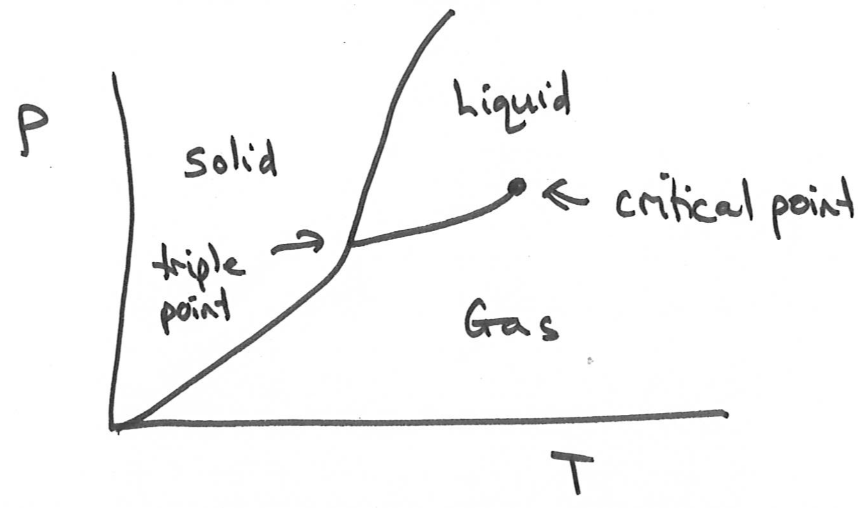
PHENOMENOLOGY OF MATTER

A typical substance changes depending on pressure & temperature

Phase Diagram



Gases - high T, low P, low density phase

Volume V m^3

Density M/V $kg\,m^{-3}$

Pressure $P = \frac{\text{Force}}{\text{Area}}$ Pa, $N m^{-2}$

at a point exerted equally in all directions

Temperature T K

We have an intuitive feel for what it is...

it's related to **heat** - energy transferred in & out of gas

Experimental studies revealed:

Boyle's Law: $P \propto 1/V$ at fixed T

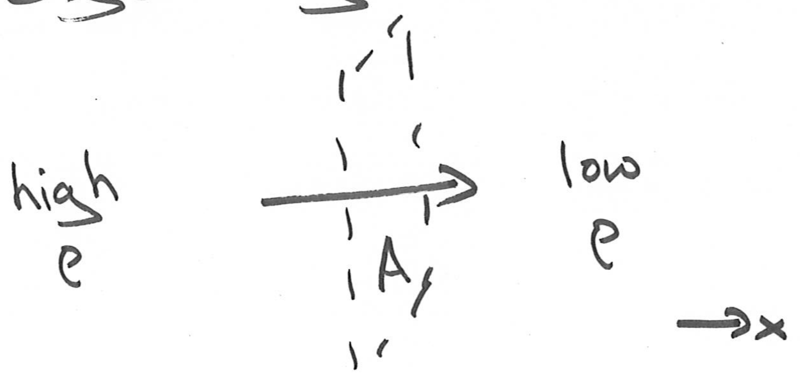
Charles' Law: $P \propto T$ at fixed V

Guy Lussac's Law: $V \propto T$ at fixed P

It was noted that the volume of a gas decreases by $\sim V/273$ per degree... so is there <u>absolute zero</u> $-273°C$ where $V=0$?

<u>Transport Laws</u>

Identity (eg gas colour), energy & momentum can move from high concentration to low



<u>Diffusion</u>

Fick's Law: $$\frac{dM}{dt} = -DA\frac{d\rho}{dx}$$

mass ~~amount~~ flowing across dashed line per second

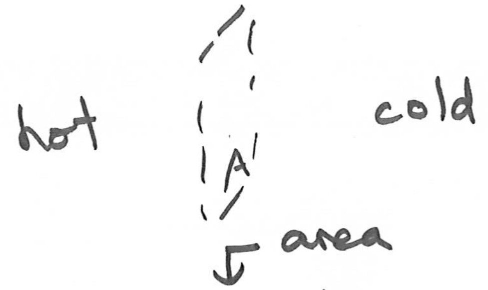
flow against the gradient

area flowing across

density gradient in x direction

D is <u>diffusion coefficient</u> $m^2 s^{-1}$

Thermal Conduction

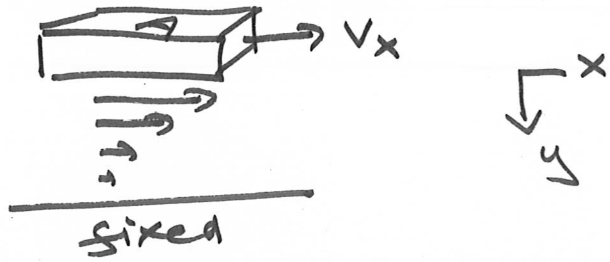


Fourier's Law:

$$\frac{dQ}{dt} = -\,K A \frac{dT}{dx}$$

- $\frac{dQ}{dt}$: heat flow per second
- K : thermal conductivity, $J\,m^{-1}s^{-1}K^{-1}$
- $\frac{dT}{dx}$: temperature gradient

Viscosity

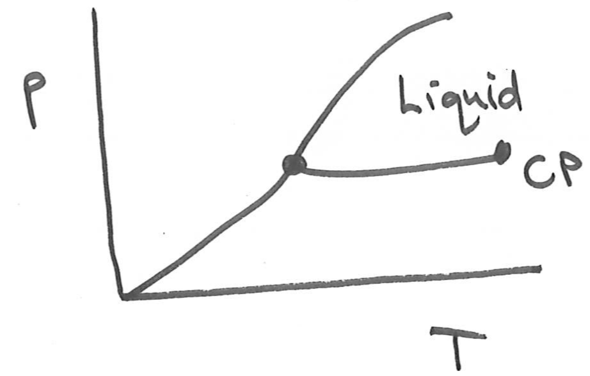


$$F_x = -\,\eta\, A \frac{dv_x}{dy}$$

- F_x : drag force in x
- η : viscosity coefficient, $N m^{-2} s^{-1}$
- A : area
- $\frac{dv_x}{dy}$: velocity gradient in y in gas

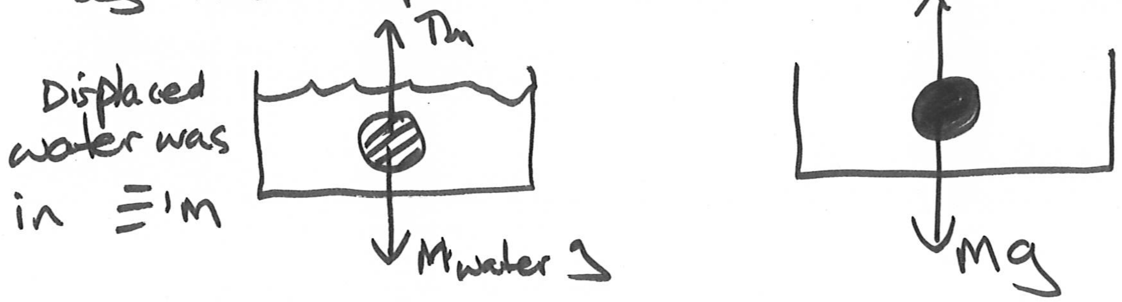
Do we expect you to remember these equations?
Well... yes... but the "derivation" should make them easy to remember

eg diffusion is caused by dn/dx, $-$, A & D then naturally follow....

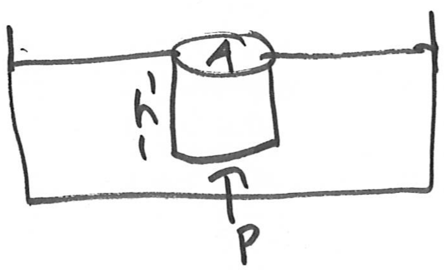


Liquids - are a denser state of matter
- largely incompressible they flow to fill an available volume equal to own
- exert pressure like gas

Archimedes' Principle there is an upwards force on an object in water equal to the weight of the displaced water



Hydrostatic Equilibrium

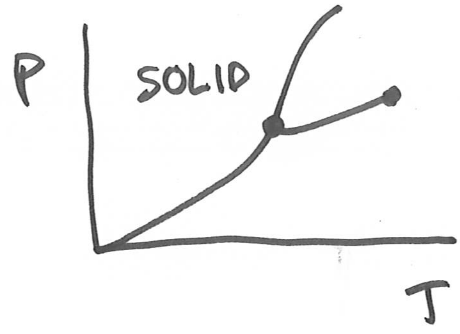


weight = up thrust

$\rho h A g = PA$

$P = \rho g h$

Note at high pressure gas & liquid phases become continuous - **critical point**



<u>Solids</u> a structurally rigid phase

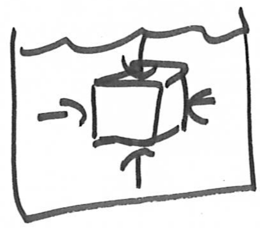
- Under a stretching force they can be made to expand a little but return to original shape when force is removed... eg Hooke's Law $F = -kx$

$$\text{stress} \propto \text{strain}$$

$$F/A = Y \frac{\Delta L}{L}$$

↑ Young's modulus

- They also contract under constant pressure (eg if immersed in a fluid)



Increasing P by ΔP causes $\frac{\Delta V}{V}$ contraction

$$\Delta P = -B \frac{\Delta V}{V}$$

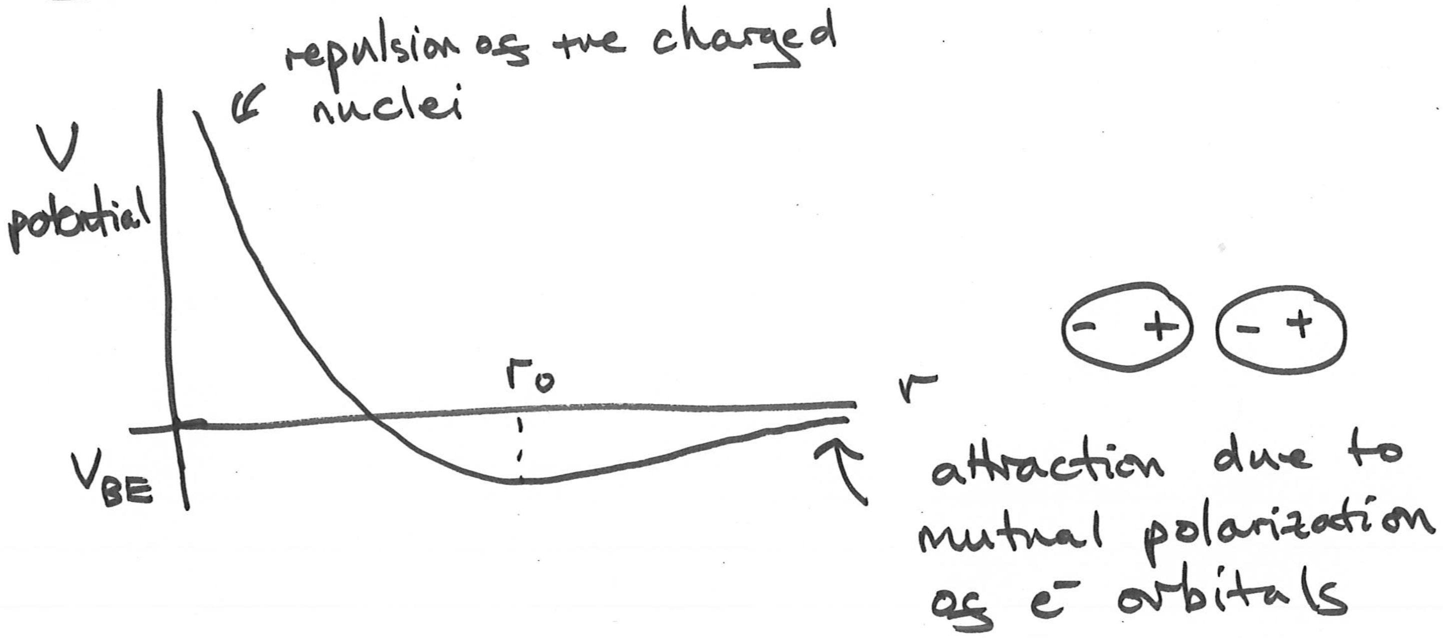
(−) since ΔV -ve! ↑ Bulk modulus

- They expand when heated

$$\Delta T = \alpha \frac{\Delta V}{V}$$

↑ thermal expansivity

The Atomic Model : clarifies a lot! The material is made of N atoms (molecules) with interatomic forces



SOLID

lattice when thermal energy $< V_{BE}$

LIQUID

thermal energy $\sim V_{BE}$

"stickyness"

GAS

thermal energy $> V_{BE}$

free widly separated gas.

Hence forth we will mostly concentrate on the gas phase & see the predictions of "kinetic theory"

EQUATION OF STATE

Avagadro added to $P \propto 1/V$, $P \propto T$, $V \propto T$ the theoretical insight that if there are atoms $P \propto N$, $V \propto N$ so proposed

$$PV = N k T_I$$

↙ here temperature of the model....

↑ number of atoms

↑ Boltzmann's constant $k = 1.38 \times 10^{-23}\ JK^{-1}$

or

$$P = n k T_I$$

Avagadro's Number: $N_A = 6.02 \times 10^{23}$

The number of atoms/molecules that weighs the atomic mass number in grams (a mole)

$$N = n_m N_A$$

↑ number of moles

eg H_2 $\quad N_A M_{H_2} \sim 6.02 \times 10^{23} \times 2 \times 1.67 \times 10^{-27}\,kg$

$\sim 0.002\ kg$ ✓

now we can write

$$PV = n_M \underbrace{N_A k}_{= R} T_I$$

$= R$ ← gas constant $8.314 \, J \, K^{-1} \, mole^{-1}$

- What is volume of 1 mole at standard temperature & pressure
  ~273 K ~101,000 Pa

$$V_M = \frac{RT_I}{P} = \frac{8.314 \cdot 273}{101\,000} = 0.0225 \, m^3$$

$= 22.5$ lt
~$(0.1m)^3$

- How many molecules in $1m^3$ at 20°C?

$$N = \frac{PV}{kT_I} = \frac{101\,000 \times 1m^3}{1.38 \times 10^{-23} \times 293}$$

$$\simeq 250 \times 10^{23}$$