One ~~more~~ property of the state of an ideal gas to talk about. The entropy.

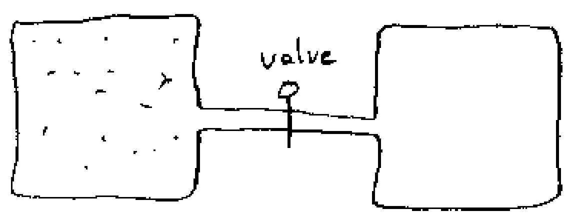
FISHBANE
Chapter 20

$$dQ = dW + dE_{INT}$$
$$= PdV + C_v\,dT$$

$$\frac{dQ}{T} = \frac{Nk_B\cancel{T}}{V\,\cancel{T}}\,dV + C_v\frac{dT}{T}$$

$$\Delta S = \int_I^F \frac{dQ}{T} = Nk_B \ln\left(V_F/V_I\right) + C_v \ln\left(T_F/T_I\right)$$

Why is this useful?



Suppose I open a valve and let the gas fill the second chamber
$\Delta E_{INT} = 0,\ \Delta Q = 0,\ \Delta W = 0$

in order to get it back into the bottle, we'd have to do work on the gas, Since we got no work out of the gas, we've really lost something by opening the valve

$$\Delta S = Nk_B \ln\left(V_F/V_I\right)$$ by opening the valve

If we return this gas to its original state, say via an isothermal contraction, it will have it's original entropy, but we had to remove heat and do work on the gas. So the entropy change of the resivoir where we took the heat is

$$Nk_B \ln\left(V_F/V_I\right) = \frac{Q}{T}$$

entropy increased.

If there is a net entropy increase in the universe to get back to our starting point, the process we were trying to reverse was "irreversible".

$$\Delta S_{universe} \geq 0$$

$\Delta S_{universe} = 0$ process reversible

$\Delta S_{universe} > 0$ irreversible

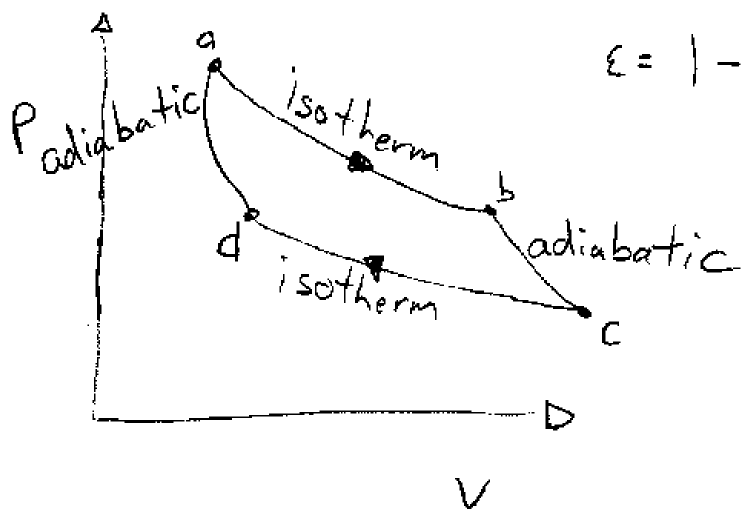
- consider our cyclic engine, if this is reversible $\Delta S = 0$
- Carnot Cycle is suppose to be most efficient between 2 temperatures

$$0 = \Delta E_{INT} = Q_{put\,in} - |Q_{absorbed}| - W_{net}$$

$$\varepsilon = \frac{\text{work you got}}{\text{energy you put in}}$$

$$Q_{put\,in} - |Q_{absorbed}| = W_{net}$$

$$\varepsilon = 1 - \frac{|Q_{Absorbed}|}{Q_{put\,in}}$$

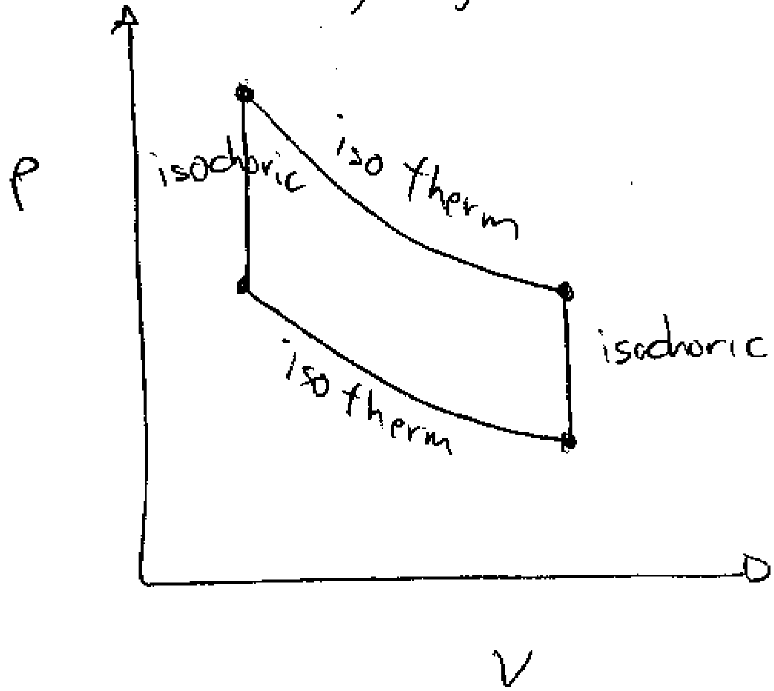


You can show that for a carnot cycle

$$\varepsilon = 1 - \frac{T_C}{T_H}$$

$$\Delta S = \frac{Q_H}{T_H} - \frac{|Q_C|}{T_C} = 0 \quad \frac{Q_H}{T_H} = \frac{|Q_C|}{T_C}$$

consider this a second and compare it to our stirling engine



The heat we put in occurs over the iso therm & the isochoric

so $\Delta S_{put\ in} = \dfrac{Q_H}{(T_H - \delta_H)}$

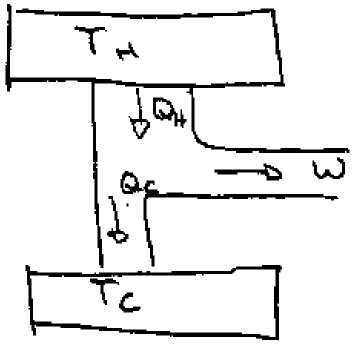
likewise $\left|\Delta S_{\substack{pull \\ out}}\right| = \dfrac{|Q_c|}{(T_c + \delta_c)}$

$$\frac{Q_H}{(T_H - \delta_H)} - \frac{|Q_c|}{T_c + \delta_c} = 0$$

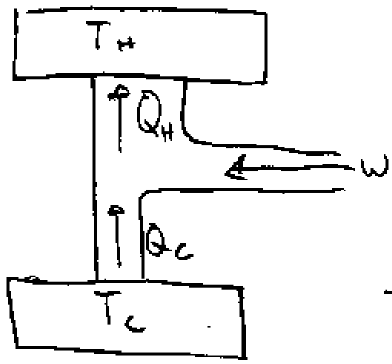
$$\text{or } \frac{|Q_c|}{Q_H} = \frac{T_c + \delta_c}{T_H + \delta_H} > \frac{T_c}{T_H}$$

so $\varepsilon < \varepsilon_{carnot}$!

It is useful to have a simplified view of engines



$\varepsilon = 1 - \frac{T_C}{T_H}$ Carnot engine



Carnot refrigerator (T_C = Fridge, T_H = room) or heat pump (T_C = Room, T_H = ground)

Talk about these using coefficient of performace (COP)

Fridge (you pay for work done)

$$COP = \frac{\text{Heat removed}}{\text{Work done}} = \frac{|Q_C|}{Q_H - |Q_C|}$$

$$= \frac{1}{\frac{T_H}{T_C} - 1}$$

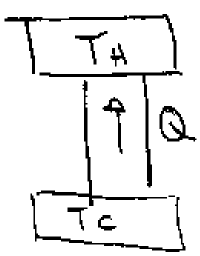
closer T_H & T_C are, the better the COP

Heat pump (you pay for work done)

$$Cop = \frac{\text{Head Added}}{\text{Work done}} = \frac{Q_H}{Q_H - |Q_C|}$$

$$= \frac{1}{1 - T_C/T_H}$$ (same deal)

can't have



$$\Delta S = -\frac{|Q|}{T_C} + \frac{|Q|}{T_H} > 0$$