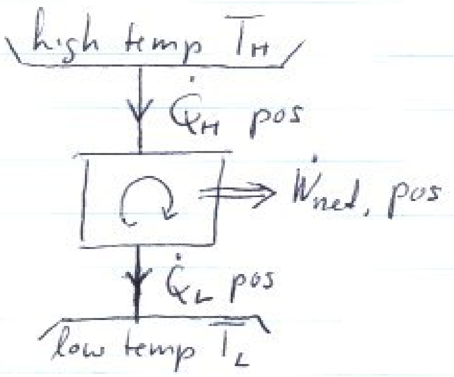
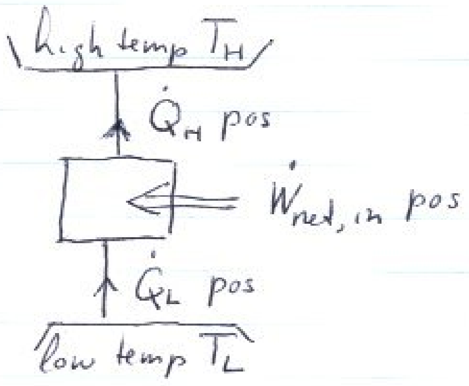
Review

1. Sign conventions are special

heat engine

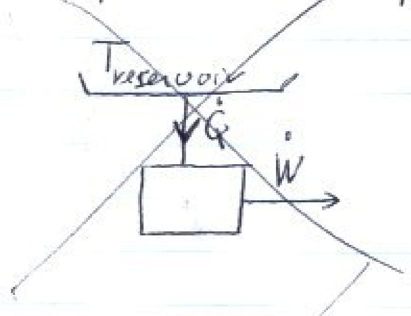


refrigeration or heat pump

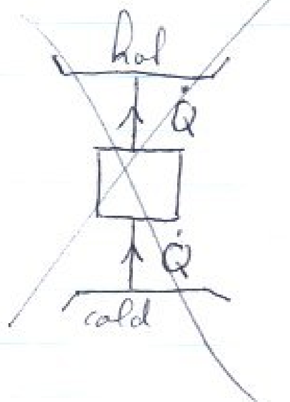


In other words, the direction is such that $\dot{Q}_H$, $\dot{Q}_L$, $\dot{W}_{net}$, $\dot{W}_{net,in}$ are normally positive numbers

2. Not posible (when positive as shown):



Kelvin Planck : you must always dump some of the heat $\dot{Q}$ to another reservoir at a lower temperature.
So you need a temperature difference and you are killing it by running the engine.



Clausius : you need to do work to move heat from cold to hot : $\dot{W}_{in}$ must be positive

3. 1st law for cycles

sum of heats in = sum of works out (only <u>one</u> equation)

4. Efficiencies for cycles operating between a hot and a cold reservoir:

thermal efficiency:

$$\eta_{TH} = \frac{\dot{W}_{net}}{\dot{Q}_H} = \frac{\dot{Q}_H - \dot{Q}_L}{\dot{Q}_H} \qquad \eta_{TH,carnot} = 1 - \frac{T_L}{T_H} \text{ : ideal}$$

coefficient of performance

$$\beta = \frac{\dot{Q}_L}{\dot{W}_{in}} = \frac{\dot{Q}_L}{\dot{Q}_H - \dot{Q}_L} \qquad \beta_{carnot} = \frac{T_L}{T_H - T_L} \text{ : ideal}$$

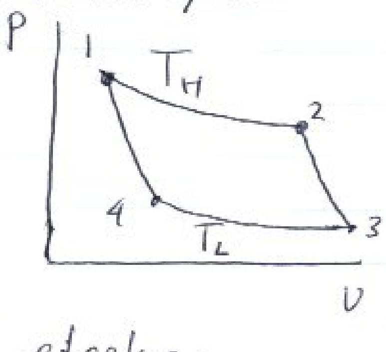
$$\beta' = \frac{\dot{Q}_H}{\dot{W}_{in}} = \frac{\dot{Q}_H}{\dot{Q}_H - \dot{Q}_L} (= 1+\beta) \quad \beta'_{carnot} = \frac{T_H}{T_H - T_L} \text{ : ideal}$$

5. Heat transfer in an ideal gas Carnot cycle:

$$q_H = RT_H \ln \frac{v_2}{v_1} \left[\frac{kJ}{kg}\right]$$

lns are equal $\updownarrow$

$$q_L = RT_L \ln \frac{v_3}{v_4} \left[\frac{kJ}{kg}\right]$$



Please: $q_H \neq T_H$ $\quad \dot{Q}_H \neq T_H$ etcetera.

Only $\frac{q_H}{q_L} = \frac{T_H}{T_L}$ and that only for a Carnot cycle.

Please T_H and T_L are <u>absolute</u>

R3

Some typical problems

a) Given partial data on heat fluxes, work rates, efficiency, figure out the missing info.

- typically must use the 1st law.
- " " " the definition of efficiency

Examples: 7.18, $\frac{26}{C}$, $\frac{29}{25}$, 32 $7.\frac{28}{C}$ $7.\frac{29}{C}$

b) Are the 1st or 2nd law violated?

- Fridges or heat pumps operating for free or worse
- Heat engines running without dumping heat in a cooler place

Example: $7.\frac{25}{21}$ $7.\frac{28}{22}$

c) Best possible performance and actual performance

- must use Carnot formulae for ideal efficiencies

Example: $7.\frac{40}{37}$, $7.\frac{41}{39}$, $7.\frac{44}{54}$, $7.\frac{52}{55}$

d) Ideal gas Carnot cycle

Example: $7.\frac{77}{73}$ $7.\frac{78}{C}$

e) Combination problems components complete cycle.

- chapter 6 material combines well with chapter 7

Example: 7.18, $\frac{32}{29}$, 40 ⟹ Exams

7.58

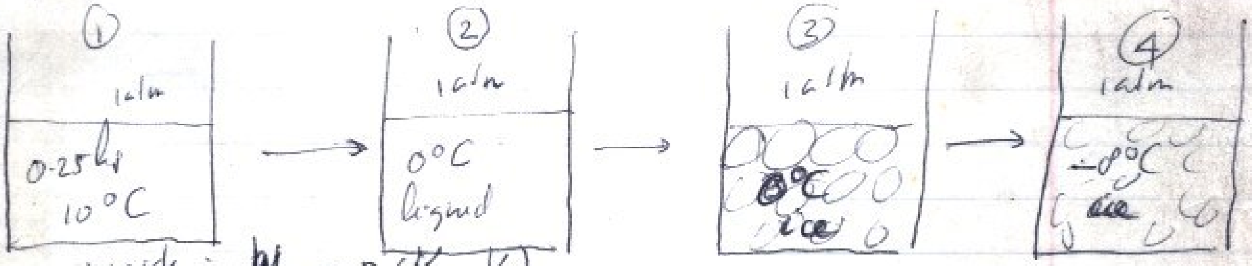
Carnot Cycle Fridge
with $T_L = -8°C$ $T_H = 35°C$
and 750 W compressor

Makes ice cubes from
0.25 kg liquid water
initially at 10°C

Asked: what time does this take if it is the only cooling load.

Answer: Find out heat that must be removed, then using the efficiency, how much work that ~~takes~~, then using the wattage, how much time

Subpart 1: heat needed to convert 10°C water to −8°C ice (1 atm)



work: $_1W_4 = p(V_4 - V_1)$

1st law

$$U_4 - U_1 = {}_1Q_4 - p(V_4 - V_1)$$

$$_1Q_4 = U_4 + pV_4 - (U_1 + pV_1) = H_4 - H_1$$

$$= m(h_4 - h_1)$$

$B.\overset{A-4}{1.1}$ @ 10°C: $h_f = h_1 = \overset{42.022}{41.99}$ kJ/kg (SAL)

$B.\overset{A-8}{1.5}$ @ −8°C (and p = .31 kPa) $h_4 = -350.\overset{04}{02}$ kJ/kg (Sat Solid)

$$_1Q_4 = 0.25\text{ kg}\,(-350.02 - 41.99)\text{ kJ/kg} = -98\text{ kJ}$$

Subpart 2: compute

$$\beta = \frac{\text{heat removed}}{\text{work done}} = \frac{|{}_1Q_4|}{\text{work done } W_{in}}$$

Carnot, so $\overset{COP_{RC}}{\beta} = \dfrac{T_L}{T_H - T_L} =$

$$\overset{COP_{RC}}{\beta} = \frac{-8+273}{35-(-8)} = 6.16$$

~~wor~~ $W_{in} = \dfrac{+98\text{ kJ}}{6.16} = 15.58\text{ kJ}$

at 750 W = 0.750 kW = 0.750 kJ/s : $\dfrac{15.58\text{ kJ}}{0.750\text{ kJ}}\text{ s} = 20.8$ sec