Topic: Quantum Physics Date:

1) Photo Electric Effect

Define Electron Volt: (eV) : eV is an alternate unit of Energy, It is defined as amount of Kinetic Energy gain by an Electron if it accelerates from Rest through a potential Difference of 1 Volt.

How much KE is gained?

$$\text{Voltage} = \frac{\text{WD}}{\text{Charge}} \Rightarrow V = \frac{KE}{Q} \Rightarrow 1 = \frac{KE}{1.6\times10^{-19}}$$

$$KE = 1.6\times10^{-19}\ J \Rightarrow 1\ eV$$

For Exams
$1\ eV = 1.6\times10^{-19}\ J$

b) Energy of a Photon :- Electromagnetic Radiations are believed to be consisting of photons. A photon is defined as a packet of Electromagnetic Radiation or a Quantum of Electromagnetic Radiation posesing a fixed amount of Energy. this Energy of a photon can be obtained using the Formula :

$E = hf$

E = Energy
f = frequency of EM Radiation
h : Plank's constant $h = 6.63\times10^{-34}\ Js$

$E = h\left(\frac{c}{\lambda}\right)$

Since
$v = f\lambda$
$c = f\lambda$
$\frac{c}{\lambda} = f$
$c = 3.0\times10^{8}\ m/s$

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High freq

VJBGYOR → low freq

Violet light have more freq hence photon have more Energy

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Calculate the Energy of a Photon which belongs to ultra violet radiation of wavelength $\lambda = 300nm$

$$E = h.\frac{c}{\lambda} \Rightarrow \frac{(6.63\times10^{-34})(3\times10^{8})}{300\times10^{-9}}$$

$E = 6.63\times10^{-19} J$

$1eV = 1.6\times10^{-19} J$

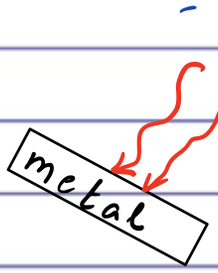
OR

$E = 4.4 eV$

⇒ Einstein's Equation of Photo Electric Emission.

⇒ Photo electric Emission Refers to emission of Electrons when the surface of the metal is Exposed to light./EMR

Thermionic Emission: emission of e^- from the surface of metal by supplying heat Energy.



Energy of a Photon

$E = hf$

bring its Electron to the surface of the metal.

Work function Energy.

$\phi = h f_o$

KE of the Electrons so that can be Eliminated from the surface.

f_o = Threshold freq [defined as the minimum frequency to bring Electron

to the surface)

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$hf = \phi + K\mathcal{E}$

- hf: Energy
- ϕ: Bringing to surface
- $K\mathcal{E}$: Kinetic Energy.

f = incident freq of EMF

f_0 = Threshold frequency (min freq to bring Electron to the surface)

$$hf = hf_0 + K\mathcal{E}$$

Question)

Sodium ϕ = 1.6 eV

Magnesium ϕ = 2.8 eV

Calcium ϕ = 3.65 eV

λ (Red) = 700 nm

Which Combination will allow Photo Electric Emission to occur.

$$E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{700 \times 10^{-9}} = 2.88 \times 10^{-19} \text{ J}$$

$$\mathcal{E} = 1.77 \text{ eV}$$

⇒ Only PEE will occur for Sodium.

→ With Red light Photo Electric Emission only take Place with sodium.

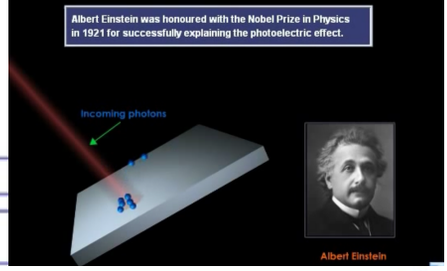

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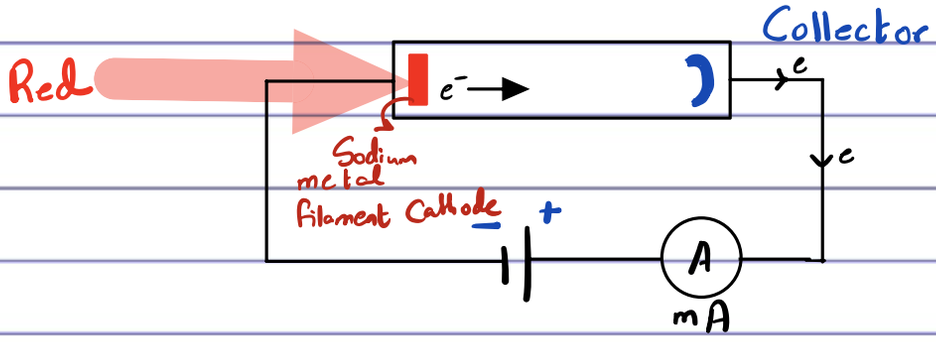
Photo cell



⇒ if current recorded then Emission occurs.

This is How Photo Electric Emission is demonstrated.

Sodium ϕ = 1.6 eV

Magnesium ϕ = 2.8 eV

Calcium ϕ = 3.65 eV

λ (Violet) = 350 nm

Which Combination will allow Photo Electric Emission to occur.

$$E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{350 \times 10^{-9}} = 5.76 \times 10^{-19}$$

$$E = 3.54\,E_v$$

⇒ Only PEE will occur for Sodium.

→ With Violet light Photo Electric Emission only take Place with sodium and Magnisium

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Conclusion: Only Certain metals when Exposed to certain EMR can cause photo Electric Emission to occur.

Photo electric Emission Equation

$hf = \phi + KE$ or $hf = hf_0 + KE$

From previous working we have established.

if $f < f_0$ no emission

if $f = f_0$ no emission

if $f > f_0$ emission occurs

f = incident frequency

f_0 = threshold frequency.

Graph Construction.

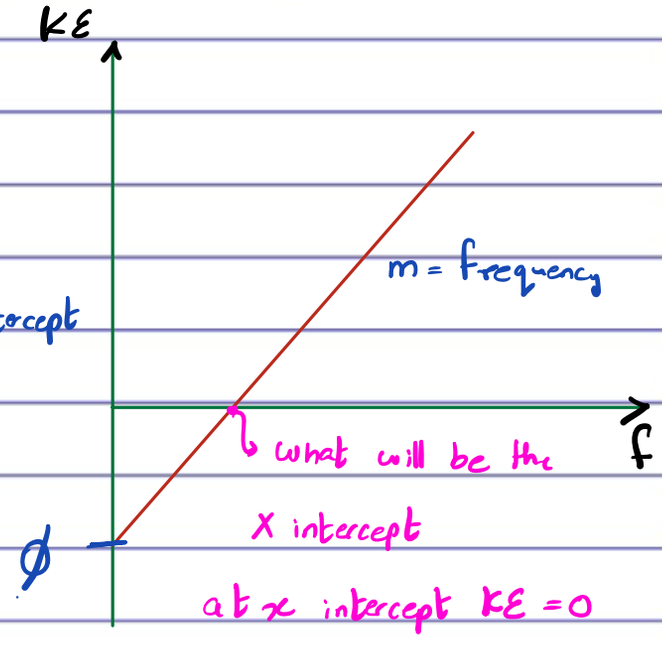
1) Graph of KE (y axis) against incident freq(f) on x axis

$hf = \phi + KE$

Rearrange $KE = hf - \phi$

$y = mx + c$

Straight line +ve gradient & -ve y intercept



$KE = 0$

$hf = \phi + KE$

$hf = \phi + 0$

$hf = hf_0$

$f = f_0$

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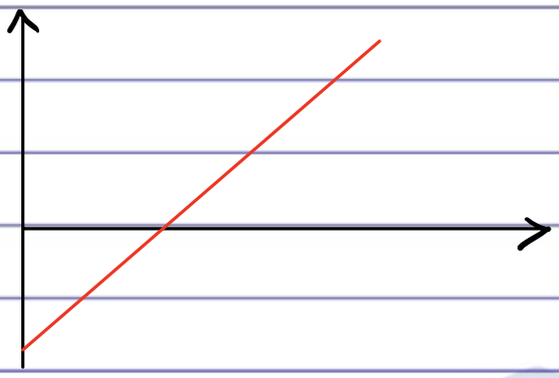
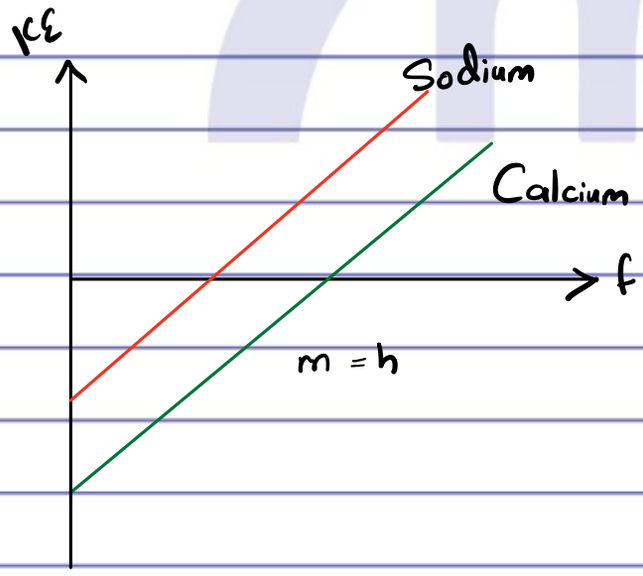
Example:

$\phi_{Na} = 1.5eV$



On the same axis construct a graph for calcium which has a higher work function than sodium.

ϕ higher ⟶ f_0 higher ie a higher x intercept new graph will remain Parallel but have a greater x intercept.



gradient gives h
since h is constant
graph remains parallel.

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Graph of $\frac{1}{\lambda}$ (y Axis) against KE (x axis)

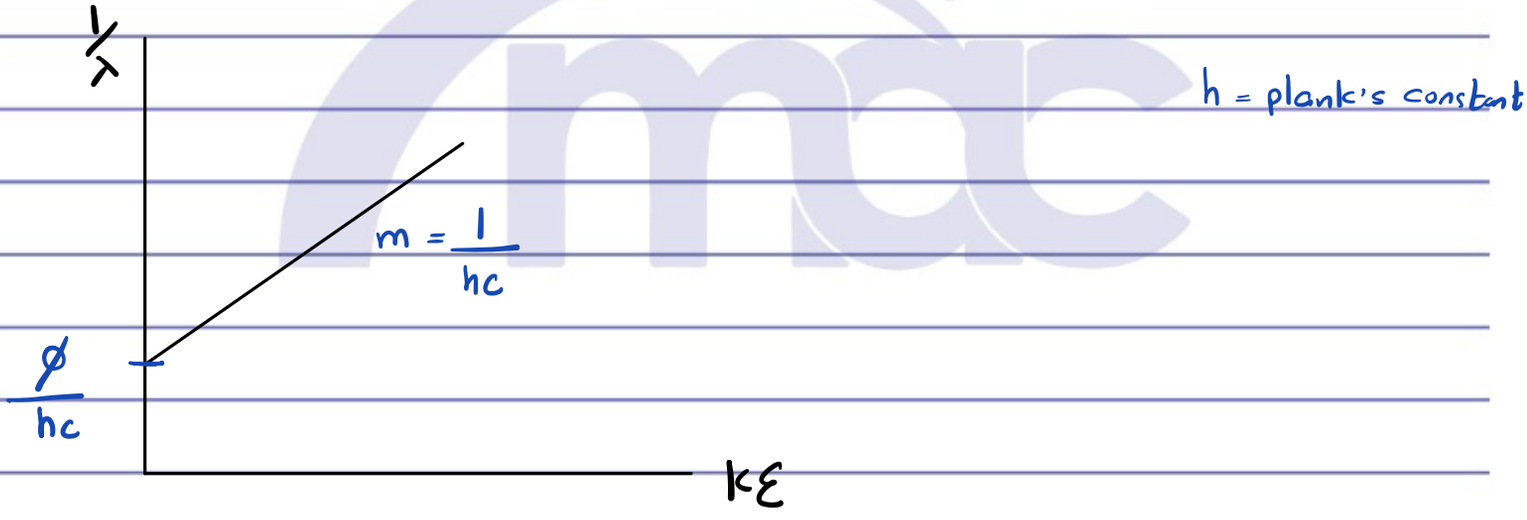
$$hf = \phi + KE$$

$$\frac{h \cdot c}{\lambda} = \phi + KE$$

$$\frac{1}{\lambda} = \frac{\phi}{hc} + \frac{KE}{hc}$$

$$\boxed{\frac{1}{\lambda} = \frac{1}{hc} KE + \frac{\phi}{hc}}$$

$$y = m x + c$$



h = plank's constant

⇒ +ve gradient and +ve y intercept.

Obtain a relationship b/w gradient and y intercept

Important.

grad = $\frac{1}{hc}$ y intercept = $\frac{\phi}{hc}$

y intercept = ϕ x gradient

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Theory :

Experimental Observations regarding photo Electric emission.

① The process of photo electric emission was observed to be an instantaneous process (i.e emission occured without any time delay)

② Emission only occured when incident frequency was greater then threshold frequency

③ When Electromagnetic Radiation of a higher frequency was used, Based on Equation $hf\uparrow = \phi + KE\uparrow$

Red → Violet

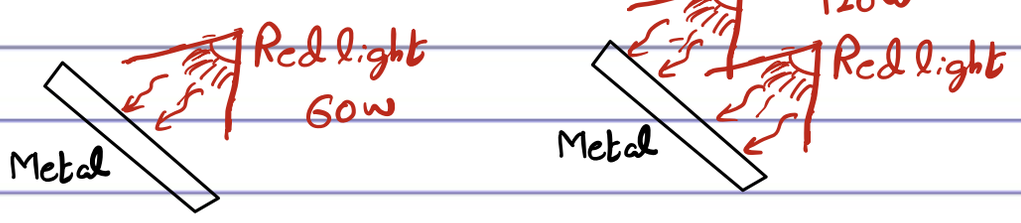
60w 60w

(ϕ Constant) (Constant for a given metal)

it was observed that the emitted electrons were emitted with a greater KE than Before. Hence we can say incident frequency affects the Kinetic Energy of the emitted Electrons.

④ If however freq was kept constant & insted intensity of light was increased than it was observed that photo Electric current also increases.

Explanation



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Intensity = Total Power falling on a metal surface per unit area {Unit = Wm^{-2}}

Intensity = $\frac{\text{Total Power}}{\text{Area}}$ $\quad E = hf \quad \frac{n_p hf}{t} \quad P = \frac{E}{t}$

$$I = \frac{(n_p) \times (hf)}{t \times A}$$

n_p = no of photons

hf = # of photons.

$$\boxed{I = \frac{n_p \cdot hf}{t\,A}}$$

hence if Intensity in increased keeping the frequency constant than it indicates that more no of photons will reach the metal surface in a given time. hence more electrons will be released

∴ We can say photo Electric current increases.

$$\uparrow I = \frac{\uparrow n_p \times hf}{t\,A}$$

$I\uparrow$; $n_p\uparrow$; $n_c\uparrow$

Current Increases.

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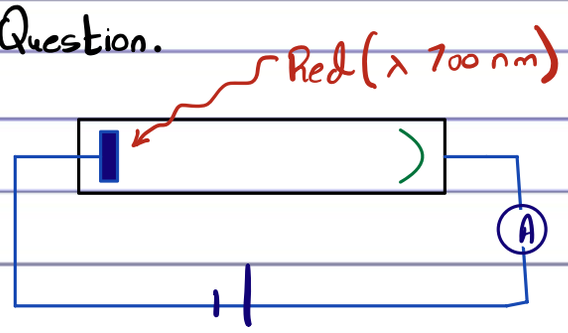
→ Example Question.



(i) determine weather emission occurs.?

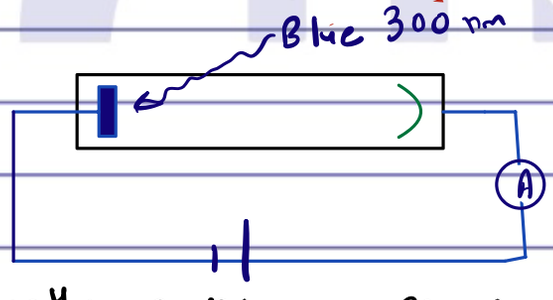
Energy of red light $E = hf$ or $\mathcal{E} = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34})(3\times10^{8})}{700\times10^{-9}}$

$\mathcal{E} = 2.84\times10^{-19}\,J$

$\mathcal{E} = 1.78\,eV$

no emission possible.

ii) Red light is replaced by blue light $\lambda = 300\,nm$



determine weather emission occurs.

$\mathcal{E} = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34})(3\times10^{8})}{300\times10^{-9}}$ $E = 6.63\times10^{-19}$

$\mathcal{E} = 4.14\,eV$

→ Emission will occur. as Energy of photon is greater than work function.

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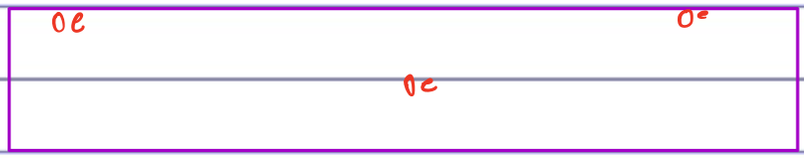
iii) Why the emitted Electrons will have a range of Kinetic Energy?



Not all free electrons are on the surface which electrons are embedded within the surface might have to use some of there energy to reach the surface before they can be emitted, hence they will be emitted with KE less than the maximum value.

iv) Calculate the kinetic Energy in eV / J in Joules for emitted Electrons.

$$hf = \phi + KE$$

$$4.14 = 3.3 + KE$$

$$4.14 - 3.3 = KE$$

$$\boxed{KE = 0.84 eV} \Leftrightarrow 1.34 \times 10^{-19} J$$

v) The battery terminals are now reversed calculate the stopping potential (vs) required?

↳ refers to the voltage of the battery applied in opposite direction which cause photo Electric current to become zero!

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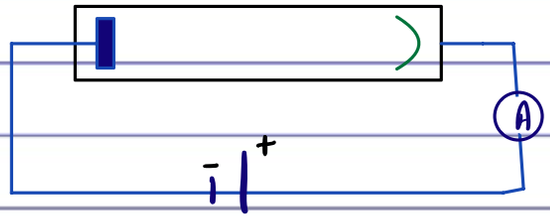

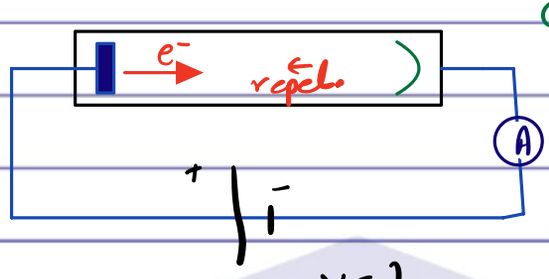

Collector became -ve.

V = ?

$$\text{Voltage} = \frac{\text{WD/ICE}}{\text{Charge}} \Rightarrow V_s = \frac{1.34 \times 10^{-19}}{1.6 \times 10^{-19}}$$

$$= \frac{0.84\ \text{eV}}{\text{e}} = 0.84\text{V}$$

$$V_s = 0.84\text{V}$$

$$\text{Voltage} = \frac{\text{KE}}{\text{Charge}}$$

OR

$$V_s = \frac{0.84\ \text{eV}}{\text{e}} = 0.84\text{V}$$

If 0.83 V are applied in reverse direction there will be no electron in the Ammeter.

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* What is the significance and importance of photo electric emission.

* Photo electric emission provides us with the evidence that Electromagnetic Radiations exhibit a "Dual Nature" i.e EMR exist as both wave aswell as particle.

Dual Nature of EM Radiation.

* It was initially believed that Electromagnetic radiations only had wave properties.

→ If wave nature was used to explain the phenomena of photo Electric Effect than any frequency (even less than f_0) if exposed for a sufficient amount of time would have eventually caused photo-electric Emission to occur. This however was not the case and the fact that, the process was observed to be instantaneous and that it only occured when incident frequency was greater than fundimental frequency (f_0), provided evidence that Electromagnetic Radiation also exhibit particulate nature ie they also behave as particle & this lead to the term Wave particle duality. (Dual nature of Electromagnetic Radiations)

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i) Which phenomenon exhibits that EMR have wave properties

① As physics :- Interference, Diffraction, Superposition.

ii) Which phenomena exhibits that EMR have particle like properties

② EMR have Particle-like properties Photo-electric effect

⇒ Dual Nature of Electrons.

It was initially believed that electron only behave as particles i.e they had a particulate nature, however it was later on established that electron also exhibits wave like properties. hence term Wave particle Duality. is also applicable for electrons.
This nature of electrons can be verified by allowing electrons to strike a fluorescent screen.
Bright spots of light are observed to be uniformly distributed on the screen
This implies that KE of electrons is converted to light energy as e^- strike the fluorescent screen.
Since $\left(KE = \frac{1}{2}mv^2\right)$ it is associated with mass this confirmed the particle nature of electrons.
The wave nature can be established by making electrons undergo diffraction (i.e electron diffraction)

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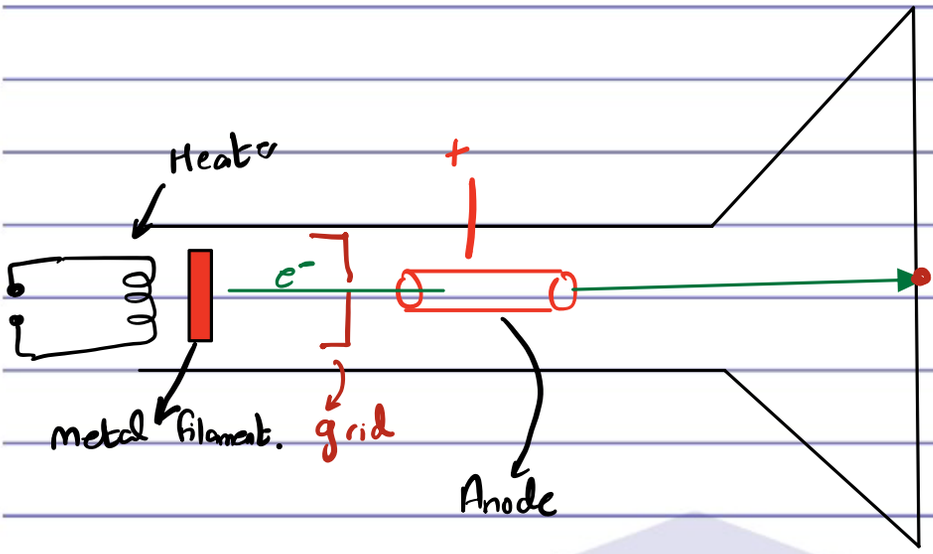
How to confirm Particle like properties.



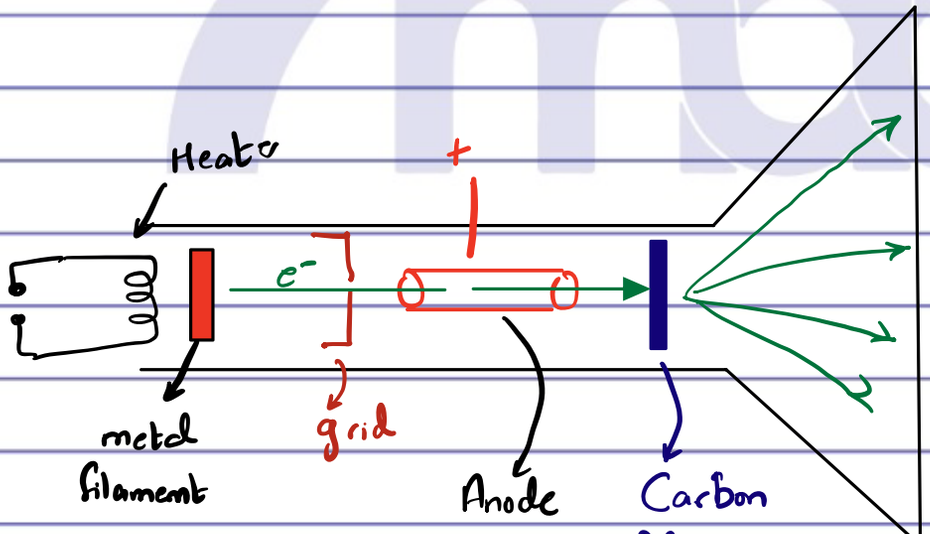
ICE → Light

Bright spots are observed.

grid = to focus electron in a beam

Anode = to speed up the electrons.

How to confirm wave nature of electrons.



Electrons will spread out diffract as they pass through the carbon film. Diffraction is a property associated with waves ∴ electron diffraction exhibits the wave nature of Electrons.

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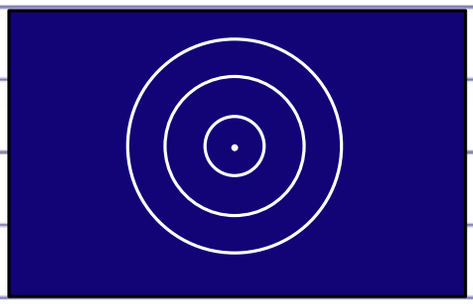
Front View of Screen



Concentric circle are observed on the screen

Reason: Electrons diffract in all direction in all planes. Concentric circles are observed on screen.

Once the dual nature of electrons was established

Scientist De-Broglie tried to obtain a relationship between wave length (λ) of electron and its momentum (p) this was known as De-Broglie's wavelength.

$$\lambda = \frac{h}{p} \Rightarrow \lambda = \frac{h}{mv}$$

λ = wavelength

h = Plank's constant

p = momentum

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Show that wavelength (λ) is associated with the electron when accelerates from rest through a potential difference "V" is given by the equation

$$\lambda = \frac{h}{\sqrt{2mqV}}$$

λ = wavelength

q = charge

V = P.D

m = mass

$$V = \frac{WD}{charge}$$

$$V = \frac{\frac{1}{2}mv^2}{q}$$

$$v = \sqrt{\frac{2qV}{m}}$$

Use De broglie's equation

$$\lambda = \frac{h}{p} \quad \text{or} \quad \lambda = \frac{h}{mv}$$

$$\lambda = \frac{h}{m\left(\sqrt{\frac{2qV}{m}}\right)}$$

$$\lambda = \frac{h}{\sqrt{2qmV}}$$

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(2) Hence calculate the wavelength (λ) associated with an electron if it accelerate from rest to a potential difference of 400V ?

From the above derivation we arrived at the result

$$\lambda = \frac{h}{\sqrt{2mqV}}$$

$m = 9.11 \times 10^{-31}$

$q = 1.6 \times 10^{-19}$

$V = 400V$

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

replace to get (λ)

$$\lambda = 6.1 \times 10^{-11} m$$

Show that the wavelength (λ) associated with an electron is related to its KE(E) according to the equation

$$\lambda = \frac{h}{\sqrt{2mE}}$$

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

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

$$v = \sqrt{\frac{2E}{m}}$$

De Broglie's Equation

$$\lambda = \frac{h}{p} \quad \text{or} \quad \lambda = \frac{h}{mv}$$

$$\lambda = \frac{h}{m\left(\sqrt{\frac{2E}{m}}\right)} \Rightarrow \lambda = \frac{h}{\sqrt{2mE}}$$

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A proton & an Electron accelerates from rest through the same potential difference of V volts

find ratio of

$$\frac{\lambda \text{ associated with electron}}{\lambda \text{ associated with proton.}}$$

$$\lambda = \frac{h}{\sqrt{2 m q V}}$$

$$\lambda_e = \frac{h}{2\sqrt{m_e q_e V}}$$

$$\lambda_p = \frac{h}{2\sqrt{m_p q_p V}}$$

$$\frac{\lambda_e}{\lambda_p} = \frac{\sqrt{m_p}}{\sqrt{m_e}}$$

$$= \frac{\sqrt{1.67 \times 10^{-27}}}{\sqrt{9.11 \times 10^{-31}}}$$

$$\frac{\lambda_e}{\lambda_p} = \frac{43}{1}$$

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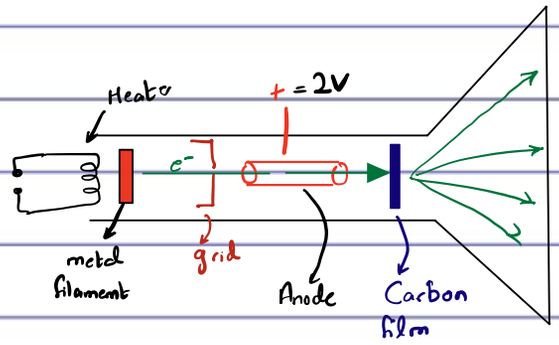
5) An Electron accelerates through a p.diff (V) and undergoes diffraction after passing through the carbon film as shown



Suggest and Explain what changes in the appearance of the screen is expected if potential difference accelerating the electron is increased (i.e for eg to 2V)

⇒ According to the formula Voltage = $\frac{\frac{1}{2}mv^2}{q}$ as PD increases the electron will achieve a higher speed.

⇒ According to De-Broglies equation $\lambda = \frac{h}{mv}$, as speed increases the wavelength associated with electrons will decrease

$\downarrow \lambda = \frac{h}{mv\uparrow}$

Based on formula (AS level) $d\sin\theta = n\lambda$ as wavelength decreases angle of diffraction also decreases hence concentric circles will now move closer together.

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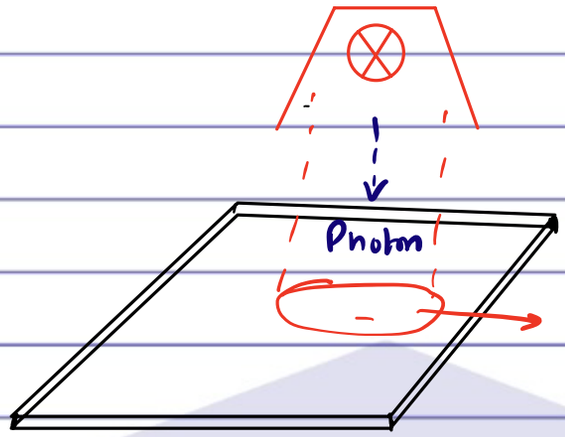
⇒ Concept of Photon Pressure.

Power = 2.7mW



$\lambda = 560\,nm$

Area $= 1.6 \times 10^{-5}\,m$

i) Calculate the energy of photon

$$\mathcal{E} = hf \quad \text{or} \quad \mathcal{E} = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34})(3\times10^{8})}{560\times10^{-9}} = 3.6\times10^{-19}\,J$$

ii) Calculate # of photons reaching the metal surface per unit time. (i.e 1 second)

N_p = No of photons.

$$\text{Power} = \frac{\text{Total Energy}}{\text{time}} \qquad P = \frac{N_p \times \frac{hc}{\lambda}}{t}$$

$$2.7\times10^{-3} = \frac{N_p\times(3.6\times10^{-19})}{t}$$

$$\boxed{N_p = 7.5\times10^{15}}$$

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Calculate momentum of Each photon.

De Broglie's $\lambda = \frac{h}{p}$

$$560 \times 10^{-9} = \frac{6.63 \times 10^{-34}}{p}$$

$$p = \boxed{1.2 \times 10^{-27} \text{ Ns}}$$

iv) Total momentum of all photons arriving per unit time.

$= N_p \times p$

$= 7.5 \times 10^{15} \times 1.2 \times 10^{-27} \Rightarrow$

Total momentum per unit time = force $= 8.9 \times 10^{-12}$ N

Assuming all photons are absorbed calculate the force

$\therefore F = 8.9 \times 10^{-12}$ N $\qquad F = \frac{\Delta p}{t}$

$\Rightarrow$ Hence calculate Photon Pressure

$$\text{Photon pressure} = \frac{F}{A} = \frac{8.9 \times 10^{-12}}{1.6 \times 10^{-5}} = \boxed{5.6 \times 10^{-7} \text{ Pa}}$$

Topic: Energy levels in atoms. Date:

1) Energy level in an atom.

It is believed that electron only orbits in certain allowed discrete orbits.

- These orbits are called Energy levels.
- The Electron normally occupies the lowest energy level available & is said to be in its ground state. where it has the least amount of Energy. In this manner, the electron is in its most stable state.
- If this electron absorbs sufficient energy (from the bombardment of the incoming photon), than this electron may be boosted to one of its many othe higher Energy levels & if this transition happens this electron is said to be in an excited state & the energy absorbed by this electron to Jump from this ground state to an higher energy level is known as excitation Energy.

⇒ Sometimes an electron may recieve sufficient Energy which enables it to escape completely from attractive forces of nucleus. When this occurs atom is said to be ionized & this Energy is termed as ionization Energy.

* The Energy level of the atom can be constructed as discrete Horizontal lines shown below.
* The Energy content of these energy levels is measured either in Joules or in Electron Volt (eV)

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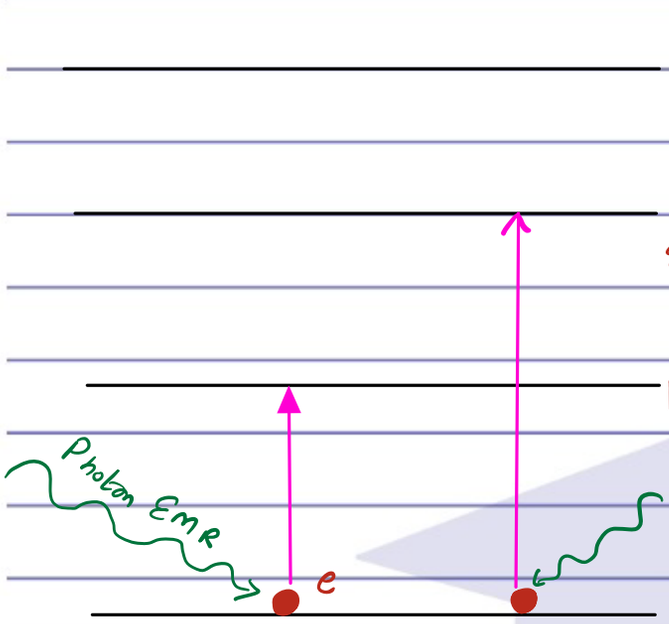
Diagramatic Representation of Energy level in an atom.



Fourth Exitation state. $E_5 = -0.54eV$

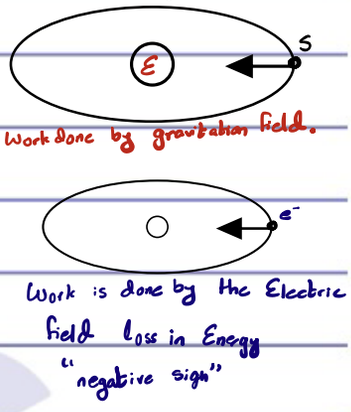
Third Excitation State. $E_4 = -0.85eV$

Second Excitation state. $E_3 = -1.5eV$

First Excitation state $E_2 = -3.4eV$

Ground state $E_1 = -13.6eV$

Why are Energies in Negative



i) Calculate the λ of the EMR that can cause an Electron to transit from E_1 to E_2 ?

ΔE = change in Energy

$$\Delta E = hf \quad \text{or} \quad \Delta E = h\frac{c}{\lambda}$$

$$E_2 - E_1 = h \cdot \frac{c}{\lambda}$$

$$[-3.4 - (-13.6)]\ eV = \frac{(6.63\times10^{-34})(3\times10^{8})}{\lambda}$$

$$10.2\times1.6\times10^{-19} = \frac{(6.63\times10^{-34})(3\times10^{8})}{\lambda} \Rightarrow \boxed{\lambda = 122\ nm}$$

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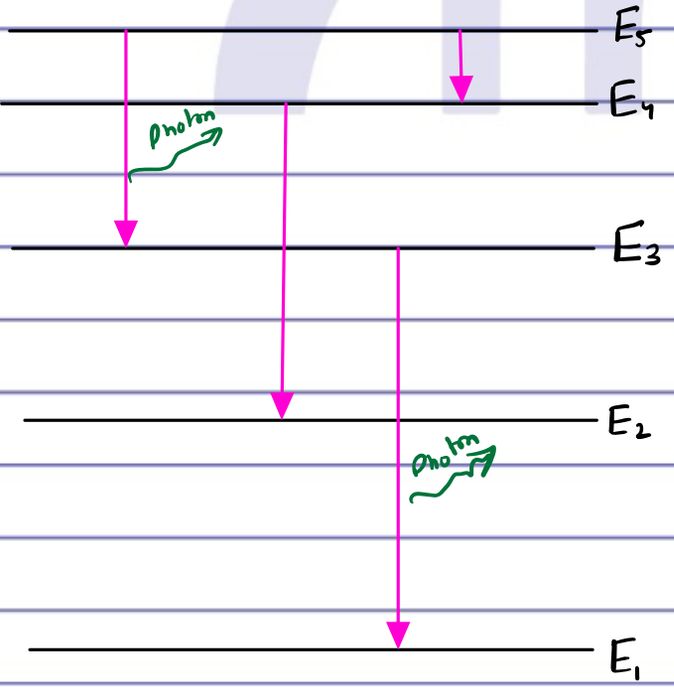
Calculate the λ of the incoming EMR that can cause an Electron to transit from E_1 to E_3?

$$\Delta E = \frac{h \cdot c}{\lambda}$$

$$E_3 - E_1 = \frac{hc}{\lambda}$$

→ All the vertical arrows pointing upwards represents gain of Energy by an e^- causing Excitation. These lines are termed as **Absorption Spectral lines.**

(3)



* When Electron reaches a higher Energy level it is considered to be unstable ∴ it will eventally shift/drop down into a lower energy level & in doing so, it will emit EMR, hence Vertical lines in the downward direction indicates de exitation of Electrons and are classified as **Emission Spectral lines.**

Topic: _____ Date: _____

Conclusion: Since only certain wavelength / frequency are absorbed/ Emitted ∴ this provides evidence that Electron Exist in fixed Energy levels, hence each atom/element will have a unique discrete emission spectra/ absorbtion spectra.

Q) Suggest Why existance of Spectral lines provides evidence for the existence of discrete Energy levels in an atom (3 Marks)

Ans) Each Spectral line corelates to a fixed energy change b/w any 2 energy levels

- Based on $\Delta E = \frac{hc}{\lambda}$ each energy level correspond to a unique wavelength.
- Since only certain wavelength are absorbed / emitted this indicates atoms have discrete Energy levels.

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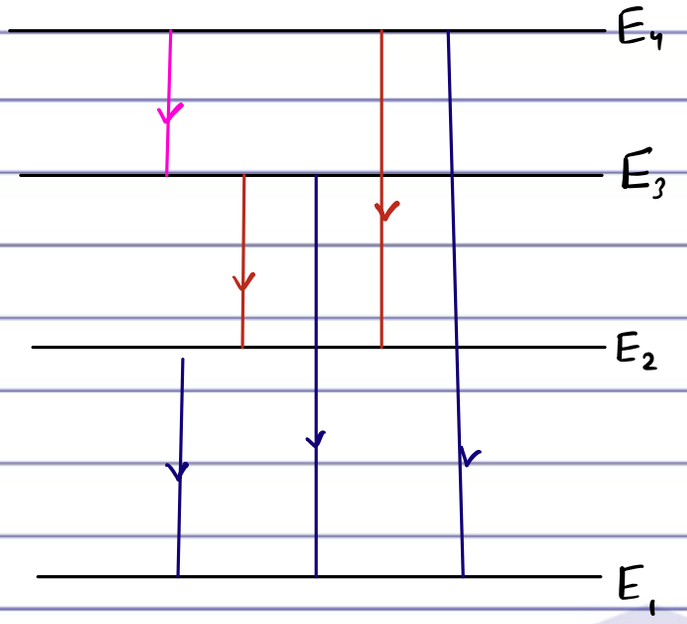


Suggest the maximum possible # of emission spectral lines that can be formed due to Electron transmiting b/w the given energy levels?

Total of 6

$E_4 \rightarrow E_1$ $E_3 \rightarrow E_2$ $E_4 \rightarrow E_3$

$E_3 \rightarrow E_1$ $E_4 \rightarrow E_2$

$E_2 \rightarrow E_1$

Permutation and Combination

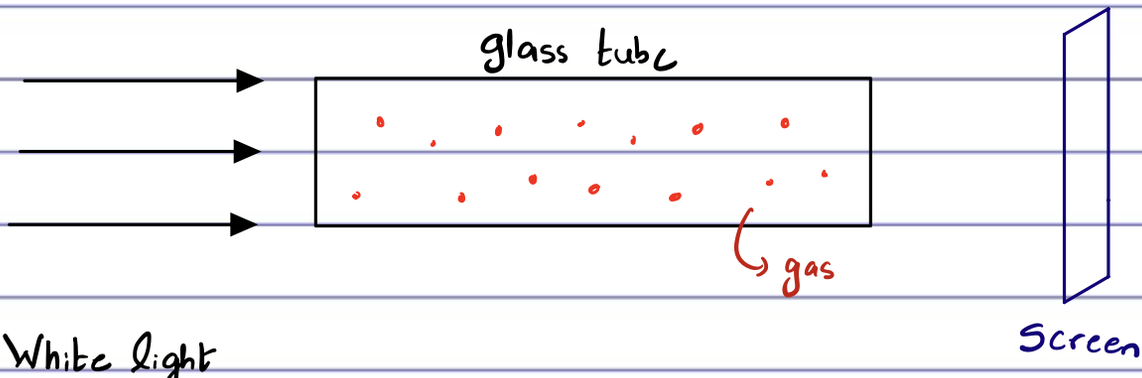
$4C_2 = 6$ ways.

6 unique wavelengths can be emitted if e^- in this atom is allowed to form all transitions.

Explination.

Topic: _____ Date: _____

How can we Experimentally decide which wavelength are going to be absorbed/Emitted by a perticular atom.



White light

Violet → Red

λ=400nm → 700nm

What will be appearence on the screen.

Those wavelength which will not cause any excitation will pass right through the tube & will reach the screen

Whereas.

The wavelength which are going to be absorbed by the gas, will not emerge out from the other side with full intensity.

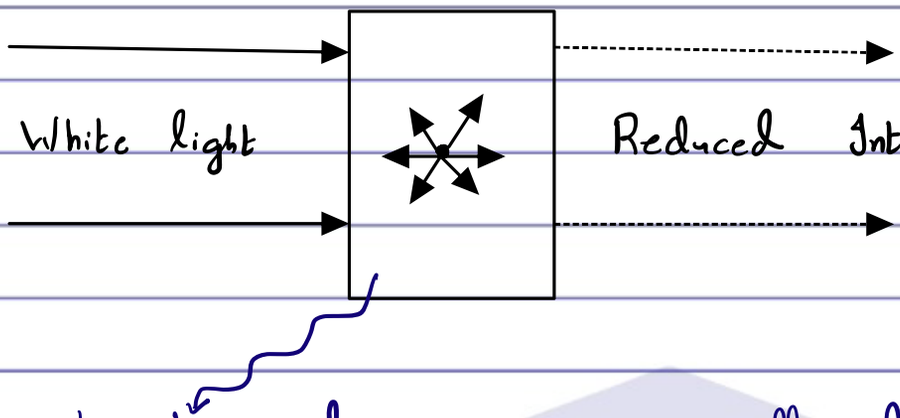
Observations.

Screen → High Intensity

Screen → low Intensity (Zero Intensity) (Dark lines)

Topic: Actual Experiment: Date:

⇒ Experiment to determine absorption spectrum for any gas.



⇒ absorption and reemission in all directions for certain wavelengths.

The absorption spectrum of Hydrogen is produced when white light passes through a tube filled with H_2 gas. Fig 1, If the light that passed through the Hydrogen gas is observed, certain positions of the continuos spectrum of white light are observed to be dark lines. This is the absorbtion spectrum of Hydrogen.

The position of the dark lines coincides exactly with the emission spectrum of hydrogen. The existance of these dark lines is due to photons of certain frequencies/wavelength in the incident light being absorbed by Hydrogen atom. The photons observed are those which have the same frequencies/wavelengths whose Energy corresponds to the Energy difference b/w any two energy levels

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i.e Energy of incoming Photon is observed to raise the electron to a higher level, when the excited Electron returns to its orignal Energy level, the difference in energy is radiated in all directions. Since the component of Intensity of this emitted light in the orignal direction of incidence of white light is only a small fraction of that emitted, light of this wavelength has a lower intensity compared to those wavelengths which are not absorbed. Hence the re emitted light of definate wavelength are seen only as dark lines/low intensity lines against the continuous spectrum of white light.

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