Spectra – BMcMULLEN

Energy level diagrams

The photoelectric effect provides evidence for the discrete rather than the continuous nature of electromagnetic radiation.

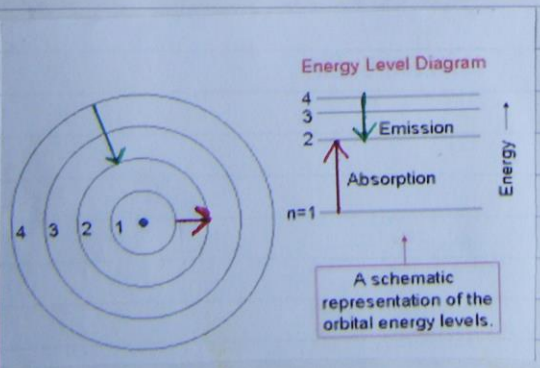
1) Absorption Spectra

Electrons gain energy by absorbing photons of electromagnetic radiation.

2) Emission Spectra

Electrons give off energy in the form of photons.

What is a photon?
This is a packet or a bundle of wave energy.

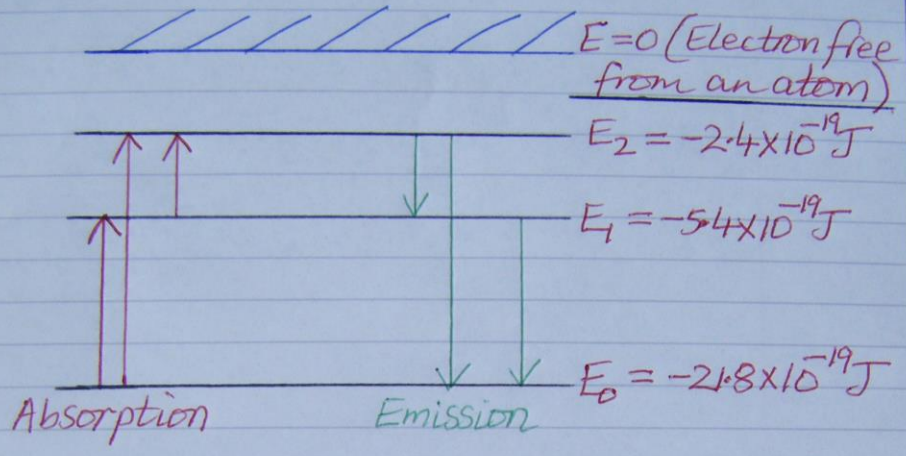


1 → 2 Absorption

4 → 2 Emission

Energy level diagram for Hydrogen

* Hydrogen is the most basic element *



- There are three energy levels within the Hydrogen atom.
- The lowest energy level is called the ground state. This energy level is nearest the nucleus of the Hydrogen atom.
- The highest energy level within the Hydrogen atom is E_2 ie it is the least negative of all of the energy levels.
- E=0 shows that an electron is free from the atom, with the negative energy levels that electrons can exist in within the atom being a reference frame for this.

- The energy level diagram can be thought of as a lift system in a block of flats, with the exception that each floor while ascending in the lift get closer and closer together.
- Electrons can only exist in each of these discrete energy levels
- $E_2 > E_1$ and $E_2 > E_0$ and $E_1 > E_0$.

ie The higher the energy level the less negative the energy in the energy level and vice-versa.

Why are energy levels negative?
An electron which is free from an atom has an energy of 0J.

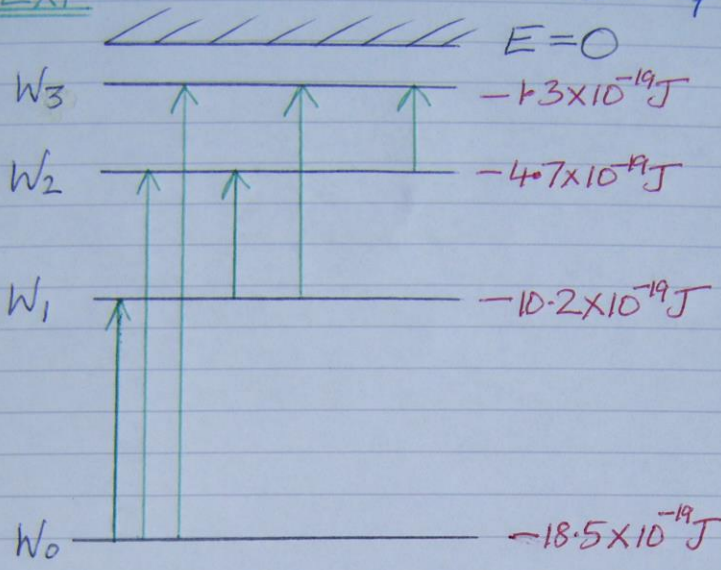
To allow an electron in one of these orbits (energy levels) to escape from an atom then it must be provided with energy in the form of absorbing a photon.

∴ Conclusion
Energy of an electron in Hydrogen $= -5.4 \times 10^{-19}$ J

Then the electron must absorb a photon of energy 5.4×10^{-19} J.

$\Rightarrow -5.4 \times 10^{-19}\text{J} + 5.4 \times 10^{-19}\text{J} = 0\text{J}$ ∴ Electron free from an atom.

Ex1 (Sometimes W is used instead of E in these diagrams.)



Q a) Draw and state the number of transition lines present in this absorption spectra.

A a) $W_0 \to W_1$, $W_0 \to W_2$, $W_0 \to W_3$, $W_1 \to W_2$, $W_1 \to W_3$ and $W_2 \to W_3$.

ie 6 transition lines.

Q b) Which transition lines give rise to photons of

i) The highest frequency. (lower wavelength)

ii) The lowest frequency (highest wavelength)

A b) i) $W_0 \rightarrow W_3$. From $E = hf$ $\therefore E \propto f$

This means the greater the energy jump the higher the frequency. (lower wavelength)

ii) $W_2 \rightarrow W_3$ as $E \propto f$

This means the smaller the energy jump the smaller the frequency. (Higher the wavelength)

Q c) Calculate or find:

i) The highest frequency of photons absorbed.

ii) The highest wavelength of photons absorbed.

A c) i) $E = hf$, $W_0 \rightarrow W_3$ $(18.5 - 1.3 = 17.2)$

$\Rightarrow 17.2 \times 10^{-19} = 6.63 \times 10^{-34} \times f$

Always positive!! $\Rightarrow f = \frac{17.2 \times 10^{-19}}{6.63 \times 10^{-34}} = \underline{2.59 \times 10^{15} Hz}$

ii) $E = hf$, $W_2 \rightarrow W_3$ $(f \downarrow \therefore \lambda \uparrow)$

$\Rightarrow 3.4 \times 10^{-19} = 6.63 \times 10^{-34} \times f$ $(4.7 - 1.3 = 3.4)$

$\Rightarrow f = \frac{3.4 \times 10^{-19}}{6.63 \times 10^{-34}} = \underline{5.13 \times 10^{14} Hz}$

Then $V = f\lambda \Rightarrow \lambda = \frac{V}{f} = \frac{3 \times 10^8}{5.13 \times 10^{14}} = \underline{5.85 \times 10^{-7} m}$

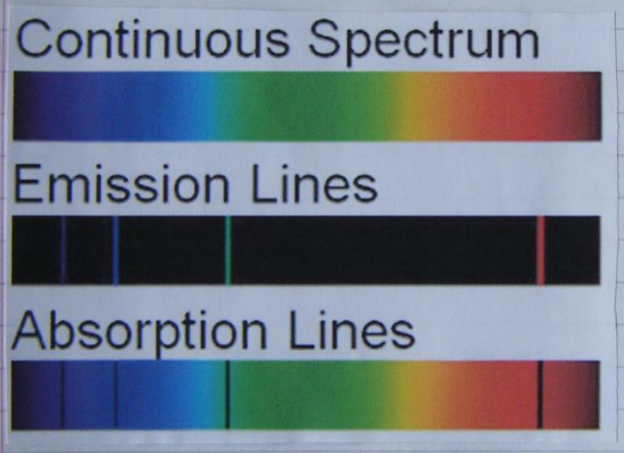
Q d) Calculate the frequency of photons that require to be absorbed for electrons in the ground state to be completely free from an atom.

A d) $E = hf$, From -18.5×10^{-19} J to 0 J.

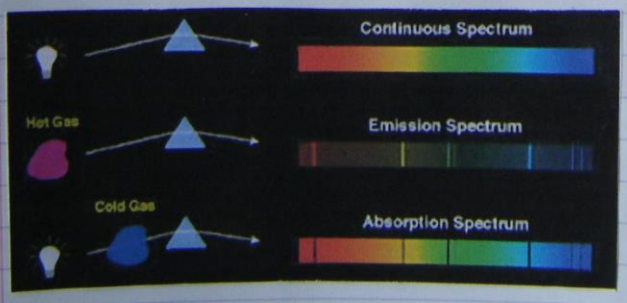
$\Rightarrow 18.5\times10^{-19} = 6.63\times10^{-34} \times f$

Always positive!

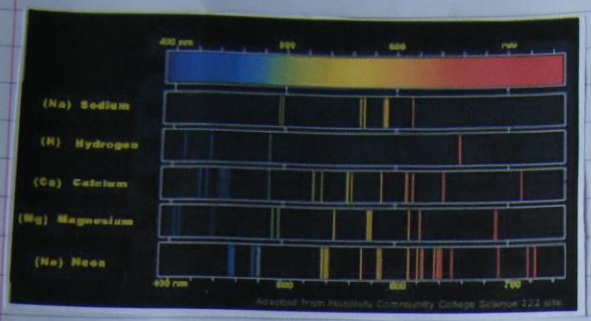
$\Rightarrow f = \frac{18.5\times10^{-19}}{6.63\times10^{-34}} = 2.79\times10^{15}$ Hz



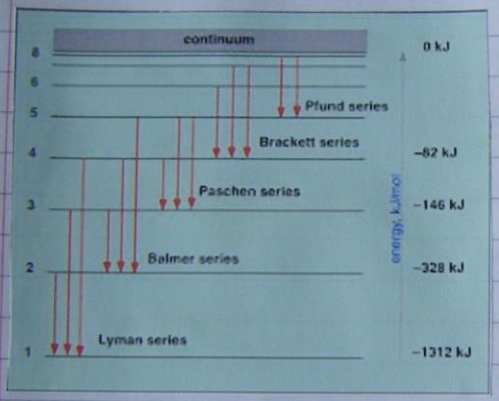
Emission Spectra
Black background with individual coloured lines relating to the wavelength of light emitted.



Absorption Spectra
The background is the entire visible spectrum (continuous spectrum) with individual black lines which show the wavelengths of light absorbed.



Each element can be identified by their emission or absorption spectra.



This diagram shows a detailed emission spectra for Hydrogen, where n=1 is called the ground state.

← FOR INTEREST ONLY!!

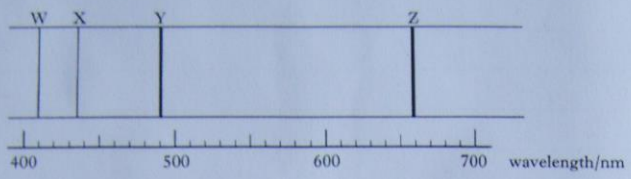
What does this caption refer to?

Is light a wave or a particle?

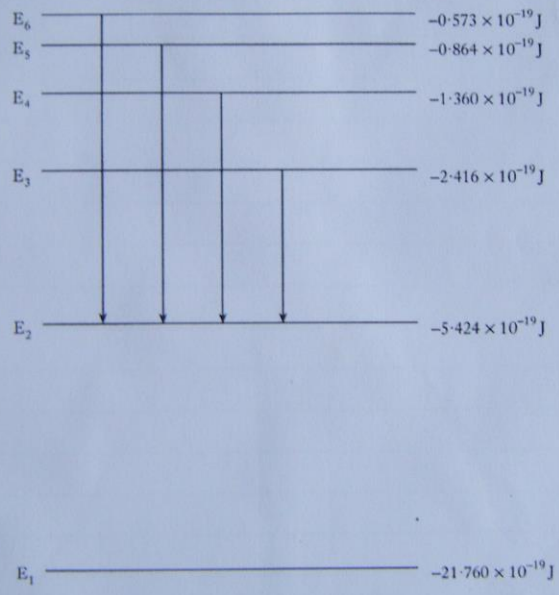
Wave-Particle duality!!

Ex2 (1998 PII PAST PAPER Q9)

The line emission spectrum of hydrogen has four lines in the visible spectrum as shown in the following diagram.



These four lines are caused by electron transitions in a hydrogen atom from high energy levels to a low energy level E_2 as shown below.



(*a*) From the information above, state which spectral line W, X, Y or Z is produced by an electron transition from E_3 to E_2. **1**

(*b*) Explain why lines Y and Z in the line emission spectrum are brighter than the other two lines. **1**

(*c*) Infrared radiation of frequency $7{\cdot}48 \times 10^{13}$ Hz is emitted from a hydrogen atom.

(i) Calculate the energy of one photon of this radiation.

(ii) Show by calculation which electron transition produces this radiation. **4**

(6)

Ex 2 Solutions.

a) $E_3 \rightarrow E_2$

Of the 4 transition lines in the energy level diagram $E_3 \rightarrow E_2$ is the smallest energy jump.

- Smallest energy jump $\Rightarrow$ smallest frequency of light emitted
- Smallest frequency of light emitted $\Rightarrow$ Highest wavelength of light emitted.
- Highest wavelength of light emitted $\Rightarrow$ Line Z $= 660\text{nm}$.

b) More electrons per second are making the transition between the energy levels associated with lines Y and Z.

c) i) $E = hf = 6.63\times10^{-34} \times 7.48\times10^{13}$

$\Rightarrow E = 4.96\times10^{-20}\text{J}$

ii) $4.96\times10^{-20}\text{J} = 0.496\times10^{-19}\text{J}$

This occurs in the transition from $E_5 \rightarrow E_4$.

$1.360\times10^{-19}\text{J} - 0.864\times10^{-19}\text{J} = 0.496\times10^{-19}\text{J}$

LASERS. * (For background reading and interest only in CfE H) (10)

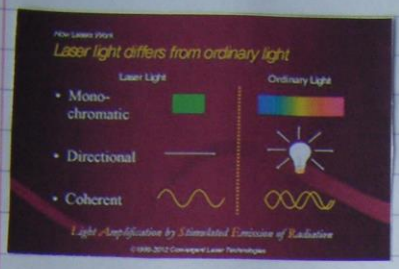
L I G H T A M P L I F I C A T I O N by the S T I M U L A T E D E M I S S I O N of R A D I A T I O N S

Applications of Lasers

- Laser eye surgery
- Laser guided missile systems
- Laser gun sights
- Laser printers
- Laser pens
- Keyhole surgery
- Tattoo removal
- Black and Decker tools (to measure length accurately)

Light from a lamp and a laser

- A laser is a concentrated highly Irradiant beam of light of one colour. (Not always red!!) The irradiance of the laser beam stays constant over very large distances.
- Lamps give out light in all directions and are not always one colour. White light is made up of 7 colours. ie ROYGBIV.



Highlighting the comparisons between laser light and light from a lamp.

A selection of lasers of different class and different wavelengths.

NB All lasers do not consist of red light.

Laser shows are very common on the nightclub scene.

Laser eye surgery.

This procedure is very popular among people with sight defects.

I will stick to wearing my glasses thank you very much!!

The power of a Laser

- Range of power in a laser $mW \rightarrow MW$

Why can a mW laser do more damage than a MW laser?

- The damage that a laser can do is down to two things:

- Power of a laser
- The cross sectional area of a laser beam where

$$I = \frac{P}{A}$$

∴ The damage is caused is related to the Irradiance of a laser beam.

Laser Laughs

Ex3

Q Calculate the Irradiance of a laser beam on a wall if it has a power of 0.5mW and a beam diameter of 8mm.

$\Downarrow$ $r = 4mm$

A $I = ?$

$P = 0.5mW = 0.5 \times 10^{-3} W$

$A = \text{Circle} = \pi r^2 = \pi \times (4 \times 10^{-3})^2 = 5.03 \times 10^{-5} m^2$

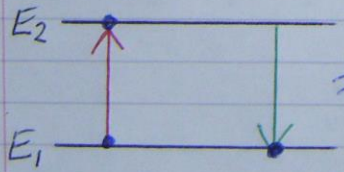
$$I = \frac{P}{A} = \frac{0.5 \times 10^{-3}}{5.03 \times 10^{-5}} = 9.94 W m^{-2}$$

Laser Emission

Two types
- Spontaneous Emission
- Stimulated Emission

Spontaneous Emission

Different energy levels have different stabilities.



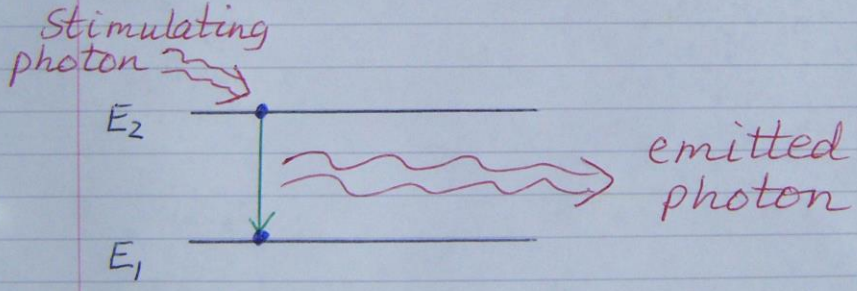
$\Rightarrow$ Energy is given off in the form of a photon of light.

If an electron is raised to an energy level that is unstable then it will immediately fall back down to a lower energy level with a photon of light given off.

Real life situation

A family move from a house that they have lived in for a number of years into a bigger house in a more expensive area.
After a short period of time they realise that they cannot afford to continue living in the more expensive house.
They then sell the more expensive house and move back to a house similar in price to the one that they left originally.

Stimulated Emission



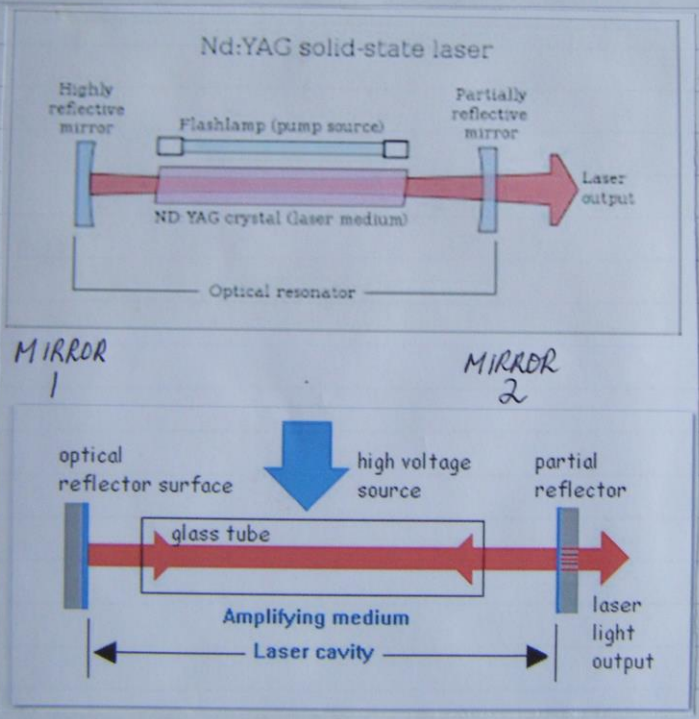
When an electron in a relatively stable energy level is encouraged or stimulated to a lower energy level then a photon of light will be emitted.

Real life situation

Son or daughter who has a house of their own encourage or stimulate their parents to sell the bigger

family home and downsize into a smaller home. The equity that the parents make off this transaction could be spent on treating themselves on holidays and taking away any money worries or other considerations.

Construction of a laser.



- MIRROR 1 → SILVERED MIRROR (100% REFLECTING)
- MIRROR 2 → HALF SILVERED MIRROR (<100% REFLECTING)
  - THINNER LAYER THAN MIRROR 1.

- The laser cavity consists of a light tight tube containing 'excited gas atoms'.
- Light is continually reflected back and forth between the two mirrors. This creates a rapidly increasing number of photons being produced.
- These photons stimulate the electrons in the gas atoms to fall to a lower energy level. In the process this emits a photon which is in phase, parallel and of the same frequency as the stimulating photon.
- The Irradiance of the laser beam is very high and this leaves the half-silvered mirror end of the laser for the application required.
- Laser beams do not spread out and remain highly irradiant and concentrated over a large distance.