Thermal Physics

$\boxed{Q = mc\Delta T}$

Q: heat energy [J]

m: mass [kg]

c: specific heat capacity [$J\,kg^{-1}\,K^{-1}$] → Energy change to change the temp. of 1kg of substance by 1K or °C

ΔT: temp. change [K] (or °C, same numerical value)

"Specific" means per unit mass ie for 1 kg → Heat capacity: Energy change to change the temp. of an object by 1K or °C

Heating 2 different things:

$\Delta T = \frac{Q}{mc}$

1kg of c = 4200 (water)

2kg of c = 390 (copper)

$\Rightarrow \Delta T = \frac{Q}{\underbrace{1 \times 4200 + 2 \times 390}_{\text{Add heat capacities of everything}}}$

$C = mc$

NOT SPECIFIC HEAT CAPACITIES

Mixing 2 different things:

Q lost by hot thing = Q gained by cold thing

$-mc\Delta T = mc\Delta T \Longrightarrow -mc(T_{new} - T_{old}) = mc(T_{new} - T_{old})$

1 thing

Same new temp.

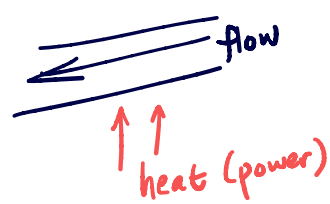
other thing

Continuous Flow Heating

flow rate [$kg\,s^{-1}$] mass per second

Power of heater $= \frac{Q}{t} = \frac{mc\Delta T}{t} = \left(\frac{m}{t}\right) c\,\Delta T$

Remember: not always 100% efficient



Specific Latent heat, L

$\boxed{Q = mL}$

Energy required to change state between ___ and ___ of 1kg of substance with no temp. change.

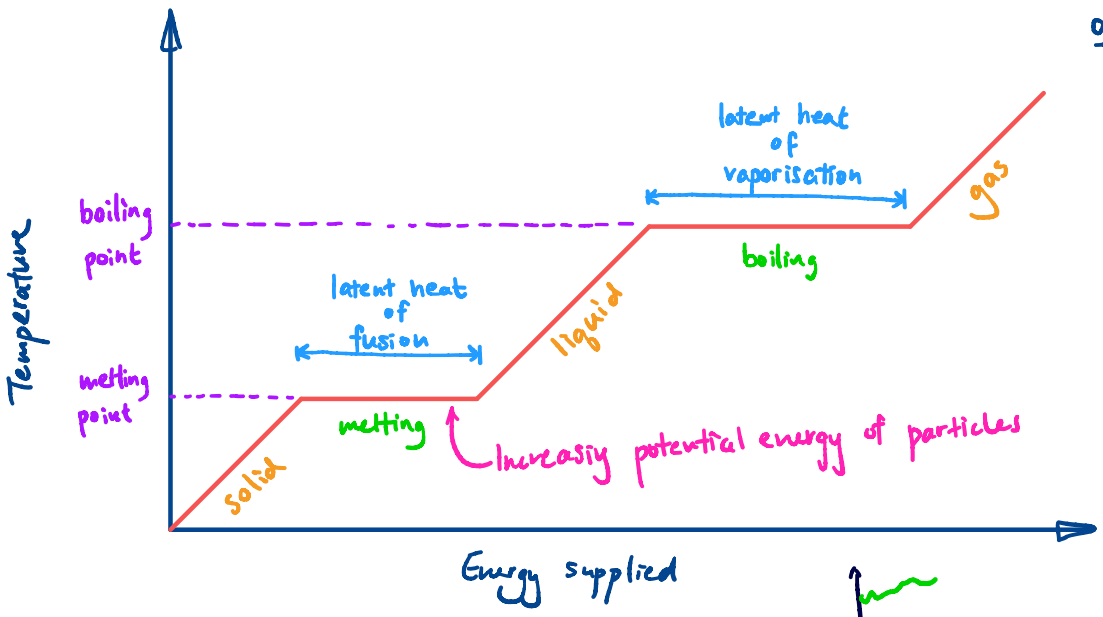
states go here

Specific latent heat of fusion solid ⟷ liquid

Specific latent heat of vaporisation liquid ⟷ gas

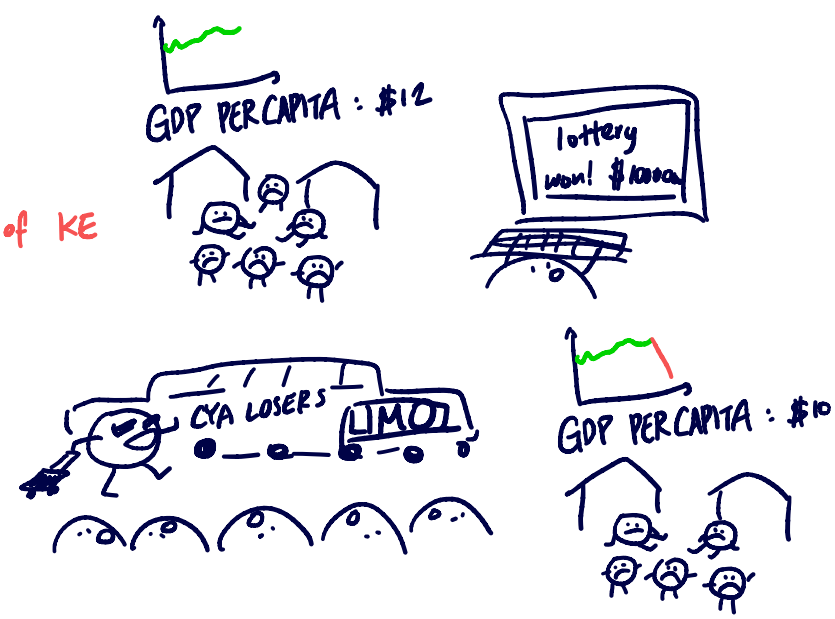
Internal Energy, U

Sum of molecule's kinetic and potential energies



Cooling by evaporation

- Hot liquids have molecules with a range of KE
- Faster molecules escape (evaporation)
- Average KE of remaining molecules is lower
- Temperature is lower



Increasing RATE of evaporation.

- Hotter liquid
- More surface area (in contact with air)
- More air flow (remove saturated air from above liquid)

1st LAW OF THERMODYNAMICS

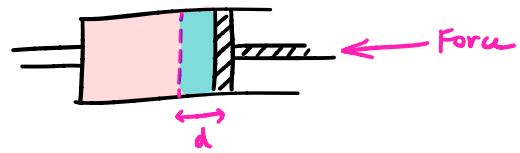
$Q = \Delta U + W$

Q = heat energy to the system

ΔU = change of internal energy

W = work done by the system

Work done by a gas



Work = Fd

Pressure = $\frac{F}{A} \Rightarrow F = PA$

$A \cdot d = \Delta V$

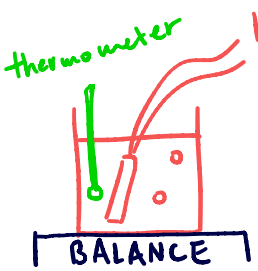
$W = PAd$

$W = P\Delta V$

constant pressure only!

Measuring Specific Latent Heat

Vaporisation



submersion heater

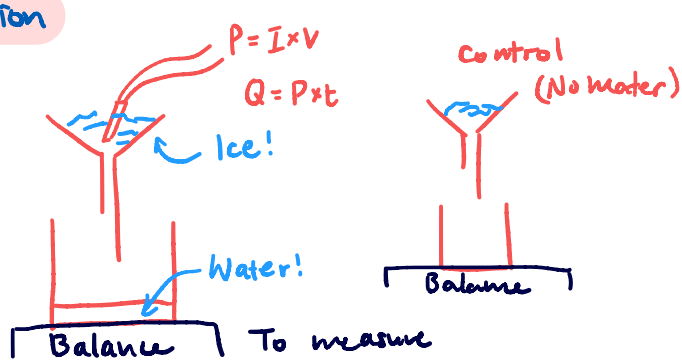
$P = I \times V$

$Q = P \times t$

start time when T = 100°c or other boiling point

to measure mass evaporated

Fusion



To measure mass melted

Sanity Check!

Density of Water = $1000\ kgm^{-3}$ Density of Air $\approx 1\ kgm^{-3}$

IDEAL GAS

Assumptions:

- Molecules FAR apart (no intermolecular forces unless they collide)
- Molecules are very ~~Jonathan~~ small compared to the size of the container
- Molecules in constant random motion
- Molecules fill their container

$$\boxed{pV = nRT}$$ (obviously)

Pressure

Particles collide with container walls

Experience change in momentum

↳ Force on particle (N2L)

Force on wall (N3L)

Pressure = $\frac{F}{A}$, pressure on wall

IDEAL GAS LAW (alpha version, not feature-complete)

Boyle's law: $p \propto \frac{1}{V}$ or $pV = \text{constant}$

(constant temp. & amount of gas)

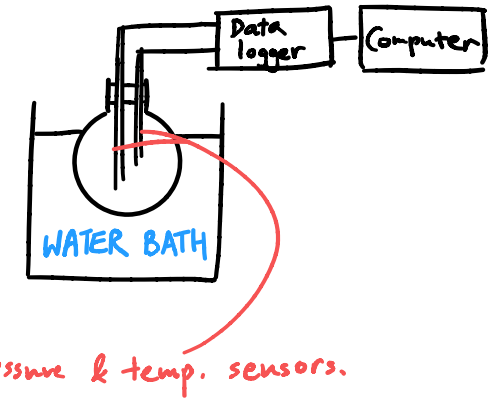
Pressure law: $p \propto T$ or $\frac{p}{T} = \text{constant}$

when $T = 0\,K$, $p = 0$ ← kelvin!

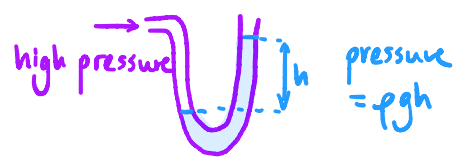
(constant volume & amount of gas)

Charles' law: $V \propto T$ or $\frac{V}{T} = \text{constant}$

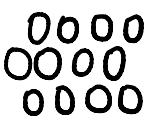
(constant pressure & amount of gas)



Manometer



What is the MOLE?



1 dozen eggs

This guy!

I have 6.022×10^{23} children!?

No, I said your child is a mole.

1 mole of molecules.

c^2_{RMS} is the mean square speed.

c^2_{RMS} can be written as $\overline{c^2}$ or $\langle c^2 \rangle$

KINETIC THEORY OF GASES

KINETIC GAS EQUATION

$$pV = \frac{1}{3} N m c^2_{RMS}$$

- p: Pressure [Pa]
- V: Volume [m^3]
- N: # of molecules
- m: Mass of 1 molecule [kg]
- c_{RMS}: RMS molecular speed [ms^{-1}]
- RMS: root mean square

- What affects pressure?

  - $E_k = \frac{1}{2}mv^2 \Rightarrow E_k \uparrow$, velocity $\uparrow$
    - → collision rate $\uparrow$
    - → greater momentum, $\Delta p \uparrow$

    } rate of change of momentum $\left(\frac{\Delta p}{\Delta t}\right) \uparrow$, force on walls $\uparrow$

  - Particle mass ⇒ mass $\uparrow$
    - → $\Delta p \uparrow \longrightarrow \frac{\Delta p}{\Delta t} \uparrow$, force on walls $\uparrow$

  - # of Particles ⇒ # $\uparrow$
    - → collision rate $\uparrow \longrightarrow \frac{\Delta p}{\Delta t} \uparrow$, force on walls $\uparrow$

MORE ON THE

KINETIC GAS EQUATION (and proving it)

$$C_{RMS} = \sqrt{\frac{100^2 + 200^2 + 300^2 + 400^2}{4}}$$

← sum of square velocities of each particle

← # of particles

↑ square root

C_{RMS}^2 will be the mean of the square velocities

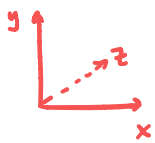
The proof is out of syllabus. (but still good to know)

cube volume, side length l

→ particle moves in +ve x dir.

initial $p = mu$

← after rebound (elastic collision) $p = -mu$



How often does this happen?

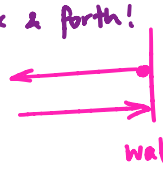
$\Downarrow$

$\Delta p = -2mu$

$$\text{Force} = \frac{\Delta p}{\Delta t} = \Delta p \times \text{frequency}$$

$$= -2mu \cdot \frac{u}{2l} = -\frac{mu^2}{l}$$

back & forth!



distance travelled $= 2l$

$u = \frac{d}{t}$ $\quad t = \frac{d}{u} = \frac{2l}{u}$

how many times per second?

$f = \frac{1}{T} = \frac{u}{2l}$

Force of one particle. $\boxed{\frac{mu^2}{l}}$

$$\boxed{\text{Force of all particles}} = \frac{mu_1^2}{l} + \frac{mu_2^2}{l} + \frac{mu_3^2}{l} + \dots = \frac{m}{l}\left(u_1^2 + u_2^2 + u_3^2 + \dots\right) = \frac{mN\overline{u^2}}{l}$$

$$\overline{u^2} = \frac{u_1^2 + u_2^2 + u_3^2 + \dots}{N}$$

$$\text{Pressure on wall} = \frac{mN\overline{u^2}/l}{l \times l} = \frac{mNu^2}{V} \quad (V = \text{volume})$$

$\rightarrow p = \rho u^2$ (pressure on wall in ONE AXIS)

Notice: $\frac{mN}{V} = \frac{\text{total mass}}{V} = \rho = \text{density}$

Considering 3 AXES: resultant velocity, $c \Rightarrow c^2 = u^2 + v^2 + w^2$ (pythagoras' theorem)

$\boxed{\overline{c^2} = \overline{u^2} + \overline{v^2} + \overline{w^2}}$ (since $\frac{u_1^2 + u_2^2 + u_3^2 + \dots}{N} + \frac{v_1^2 + v_2^2 + v_3^2 + \dots}{N} + \frac{w_1^2 + w_2^2 + w_3^2 + \dots}{N} = \frac{c_1^2 + c_2^2 + c_3^2 + \dots}{N}$)

Assuming particles move randomly, $\overline{u^2} = \overline{v^2} = \overline{w^2} \Rightarrow \overline{c^2} = 3\overline{u^2}$ (just stastically)

$\overline{u^2} = \frac{1}{3}\overline{c^2}$

$$p = \rho\overline{u^2} = \frac{1}{3}\rho\overline{c^2} = \frac{1}{3} \cdot \frac{mN}{V} \cdot \overline{c^2}$$

← substitute

$$\Rightarrow \boxed{pV = \frac{1}{3}Nm\overline{c^2}}$$

IDEAL GAS EQN × KINETIC GAS EQN

$pV = nRT = \frac{1}{3}Nm\overline{c^2}$

$\frac{N}{n} = N_A$ = Avogadro's number, 6.02×10^{23}

$RT = \frac{1}{3}m\overline{c^2} \cdot \frac{N}{n} = \frac{1}{3}m\overline{c^2} \cdot N_A$

$\frac{1}{3}m\overline{c^2} = \frac{R}{N_A} \cdot T$

$k = \frac{R}{N_A}$ = Boltzann's Constant

$\frac{1}{2}m\overline{c^2} = \frac{3}{2} \cdot \frac{R}{N_A} \cdot T$

$\frac{1}{2}m\overline{c^2} = \frac{3}{2}kT$

$\overline{E_k} = \frac{1}{2}m\overline{c^2}$ = Average kinetic energy of one particle

$\overline{E_k} = \frac{3}{2}kT \longleftarrow \overline{E_k} \propto T$ Temp. proportional to average kinetic energy!

1mole of gas, 100 kPa, $0.024 m^3$, 4.8×10^{-26} kg per molecule

$pV = \frac{1}{3}Nm\overline{c^2}$

$\overline{c} = \sqrt{\frac{3pV}{Nm}} = \sqrt{\frac{3 \times 100000 \times 0.024}{6.02 \times 10^{23} \times 4.8 \times 10^{-26}}} = 499.1687... \approx 500 ms^{-1}$