Properties of air:

- Volume \( V \)
- \# of molecules \( n \)
- Pressure \( P \)
- Temperature \( T \)

\[
\text{Ideal Gas Law: } \quad PV = n k T
\]

If I increase the volume, pressure decreases at constant temperature.

\( V, n \text{ constant, } T \uparrow, P \uparrow \)

\( P, n \text{ constant, } T \uparrow, V \uparrow \)

Consider constant temp:

\( PV = \text{const. } \) "isotherm"

\( \text{emt+ heat} \)

Compress volume \( \Rightarrow \) pressure increases

\( P \propto \frac{1}{V} \)

Consider adiabatic: no heat in or out

\( PV^\gamma = \text{constant} \)

\[ P \quad \text{adiabat} \]

\[ V \quad \text{isotherm} \]
Silly Engine #1: Isothermal

\[ \text{Net Work} = \int P \, dV = 0 \]

(No temp gradient - how could there be?) 
Isothermal

Silly Engine #2: Adiabatic 

\[ \text{No heat flow} \]
\[ \Rightarrow \text{Net Work} = \int P \, dV = 0 \]

To get net work, I need:
- temp diff.
- heat flow
- area on PV diagram

Carnot's Insight: add heat when system is hottest \( \Rightarrow \) most efficient engine
remove heat when system is coldest
at all other times, no heat flow

Perfect Carnot Engine
Something important -

Entropy - measure of disorder

\[ ds = \frac{dQ}{T} \]

\[ \int_T ds = \int_P dV = W \]

Easier way to find work is to use entropy!

Carnot Cycle:

\[ W = \int_T ds = (T_{hot} - T_{cold})(S_{max} - S_{min}) \]

\[ W = (T_{hot} - T_{cold}) \cdot Q_{in} \]

\[ \frac{Q_{in}}{T_{hot}} \]

Efficiency:

\[ \eta = \frac{W}{Q_{in}} = \frac{T_{hot} - T_{cold}}{T_{hot}} = 1 - \frac{T_{cold}}{T_{hot}} \]

* T is measured in K

Something else important: Reversibility

Engine "reversible" if no unnecessary losses

\[ Q_{hot} \]
\[ \downarrow \rightarrow \omega \text{ reverse:} \]
\[ \downarrow \]
\[ Q_{cold} \]

\[ Q_{out} \]
\[ \uparrow \rightarrow \omega \]
\[ \uparrow \]
\[ Q_{in} \]

* a refrigerator is a heat cycle in reverse
* Heat pump: make my house warmer by making outside colder