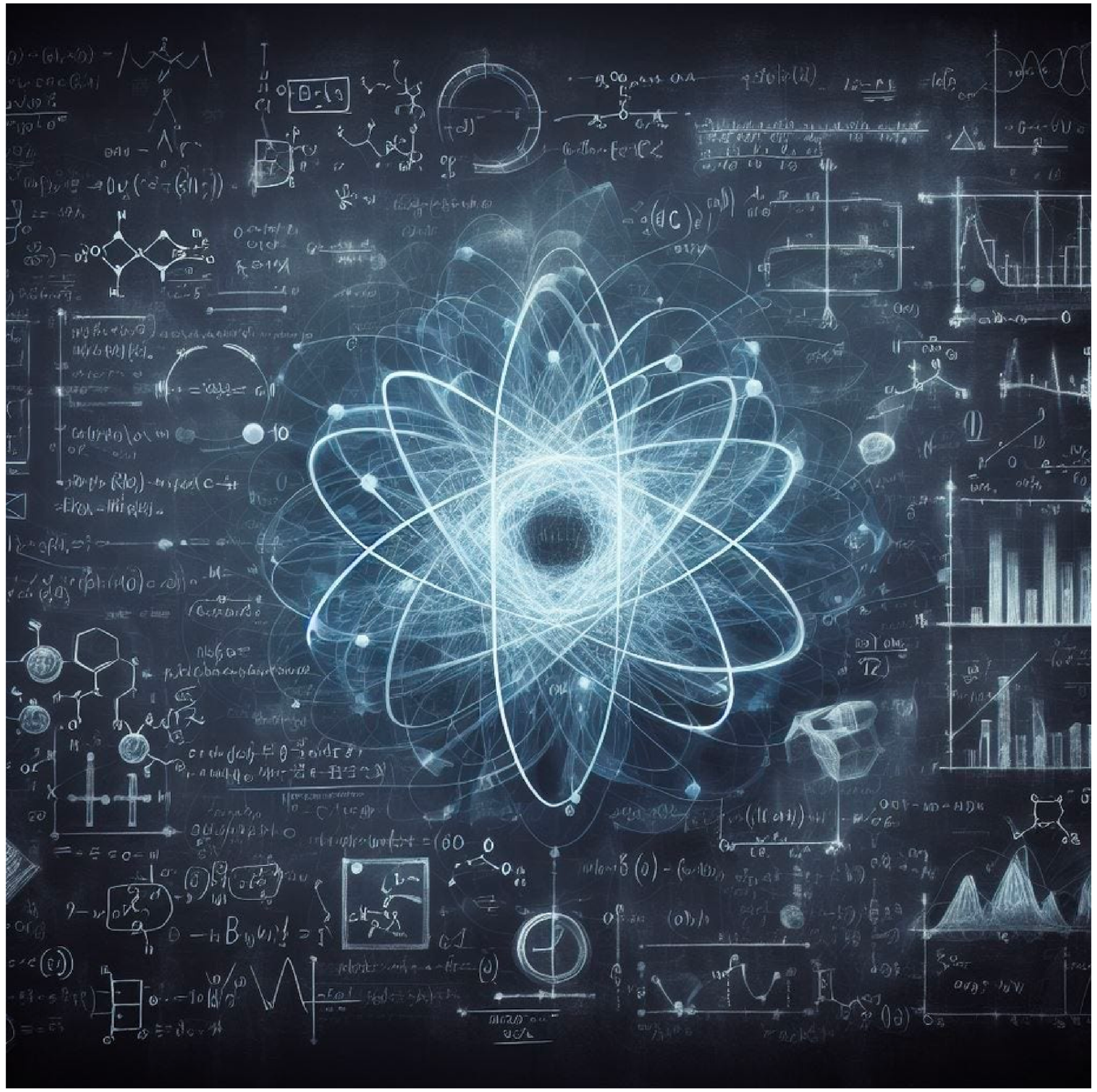
9702 C22 Quantum physics



Photon

Photons are fundamental particles which make up all forms of **EM radiation**

A photon is a **massless "packet" or "quantum"** // **quantised** of EM radiation

-->energy is not transfer continuously, but as discrete packets of energy

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

$$p = \frac{E}{c}$$

Where:

- E = energy of the photon (J)
- h = Planck's constant (J s)
- c = the speed of light (m s^{-1})
- f = frequency in Hertz (Hz)
- λ = wavelength (m)

Photon travelling in a vacuum has no momentum, despite it having no mass

(h=6.63*10^-34 Js)

Electron Volt

electron volt = energy gained by an electron travelling a p.d. of 1V

$1e = 1.60 \times 10^{-19} C$

$V = \frac{E}{Q}$

$E = QV = 1.6 \times 10^{-19} C \times 1.0V$

$= 1.60 \times 10^{-19} J$

$\therefore 1eV = 1.60 \times 10^{-19} J$

$$J \xrightarrow{\div (1.60 \times 10^{-19})} eV \xrightarrow{\times 10^{-6}} MeV$$

if electron accelerates from rest $eV = E_k$

$eV = \frac{1}{2}mv^2$

$\Rightarrow v = \sqrt{\frac{2eV}{m}}$

Photoelectric Effect

Photoelectric effect is the phenomena in which **electrons are emitted from the surface of metal upon the absorption of EM radiation**

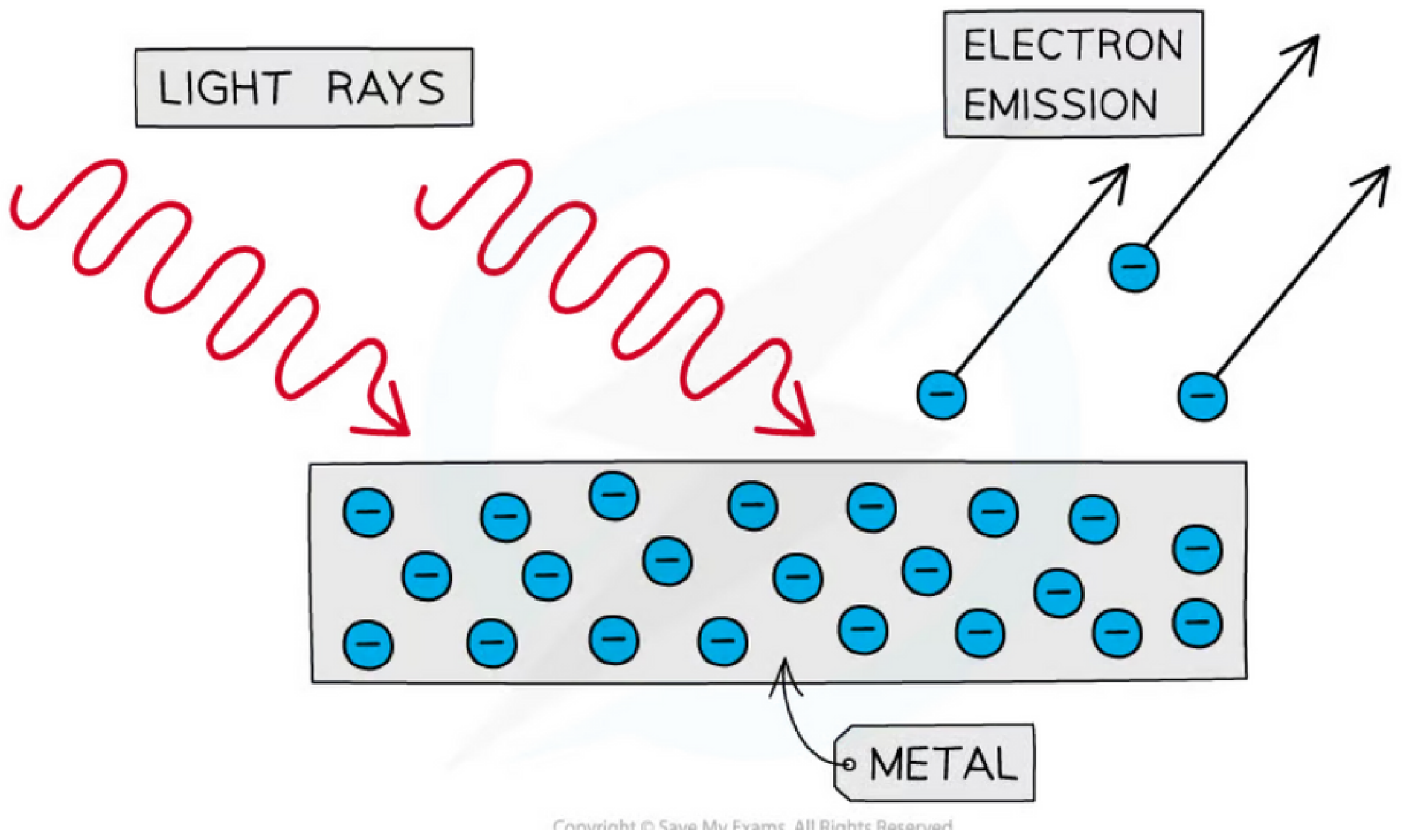
Electrons removed from a metal in this manner are also known as **photoelectrons**

Photoelectric effect provides evidence that light is **quantised** (i.e. carried in discrete packets)

-->**1 electron can absorb only 1 photon**
-->so only the frequency of light **above threshold frequency** will emit a photoelectron

threshold frequency = minimum frequency of incident EM radiation required to remove a photoelectron from the surface of a metal

threshold wavelength = longest wavelength of incident EM radiation that would remove a photoelectron from the surface of a metal



Photoelectric Equation

due to conservation of energy:

$$E = hf = \Phi + \tfrac{1}{2}mv^2_{max}$$

Symbols:

- h = Planck's constant (J s)
- f = the frequency of the incident radiation (Hz)
- Φ = the work function of the material (J)
- $\tfrac{1}{2}mv^2_{max}$ = the maximum kinetic energy of the photoelectrons (J)

E=photon energy(J)

Φ = work function (or threshold energy) = minimum energy required to release a photoelectron from the material's surface

When $hf_0 = \Phi$, where f_0 = threshold frequency, photoelectric emission only just occurs

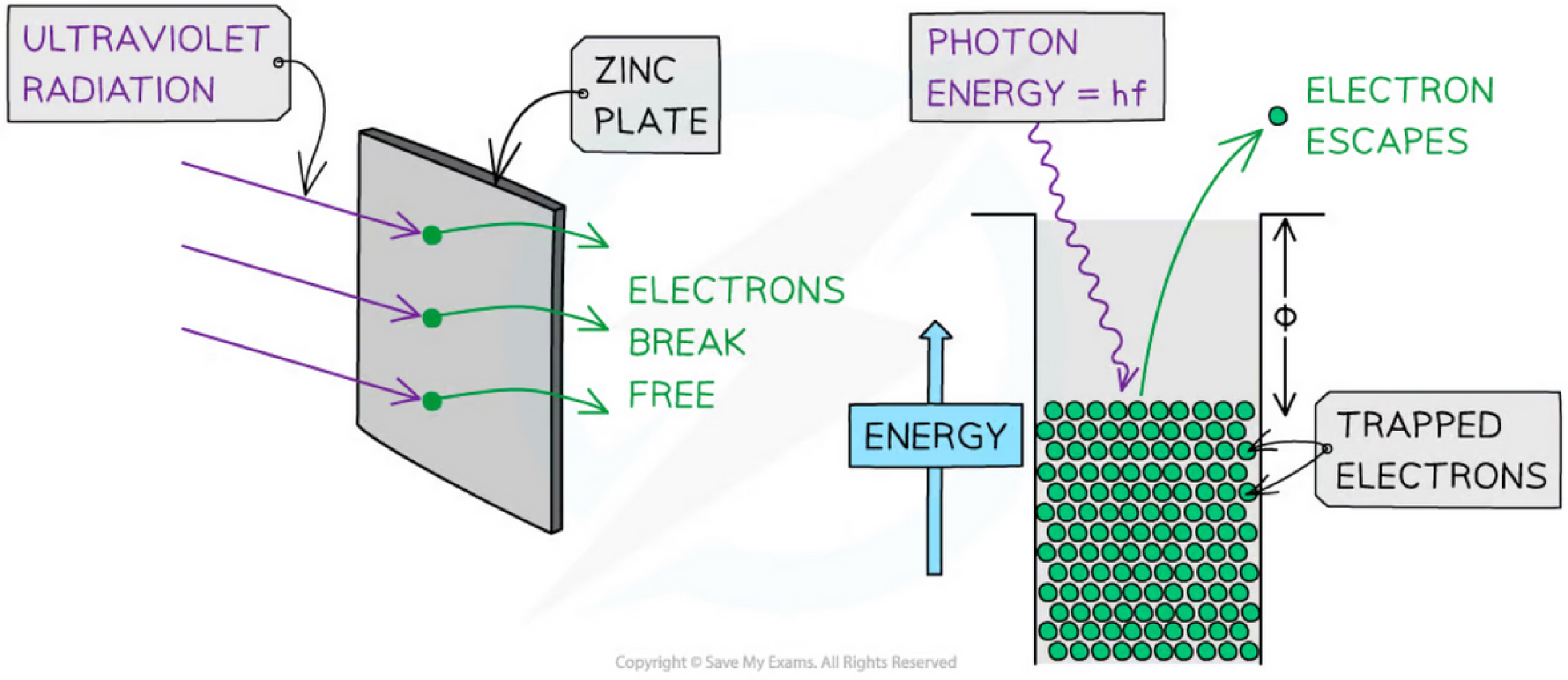
if incident photon frequency < threshold frequency (i.e. not enough energy to overcome Φ) : then no electrons will be emitted

Potential well

Consider the electrons in metal as trapped inside an "potential well" where the energy between the surface and the top of the well is equal to Φ

1. A more tightly bound electron requires more energy to reach the top of the well
2. A less tightly bound electron requires less energy to reach the top of the well

electron can only escape the metal surface if it absorbs a photon which has energy=**Φ or higher**



Intensity and Photoelectric Current

Ek max of photoelectrons is independent on the intensity of incident radiation

This is because each electron can only absorb one photon

Ek is only dependent on the frequency of the incident radiation

-->Therefore increasing no.of photons will not increase Ek, but it will increase no. of photoelectrons emitted

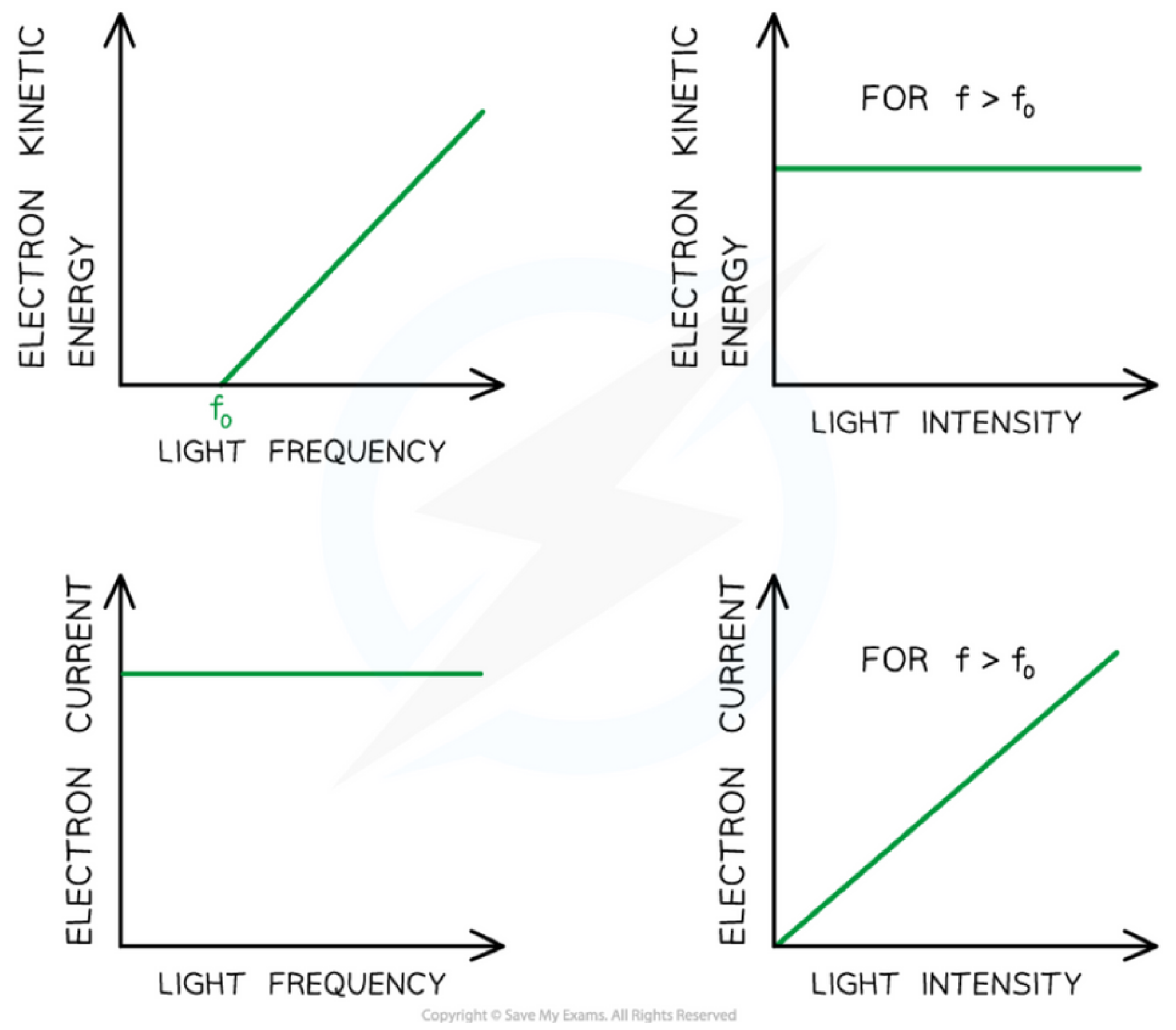
(intensity = no. of photons incident on metal surface)

Photoelectric current = no. of photoelectrics emitted per second

Photoelectric current is proportional to the intensity of radiation incident on the metal surface

gradient of electron Ek against light frequency graph = Planck constant

f0 = work function



Wave-Particle Duality - Light as a Wave

Phenomenon when **light waves can behave like particles**(i.e. photons and waves) is called the wave-particle duality

Einstein proposed that light can behave like particles(photon) that is a **quanta of energy**

photon model(photoelectric effect) of light explains that:

1.EM waves carry energy in discrete packets called photons

2.Energy of photons are quantised according to E=hf

3. 1electron absorb 1 proton - so frequency>threshold frequency will emit a photoelectron

The wave theory of light suggests...	This is wrong because...
Any frequency of light can give rise to photoelectric emission if the exposure time is long enough	Photoelectrons will be released immediately if the frequency is above the threshold for that metal
The energy absorbed by each electron will increase gradually with each wave	Energy is absorbed instantaneously – photoelectrons are either emitted or not emitted after exposure to light
The kinetic energy of the emitted electrons should increase with radiation intensity	If the intensity of the light is increased, more photoelectrons are emitted per second

wave theory of light does not support a threshold frequency:

1.wave theory suggests any frequency of light can give rise to photoelectric emission if the exposure time is long enough - because energy absorbed by each electron will increase gradually with each wave

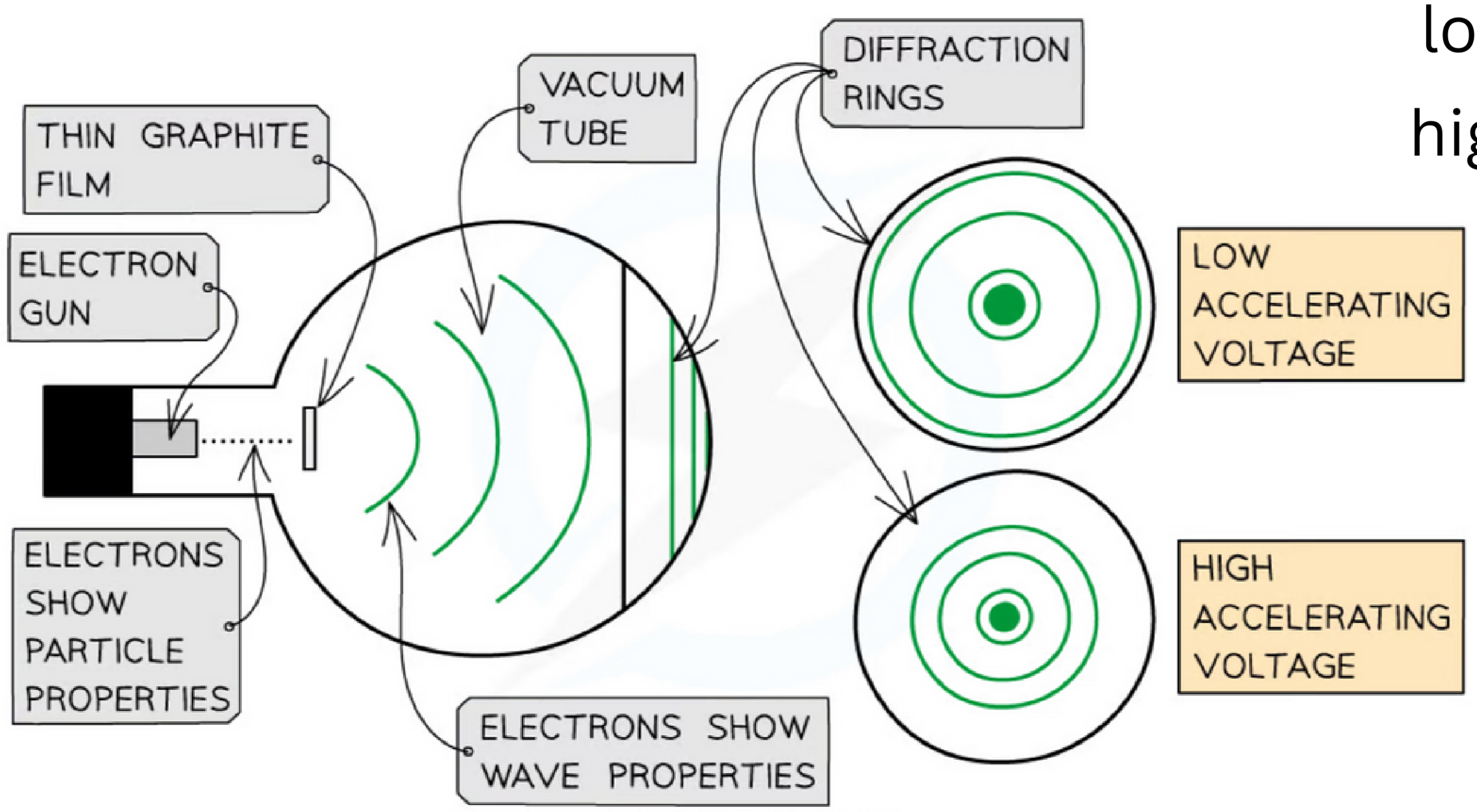
2.also Ek of emitted electrons should increase with radiation intensity

3. if frequency>threshold frquency + intensity increases, more photoelectrons are emitted per second

-->However none of these are observed in photoelectric effect. Wave theory FAILED to explain the photoelectric effect

Wave-Particle Duality - Electron as a Wave

Louis de Broglie discovered that **electrons can behave as a wave**



lower accelerating voltage = increase diameter of the rings

higher accelerating voltage = decrease diamter of the rings

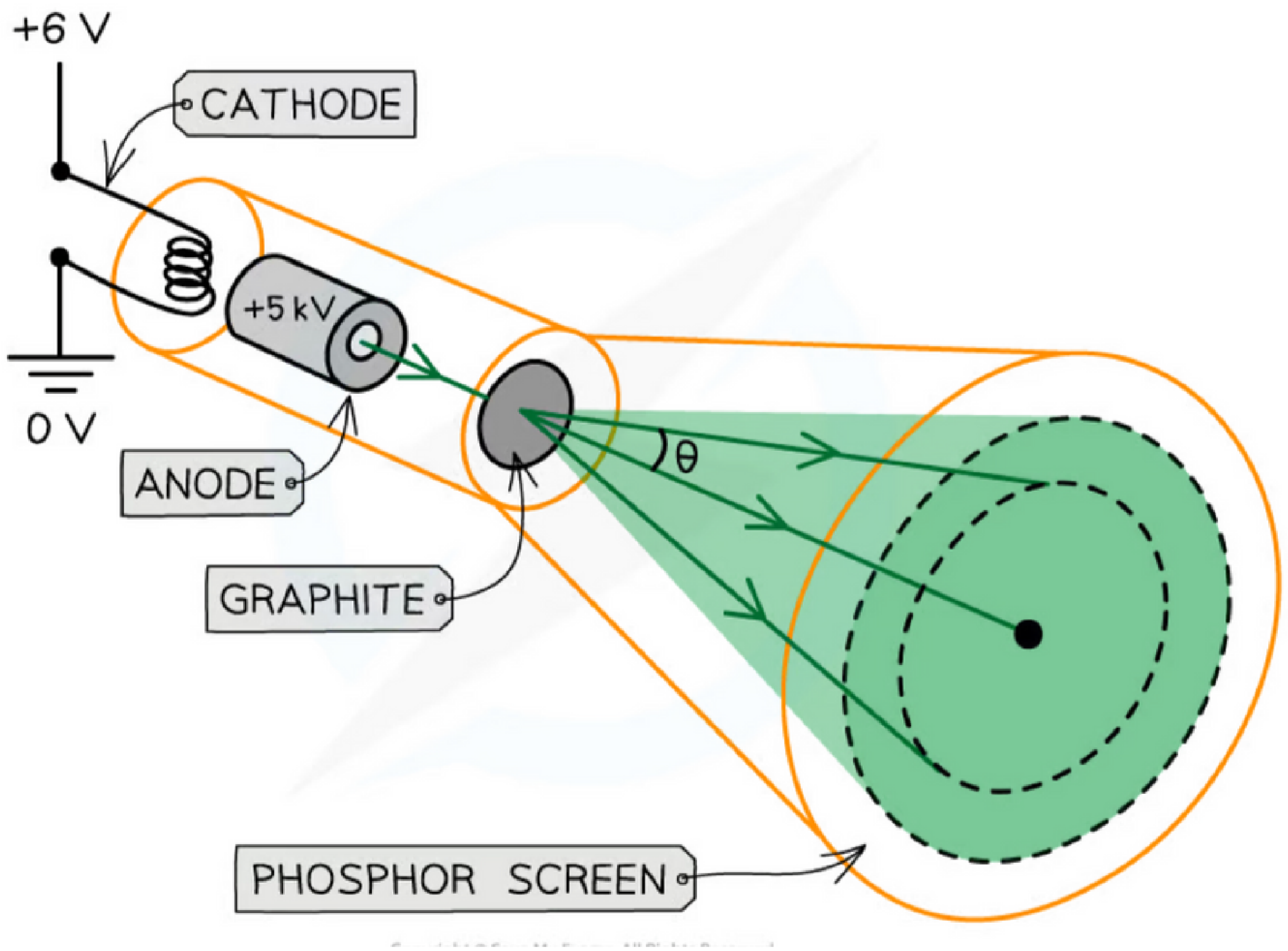
Gap size or Atomic lattice must be similar to electron size in order to observe diffraction of electron

-->e.g. graphite film is suitable as the gaps between neighbouring planes of the atoms in the crystals act as slits

To observe diffraction patern, a series of concentric rings is used to display

if electrons acted as particles, a pattern would not be observed, instead the particles would be distributed uniformly across the screen

Electron diffraction tube



Electrons are accelerated in an electron gun to a high potential (e.g. 5000V) and are then directed through a thin graphite film

Electrons diffract from the gaps between carbon atoms and produce a circular pattern on a fluorescent screen made from phospher

increasing voltage between anode and cathode, causes the energy and hence speed of electrons increase (radius of diffraction pattern decreases)

Ek of electron is proportional to voltage across anode-cathod: **Ek=eV**

de Broglie Wavelength

De Broglie proposed that electron can behave as a wave and therefore hold wave properties such as **wavelength**

-->this became known as the **de Broglie wavelength**

de Broglie wavelength = wavelength associated with a moving particle

$$p = mv$$

$$v = \frac{p}{m}$$

$$v^2 = \frac{p^2}{m^2}$$

$$E_k = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\frac{p^2}{m^2}\right) = \frac{p^2}{2m} \quad // \quad p = \sqrt{2mE_k}$$

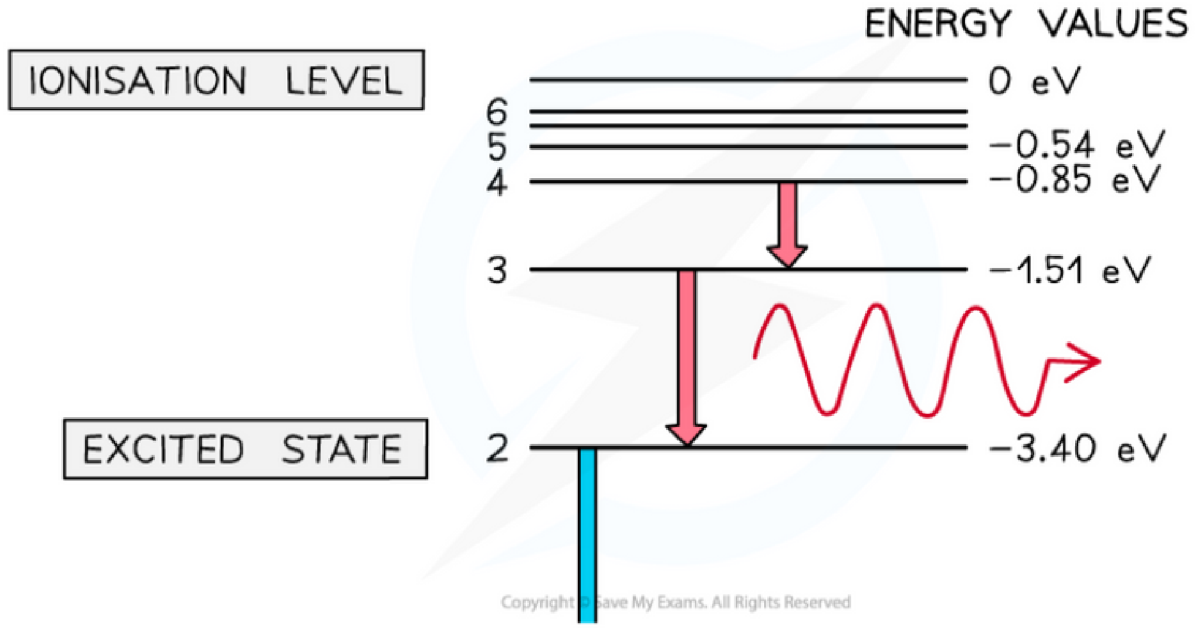
$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mE_k}}$$

Electron energy levels

Electrons in an atom have certain specific electron energy levels(electron shell)

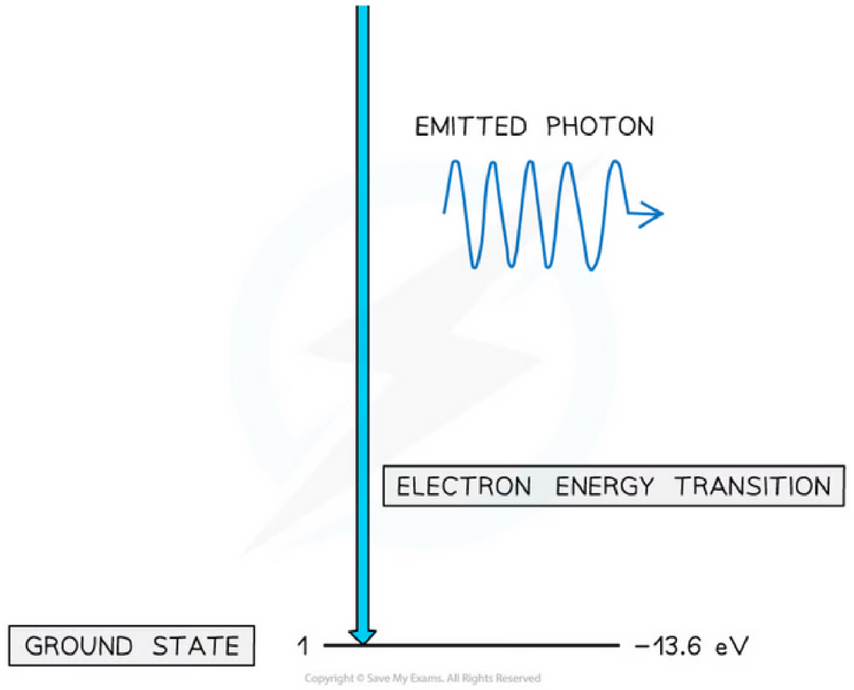
They can be represented as a series of stacked horizontal lines increasing in energy

Electrons tend to be in the **ground state(lowest energy)**



When electron **excited,** electrons move up an energy level + they are said to be in an **excited state**

If electron gains enough energy to be removed from the atom ENTIRELY, this is known as **ionisation**



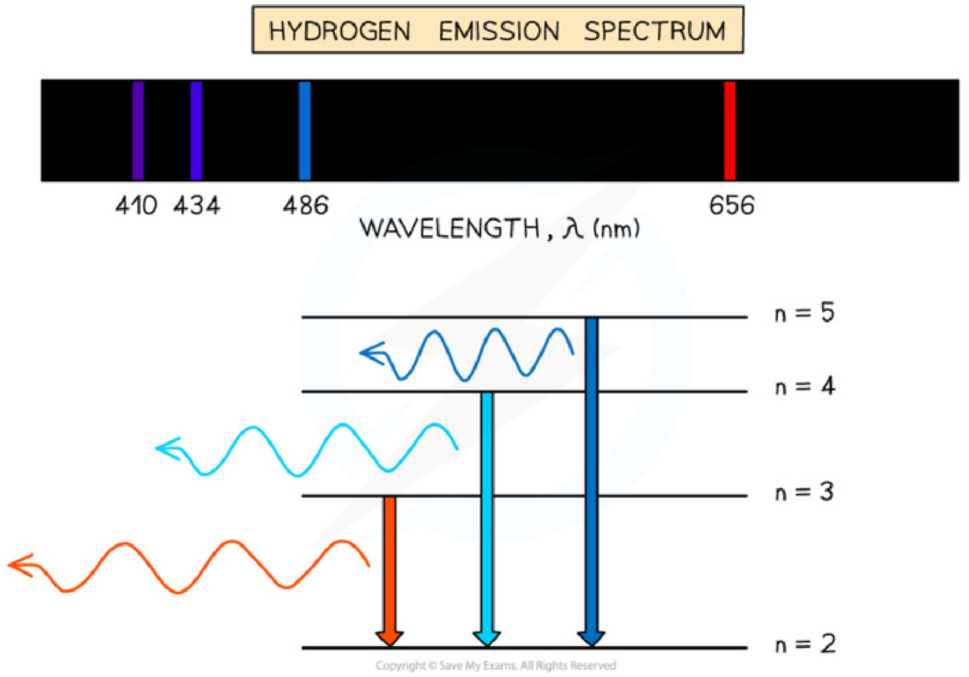
when electron **deexcited**(or relaxation) is fall back to a lower energy state + releases energy in the form of a proton

Line Spectra

Line spectra is a phenomenon which occurs when **excited atoms emit light of certain wavelengths** which correspond to different colours

-->emitted light can be observed as a series of coloured lines withh dark spaces in between - series of coloured line = line spectra (aka atomic spectra)

There are 2 types of line spectra: **emission spectra** and **absorption spectra**



Emission Spectra

when electron deexcited, it results in emission of photon

Each transition when electron deexcited corresponds to a different wavelength of light + line in spectrum

-->resulting emission spectrum contains a set of <u>discrete wavelength</u> represented by coloured lines on a black background

therefore electrons in atom can only transition between **<u>discrete energy levels</u>**

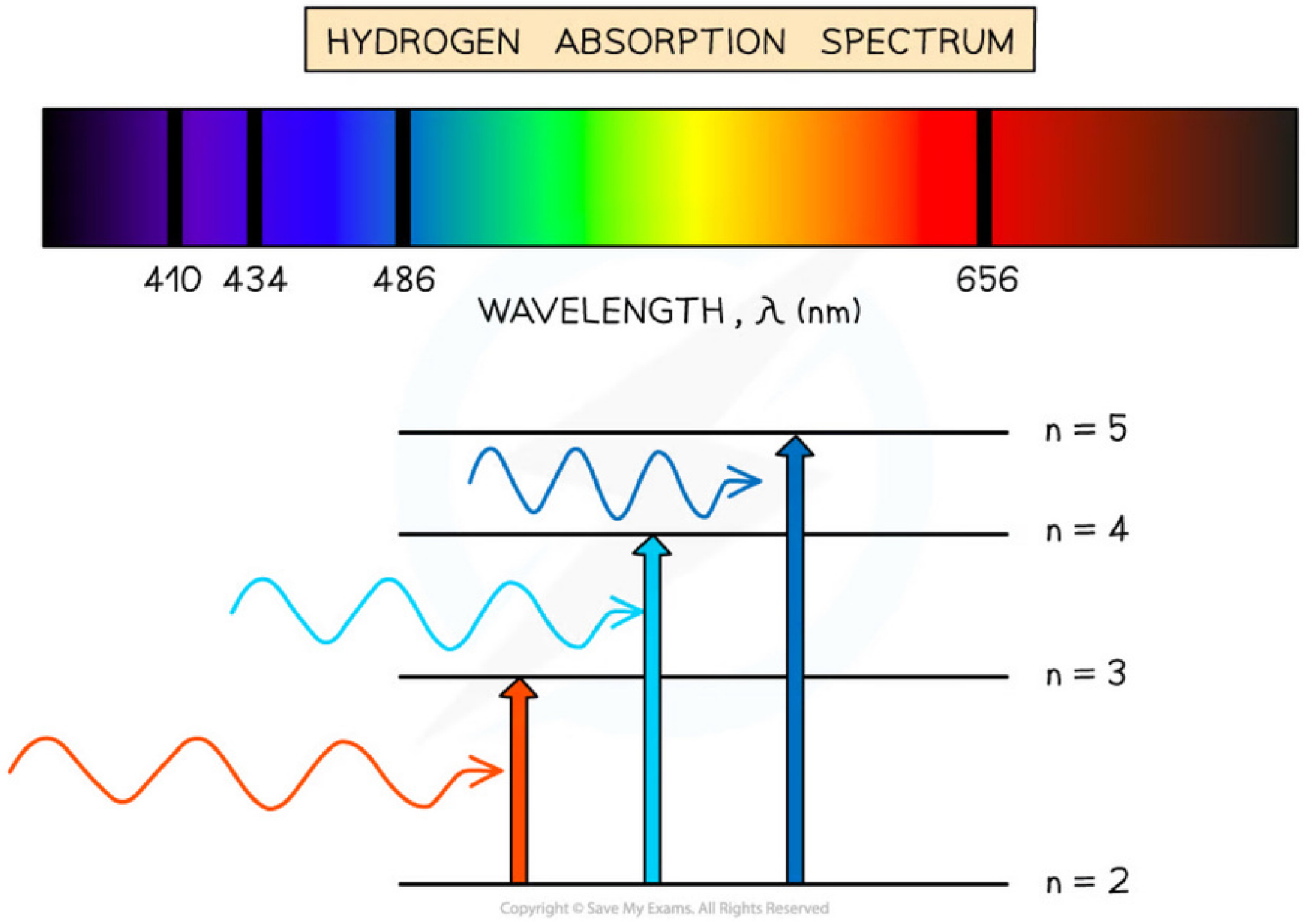
$$\Delta E = hf = \frac{hc}{\lambda}$$

Absorption Spectra

When electron absorbs a photon, electron excited to the excited state

When white light passes through a COOL + Low Pressure gas it is found that that light of certain wavelengths are missing - this is known as absorption spectrum

Absorption spectrum consists of a continuous spectrum containg ALL the colours with dark lines at certain wavelengths(so certain energy levels)



When electrons deexcited, photons are emitted in all directions, rather than in the original direction of the white light. Therefore some wavelengths are missing

photon energy = difference between two energy levels = relates to a single frequency/wavelength

(wavelength missing is the same both in absorption and emission spectra of the same element)

Discrete Energies

Difference between two energy levels = specific photon energy

$$\Delta E = hf = E_2 - E_1$$

$$\lambda = \frac{hc}{E_2 - E_1}$$

Where,

- E_1 = Energy of the lower level (J)
- E_2 = Energy of the higher level (J)
- h = Planck's constant (J s)
- f = Frequency of photon (Hz)