Recall Last time, talked about

First law:

$dE = đq + đw$ (sign has increase in system for heat in and work on)

2nd law (next time)

3rd Law (Exists absolute zero, return later)

Zeroth Law

If C is in thermal Eq w/ A & B, then A & B are in thermal Eq

Reminder about work

$$W = -\int_{r_0}^{r_1} F\, dr \rightarrow \quad dw = -F dr$$

P-V $\quad P = F/A \Rightarrow \quad dw = -P \cdot A dr$
$$= -P \cdot dV$$

if $P = P_{sys}$, & $dV < 0$, energy increases

change against pressure

Going to talk about work in 4 possible changes of state, especially for ideal Gas

1. Const pressure
2. Const volume
3. Const temp
4. Adiabatic

} can be confusing, will do examples on worksheet

First, Jump ahead to talk about heat & heat capacity

Heat is "amount of energy that flows as a result of a difference in temp" (Also, anything that changes $\mathcal{E}$ & isn't work)

In equation form $dq = C\,dT$ ← extensive defn where C is the heat capacity another response function. Does not have to be ind. of Temp. $\Rightarrow C = dq/dT$

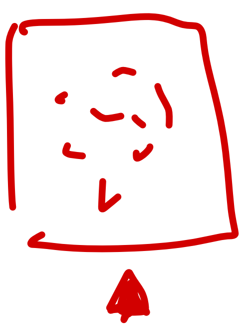
We know from experience C is how much energy a system can store under particular thermodynamic conditions

In fact, 2 heat capacities, @ const V & const P

$$C_V = \left(\partial q/dT\right)_V \qquad C_P = \left(\partial q/dT\right)_P$$

Should one be bigger than the other?

$C_V > C_P$? $\quad$ $C_P > C_V$? $\quad$ $C_P = C_V$? depends?



How much heat flows?

Suppose $C(T) \approx C$ for $T_{min} < T < T_{max}$

$$q = \int_{T_{min}}^{T_{max}} C\,dT = C\left(T_{max} - T_{min}\right) = C\Delta T$$

$(= nc\Delta T)$ ← may remember

How much does this change internal energy?

$\Delta \mathcal{E} = q + w$, so,

(adiabatic expansion later)

a) const volume

$w = 0$, $\Delta \mathcal{E} = C_V \Delta T$

b) Const pressure

$w = -P\Delta V$, $\Delta \mathcal{E} = C_p \Delta T - P\Delta V$

Return to C_p vs C_V:

$d\mathcal{E} = dq \cancel{- PdV}$

$C_V = \left(\partial q / \partial T\right)_V \underset{\substack{\uparrow \\ \text{first law}}}{=} \left(\partial \mathcal{E} / \partial T\right)_V$ ← heat capacity measures energy change as we said

$C_p = \left(\partial q / \partial T\right)_P = \left(\dfrac{\partial(\mathcal{E} + PdV)}{\partial T}\right)_P$

Imagine exists $H = \mathcal{E} + PV$

$dH = \mathcal{E} + PdV + VdP$ (product rule)

@ const P, $dH = \mathcal{E} + PdV$

so $C_p = \left(\frac{\partial H}{\partial T}\right)_p$, C_p measures increase in Enthalpy! due to heat flow

Consider Ideal Gas! (Table 3.1, pg 98)

① $PV = nRT$

② $\mathcal{E} = \frac{3}{2} nRT$ (monotomic) (will show later in class)

$\Rightarrow C_v = \frac{3}{2} nR$ (ind of temp!)

$$C_p = \frac{\partial}{\partial T}\left(\mathcal{E} + PV\right) = \frac{\partial}{\partial T}\left(\frac{3}{2} nRT + nRT\right)$$

$$= \frac{5}{2} nR$$

$C_p > C_v$! by $nR = Nk_B$

True for any ideal gas,

$$C_p - C_v = nR$$

Work & Energy Change for changing conditions on a gas

$$w = -\int_{V_i}^{V_f} p\,dV \quad , \text{ area under P-V curve } \star$$

Lets draw some.

const P ①

$w = -P_{sys}\Delta V$

$$\Delta E = q - P_{sys}\Delta V = C_p\Delta T - p\Delta V$$

How much does T change? Need to know about gas.

Worksheet: Ideal gas:

mono ↓ dia ↓

$A = 5/2, 7/2$

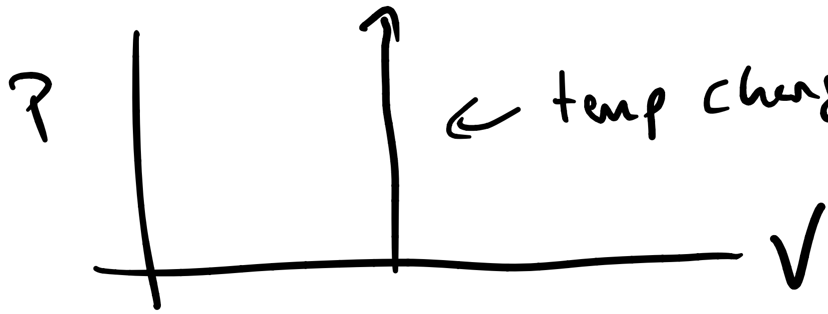
$T = \frac{PV}{nR} \Rightarrow \Delta T = P(V_2 - V_1)/nR$

$\Delta E = (A-1)P\Delta V = (A-1)nR\Delta T$ get second way ☆

const V ②

$dw = -PdV = 0$, no work!

$\Delta E = C_V \Delta T$ from first law & energy rule



← temp changes, no area

Isothermal, reversible ③

← guess from ideal gas

$P = nRT/V$

$$w = -\int_{V_i}^{V_f} P(V)\,dV \underset{\text{ideal gas}}{\overset{*}{=}} -\int_{V_i}^{V_f} \frac{nRT}{V}\,dV$$

$$= -nRT \ln(V_f/V_i)$$

Expanding but const T -

Q: $dq = 0$? $dq > 0$ $dq < 0$?

$dE = q + w$

Ideal gas, $dE = 0$, $E(N, V, T) = E(T)$

$\Rightarrow q = +nRT \ln(V_2/V_1)$

$dq > 0$ for this process!

Adiabatic Expansion (4) (hardest)

$dE = dq_r + dw = dw$

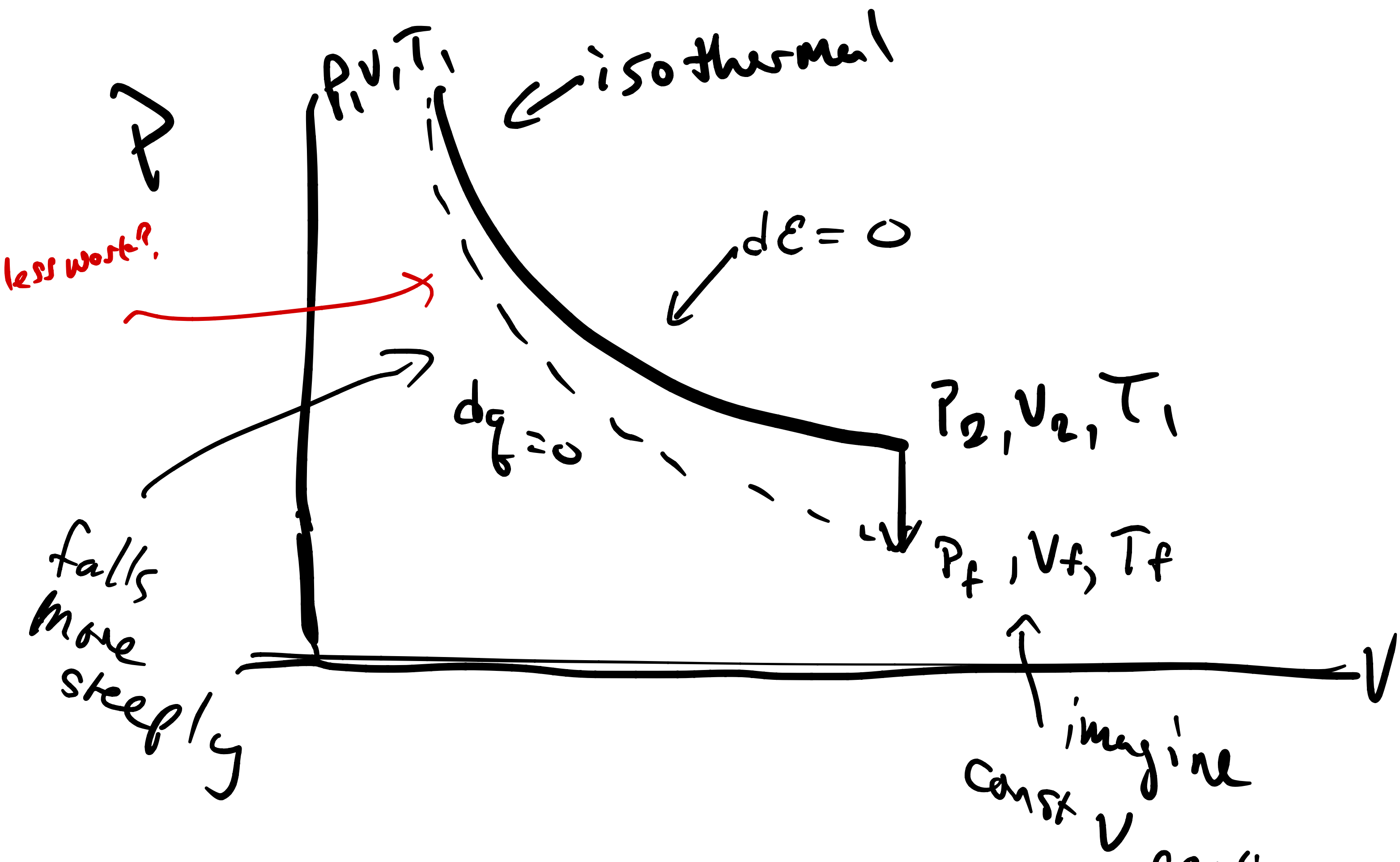
$dw = -PdV \underset{\substack{\uparrow \\ \text{ideal gas}}}{=} -\frac{nRT(V)}{V} dV$

need to know how T changes w/ volume to find work/energy

Expansion means $-PdV < 0$, Energy goes down. This means final energy is lower. For ideal gas $E \propto T \Rightarrow$ expansion leads to cooling

lower T → lower pressure too

What does it look like compared to isothermal



So ΔE total $= 0 + C_v \Delta T$

or $dE = C_v dT$

$$\Rightarrow \frac{C_v dT}{T} = -\frac{nR}{V} dV$$

$$\Rightarrow C_v \ln(T_f/T_i) = -nR \ln(V_f/V_i)$$