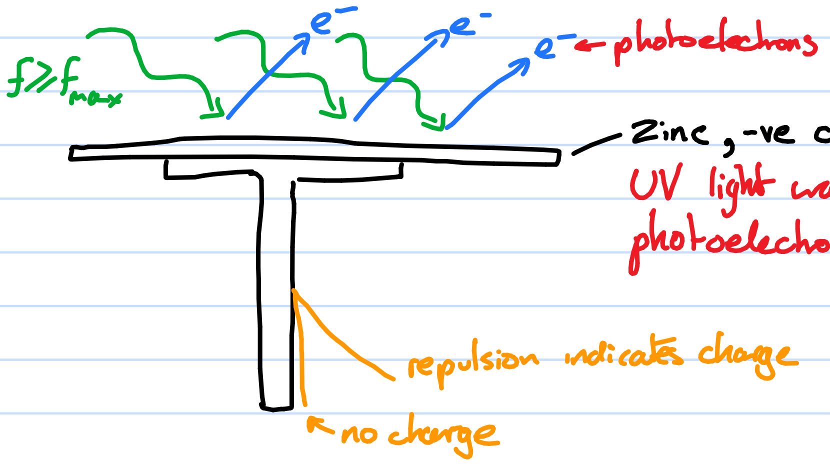
The Photoelectric Effect

- Electrons emitted from metal surface when electromagnetic radiation of sufficiently high frequency was incident upon the metal, this is the threshold frequency, f_{min}. Regardless of light intensity. Could not be explained by wave theory which stated power delivered $\propto$ amplitude^2.

- Photoelectron emission rate $\propto$ intensity $\propto$ amplitude^2 AS LONG AS $f \geq f_{max}$

- Photoelectron emission was immedrate



UV light was required for photoelectron emission.

planck's Constant

Einstein (1905), $E \propto f$ quantised – discrete packets $E = hf$

$h = 6.63 \times 10^{-34}$ Js

"what if <u>all</u> light is quantised?" Quanta of light = photons

$E = hf = \frac{hc}{\lambda}$ $(c = f\lambda)$ Energy conservation : $E_{in} = E_{out}$

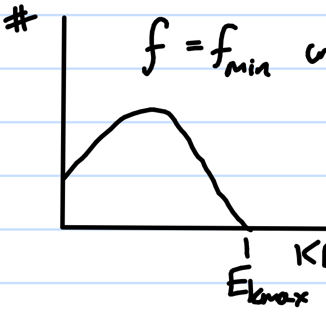
$$\overbrace{hf}^{IN} = \overbrace{\phi + E_{kmax}}^{OUT}$$

photon energy

work function

maximum photoelectron kinetic energy

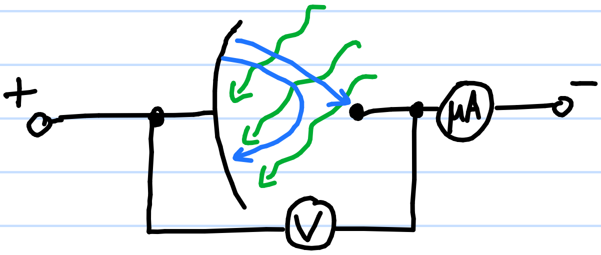
work function : Minimum energy needed to free electron from surface of metal



$f = f_{min}$ when $E_{kmax} = 0$ $\therefore$ $hf_{min} = \phi$

- when $V = V_s$ (stopping potential), $I = 0$

VACUUM PHOTOCELL



- Work done on electrons moving across photocell

$W = eV$

when $W = E_{kmax}$ then

$I = 0$

$hf = \phi + eV_s$

More about photoelectricity

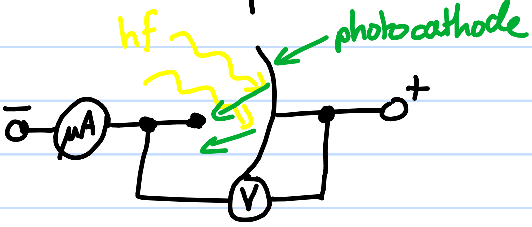
$$hf = h\frac{c}{\lambda} = \phi + E_{kmax}$$

photon energy

work function

maximum KE of photoelectrons

Vacuum photocell

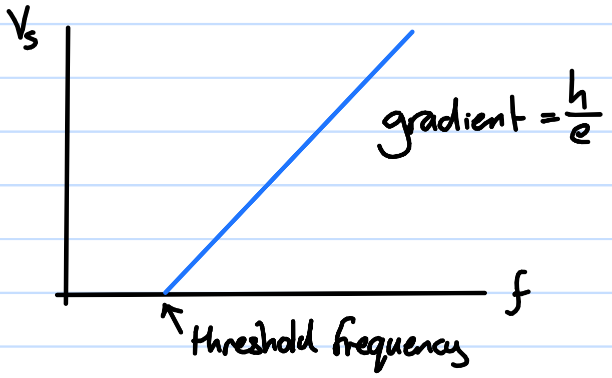


photocurrent becomes zero when $V = V_s$, $E_{kmax} = eV_s$

Experiment to measure ϕ:

1. $V = 0$ at start
2. Increase V until photocurrent $= 0$
3. Measure V, $V = V_s$
4. Do for different photon energies

Results of experiment:



$hf = \phi + eV_s \Rightarrow$ into form $y = mx + c$

variable

variable

constants

V

con

V

con

$$V_s = \frac{h}{e}f - \frac{\phi}{e}$$

If e is known, $h =$ gradient $\times e$

read a value of V_s and f from graph, use to calculate ϕ

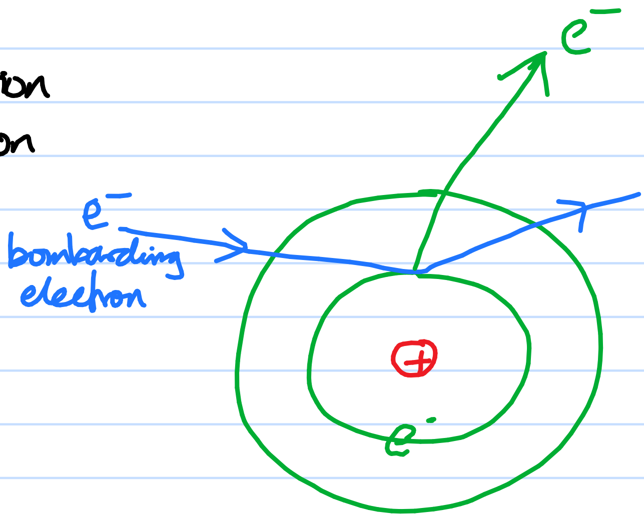
$$\boxed{Q = It}$$

Collisions of electrons with atoms

Two things can happen:
- Ionisation
- Excitation

IONISATION

- Changing atoms into ions
  - we are interested in ionisation by bombardment, always get +ve ions by this method

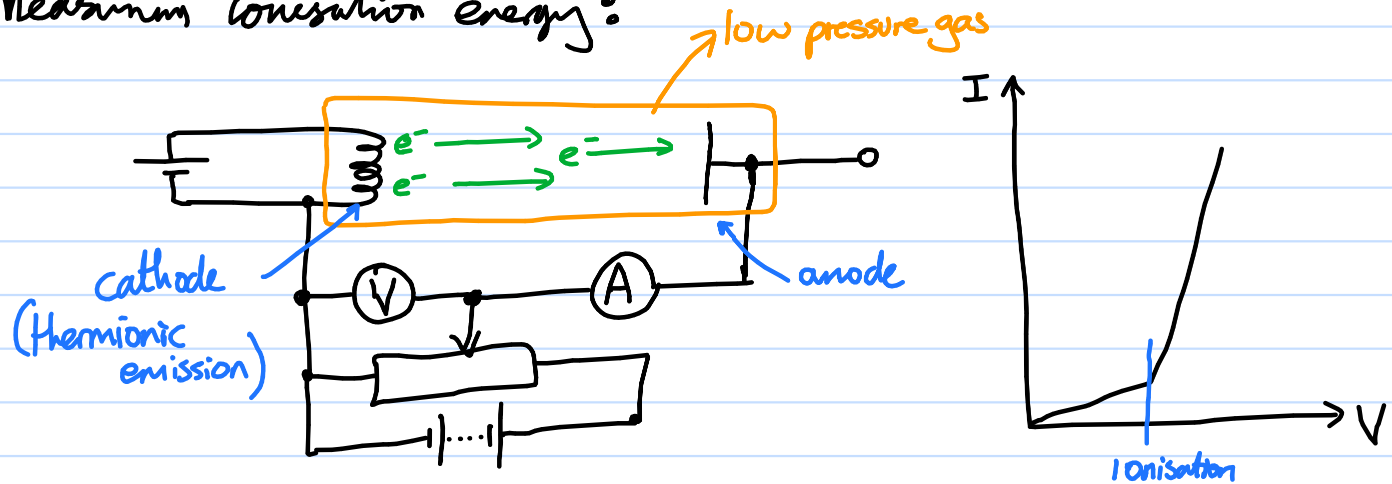


Ionisation energy: Minimum energy needed to free an electron from the atom in the ground state

fill shells 2, 8, 18

A bombarding electron carrying KE greater than ionisation energy of atom in ground state can ionise the atom.

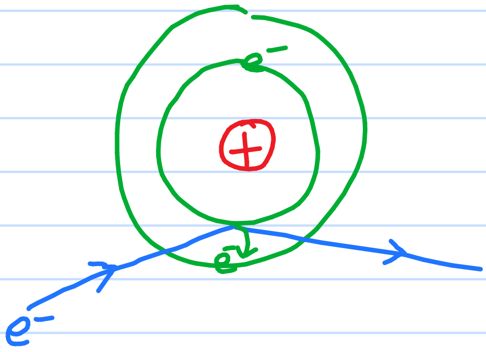
Measuring ionisation energy:



$$V = \frac{W}{q} = \frac{W}{e} \rightarrow W = eV$$

1eV of energy is transferred when 1 electron moves across a p.d. of 1V

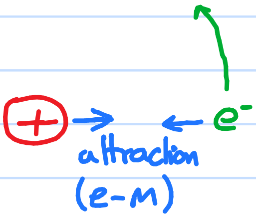
EXCITATION



Excitation energy: energy absorbed by atom when it becomes excited (stores energy)

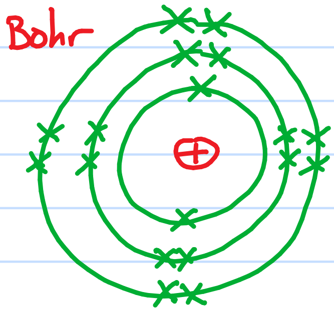
Discrete set of excitation energies possible

Energy levels in atoms



- Only certain energy levels an electron can be in. (shells)
- From Chemistry:

2 electrons in first shell because they are fermions

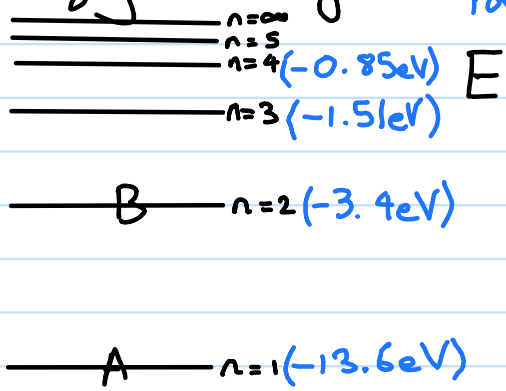


n = pricipal quantum n:

spin?

two possible spin states

Energy level diagram

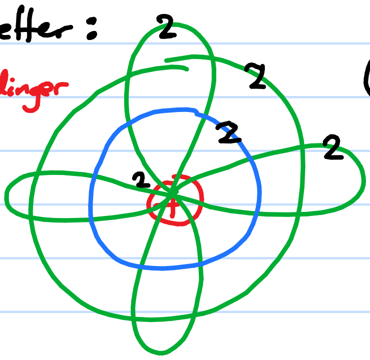


For Hydrogen:

$$E = \frac{13.6eV}{n^2}$$

Better:

Schrödinger



(subshells)

two case

A: give 14.6eV

$14.6 + (-13.6) = 1eV$ KE

B: give 4.4eV

$4.4 + (-3.4) = 1eV$ KE

De-excitation:

electron moves down an energy level only if there is space to do so

Cause photon emission. $E = hf$ is the de-excitation energy

$B \rightarrow A$ $\quad -3.4 - (-13.6) = 10.2eV$

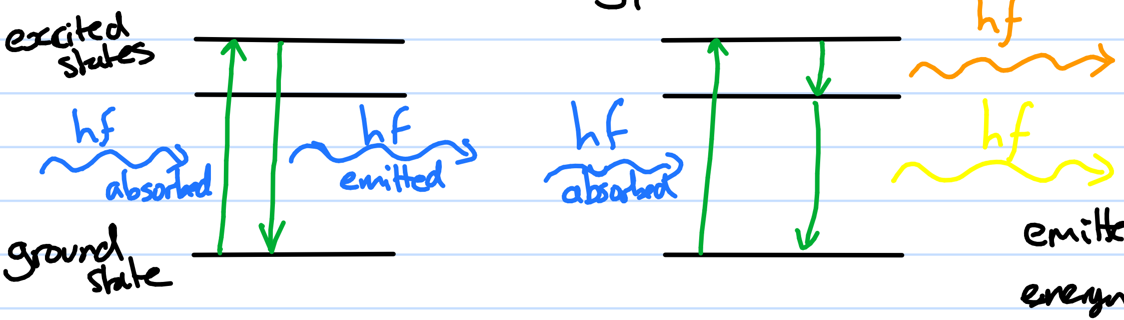
$$10.2eV \times 1.60 \times 10^{-19} \, J/eV = 1.632 \times 10^{-18} J$$

$$f = \frac{1.632 \times 10^{-18}}{6.63 \times 10^{-34}} = 2.46 \times 10^{15} Hz$$

$$c = f\lambda \rightarrow \lambda = \frac{c}{f} = 122nm \quad UV$$

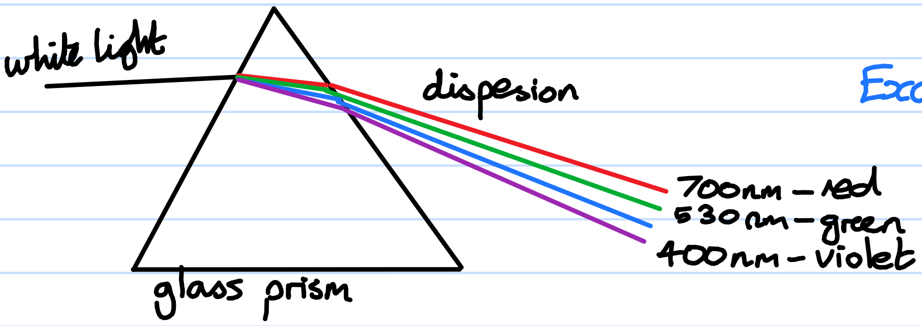
Fluorescence

- High energy photon absorbed
- Two or more lower energy photons emitted



emitted photon each lower energy than absorbed photon

Energy levels and spectra



} wavelengths $\lambda = \frac{c}{f}$

$$E = hf = h\frac{c}{\lambda}$$

Excitation energy

$$\boxed{E = E_2 - E_1}$$

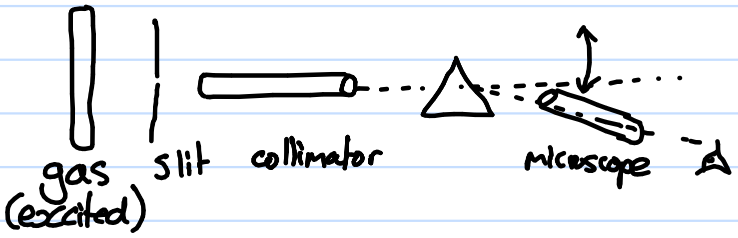
Spectrum : the colours of light emitted from a source

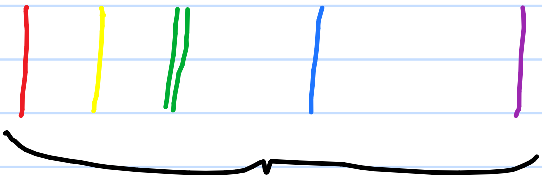
- Hot bodies – produce a continuous spectrum
- De-excitation causes discrete spectrum

!! Certain colours because there are certain excitation energies

∴ Certain values of photon energy. (quantum)

Producing a line spectrum



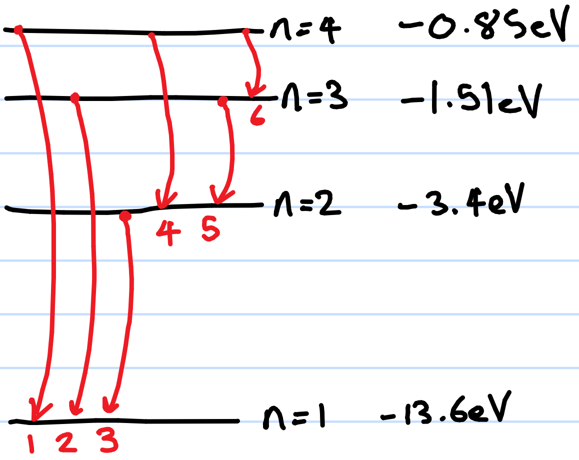


- emission spectrum
- line spectrum

- Use to analyse composition of gas.
- called spectrometry!

Hydrogen spectrum

$$E_n = \frac{13.6eV}{n^2}$$



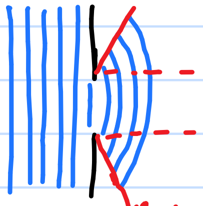
1 • $-0.85 - (-13.6eV) = 12.75eV$
• $12.75 \times 1.60 \times 10^{-19} = 2.04 \times 10^{-18} J$
• $\lambda = \frac{hc}{E} = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{2.04 \times 10^{-18}} = 97.5nm$

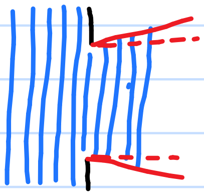
4 • $-0.85 - (-3.4) = 2.55eV$
• $2.55 \times 1.60 \times 10^{-19} = 4.08 \times 10^{-19} J$
• $\frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{4.08 \times 10^{-19}} = 487.5nm$

Wave-particle duality

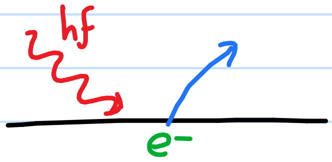
Waves transmit energy without transmitting matter
waves can superposition - add up effects of multiple waves

wave-like: DIFFRACTION





Particle-like: No diffraction



Photoelectric effect

Light does this... ... AND this! (dual nature)

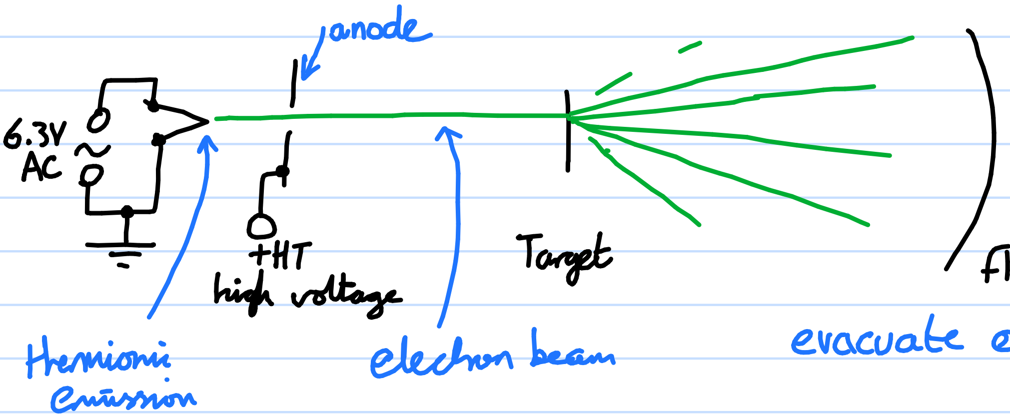
De Broglie hypothesis : dual nature of matter (eg - electrons)

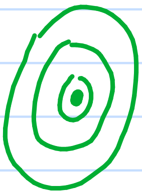
Matter waves can be observed to diffract. $\lambda \propto d\sin\theta$
What is the wavelength of matter waves?

$$\lambda = \frac{h}{p}$$ Link between waves and particles!

p for matter : $p = mv$ $\therefore$ $\lambda = \frac{h}{mv}$

Evidence for wave nature of electrons





ring pattern is diffraction pattern

evacuate experiment (in a vacuum)

Energy levels in atoms:

- Stationary waves
- Electron shells

} link for later