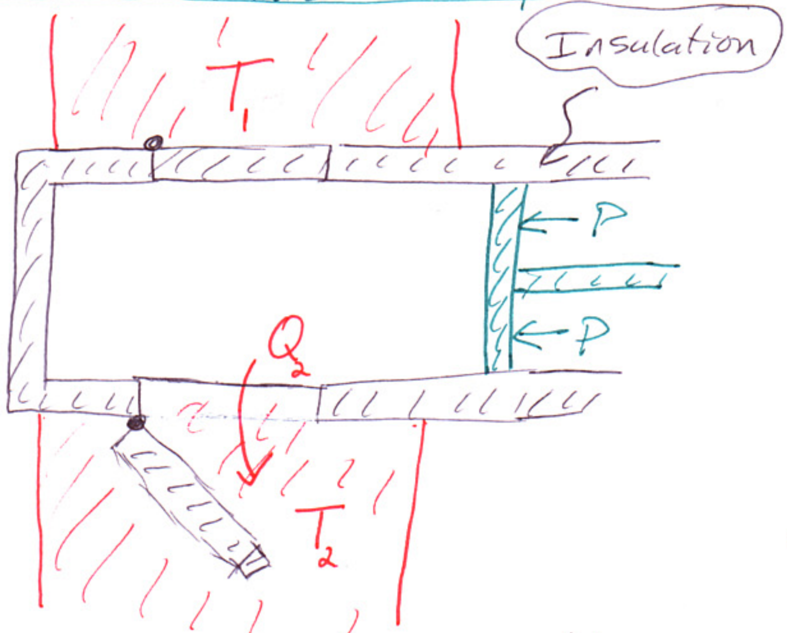
Today we'll examine second law:

- First Law of Thermodynamics!
  Energy is Conserved (You can't win)
- Second law of thermodynamics
  Entropy never decreases (You usually lose)

What does this mean in practise?



Prototype engine:

- Hot bath T_1 (Coal fire)
- Cold bath T_2 (Lake Cayuga)
- Piston, well insulated

- How much mechanical work W can we extract, by warming up Cayuga lake by a heat flow Q_2?

Problem Set!
How much work W does it require to cool our refrigerator by a heat flow Q_2?
Run engine backward!

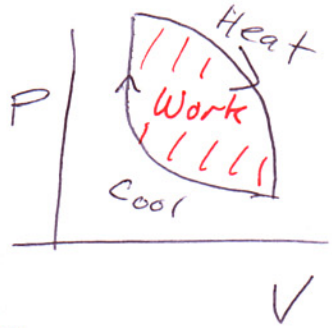
First Law! $W = Q_2 - Q_1$

Energy from Boiler
⇒ Mechanical Energy

Second Law! Can only tie.
Reversible Engine/Refrigerator Can't be Beaten [Carnot cycle].

Basic idea:

Heat gas → push piston out
Cool gas → piston moves in
Extract work



$$W = \int_{\text{cycle}} P\,dV = \text{Area inside P–V Loop}$$

Heat flows in & out Q_1, Q_2.

How to Avoid Irreversibility:

- No Friction
- ⊛ Never let hot things touch cold ones
- Move pistons slowly (no sound waves)
- Never let high pressures expand into low pressures

⊛ Change temperature by compression with both insulating doors shut! Adiabatic

Heat flow Q_1 at T_1, Q_2 at T_2: Isothermal

$PV = N k_B T$

$\Rightarrow$ Isothermal lines $P = (NkT)/V$

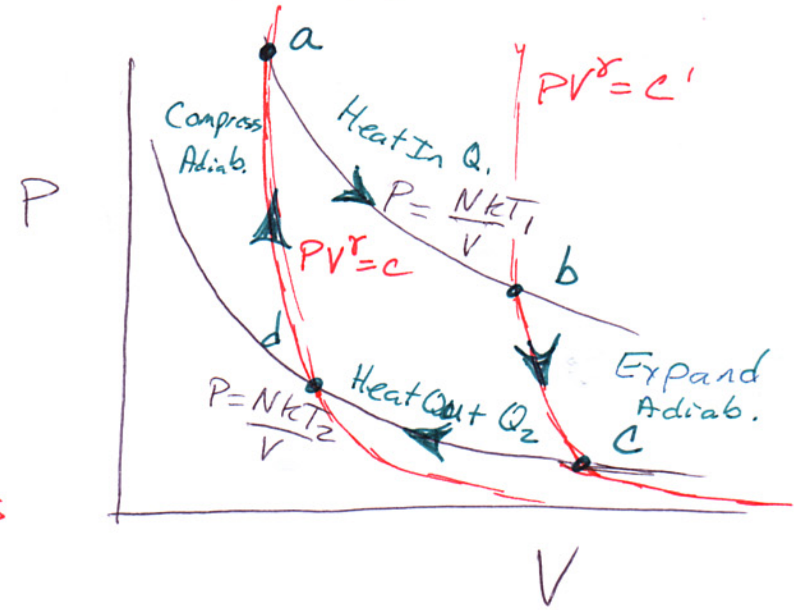
Adiabatic

$PV^{\gamma} = \text{Constant}$

$\gamma = 4/3$ photon gas

$\gamma = 5/3$ monatomic gas

$\gamma \sim 1.4$ N_2, O_2, air



Carnot Cycle: <u>Reversible</u>
(Given work W, can put the heat back).

Second Law Restated: No engine can pull heat from T_1 and leave it at T_2 and do <u>more</u> work than the Carnot cycle.

- because we could use the Carnot work to put the heat back and <u>you can't win</u>.

What is Q_1, Q_2, & W for Carnot cycle?

First law: $W = Q_1 - Q_2$

• Isothermal curves:

$$Q_1 = U_b - U_a + W_{ab}$$

$$= \cancel{\tfrac{2}{3}\underbrace{P_b V_b}_{NkT_1}} - \cancel{\tfrac{2}{3}\underbrace{P_a V_a}_{NkT_1}} + \int_a^b \underbrace{P}_{\frac{NkT_1}{V}}\, dV$$

$$= \int_a^b \frac{NkT_1}{V} = NkT_1 \ln\left(\frac{V_b}{V_a}\right)$$

$$Q_2 = -\int_c^d P\, dV = NkT_2 \ln\left(\frac{V_c}{V_d}\right)$$

Adiabatic Curves: $pV^\gamma = \text{Constant}$

$$P_b V_b^\gamma = P_c V_c^\gamma \qquad P_b V_b = NkT_1 \qquad P_c V_c = NkT_2$$

$$(NkT_1) V_b^{\gamma-1} = (NkT_2) V_c^{\gamma-1}$$

$$T_1 V_b^{\gamma-1} = T_2 V_c^{\gamma-1}$$

$$\Rightarrow \boxed{\frac{V_b}{V_a} = \frac{V_c}{V_d}}$$

Also $T_1 V_a^{\gamma-1} = T_2 V_d^{\gamma-1}$

$$\frac{Q_1}{T_1} = Nk \ln\left(\frac{V_b}{V_a}\right) = Nk \ln\left(\frac{V_c}{V_d}\right) = \frac{Q_2}{T_2}$$

We define the entropy flow into a bath to be

$$\boxed{S = Q/T}$$

So for a reversible engine

Entropy flow from bath 1 into piston Q_1/T_1

= Entropy flow from piston into Cayuga lake: Q_2/T_2

- Most other engines will create entropy
- Tomorrow, find out how thermodynamic entropy relates to statistical mechanics entropy.