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 practice?

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

\[ W = \int P \, dV = \text{Area inside P-V Loop} \]

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
\[ PV = Nk_B T \]

\[ \Rightarrow \text{Isothermal lines } P = \frac{(NkT)}{V} \]

Adiabatic

\[ PV^\gamma = \text{Constant} \]

\( \gamma = \frac{5}{3} \) photon gas

\( \gamma = \frac{5}{3} \) monatomic gas

\( \gamma = 1.4 \) \( N_2, O_2 \), air

Carnot Cycle: Reversible

(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 more work than the Carnot cycle.

- because we could use the Carnot work to put the heat back and you can't win.
What is $Q_1$, $Q_2$, & $W$ for Carnot cycle?

First law: $W = Q_1 - Q_2$

- Isothermal Curves:

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

$$= \frac{2}{3} \int P_{NkT_1} V_b^2 - \frac{3}{2} \int P_{NkT_1} V_a + \sum_a P_a dV$$

$$= \sum_a NkT_1 \frac{V}{V} = NkT_1 \ln \left( \frac{V_b}{V_a} \right)$$

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

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

$$P_b V_b^{\gamma} = P_c V_c^{\gamma} \quad P_b V_b = NkT_1 \quad P_c V_c = NkT_2$$

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

$$T_1 V_b^{\gamma-1} = T_2 V_c^{\gamma-1} \implies \frac{V_b}{V_a} = \frac{V_c}{V_d}$$

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

\[ S = \frac{Q}{T} \]

So for a reversible engine

\[
\text{Entropy flow from bath 1 into piston } \frac{Q}{T} = \text{Entropy flow from piston into Cayuga Lake.}
\]

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