Heat capacity: $C_2(T) = DT$ ($D \rightarrow$ const.)

For vdW sys. (see obj #4-4-2)

we know:

$$\begin{cases} S = NR\ln[(v-b)(u+a/v)^c] + S_0 \quad (N \rightarrow 1) \\ \dfrac{1}{T} = \dfrac{cR}{u+a/v} \rightarrow u = cRT - a/v \end{cases}$$

$$\Rightarrow \begin{cases} \Delta S_1 = R\ln\left(\dfrac{v_f-b}{v_0-b}\right) + cR\ln\dfrac{T_f}{T_0} \\ \Delta U_1 = cR(T_f - T_0) - \left(\dfrac{a}{v_f} - \dfrac{a}{v_0}\right) \end{cases}$$

$\Rightarrow$ For sys 2.

$$Q_2 = \int_{T_{20}}^{T_{2f}} C_2(T)\,dT = \int_{T_{20}}^{T_{2f}} DT\,dT = \frac{1}{2}D(T_{2f}^2 - T_{20}^2)$$

$$\Delta S_2 = \int_{T_{20}}^{T_{2f}} \frac{C_2(T)\,dT}{T} = D(T_{2f} - T_{20})$$

$\Delta S_{total} = \Delta S_1 + \Delta S_2 = 0 \longrightarrow$ max W condition.

$$\rightarrow R\ln\frac{(v_f-b)}{(v_0-b)} + cR\ln\frac{T_f}{T_0} + D(T_{2f} - T_{20}) = 0$$

$$\rightarrow T_{2f} = T_{20} - \frac{R}{D}\ln\left(\frac{v_f-b}{v_0-b}\right) - \frac{cR}{D}\ln\frac{T_f}{T_0}$$

$$\rightarrow \Delta U_1 + Q_2 + W_3 = 0$$

$$\rightarrow W_3 = -Q_2 - \Delta U_1 = \frac{1}{2}D(T_{20}^2 - T_{2f}^2) - cR(T_f - T_0) - \left(\frac{a}{v_f} - \frac{a}{v_0}\right)$$

Max work

Obj # 6. Heat Engines (Entropy)

1. Coefficients of Engines.
2. Carnot Cycles.
3. Measurability of T, and S
4. Engine performance (power)
5. Other engine cycles.

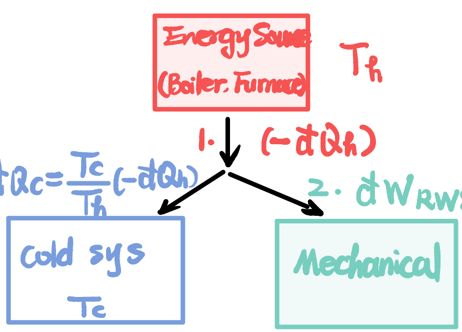
Generally, we have: 1> $(đQ_h + đW_h) + đQ_c + đW_{RWS} = 0$

2> $dS = 0 = dS_h + dS_c$

$$= \frac{đQ_h}{T_h} + \frac{đQ_c}{T_c}$$

1. Heat Engine, refrigerator, heat pump.

1> Heat Enigine.



3. $đQ_c = \frac{T_c}{T_h}(-đQ_h)$

2. $đW_{RWS} = (1 - \frac{T_c}{T_h}) \cdot (-đQ_h)$

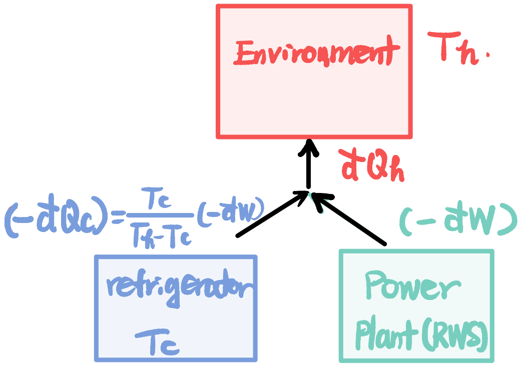
Efficiency of the engine.

$$\varepsilon_E = \frac{đW_{RWS}}{(-đQ_h)} = 1 - \frac{T_c}{T_h}$$

*. $\varepsilon_E \uparrow$ w/ $T_c \downarrow$

$\varepsilon_E \to 1$ w/ $T_c \to 0$

2> For refrigerator: Extract heat from cold sys.



$$\varepsilon_R = \frac{(-đQ_c)}{(-đW)} = ? = \frac{T_c}{T_h-T_c}$$

1> Energy conservation:

$$đQ_h = (-đQ_c)+(-đW)$$

2> Entropy:

$$dS_{total} = 0 = dS_h + dS_c$$

$$\frac{đQ_h}{T_h} + \frac{đQ_c}{T_c} = 0$$

$$đQ_c = \frac{T_c}{T_h}(-đQ_h) \leftarrow$$

$$\rightarrow đQ_c = \frac{T_c}{T_h}(đQ_c + đW)$$

$$\rightarrow đQ_c\left(1-\frac{T_c}{T_h}\right) = \frac{T_c}{T_h}\cdot đW$$

$$\rightarrow đQ_c = \frac{T_c}{T_h-T_c}\cdot đW$$

$$\varepsilon_R = \frac{T_c}{T_h-T_c}$$

*. if $T_c \rightarrow T_h$, $\varepsilon_R \rightarrow$ large. (or $\rightarrow \infty$) (why?)

*. if $T_c \rightarrow 0$, $\varepsilon_R \rightarrow$ small (or $\rightarrow 0$) (why?)

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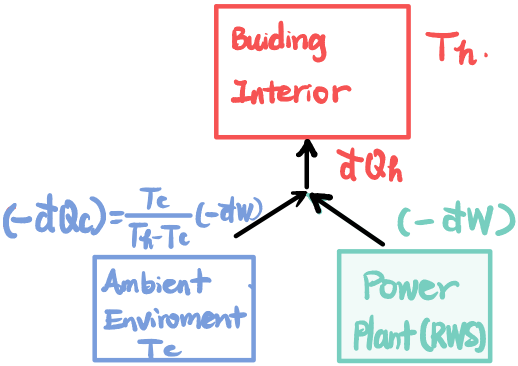
3. heat pump: heat a warm sys.



$$\varepsilon_h = \frac{đQ_h}{(-đW)} = \frac{T_h}{T_h - T_c}$$

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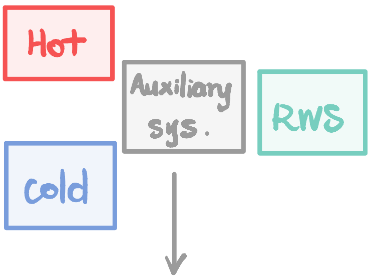
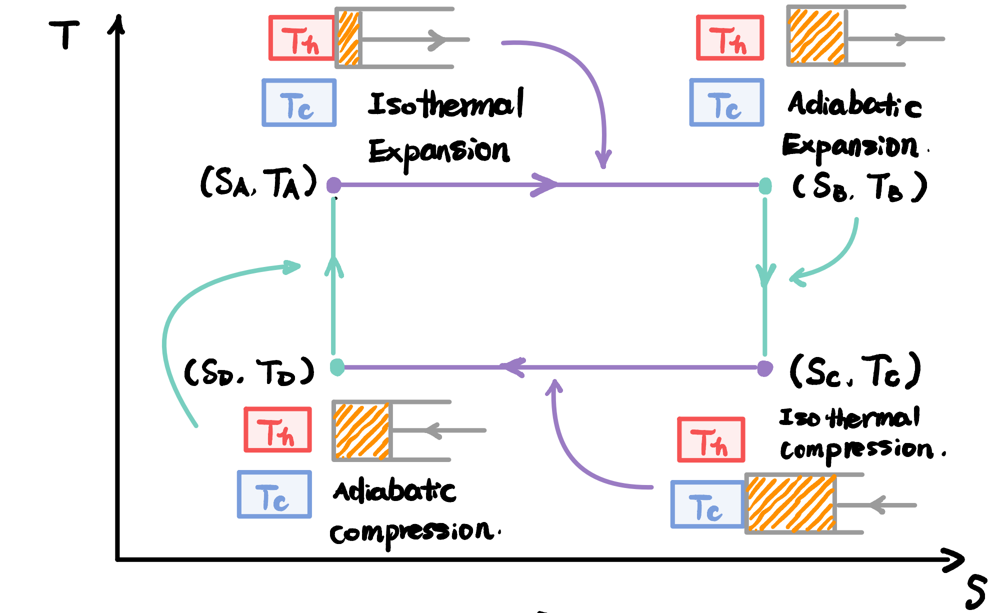
2. The carnot cycle.



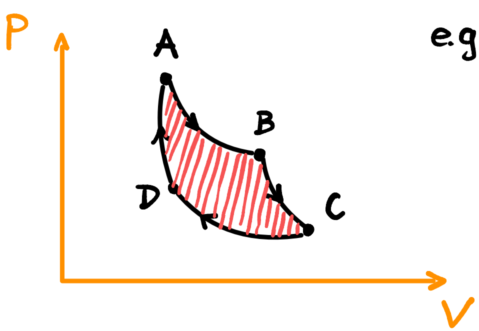
1> offers a manner by which heat are conveyed to the RWS

"cycle" $\left\{ \begin{array}{l} \text{2> can be restored to the initial state at the end of the process.} \\ \text{3> NOT enter the overall energy or Entropy accounting.} \end{array} \right.$



$$\begin{cases} 1\rangle\ T_A = T_B = T_h > \underset{\text{cold}}{T_c} = T_C = T_D \\ 2\rangle\ S_A < S_B,\quad S_B = S_C,\quad S_C > S_D,\quad S_D = S_A \end{cases}$$

Efficiency: $$\varepsilon = \frac{\overbrace{T_h \cdot \Delta S}^{Q_h} - \overbrace{T_c \cdot \Delta S}^{Q_c}}{T_h \cdot \Delta S} = 1 - \frac{T_c}{T_h}$$



e.g.. Assuming ideal gas. $(PV = nR\underline{T})$

EOS: $P = P(S, V, N)$

of the specific sys.

3. Measurability of T and S.

1> why ?

- Engine efficiency : $\varepsilon_E = 1 - \frac{T_c}{T_h}$.
- ε_E can be measured : by heat flux and work.
- define standard T. : ice / water / vapor $\downarrow$ cold sys. w/ T_c.

2> For "S". $đQ = T \cdot dS \rightarrow dS = \frac{đQ}{T}$

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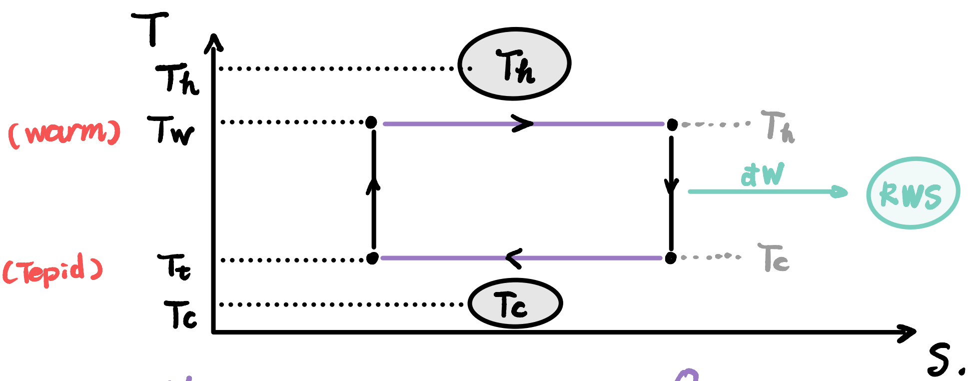
4. Engine performance :

* Power output : work done per unit time.

Knowing $\frac{Q}{t} = \sigma (T_2 - T_1)$

$\sigma \downarrow$ conductance (heat)



$\left(\frac{W}{t}\right)_{max} \uparrow$ $\quad t = \frac{Q}{\sigma (T_2 - T_1)}$

$$t = \frac{(-Q_h)}{\sigma_h (T_h - T_w)} + \frac{Q_c}{\sigma_c (T_t - T_c)}$$

(Assume the adiabatic process takes neglible time:)

$$W = \varepsilon \cdot (-Q_h) = \left(1 - \frac{\tilde{T}_c \to T_t}{\tilde{T}_h \to T_w}\right)(-Q_h) = \frac{T_w - T_t}{T_w}(-Q_h)$$

$$\rightarrow \quad (-Q_h) = \frac{T_w}{T_w - T_t} \cdot W$$

$$Q_c = \frac{\tilde{T}_c}{\tilde{T}_h}(-Q_h) \approx \frac{T_t}{T_w}(-Q_h) = \frac{T_t}{T_w - T_t} \cdot W$$

$$\Rightarrow \quad t =$$