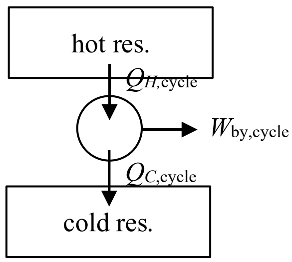
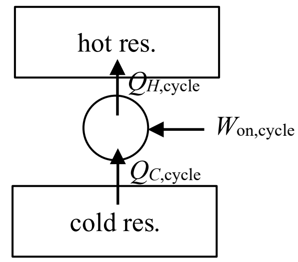
Thermodynamic Cycles and the Second Law
Absolute Temperature Scale



power cycle



refrigeration or heat pump cycle

From the First Law for the cycle,

$\Delta E_{sys,cycle} = 0 = Q_{into,cycle} - W_{by,cycle} = Q_{into,cycle} + W_{on,cycle}$

power cycle: $0 = (Q_{H,cycle} - Q_{C,cycle}) - W_{by,cycle}$ => $W_{by,cycle} = Q_{H,cycle} - Q_{C,cycle}$

refrigeration or heat pump cycle: $0 = (Q_{C,\text{cycle}} - Q_{H,\text{cycle}}) + W_{\text{on,cycle}} \Rightarrow W_{\text{on,cycle}} = Q_{H,\text{cycle}} - Q_{C,\text{cycle}}$

Power cycle thermal efficiency

$\eta = \frac{W_{by,cycle}}{Q_{H,cycle}} = \frac{Q_{H,cycle} - Q_{C,cycle}}{Q_{H,cycle}} = 1 - \frac{Q_{C,cycle}}{Q_{H,cycle}}$

From the Kelvin-Planck Statement of the Second Law: $Q_{C,\text{cycle}} \neq 0$ =>

Refrigeration cycle coefficient of performance

$COP_{ref} = \frac{Q_{C,cycle}}{W_{on,cycle}} = \frac{Q_{C,cycle}}{Q_{H,cycle} - Q_{C,cycle}} = \frac{1}{Q_{H,cycle}/Q_{C,cycle} - 1}$

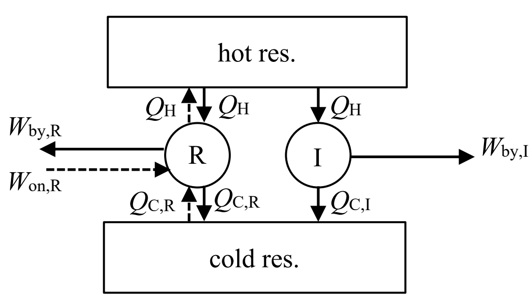
Heat pump cycle coefficient of performance

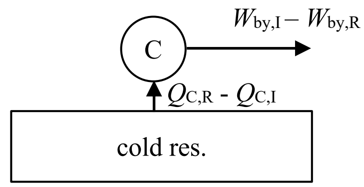
$COP_{ref} = \frac{Q_{H,cycle}}{W_{on,cycle}} = \frac{Q_{H,cycle}}{Q_{H,cycle} - Q_{C,cycle}} = \frac{1}{1 - Q_{C,cycle}/Q_{H,cycle}}$

From the Clausius Statement of the Second Law: $W_{\text{on,cycle}} \neq 0$ =>

Second Law Corollaries

1. $\eta_{\text{irreversible}} < \eta_{\text{reversible}}$ (same thermal reservoirs)
2. $\eta_{\text{peversible,1}} = \eta_{\text{reversible,2}}$ (same thermal reservoirs)
3. $COP_{\text{irreversible}} < COP_{\text{reversible}}$ (same thermal reservoirs)
4. $COP_{\text{reversible,1}} = COP_{\text{reversible,2}}$ (same thermal reservoirs)





Kelvin-Plank Statement of the Second Law:

$W_{by,net,cycle} \begin{cases} < 0 & \text{internal irreversibilities are present} \\ = 0 & \text{internal irreversibilities are not present} \end{cases}$ (single reservoir)

Absolute Temperature Scale

- Reversible cycle performance depends solely on the heat transfer from the thermal reservoirs since all reversible cycle efficiencies are identical.
- The heat transfer from the reservoirs is driven by the reservoir temperatures.
- Thus, the reversible cycle performance is solely a function of the reservoir temperatures,

$$\left.\frac{Q_C}{Q_H}\right|_{\substack{\text{rev,}\\ \text{cycle}}} = fcn\left(\frac{T_C}{T_H}\right)$$

- The Kelvin absolute temperature scale is defined as one where the function is,

$$\left.\frac{Q_C}{Q_H}\right|_{rev,cycle} \equiv \frac{T_C}{T_H}$$

and $T_{\text{triple pt of water}} = 273.16\text{ K}$.