 10^{-3} - 0.31 \times 1.01 \times 10^5 \times 8 \times 10^{-3} \right)
\]

\[
Q_{ca} = -548 \text{ J} < 0 \iff Q_L
\]

c) \( W = Q_H - |Q_L| = 1470 - 548 = 922 \text{ J} \)

d) \( \varepsilon = \frac{W}{Q_H} = \frac{922}{1470} = 0.627 \approx 63\% \)
The electric motor of a heat pump transfers energy as heat from the outdoors, which is at $-5.0\, ^\circ C$, to a room that is at $17\, ^\circ C$. If the heat pump were a Carnot heat pump (a Carnot engine working in reverse), how much energy would be transferred as heat to the room for each joule of electric energy consumed?

**Ideal heat pump (Carnot heat pump)**

\[ W = 1\, J \quad T_L = -5\, ^\circ C = 268\, K \]
\[ T_H = 17\, ^\circ C = 290\, K \]

\[ Q_H ? \]

Carnot \[ \Rightarrow \quad \frac{Q_H}{|Q_L|} = \frac{T_H}{T_L} \quad \Rightarrow \quad \frac{Q_H}{Q_H - W} = \frac{T_H}{T_L} \]

\[ Q_H = (Q_H - W) \frac{T_H}{T_L} \quad \Rightarrow \quad Q_H \left(1 - \frac{T_H}{T_L}\right) = -W \frac{T_H}{T_L} \]

\[ Q_H = \frac{-W}{1 - \frac{T_L}{T_H}} = \frac{1}{1 - \frac{268}{290}} = 13.2\, J \]
The motor in a refrigerator has a power of 200 W. If the freezing compartment is at 270 K and the outside air is at 300 K, and assuming the efficiency of a Carnot refrigerator, what is the maximum amount of energy that can be extracted as heat from the freezing compartment in 10.0 min?

\[ P = 200 \text{ W} \]

refrigerator

\[ T_L = 270 \text{ K} \]

\[ T_H = 300 \text{ K} \]

Coefficient of performance for Carnot refig.

\[ K_c = \frac{T_L}{\Delta T} = 9 = \frac{|Q_L|/t}{W/t} \]

\[ |Q_L| = 9 \times P = 9 \times 200 = 1800 \text{ J/s} \]

in 10 min

\[ |Q_L| = 10.8 \times 10^5 \text{ J} \]