Saw last time how Weird QM is

The early years of Quantum theory were a time of guesswork, inspired by

- Inconsistencies
- Absurdities

in applying Classical Physics (EM + Stat Mech + Mechanics + Relativity) to properties of atoms, radiation, & their interaction

This will be the subject of next few weeks

Later (1920's) this led to a systematic theory

We will come to this at end of course

Early Atomic theory

The world is Quantized!

Matter is made of atoms

Feynmans Atomic fact: All things are made of atoms
little particles that move around in motion

Old idea:

- Can be traced back to the Greeks
  Democritus 400s BC
  Not scientific, But hugely historically influential

= Scientific application of atomic theory
  18C properties of gases
  19C Chemistry
  Electrolysis
  1895 Discovery of the electron

Gases

$pV \sim$ constant "Boyle Law"
(at constant T)

$V \sim T$ "Charles Law"
(at constant P)

Daniel Bernoulli: showed could explain these from a model of gas as moving particles.

n – $\frac{\text{Particles}}{\text{volume}}$ v – velocity

$P \sim nv^2$
↑ rate × force

$P \sim \frac{N_{pt}}{V} v^2$

$PV \sim v^2 \sim T$
↑
Bernoulli assumed

Rudolf Clausius 1857

Showed how to extend this to

$PV = NkT$

↳ Not clear if k depends on gas properties

Chemistry

Chim (water, fire, earth, wind, metal)

Greeks: fire, water, earth, air

Modern Chemistry

18C list of 55 elements

H, O, N, S, C, P

Iron, copper, tin, lead, gold ...

Some compounds: (fire, Potash) thought were atoms

John Dalton "Law of Combining Weight"

In reactions, weights in fixed ratios

ex: 1 g hydrogen burns w/ 8 g O

leaving 9 g water

Allows you to measure relative masses of reactants & products

→ Not clear if these are actually atoms or compounds!

Can quote masses relative to compound w/ smallest relative mass ≡ m_1 "atomic weight unity"

Gay-Lussac "Law of Combining Volumes"

Gases (fixed P & T) always combine in fixed ratios of volumes

eg: 2L "H" burns in 1L "O" to give water

Correct theoretical explanation 1811 by Count Amadeo Avogadro

A-Principle

Equal Volumes (fixed T & P) of gases contain equal #'s of particles "molecules"

↳ Atoms or Combinations of Atoms

2L "H" + 1L "O" = water + nothing else

$\Rightarrow$ water H_2O

Now use Dalton can get $m_H = 8\, m_O$ from combination of mass law.

Note 2L "H" + 1L "O" gives 2L H_2O

$\Rightarrow$ $2H_2 + O_2 \rightarrow 2H_2O$

A's Principle quickly provided correct results for many gases.

Think about it more

Avogadro's Principle + Gas law $\Rightarrow$ $k = \frac{PV}{NT}$ must be same for all gases

Avogadro's Number

If the number is constant for all gasses

Can define it in terms of # molecules/atoms per atomic weight unit

$N_A = \frac{1}{m_1}$ (# molecules in fixed amount (mole) of gas)

In late 19C Physics, measuring N_A one of the great challenges

Note many didn't believe in it

Atoms fictional counting device.

$$PV = NkT$$

Could measure R where,

$$PV = nRT \qquad R \equiv kN_A = \frac{k}{m_1}$$

n ↑ # atomic weight units

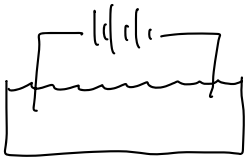
Electrolysis

Electricity + Magnetism known to the ancients

By end of 19C had Maxwells equations

Electrolysis:

eg: Bubbles of H_2 & O_2 when Battery connected to terminals in water



Lots of expiments with diffent solutions

(how we discovered Chlorine, when using salt)

$H_2O \rightarrow H^+$ which get attracted to the
OH^- electrodes

$2H^+ + charge \rightarrow H_2$

$4 OH^- \rightarrow 2H_2O + O_2 + charge$

Faradays theory 1 unit of charge to convert singly charged ion

Measured $F = 10^2$ C/kg for 1 mol (mole) of ions

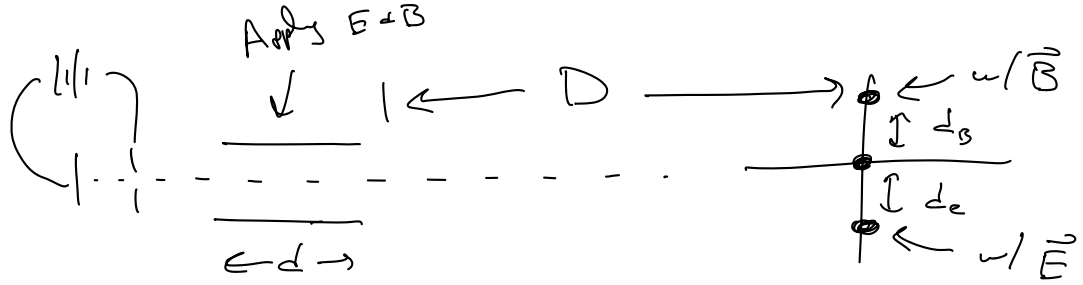
$= N_A e$

$F = \frac{e}{m_1}$ ↖ ↖ Neither of these known. only product.

Discovery of the electron

Key invention of good air pumps. "Cathode Rays"

Could get electric currents to travel w/o wires!



$D \gg d$

$$d_e = \frac{eEdD}{mv^2} \qquad d_B = \frac{evBdD}{mv^2}$$

$$d_x = v_\perp \times \text{time in D}$$

$$= (a_\perp \times \text{time in d}) \times \frac{D}{v}$$

$$= \frac{F}{m} \times \frac{d}{v} \times \frac{D}{v}$$

Note: only sensitive to e/m — 2 eqns 2 unknowns

Also don't know v $\Rightarrow$ Solve for v

Determine $\frac{e}{m}$

Thompson found (1897) $\frac{e}{m_{ray}} \sim 10^5 \frac{C}{Kg}$ (Electrolysis $\left(\frac{e}{m_1} \sim 10^2 \frac{C}{Kg}\right)$)

If particles in rays same as in electrolysis

then e - same

$$\Rightarrow \quad m_{ray} \sim 10^{-3} m_1$$

Big Suprise! $m_1 \sim$ mass lightest atom

$m_{ray} \equiv m_e << m_{atom}$

1st (indirect) Indication that atoms have substate!

Atomic Scale

19c Physics measured Ratios of quantities that characterize scale of atoms / molecules.

$$\frac{e}{m_1}, \quad \frac{e}{m_e}, \quad R = \frac{k}{m_1}, \quad \left(N_A = \frac{1}{m_1}\right)$$
(custom)

Could measure one of the m_1, m_e, k, e directly then solve for others.

20c reliable measurements on atomic scale (1st major success of 20c)

Atomic Scale determined 3 ways

- Measurement of e "oil drop experiment"
- " " $N_A = \frac{1}{m_1}$ { - Brownian Motion
  - Blue Sky.
- Measurement of k from study of "Black Body" Radiation

Importance of these measurements of atomic scale was in proving the Reality of atoms.

All previously arguments for atoms circumstancial

Ideal gas law derived by considering motions of individual particles, But conclusions only held w/ Bulk properties.

Note: With thermodynamics can derive powerful results w/o committing to the existence of atoms

Measurement of e "Oil drop experiment"

determined from first measurement of e
w/ oil droplets

measured e, $\Rightarrow m_e$

m_i from Faraday

More important observe that droplet charges are
integer multiples $\Rightarrow$ charge quantized.