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Office hours: anytime you can find me.

Eric Mazur "Confessions of a Converted Lecturer"

"5 minute university"

Statistical Physics

$N_A \sim 10^{23}$ $3\vec{p} + 3\vec{r}$ for each particle

$\sim 10^{23}$ initial values

$1MB \sim 10^6 B$

$1GB \sim 10^9 B$

$1TB \sim 10^{12} B$

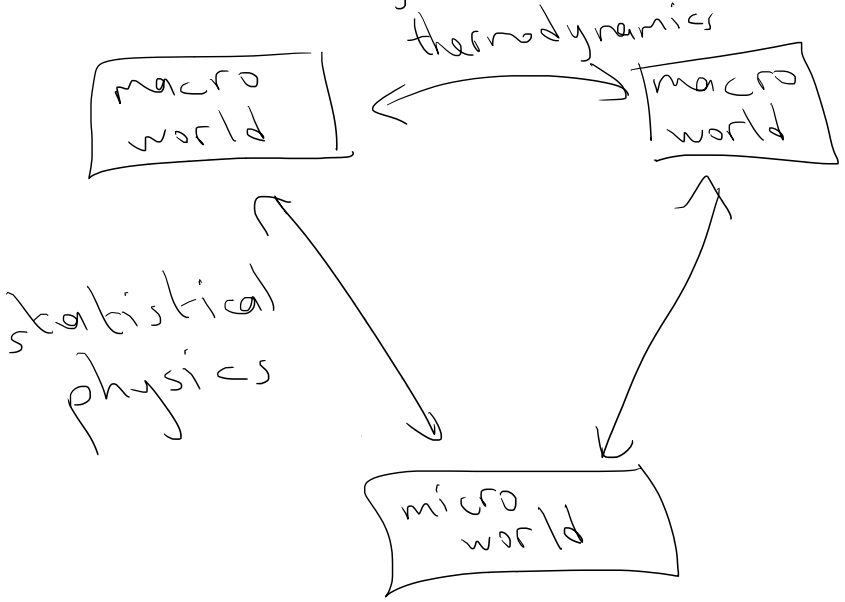
10^{11} TB of storage

$10^6 \, 10^N \sim 10^{N+6} \sim 10^N$

Change question:

macroscopic properties: T, phase transitions, composition, density, volume, pressure, CM velocity, energy, conductance,

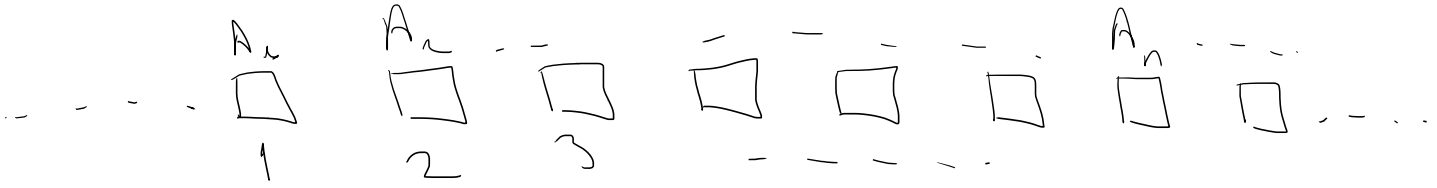
Thermodynamics $PV = NkT$



0th Law of Thermodynamics

If A & C are in thermodynamic equilibrium & B & C are in thermodynamic equilibrium ⇒ A & B are also in thermodynamic equilibrium

thermodynamic equilibrium } no energy, matter, ... flows within the system.



1st Law

$$\Delta U = \Delta Q - \Delta W$$

$$\Delta Q = \Delta U + \Delta W$$

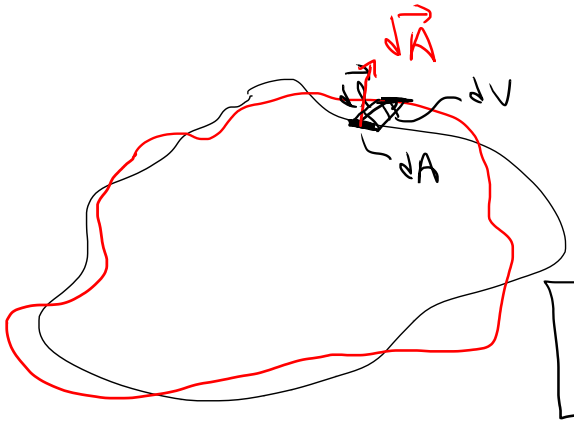
U: internal energy

ΔQ: heat <u>given</u> to the system
(if heat is taken from the system
$\Rightarrow \Delta Q < 0$)

ΔW: work done <u>by</u> the system.
(if work is done <u>on</u> the system,
$\Delta W < 0$

$$dW = \vec{F} \cdot d\vec{l}$$

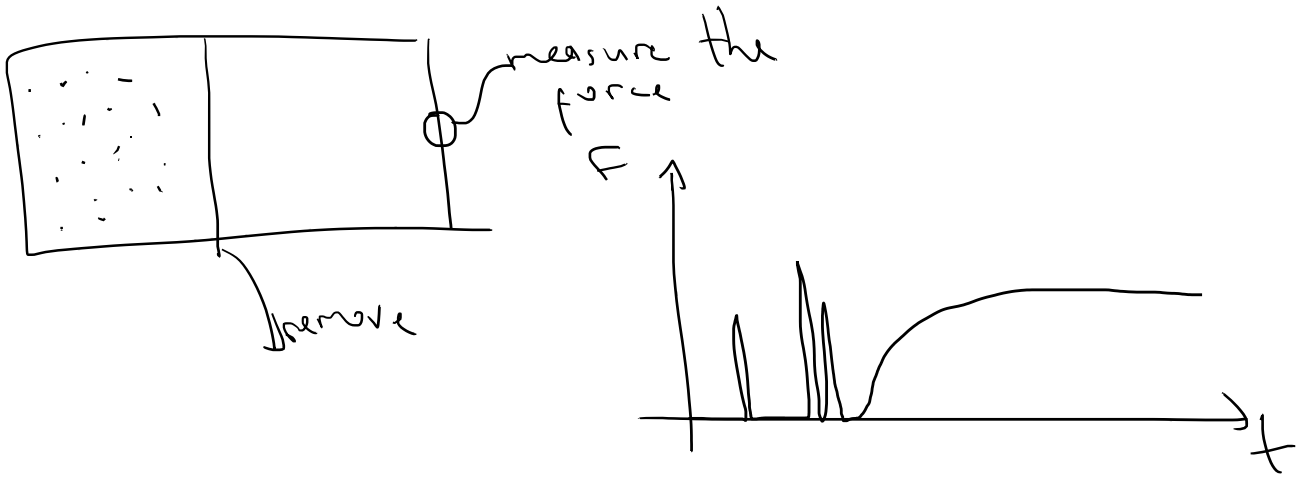
$$dW = \left(\frac{F}{dA}\right) d\vec{A} \cdot d\vec{l}$$



$$dW = \underbrace{\left(\frac{F}{dA}\right)}_{P} dV$$

$$dW = P\,dV$$

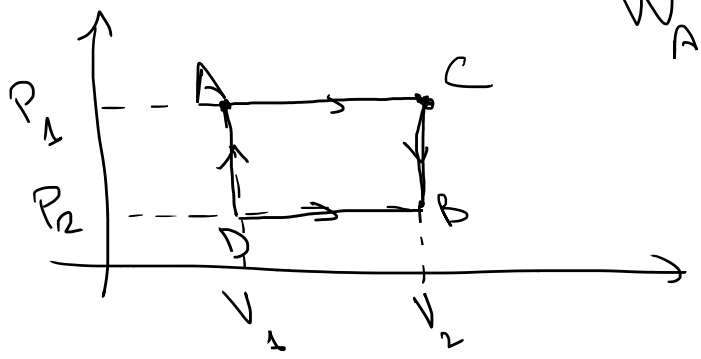
P exists only of $\exists$ mechanical equilibrium.



P : pressure of the system

dV : change in the volume of the system.

$$\delta W = P\,dV$$



$$W_{A\to C\to B} = \int_A^B P\,dV$$

$$= \int_A^C P\,dV + \int_C^B P\,dV \quad (\int_C^B P\,dV = 0)$$

$$= P_1(V_2 - V_1)$$

$$W_{A\to D\to B} = \int_A^B P\,dV = \int_A^D P\,dV \;(=0) + \int_D^B P\,dV = P_2(V_2 - V_1)$$

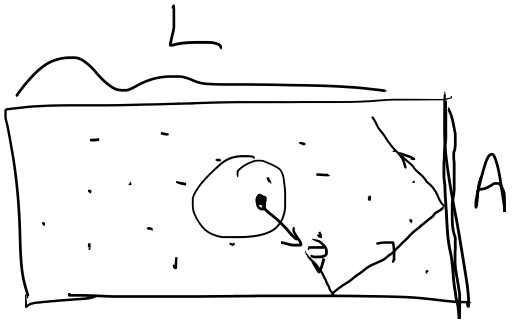
$$W_{A\to D\to B} \neq W_{A\to C\to B}$$

δW is NOT the differential of W

ΔW difference

there does not exist a state function whose difference gives you ΔW

Kinetic Theory (internal energy of the ideal gas



$$\Delta \vec{p} = 2mv_x \hat{x}$$

$$U = \langle E \rangle = \left\langle \sum_i \frac{1}{2} m v_i^2 \right\rangle$$

$$= \frac{1}{2} \sum_i \langle m v_i^2 \rangle$$

$$\boxed{U = \left\langle \frac{1}{2} m v^2 \right\rangle N}$$

$$P = \frac{F}{A} = \frac{1}{A} N \left\langle \frac{\Delta p}{\Delta t} \right\rangle$$

$$= \frac{1}{A} N \left\langle \frac{2mv_x}{\frac{2L}{v_x}} \right\rangle$$

$$P = \frac{1}{V} N \langle m v_x^2 \rangle$$

$$\frac{1}{3}\langle v^2 \rangle = \langle v_x^2 \rangle = \langle v_y^2 \rangle = \langle v_z^2 \rangle$$

$$PV = N \langle m v_x^2 \rangle$$

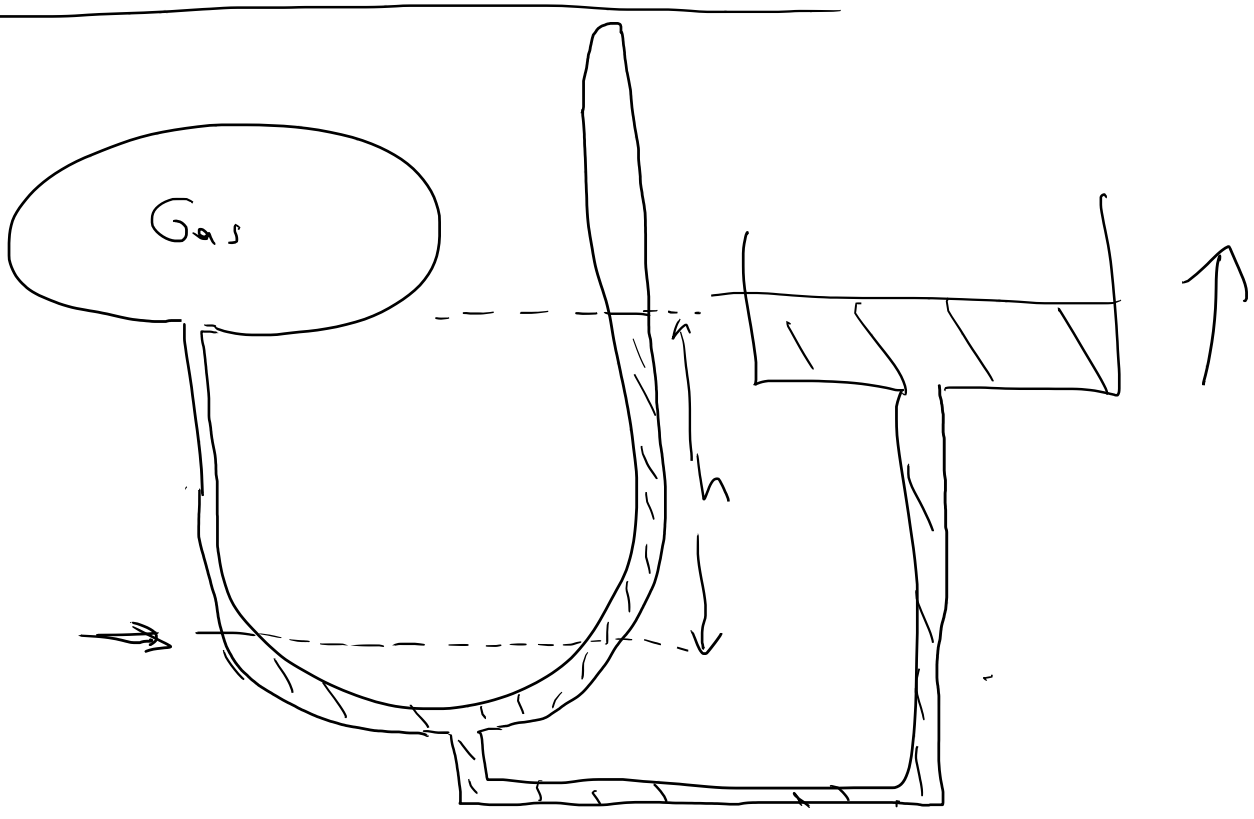
$$\frac{F}{A} = \frac{\langle F(t) \rangle_t}{A} = \frac{\langle F(t) \rangle_t}{A} = \frac{\left\langle \frac{\Delta \vec{p}}{\Delta t} \right\rangle_t}{A}$$

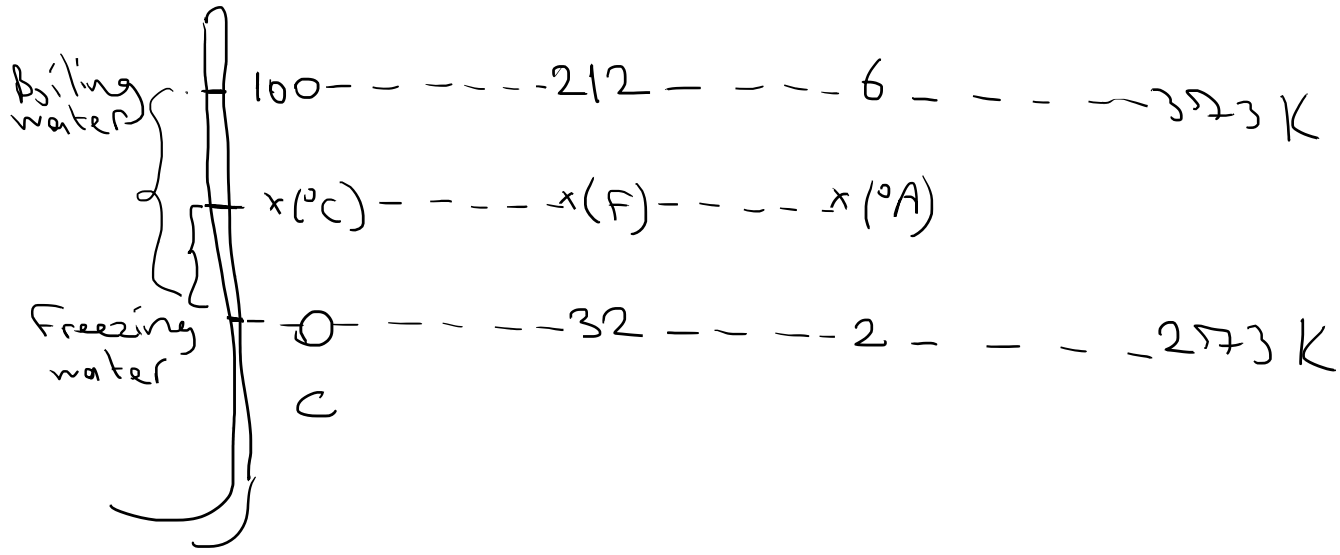
$$= \frac{\sum \langle \Delta \vec{p} \rangle_t}{\Delta t \, A}$$

$$PV = \frac{2}{3} N \underbrace{\left\langle \frac{1}{2} m v^2 \right\rangle}_{U}$$

$$PV = \frac{2}{3} U$$

Ideal Gas Thermometer





$$\frac{x(^\circ C) - 0}{100} = \frac{x(F) - 32}{180} = \frac{x(^\circ A) - 2}{4}$$

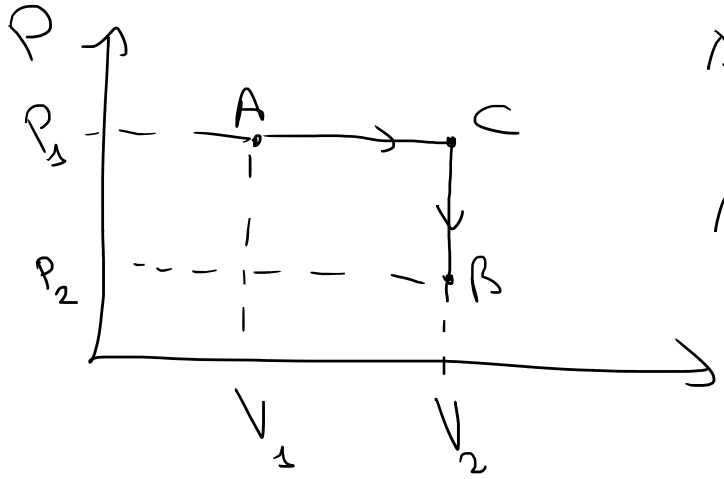
$$PV = \frac{2}{3} N \left\langle \frac{1}{2} m v^2 \right\rangle \equiv N k_B T$$

$$\left\langle \frac{1}{2} m v^2 \right\rangle = \frac{3}{2} k_B T \Longleftarrow \text{absolute temperature scale.}$$

$$T(K) \equiv T(^\circ C) + 273, \ldots$$

$$U = \frac{3}{2} PV = \frac{3}{2} N k T \Big\} \; U \text{ is a state function}$$

$$\Delta U = \Delta Q - \Delta W \Rightarrow \Delta Q = \Delta U + \Delta W$$



$$\Delta W_{A\to C\to B} = P_1(V_2 - V_1)$$

$$\Delta U = U_B - U_A$$

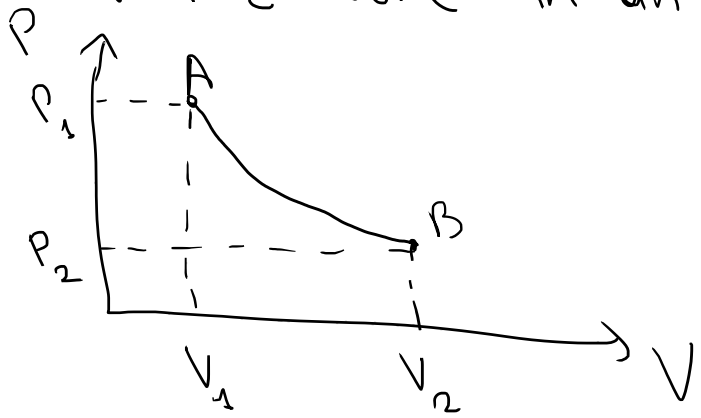
$$= \frac{3}{2}(PV)_B - \frac{3}{2}(PV)_A$$

$$\Delta U = \frac{3}{2}P_2V_2 - \frac{3}{2}P_1V_1$$

$$\Delta Q_{A\to C\to B} = P_1(V_2 - V_1) + \frac{3}{2}P_2V_2 - \frac{3}{2}P_1V_1$$

Isothermal Process — T is constant

Work done in an isothermal process



$$PV = NkT = \text{constant}$$

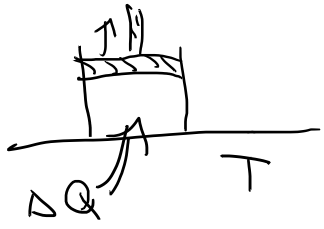
$$U = \frac{3}{2}NkT$$

$$\Delta U = 0$$

$$\Delta W^T_{A\to B} = \int_{V_1}^{V_2} P\,dV = \int_{V_1}^{V_2} \frac{NkT}{V}\,dV = NkT\ln\frac{V_2}{V_1}$$

$$\Delta Q^T_{A\to B} = \Delta U + \Delta W = NkT\ln\left(\frac{V_2}{V_1}\right)$$

($\Delta U = 0$)



Adiabatic Processes

$$\Delta Q = 0$$

$$\Delta W = ? \quad = \int_{V_A}^{V_2} P\,dV = ?$$

$$\Delta U = \Delta Q - \Delta W$$

$$\Delta\left(\frac{3}{2}PV\right) = -P\Delta V$$

$$d\left(\frac{3}{2}PV\right) = -P\,dV$$

$$\frac{3}{2}P\,dV + \frac{3}{2}V\,dP = -P\,dV$$

$$\frac{5}{2}P\,dV + \frac{3}{2}V\,dP = 0$$

$$\frac{1}{PV}\left(\frac{5}{3}P\,dV + V\,dP = 0\right)$$

$$\frac{5}{3}\frac{dV}{V} + \frac{dP}{P} = 0$$

$$\frac{5}{3}d\ln V + d\ln P = 0$$

$$d\left(\ln P + \frac{5}{3}\ln V\right) = 0$$

$$\Rightarrow \ln P + \frac{5}{3}\ln V = \text{const} \Rightarrow \ln\left(PV^{\gamma}\right) = \text{const}$$

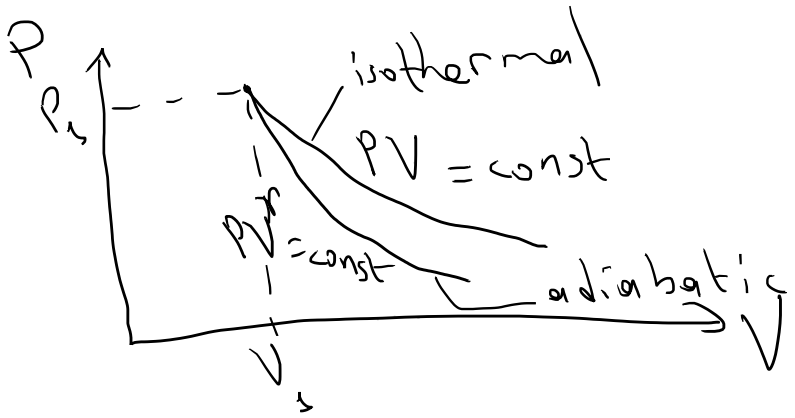
($\frac{5}{3} = \gamma$)

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

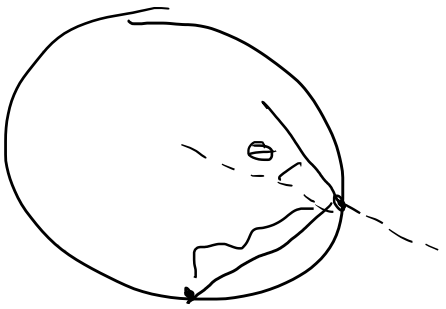
in an adiabatic process.

adiabatic eqn.

$$\text{const} = PVV^{\gamma-1} = NkTV^{\gamma-1} \Rightarrow TV^{\gamma-1} = \text{const}$$



HW



show that

$$PV = N\frac{2}{3}\left(\frac{1}{2}mv^2\right)$$