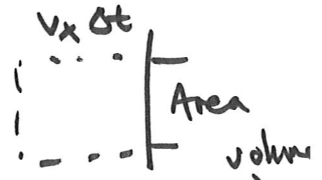
ENERGY & MATTER SYNOPTIC

IDEAL GAS : molecules, N - uniform & random motion
small relative to separation
Newton's laws
Only elastic collisions with walls & each other

$$\rightarrow V, \quad \rho = \frac{Nm}{V}, \quad P = \tfrac{1}{3} n m \overline{v^2}$$



$$U = KE = \tfrac{1}{2} m \overline{v^2} N$$

$$F = \frac{2 m v_x}{\Delta t} \quad \tfrac{1}{2} n (v_x A \Delta t)$$

1/2 going left   number/vol

$$\overline{v_x^2} = \tfrac{1}{3} v^2$$

$$\rightarrow \quad PV = NkT_I$$

$$\tfrac{1}{2} m \overline{v^2} = \tfrac{3}{2} k T_I \quad \& \quad U = N \tfrac{1}{2} m \overline{v^2}$$

EQUIPARTITION : $\tfrac{1}{2} kT$ energy / degree of freedom

Fails if $kT <$ quantum excitation

HEAT CAPACITY: $C_v = \left(\frac{\partial Q}{\partial T}\right)_V \qquad C_p = \left(\frac{\partial Q}{\partial T}\right)_p$

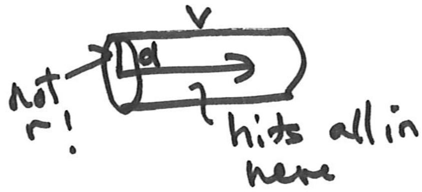
monatomic : $U = \tfrac{3}{2} kT$ or $U = \tfrac{3}{2} n_m \underbrace{N_A k}_{R} T$

BOLTZMANN FACTOR $P(E) \propto e^{-E/kT}$

MEAN FREE PATH $\lambda = \text{speed}/\text{collision rate}$

↳ $\pi d^2 v n$

$$\lambda \sim \frac{1}{\pi d^2 n}$$



RANDOM WALKS

In N steps travel $N\lambda$ but distance from start $\sqrt{N}\lambda$

DIFFUSION: $\frac{dN}{dt} = -DA\frac{dn}{dx}$ $\propto$ density gradient

$D \sim \lambda \bar{v}$ "$m^2 s^{-1}$"

THERMAL CONDUCTION: $\frac{dQ}{dt} = -KA\frac{dT}{dx}$ $\propto$ temperature gradient

$K \sim \lambda \bar{v} C$

THERMODYNAMICS

0TH Law: A in thermal Ξ'm with B & C $\Rightarrow$ B&C in thermal Ξ'm

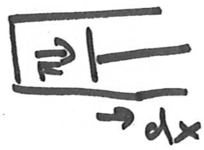
1ST Law: Energy conservation $\boxed{\Delta U = Q + W}$

"work generates heat $\rightarrow$ energy"

internal energy; heat in; work done on gas

sign!

Work by gas $= \int P\,dV$



$PA \cdot dx$

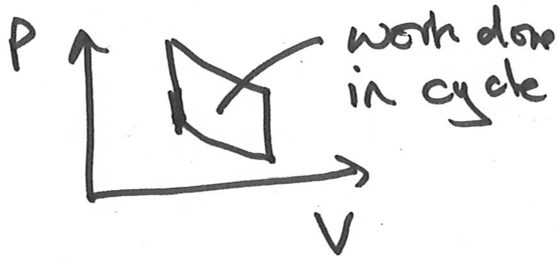
At constant P $\quad P\,dV \underset{\text{mole}}{\overset{\text{one}}{\Rightarrow}} R\,dT$

$C_p = C_v + R$

Isothermal: T = const $\quad W = \int P\,dV = \int_{V_1}^{V_2} \frac{n_m R T_I}{V}\,dV$

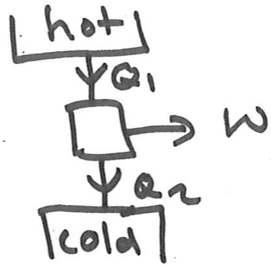
Adiabatic: no energy in $\rightarrow \Delta U = W \Rightarrow \boxed{PV^\gamma = \text{constant}}$

PV Indicator Diagrams



2ND Law: You can only extract work from heat flow from hot $\rightarrow$ cold body

Carnot Engines



$$\eta = \frac{W}{Q_1}$$

at best $= \frac{Q_1 - Q_2}{Q_1}$

Reverse arrow
$\Rightarrow$ heat pump
$\eta = \frac{Q_1}{W} > 1$

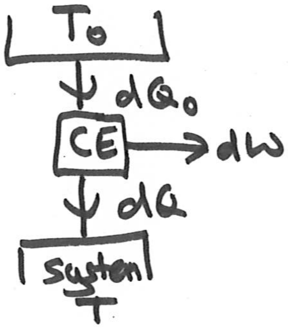
Ideal Gas Realization

expand isothermally heat in | expand adiabatically | isothermal compress heat out | adiabatically expand

complete cycle
reversible

Defining T : Use Q_1, Q_2 as Carnot to define $\propto T_1, T_2$ $\qquad T_{ideal} = T$

Entropy



$$\frac{dQ_0}{dQ} = \frac{T_0}{T}$$

Do process where CE does W & system somehow returned to initial state

$$Q_0 = \oint dQ_0 = T_0 \oint \frac{dQ}{T} \leq 0$$

You can't extract work just from hot thing

$dS = \frac{dQ}{T}$ is a function of the state of T_0 reservoir

Statistical interpretation is movement to most likely state $\quad S = k \ln W$

2^{nd} Law Refresh: Entropy always rises.

Enthalpy: energy changes involving gas expansion
minimize $H = U + PV$

Gibb's Free Energy: if also allow to thermalize with environment then S of system + Universe must grow
$\Rightarrow$ minimize $G = U + PV - TS$

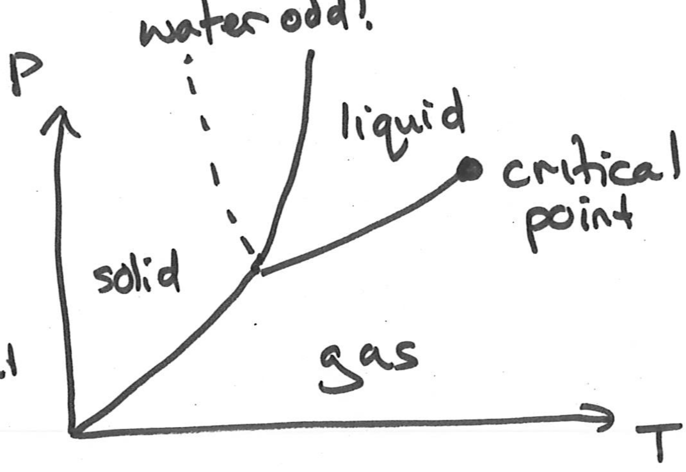
Phase Diagrams

Slopes given by
Clausius – Clapyron eq'n

$$\frac{dP}{dT} = \frac{L}{T(v_2 - v_1)}$$

$L \in$ Latent heat

v: volumes/mole



Van der Waals Gases

$$\left(P + N^2 \frac{a}{V^2}\right)(V - Nb) = NkT$$

includes inter-atomic forces. Size of force $\propto N/V$ & number of collisions $\propto N/V$

removes finite volume of atoms from V