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^o F subsurface temp. at 40^o latitude

$$\rightarrow T_C = 286K$$

70^o F room temperature

$$\rightarrow T_H = 294K$$

$$\frac{|Q_H|}{\Delta W} \leq \frac{294}{8} \sim 37$$

$\underline{3^{rd}\text{ law}}$ $$\lim_{T\to 0} S = S_0$$

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

$$\underline{\alpha} \equiv \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P = -\frac{1}{V}\left(\frac{\partial S}{\partial P}\right)_T \rightarrow 0 \quad \text{as } T \rightarrow 0$$

$$\underline{C_P - C_V} = \frac{VT\alpha^2}{\mathcal{K}_T} \rightarrow 0 \quad \text{as } T \rightarrow 0$$

$$S(T) - S(0) = \int_{T=0}^{T} \frac{C_V(T')}{T'}\, dT' \Rightarrow \underline{C_V(T)} \rightarrow 0 \quad \text{as } T \rightarrow 0$$