Refrigerator Run cycle backwards, extract heat at cold end, dump it at hot end

\[
\frac{\text{HEAT EXTRACTED (COLD END)}}{\text{WORK DONE ON SUBSTANCE}} = \frac{|Q_C|}{\Delta W} = \frac{|Q_C|}{|Q_H| - |Q_C|}
\]

For the special case of a quasi-static Carnot cycle

\[
= \frac{T_C}{T_H - T_C}
\]
• As with engine, can show Carnot cycle is optimum.

• Practical: increasingly difficult to approach $T = 0$.

• Philosophical: $T = 0$ is point at which no more heat can be extracted.
Heat Pump Run cycle backwards, but use the heat dumped at hot end.

\[
\frac{\text{HEAT DUMPED (HOT END)}}{\text{WORK DONE ON SUBSTANCE}} = \frac{|Q_H|}{\Delta W} = \frac{|Q_H|}{|Q_H| - |Q_C|}
\]

For the special case of a quasi-static Carnot cycle

\[
= \frac{T_H}{T_H - T_C}
\]
55° F subsurface temp. at 40° latitude

\[ \rightarrow T_C = 286K \]

70° F room temperature

\[ \rightarrow T_H = 294K \]

\[ \frac{|Q_H|}{\Delta W} \leq \frac{294}{8} \sim 37 \]
$3^{rd}$ law \[ \lim_{T \to 0} S = S_0 \]

At $T = 0$ the entropy of a substance approaches a constant value, independent of the other thermodynamic variables.

- Originally a hypothesis
- Now seen as a result of quantum mechanics

Ground state degeneracy $g$ (usually 1)

$\Rightarrow S \to k \ln g$ (usually 0)
Consequences \[ \left( \frac{\partial S}{\partial x} \right)_{T=0} = 0 \]

Example: A hydrostatic system

\[ \alpha \equiv \frac{1}{V} \left( \frac{\partial V}{\partial T} \right)_P = -\frac{1}{V} \left( \frac{\partial S}{\partial P} \right)_T \to 0 \text{ as } T \to 0 \]

\[ \frac{C_P - C_V}{K_T} = \frac{VT\alpha^2}{K_T} \to 0 \text{ as } T \to 0 \]

\[ S(T) - S(0) = \int_{T=0}^{T} \frac{C_V(T')}{T'} dT' \Rightarrow C_V(T) \to 0 \text{ as } T \to 0 \]