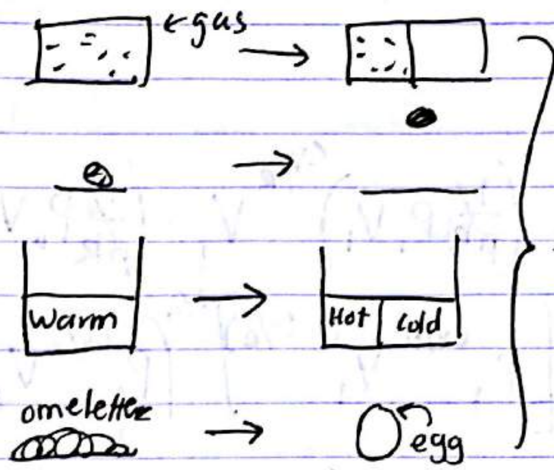
09/15/15

Chapter 20 Lecture

Second Law Thermodynamics
- Carnot (tried to make an awesome steam engine)
- All laws we have dealt with involve conservation of energy

What will never happen



these processes do obey conservation of energy, but there will never happen!
what's in common:
disordered → ordered

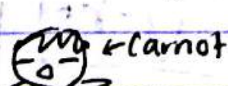
To cope, we make a new law.
★ there is only one direction cons. energy can flow.

2nd Law: Energy of universe will always increase
↓
order, universe disorder will increase.
Fancy word: entropy of universe always increases

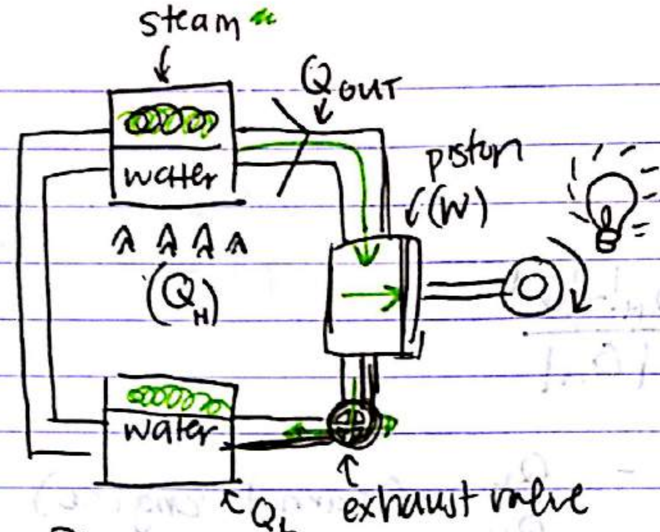
Heat Engine
↓ ↓
Q Mech. Work (W)

Thermal Efficiency (η) = $\frac{\text{what you get}}{\text{what you pay}} = \frac{W}{Q_H}$

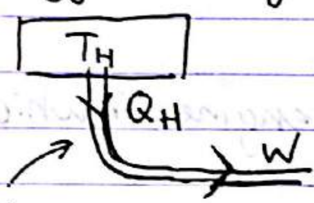
$\eta < 1$ is alternate 2nd law expression ← "My engine is the best!"

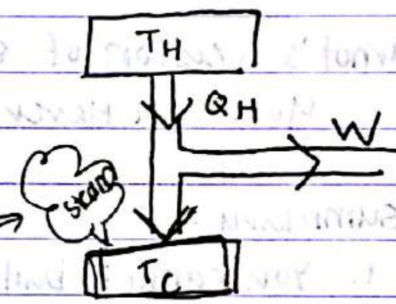


← $\eta = 1$ = BEST!!!
($Q_H \xrightarrow{\text{all}} W$), "impossible"



Energy-Flow Diagram:





$\eta = 1$ (ideal), impossible.

$\eta < 1$ (experimentally)

same T_H ⇒ Pressure is same

$W_{by\,gas\,on\,piston}$

Assumption: $\Delta T = 0$ → same pressure

W ① Work done by gas on piston

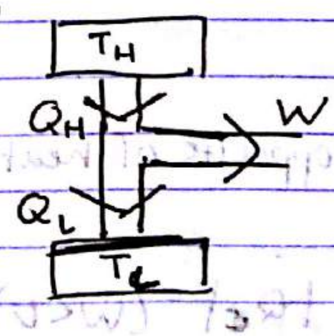
W ② Work done by piston to push gas through exhaust valve.

$W_1 = -W_2$

$W_{NET} = 0$. :(

∴ This assumption is wrong

Thus,



$W = Q_H + Q_L = |Q_H| - |Q_L|$

Convention: heat coming out is plus sign, coming in is (−) sign

$$\eta = \frac{W}{Q_H}$$

$$= \frac{|Q_H| - |Q_L|}{|Q_H|}$$

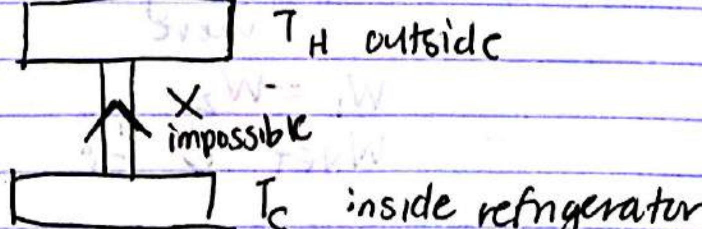
$$= 1 - \frac{Q_L}{Q_H} \quad \text{(Carnot Engine)}$$

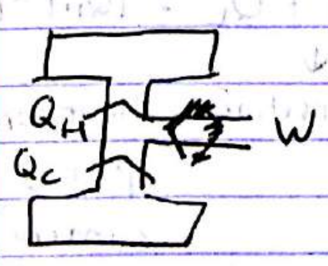
Carnot's version of second law:
You can never build an engine in which $\eta = 1$

In summary:

1. You cannot build an engine whose sole effect is to transfer heat from cold body to hot body
2. You cannot build a system that absorbs heat from a reservoir T and converts it all to work
3. You cannot build a system in which $\eta = 1$
4. Energy (entropy) of the universe always increases

<u>Refrigerator</u> (heat engine that operates in reverse mode)





$Q_C > 0$ (opposite of heat engine)

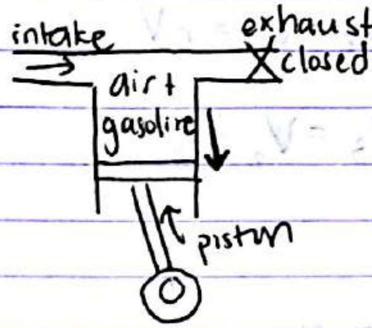
$Q_H < 0$

$W = |Q_H| - |Q_C| \quad (W < 0)$

coefficient performance

$$COP = \frac{Q_c}{W} = \frac{|Q_c|}{|Q_H| - |Q_c|}$$

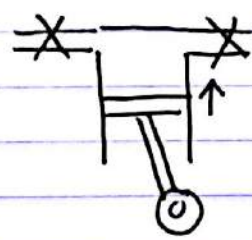
Otto Cycle

① 

* expansion

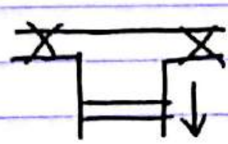
$V_{initial} = V$

$V_{final} = rV$, r = compression ratio ($r \sim 8, 10$)

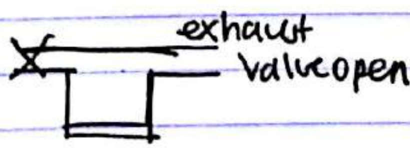
② 

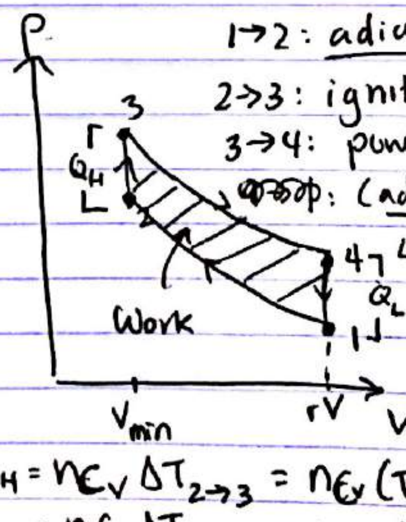
* compression

ignition occurs @ minimum V.

③ 

* power stroke

④ 



1→2: adiabatic comp.
2→3: ignition
3→4: power stroke (adiabatic exp)
4→1: restart

$$\eta = 1 - \frac{Q_c}{Q_H} = \frac{(T_3 - T_2) - (T_1 - T_4)}{(T_3 - T_2)}$$

← $Q_H = nC_v \Delta T_{2\to3} = nC_v(T_3 - T_2) > 0$

$Q_L = nC_v \Delta T_{4\to1} = nC_v(T_1 - T_4) < 0$

$$\eta = \frac{(T_3 - T_2) - (T_1 - T_4)}{(T_3 - T_2)}$$

$TV^{\gamma-1}$ = constant

$T_3 V_3^{\gamma-1} = T_4 V_4^{\gamma-1}$ $\quad\quad$ $V_4 = V_1 = rV$

$T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$ $\quad\quad$ $V_3 = V_2 = V$

Do math,

$$\eta = 1 - \frac{1}{r^{\gamma-1}} \quad \text{(otto engine)}$$

Diesel Engine: