Chapter
25

Electron, Photon, Photoelectric Effect and X-rays

Electric Discharge Through Gases

At normal atmospheric pressure, the gases are poor conductor of electricity. If we establish a potential difference (of the order of 30 *kV*) between two electrodes placed in air at a distance of few *cm* from each other, electric conduction starts in the form of sparks.

The discharge of electricity through gases can be systematically studied with the help of discharge tube shown below

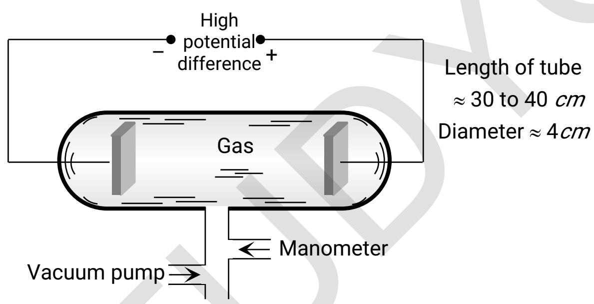

Fig. 25.1

As the pressure inside the discharge tube is gradually reduced, the following is the sequence of phenomenon that are observed.

(1) At normal pressure no discharge takes place.

(2) At the pressure 10 *mm* of *Hg*, a zig-zag thin red spark runs from one electrode to other and cracking sound is heard.

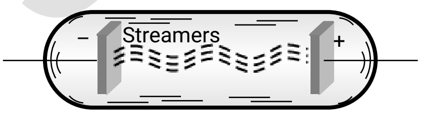

Fig. 25.2

(3) At the pressure 4 *mm.* of *Hg*, an illumination is observed at the electrodes and the rest of the tube appears dark. This type of discharge is called dark discharge.

(4) When the pressure falls below 4 *mm* of *Hg* then the whole tube is filled with bright light called positive column and colour of light depends upon the nature of gas in the tube as shown in the following table.

Table 25.1 : Colour for different gases

Gas	Air	H_2	N_2	Cl_2	CO_2	Neon
Colour	Purple red	Blue	Red	Green	Bluish white	Dark red

(5) At a pressure of 1.65 *mm* of *Hg* :

Sky colour light is produced at the cathode it is called as negative glow. Positive column shrinks towards the anode and the dark space between positive column and negative glow is called Faradays dark space (*FDS*).

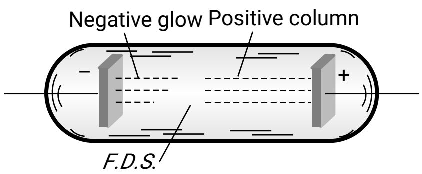

Fig. 25.3

(6) At a pressure of 0.8 *mm Hg* : At this pressure, negative glow is detached from the cathode and moves towards the anode. The dark space created between cathode and negative glow is called as Crook's dark space. Length of positive column further reduced. A glow appear at cathode called cathode glow.

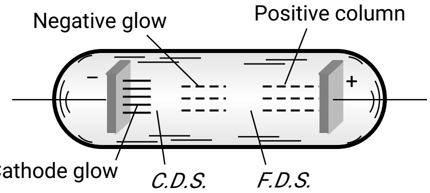

Fig. 25.4

(7) At a pressure of 0.05 *mm* of *Hg* : The positive column splits into dark and bright disc of light called striations.

(8) At the pressure of 0.01 or 10^{-2} *mm* of *Hg* some invisible

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particles move from cathode whic
tube on the opposite side of cath
These invisible rays emerging fr
rays.

(9) Finally when pressure 10^{-4} mm of Hg, p
there is no discharge in tube.

Cathode Rays

(1) Cathode rays, discovered by

(2) They are streams of fast mov

(3) They can be produced by us
containing gas at a low pressure 10^{-2} mm of Hg. o

(4) The cathode rays in the disc
produced due to ionisation of gas
due to collision of positive ions.

(5) Cathode rays travel in strai

(6) Cathode rays are emitted n
surface. Their direction is inde
anode.

(7) Cathode rays exert mechanic
strike.

(8) Cathode rays produce heat v
surface.

(9) Cathode rays produce fluore

(10) When cathode rays strike
metal of high atomic weight X-rays hi
emitted from the objects.

(11) Cathode rays are deflected
by a magnetic field.

(12) Cathode rays ionise the ga
passed.

(13) Cathode rays can penetrate

(14) Cathode rays are found $\frac{1}{30}$ th
to $\frac{1}{10}$ th of velocity of light.

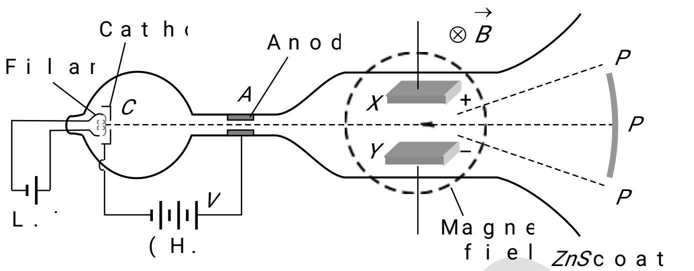
J. J. Thomson's Experiment

(1) It's working is based on th
electron is subjected to the cro $\vec{E}$
magnetic field $\vec{B}$, it experiences
case the forces on the electrons
these fields are equal and oppo
undeflected.

(2) When no field is applied, t
illuminations at point P

(3) In the presence of any fiel
electron beam deflected up P' or down P''

(4) If both the fields are app
adjusted such that electron bea
produces illumination at point P.



In this case; Electric force eE = evB = Magn

Fig. 2

$\Rightarrow v = \frac{E}{B}$; v = velocity of electron

(5) As electron beam accelerated f
loss in potential energy appears as g
If suppose V the potential difference
anode then, loss in potential energy eV

And gain in kinetic energy at anode $= \frac{1}{2}mv^2$

i.e. $eV = \frac{1}{2}mv^2 \Rightarrow \frac{e}{m} = \frac{v^2}{2V} \Rightarrow \frac{e}{m} = \frac{E^2}{2VB^2}$

Thomson found $\frac{e}{m} = 1.77 \times 10^{11}\ C/kg$.

If one includes the relativistic v
$(m = m_0 / \sqrt{1 - v^2/c^2})$, then specific charge o
decreases with the increase in its ve

(6) The deflection of an electron i
given by $y = \frac{1}{2}\left(\frac{eE}{m}\right)\frac{l^2}{v^2}$; where l = length of each pl
deflection of electron in the field; v = speed of
electron.

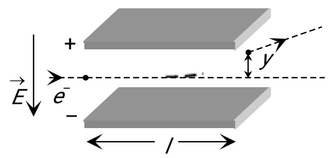


Fig. 2

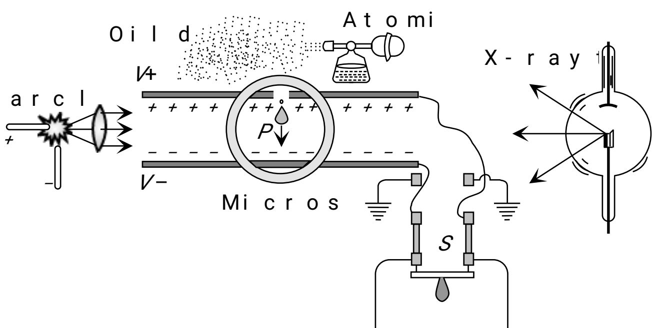
Millikans Oil Drop Experiment

(1) Millikan performed the pionee
for the precise measurement of the ch

(2) By applying suitable electri
plates, the charged oil droplets cou
even held stationary in the field o
time. He found that the charge on an o
integral multiple of an elementary c $1.6 \times 10^{-19}\ C$

(3) In this experiment charge on th

$$q = \frac{6\pi\eta(v_1 + v_2)d}{v}\left[\frac{9\eta v_1}{2g(\rho - \sigma)}\right]^{1/2}$$



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where η = Coefficient of viscosity, v_1 = Terminal velocity of drop when no electric ... plates, v_2 = Terminal velocity of drop ... applied between the plates.

V = Potential difference bet... Separation between plates, ρ = density of oil, σ = Density ...

Positive Rays

When potential difference is a... of a discharge tube at (10^{-3} mm of Hg), electrons are ... the perforated cathode. As they m... energy. These energetic electron... of the gas in the discharge tube, ... positive ions so formed at variou... anode, travel towards the cathod... the positive ions when reach the ... the holes in the cathode and a fai... from each hole on the backside of ... positive rays, which are coming ou...

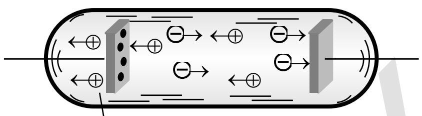


Fig. 2

(1) Positive rays are positive ... experimental gas does not have is... has isotopes then positive rays ar... different masses.

(2) They travel in straight line ... placed in their path. But the spee... smaller than that of cathode rays.

(3) They are deflected by elect... the deflections are small as compa...

(4) They show a spectrum of vel... ions move with different velociti... much less than that of cathode ray...

(5) q/m ratio of these rays depend... gas in the tube (while in case of q/m is ... constant and doesn't depend on th... q/m for hydrogen is maximum.

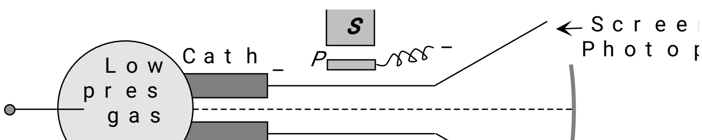
(6) They carry energy and moment... positive rays is more than that of ...

(7) The value of charge on posi... multiple of electronic charge.

(8) They cause ionisation (whi... produced by cathode rays).

Thomson's Mass Spectrograp...

It is used to measure atomic mas... gas. This is done by measuring q/m of singly ionised ... ion of the gas.



(1) The positive ions are produce... hand side. These ions are accelerate... of the positive ions pass through th... This fine ray of positive ions is sub... E and magnetic field B and then allowed to strike a ... ($\vec{E} \parallel \vec{B}$ but $\perp \vec{v}$).

(2) If the initial motion of the io... $+x$ electric and magnetic fields are ap... $+y$ force due to electric field is and due... magnetic field is along z-direction.

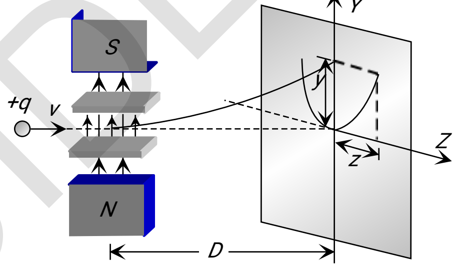


Fig. 2

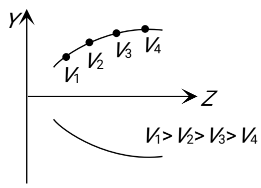
The deflection due to electr... $y = \frac{qELD}{mv^2}$ ..... (i)

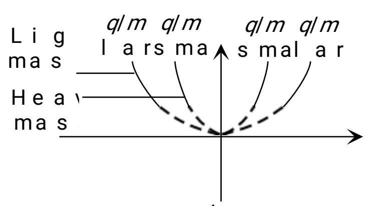
The deflection due to magnetic f... $z = \frac{qBLD}{mv}$ ..... (ii)

From equation (i) and (ii), $z^2 = k\left(\frac{q}{m}\right)y$

where $k = \frac{B^2LD}{E}$; This is the equation o... means all the charged particles movi... but of same q/m value will strike the screen ... on a parabolic track as shown in the a...

(3) All the positive ions of same q/m moving with different ... velocity lie on the same parabola. Hi... the value of y and z. The ions of different spec... on different parabola.





(A Fig. 25 (B

(4) The number of parabola tells t... present in the given ionic beam.

Bainbridge Mass Spectrograph

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In Bainbridge mass spectrogra
velocity are selected by using a v
are subjected to a uniform magnet
velocity of the particles. The par
isotopes follow different circul

(1) **Velocity selector :** The positive ions h
velocity is isolated from all other
chamber the electric and magneti
the particle moves undeflected. F
is $v = \frac{E}{B}$ and E, B and v should be mutually p
each other.

(2) **Analysing chamber :** In this chamber magnetic field B' is
applied perpendicular to the dir
As a result the particles move alo

$$r = \frac{mE}{qBB'} \Rightarrow \frac{q}{m} = \frac{E}{BB'r} \quad \text{also} \quad \frac{r_1}{r_2} = \frac{m_1}{m_2}$$

In this way the particles of diff
circles of different radii and rea
plate.

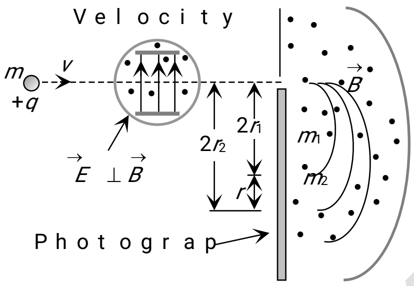


Fig. 2

Separation between two traces
$= d = 2r_2 - 2r_1 = \frac{2v(m_2 - m_1)}{qB'}$.

Matter Waves (de-Broglie Wa

According to de-Broglie a mo
sometimes acts as a wave and somet
The wave associated with movin
wave or de-Broglie wave and it pro
packets with group velocity.

(1) **de-Broglie wavelength :** According to de-B
the wavelength of de-Broglie wave

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{h}{\sqrt{2mE}} \Rightarrow \lambda \propto \frac{1}{p} \propto \frac{1}{v} \propto \frac{1}{\sqrt{E}}$$

Where h = Plank's constant, m = Mass of the particle, v =
Speed of the particle, E = Energy of the particl

The smallest wavelength whose
is that of γ-rays.

The wavelength of matter wave
microscopic particles like electron, p
particles is of the order of 10^{-10} m

(2) **de-Broglie wavelength asso
particles :** The energy of a charged parti
potential difference V is $E = \frac{1}{2}mv^2 = qV$

Hence de-Broglie wavelength $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mE}} = \frac{h}{\sqrt{2mqV}}$

$$\lambda_{Electron} = \frac{12.27}{\sqrt{V}}\,\text{Å}, \quad \lambda_{Proton} = \frac{0.286}{\sqrt{V}}\,\text{Å},$$

$$\lambda_{Deutron} = \frac{0.202}{\sqrt{V}}\,\text{Å}, \quad \lambda_{\alpha-particle} = \frac{0.101}{\sqrt{V}}\,\text{Å}$$

(3) **de-Broglie wavelength associa
particles :** For Neutron de-Broglie wavelength is

$$\lambda_{Neutron} = \frac{0.286 \times 10^{-10}}{\sqrt{E\,(\text{in } eV)}}\,m = \frac{0.286}{\sqrt{E\,(\text{in } eV)}}\,\text{Å}$$

Energy of thermal neutrons at ordi

$\because \quad E = kT \Rightarrow \lambda = \frac{h}{\sqrt{2mkT}}$; where T = Absolut
temperature, k = Boltzman's constant $= 1.38 \times 10^{-23}$ *Joule/kelvin*,
So,

$$\lambda_{Thermal\ \ neutron} = \frac{6.62 \times 10^{-34}}{\sqrt{2 \times 1.67 \times 10^{-27} \times 1.38 \times 10^{-23}\,T}} = \frac{30.83}{\sqrt{T}}\,\text{Å}$$

(4) **Ratio of wavelength of photon** The
wavelength of a photon of energy E is given by $\lambda_{ph} = \frac{hc}{E}$

While the wavelength of an electron of K is
given by $\lambda_e = \frac{h}{\sqrt{2mK}}$. Therefore, for the s

the ratio $\frac{\lambda_{ph}}{\lambda_e} = \frac{c}{E}\sqrt{2mK} = \sqrt{\frac{2mc^2K}{E^2}}$

Characteristics of Matter Wav

(1) Matter wave represents the pr
particle in space.

(2) Matter waves are not electroma

(3) de-Brogile or matter wave is i
on the material particle. It means,
wave is associated with every moving
or uncharged).

(4) Practical observation of matt
when the de-Broglie wavelength is of
particles.

(5) Electron microscope works on
waves.

(6) The phase velocity of the matt
than the speed of the light.

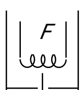
(7) Matter waves can propagate in v
not mechanical waves.

(8) The number of de-Broglie wave
orbital electron is n.

(9) Only those circular orbits a
stable whose circumference is int
Broglie wavelength associated with

Davision and Germer Experimen

(1) It is used to study the scatteri
or to verify the wave nature of elec



emitted by electron gun is made t
along cubical axis at Ni crystal ha
three dimensional diffraction gr
beam obtained from electron gun.

(2) The diffracted beam of ele
detector which can be positioned
about the point of incidence. The
electrons can also be varied by ch
the electron gun.

(3) According to classical phys
beam of electrons at all scatter
Davisson and Germer, found that
beam of electrons was not the sam
angles of scattering. It is maxim
54 *volt* potential difference.

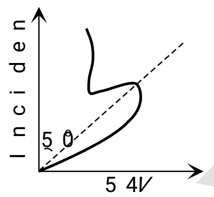


Fig. 25

(4) If the de-Broglie waves exi
should be diffracted as X-rays. Using the B
$2d\sin\theta = n\lambda$, we can determine the wavel

where *d* = distance between dif

$\theta = \frac{(180 - \phi)}{2}$ = glancing angle for incide

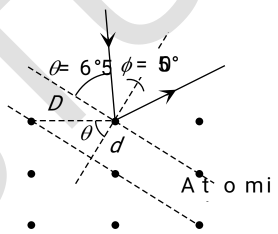


Fig. 25

The distance between diffracting planes in Ni crystal for this experiment is $d = 0.91\,Å$ and the Bragg's angle = 65°. This gives for $n = 1$, $\lambda = 2\times 0.91\times 10^{-10}\sin 65^{o} = 1.65\,Å$

Now the de-Broglie wavelength

using the formula $\lambda = \frac{12.27}{\sqrt{V}} = \frac{12.27}{\sqrt{54}} = 1.67\,Å$

Broglie hypothesis is verified.

(5) The Bragg's formula can be re
containing interatomic distance *D* and angle *φ*

$\because\ \theta = 90 - \frac{\phi}{2}$ and $d = D\cos\theta = D\sin\frac{\phi}{2}$

Using $\sin\theta = \cos\frac{\phi}{2}$

$2d\sin\theta = \lambda \Rightarrow 2(D\sin\frac{\phi}{2}).\cos\frac{\phi}{2} = \lambda \Rightarrow D\sin\phi = \lambda$

Heisenberg Uncertainty Princ

(1) According to Heisenberg's un
impossible to measure simultaneousl
momentum of the particle.

(2) Let Δx and Δp be the uncertainty in th
measurement of the position and mom
then $\Delta x\Delta p = \hbar$; where $\hbar = \frac{h}{2\pi}$ and $h = 6.63\times 10^{-34}\,J\text{-}s$ is
the Planck's constant ($\hbar = \frac{h}{2\pi} = 1.05\times 10^{-34}\,J\text{-}sec$)

A more rigorous treatment gives $\Delta x.\Delta p \ge \frac{\hbar}{2}\left(or\ \frac{h}{4\pi}\right)$

(3) If $\Delta x = 0$ then $\Delta p = \infty$ and if $\Delta p = 0$ then $\Delta x = \infty$

i.e., if we are able to measure the ex
particle (say an electron) then t
measurement of the linear momentum o
Similarly, if we are able to measure
of the particle *i.e.*, $\Delta p = 0$, then we can not measu
position of the particle at that time

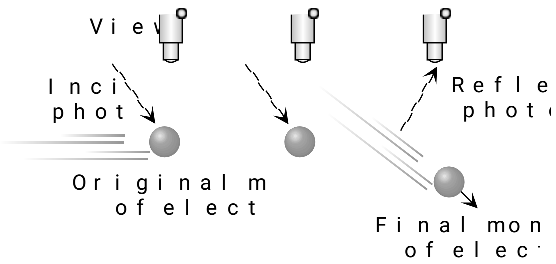


Fig. 2

An electron cannot be observed w
momentum

(4) Uncertainty principle success
(i) Non-existence of electrons in
(ii) Finite size of spectral lines

(5) The Heisenberg uncertainty pr
to energy and time, angular mome
displacement. Hence $\Delta E.\Delta t \ge \frac{h}{2\pi}$, $\Delta L.\Delta\theta \ge \frac{h}{2\pi}$ and

(6) If the radius of the nucleus is r then the probability of
finding the electron in the nucleus $\Delta x = 2r$ and the uncertainty
in momentum is $\Delta p = \frac{h}{4\pi r}$

Photon

According to Einstein's quant... the bundles (packets or quanta) c... called a photon and possessing ene...

(1) **Energy of photon :** Energy of photon is g...

$E = h\nu = \frac{hc}{\lambda}$; where c = Speed of light, h = Planck's constant $= 6.6 \times 10^{-34}$ J-sec, ν = Frequency in Hz, λ = Wavelength of light.

In electron volt $E(eV) = \frac{hc}{e\lambda} = \frac{12375}{\lambda(Å)} \approx \frac{12400}{\lambda(Å)}$

(2) **Mass of photon :** Actually rest mass o... zero. But it's effective mass is g...

$E = mc^2 = h\nu \Rightarrow m = \frac{E}{c^2} = \frac{h\nu}{c^2} = \frac{h}{c\lambda}$. This mass ... known as kinetic mass of the photo...

(3) **Momentum of the photon**

Momentum $p = m \times c = \frac{E}{c} = \frac{h\nu}{c} = \frac{h}{\lambda}$

(4) **Number of emitted photons :** The number of ... emitted per second from a source o... of wavelength λ and power P is given as $(n) = \frac{P}{E} = \frac{P}{h\nu} = \frac{P\lambda}{hc}$

where E = energy of each photon

(5) **Intensity of light (I) :** Energy crossing ... normally per second is called inte...

i.e. $I = \frac{E}{At} = \frac{P}{A}$ $\left(\frac{E}{t} = P = \text{radiation power}\right)$

At a distance r from a point source of power P intensity is given by $I = \frac{P}{4\pi r^2} \Rightarrow I \propto \frac{1}{r^2}$

(6) **Number of photons falling ... :** If P is ... power of radiation and E is the energy of a photon $n = \frac{P}{E}$

Photo-Electric Effect

The photo-electric effect is ... (called photo-electrons when lig... from the surface, the electron mu... the incident radiation to overcom... in the material of the surface.

The photoelectric effect was f... Hertz and it was investigated in d... Philipp Lenard.

The photoelectric effect is b... conservation of energy.

(1) **Work function (or threshold ... W_0):** The ... minimum energy of incident radia... electrons from metallic surface ... that surface.

$W_0 = h\nu_0 = \frac{hc}{\lambda_0}$ Joules ; ν_0 = Threshold frequ...

λ_0 = Threshold wavelength

Work function in electron volt $W_0(eV) = \frac{hc}{e\lambda_0} = \frac{12375}{\lambda_0(Å)}$

Table 25.2 : Work function of se...

Element	Work fun... (eV)	Element	Work fun... (eV)
Platinu...	6.4	Aluminu...	4.3
Gold	5.1	Silver	4.3
Nickel	5.1	Sodium	2.7
Carbon	5.0	Lithium	2.5
Silicon	4.8	Potassi...	2.2
Copper	4.7	Cesium	1.9

(2) **Threshold frequency (ν_0) :** The minimum freque... incident radiations required to ej... surface is defined as threshold freq...

If incident frequency $\nu < \nu_0 \Rightarrow$ No photoelectron em...

For most metals the threshold freq... (corresponding to wavelengths ... nm), but for potassium and cesium oxides λ it is between 400 nm and 700 ...

(3) **Threshold wavelength (λ_0) :** The maximum wavel... of incident radiations required to ... metallic surface is defined as thres...

If incident wavelength $\lambda > \lambda_0 \Rightarrow$ No photoelectron e...

(4) **Einstein's photoelectric equation :** Ei... photoelectric effect is the result o... between photon and electron in whic... absorbed

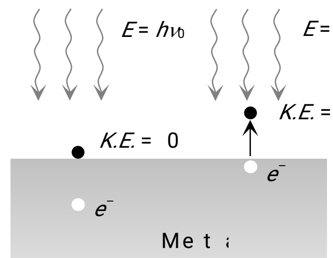


Fig. 25...

Einstein's photoelectric equation $E = W_0 + K_{max}$

where $K_{max} = \frac{1}{2}mv^2_{max}$ = maximum kinetic ... emitted electrons.

Experimental Setup for Photoe...

(1) Two conducting electrodes, the anode (Q) and the cathode (P) are enclosed in an evacuated glass...

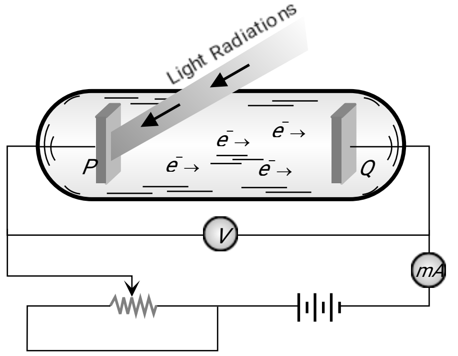


Fig. 25

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(2) The battery or other sourc creates an electric field in the d

(3) Light of certain wavelengt surface of cathode causes a curre photoelectric current.

(4) As potential difference in also increases till saturation is

(5) When polarity of battery is negative w.r.t. plate P electrons star towards the cathode.

(6) At a particular negative po will reach Q and the current will negative potential is called stopping potential. Maximum kinetic energy of photoel potential will therefore be $K_{max} = eV_0$

Effect of Intensity and Fre

(1) **Effect of intensity:** If the intensity of (while it's frequency is kept the higher value, showing that more e unit time. But the stopping potent V_0

Intensity of incident photon ∝ num photoelectron ∝ photocurrent

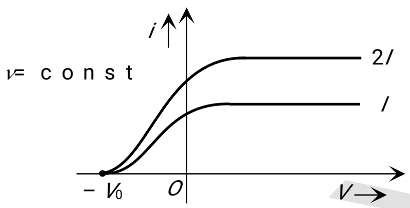

Fig. 23

(2) **Effect of frequency:** If frequency of increases, (keeping intensity i increases but their is no change i

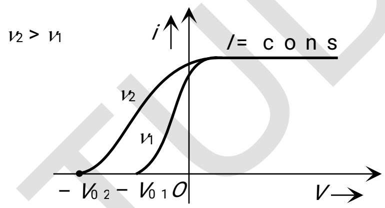

Fig. 24

Important Formulae for Phot

(1) $h\nu = h\nu_0 + K_{max}$ and $K_{max} = eV_0$

(2) $K_{max} = eV_0 = h(\nu - \nu_0) \Rightarrow \frac{1}{2}mv^2_{max} = h(\nu - \nu_0)$

(3) $v_{max} = \sqrt{\frac{2h(\nu - \nu_0)}{m}}$

(4) $K_{max} = \frac{1}{2}mv^2_{max} = eV_0 = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right) = hc\left(\frac{\lambda_0 - \lambda}{\lambda\lambda_0}\right)$

(5) $v_{max} = \sqrt{\frac{2hc}{m}\frac{(\lambda_0 - \lambda)}{\lambda\lambda_0}}$

(6) $V_0 = \frac{h}{e}(\nu - \nu_0) = \frac{hc}{e}\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right) = 12375\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right)$

Compton Effect

(1) The scattering of a photon by Compton effect.

(2) The energy and momentum is cons

(3) Scattered photon will have wavelength) as compare to incident p

(4) The energy lost by the photon i kinetic energy.

(5) The change in wavelength due t called Compton shift. Com

$$\lambda_f - \lambda_i = \Delta\lambda = \frac{h}{m_0 c}(1 - \cos\phi)$$

If $\phi = 0°, \Delta\lambda = 0$

$\phi = 90°, \Delta\lambda = \frac{h}{m_0 c} = 0.24\ nm$

$\phi = 180°, \Delta\lambda = \frac{2h}{m_0 c} = 0.48\ nm$ (called Compton wa

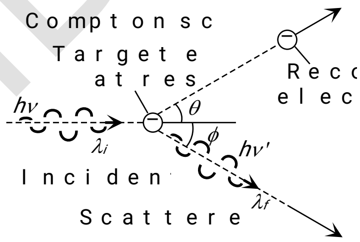

Fig. 25

X-Rays

(1) X-rays were discovered by scie they are also called Rontgen rays.

(2) Rontgen discovered that whe discharge tube is of 10^{-3} mm of Hg and potential dif kept 25 kV, then some unknown radiations (by anode.

(3) There are three essential r production of X-rays.

(i) A source of electron

(ii) An arrangement to accelerate

(iii) A target of suitable materia high melting point on which these hig

Coolidge X-Ray Tube

(1) It consists of a highly evacua cathode and target (also known as fi The cathode consist of a tungsten f coated with oxides of barium or stro of electrons even at low temperat surrounded by a molybdenum cylinder *w.r.t.* the target.

(2) The target (It is a material of melting point and high thermal condu or molybdenum is embedded in a copper

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(3) The face of the target is electron stream.

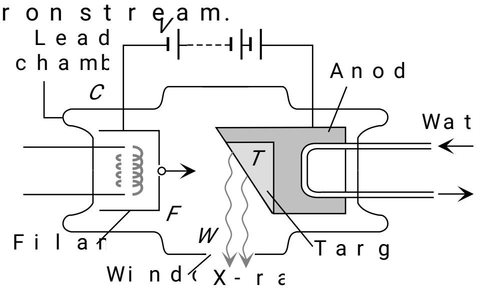

Fig. 25

(4) The filament is heated by pa... A high potential (≈ 10 kV to 80 kV) is applied ... the target and cathode to acceler... emitted by filament. The stream ... are focussed on the target.

(5) Most of the energy of the el... heat (above 98%) and only a fract... electrons (about 2%) is used to pr...

(6) During the operation of the ... is produced in this target, this ... copper anode to the cooling fins f... radiation and convection.

(7) **Control of intensity of X-ra...** intensity of X-... number of X-ray photons produce... intensity of X-rays emitted is ... electrons emitted per second fro... increased by increasing ... *intensity of X-rays ∝ Filament current*

(8) **Control of quality or penetr...** Quality of X-rays implies the pen... can be controlled by varying the ... the cathode and the target.

For large potential differen... electrons will be large and hence ... of X-rays.

Table 25.3: Types of X-...

Hard X-rays	Soft X-rays
More penetration	Less penetratio...
More frequency o... $\approx 10^{19}$ *Hz*	Less frequency o... $\approx 10^{16}$ *Hz*
Lesser wavelength... – 4Å)	More wavelength ... 10Å)

Properties of X-Rays

(1) X-rays are electromagneti... range 0.1Å – 100Å

(2) The wavelength of X-rays is ... the wavelength of light. Hence t... (This is the only difference betw...

(3) X-rays are invisible.

(4) They travel in a straight li...

(5) X-rays are measured in Rontgen ... power).

(6) X-rays carry no charge so the... magnetic field and electric field.

(7) $\lambda_{Gama\ rays} < \lambda_{X\text{-}rays} < \lambda_{UV\ rays}$

(8) They used in the study of crysta...

(9) They ionise gases

(10) X-rays do not pass through hea...

(11) They affect photographic pla...

(12) Long exposure to X-rays is inj...

(13) Lead is the best absorber of X-...

(14) For X-ray photography of huma... $BaSO_4$ is the best absorber.

(15) They produce photoelectric e...

(16) X-rays are not emitted by hydr...

(17) These cannot be used in Radar ... reflected by the target.

(18) They show all the important pr... reflection, refraction, interfere... *etc.*

Absorption of X-Rays

X-rays are absorbed when they inci...

Intensity of emergent X-rays $I = I_0 e^{-\mu x}$

So intensity of absorbed X-rays

$I' = I_0 - I = I_0(1 - e^{-\mu x})$

where x = thickness of absorber, μ = absorption coefficient

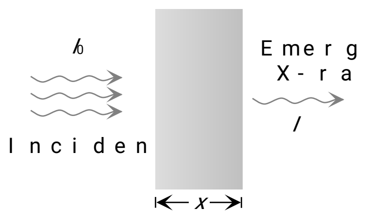

Fig. 25

$\mu \propto \lambda^3$; (λ = Wavelength of X-ray)

$\mu \propto \bar{\nu}^3$ (ν = Frequency of X-ray)

$\mu \propto Z^4$ (Z = Atomic number of target)

Classification of X-Rays

In X-ray tube, when high speed ele... they penetrate the target. They los... comes to rest inside the metal. The el... stopped makes several collisions wi... At each collision one of the followi... get formed.

(1) Continuous X-rays

(2) Characteristic X-rays

Continuous X-Rays

As an electron passes close to t of the target, the electron is def figure. This results in decelera energy of the electron during dec of X-rays.

The X-ray photons so emitted f spectrum.

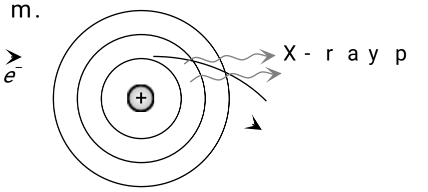

Fig. 25

(1) **Minimum wavelength:** When the electron whole of it's energy in a single co photon of maximum energy $h\nu_{max}$ is emitted

$$\frac{1}{2}mv^2 = eV = h\nu_{max} = \frac{hc}{\lambda_{min}}$$

where v = velocity of electron bef atom, V = potential difference thr accelerated, c = speed of light = $3 \times 10^8\ m/s$

Maximum frequency of radiation $\nu_{max} = \frac{eV}{h}$

Minimum wavelength = cut off wav

$$\lambda_{min} = \frac{hc}{eV} = \frac{12375}{V} Å$$

(2) **Intensity wavelength graph:** The continuous spectra consist of all the wavelen wavelength are of different inte the intensity variation of diff accelerating voltages applied to

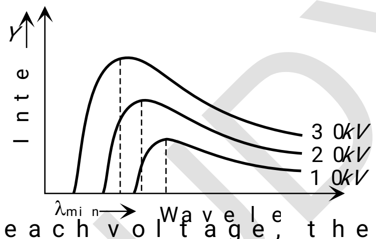

Fig. 25

For each voltage, the intensit minimum wavelength (λ_{min}) rises rapidly to then drops gradually.

The wavelength at which the depends on the accelerating volt voltage and vice-versa.

Characteristic X-Rays

Few of the fast moving electro penetrate the surface atoms of th out the tightly bound electrons e of the atom. Now when the electron created at that place.

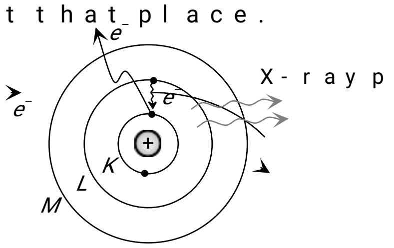

Fig. 25

To fill this vacancy electrons fro the created vacancies, we know that from a higher energy orbit E_2 to lower energy orbit E_1, it radiates energy ($E_2 - E_1$). Thus this energy differen form of X-rays of very small but def depends upon the target material. Th of sharp lines and is called characte

(1) ***K, L, M, ... series*:** If the electron strik eject an electron from the K-shell of the atom, a created in the K-shell. Immediately an elec outer shell, say L-shell jumps to the K-shell, emittin photon of energy equal to the energy two shells. Similarly, if an electron jumps from M-shell to K-shell, X-ray photon of higher ene photons emitted due to the jump of electrons from L, M, N shells to the K-shell gives $K_\alpha, K_\beta, K_\gamma$ lines of the K-series of spectrum.

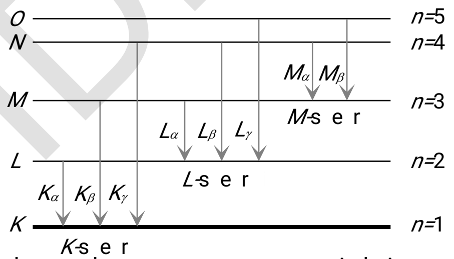

Fig. 25

If the electron striking the targe L-shell of the target atom, an electron from M, N shells jumps to the L-shell so that X-rays photons emitted.

These photons form the L-series of the spec similar way the formation of M series, N series etc. may be explained.

(2) **Intensity-wavelength graph:** At certain sharp wavelengths, the intensity of X-rays K_α, K_β .... as shown in figure. These X-r characteristic X-rays. At other wav gradually and these X-rays are calle

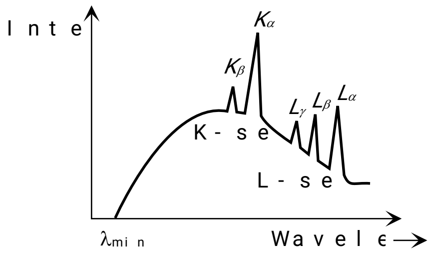

Fig. 25

Mosley's Law

Mosley studied the characteristic X-ray spectrum number of a heavy elements and conclu different elements are very similar

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number, the spectral lines mer
frequencies.

He also gave the following relat $\sqrt{\nu} = a(Z-b)$

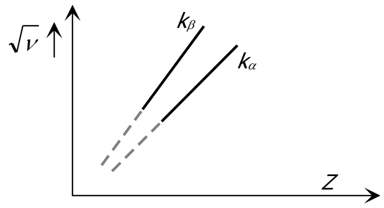

Fig. 25.29

where ν = Frequency of emitted line, Z = Atomic number of target, a = Proportionality constant, b = Screening constant, Shielding constant.

$(Z-b)$ = Effective atomic number

a and b doesn't depend on the natu values of b are as follows

$b = 1$ for K-series

$b = 7.4$ for L-series

$b = 19.2$ for M-series

(1) Mosley's law supported Bohr

(2) It experimentally determined (Z) of elements.

(3) This law established the i elements in periodic table by ato weight.

(4) Gaps in Mosley's ... Z = 43, 61, 72, 75 existence of new elements which we

(5) The atomic number of Cu, Ag and Pt were established to be 29, 47 and 78 respectively.

(6) When a vacancy occurs in the K-shell, there electron remains in K-shell. An electron in L-shell feel an effective charge (Z − 1)e due to +Ze of the n and −e from the remaining electron in K-shell, L-orbit is well shielded by the K-shell

(7) Wave length of charac

$\frac{1}{\lambda} = R(Z-b)^2\left(\frac{1}{n_1^2}-\frac{1}{n_2^2}\right)$ and energy of X-ra

$$\Delta E = h\nu = \frac{hc}{\lambda} = Rhc\,(Z-b)^2\left(\frac{1}{n_1^2}-\frac{1}{n_2^2}\right)$$

(8) If transition takes place from $n_2 = 2$ to $n_1 = 1$ (K_α-line)

(i) $a = \sqrt{\frac{3RC}{4}} = 2.47\times 10^{15}\ Hz$

(ii) $\nu_{K\alpha} = RC\,(Z-1)^2\left(1-\frac{1}{2^2}\right) = \frac{3RC}{4}(Z-1)^2$

$$= 2.47\times 10^{15}(Z-1)^2\ Hz$$

(iii) In general the wavelength of all the K-lines are

$\frac{1}{\lambda_K} = R(Z-1)^2\left(1-\frac{1}{n^2}\right)$ where n = 2, 3, 4, ...

While for K_α line $\lambda_{K\alpha} = \frac{1216}{(Z-1)^2}$ Å

(iv) $E_{K\alpha} = 10.2(Z-1)^2\ eV$

Uses of X-Rays

(i) In study of crystal structure: determined using X-ray diffraction.

(ii) In medical science

(iii) In radiography

(iv) In radiotherapy

(v) In engineering

(vi) In laboratories

(vii) In detective department

(viii) In art the change occurring examined by X-rays.

Tips & Tricks

✍ Discovery of positive rays isotopes.

✍ The de-Broglie wavelength of of an atom is equal to circumfere

✍ A particle having zero rest m and momentum must travels with a light.

✍ **de-Broglie wavelength assoc** is given $\lambda = \frac{h}{mv_{rms}} = \frac{h}{\sqrt{3mkT}}$ (Energy at temperature T is $E = \frac{3}{2}kT$)

✍ A photon is not a material pa energy.

✍ When a particle exhibits wav with a wave packet, rather then a

✍ By coating the metal surface wi strontium oxide it's work functi

✍ We must remember that inten radiation is inversely proport between source of light and P i.e. ($I \propto \frac{1}{d^2}$ so $i \propto \frac{1}{d^2}$)

✍ The photoelectric current ca some inert gas like Argon into t emitted by cathode ionise the ga current is increased.

✍ Compton effect shows that pho

✍ Production of X-ray is the r photoelectric effect.

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✍ The thickness of medium at whi
X-rays become $I' = \frac{I_0}{2}$ i.e. is called half v
$(x_{1/2})$ and it is $x_{1/2} = \frac{0.693}{\mu}$ as .

✍ Continuos X-rays are produce
called "Bremsstrahlung". It me
radiation.

✍ The wavelength of characteri
on accelerating voltage. It dep Z
of the target material.

✍ In characteristic $\lambda_{K\alpha} < \lambda_{L\alpha} < \lambda_{M\alpha}$ pec
$\nu_{K\alpha} > \nu_{L\alpha} > \nu_{M\alpha}$ also $\lambda_{K\alpha} > \lambda_{K\beta} > \lambda_{K\gamma}$

✍ Nearly all metals emits photo
UV light. But alkali metals lik
rubidium and cesium emit phot
exposed to visible light.

✍ Oxide coated filament in vacu
electrons at relatively lower t

✍ Conduction of electricity in
because colliding electrons ac
to increase in mean free path.

✍ Kinetic energy of cathode ray
and work function of cathode.

✍ Photoelectric effect is due t

✍ Hydrogen atom does not emit X-
levels are too close to each othe

✍ The essential difference bet γ-ray
that γ-rays emits from nucleus whi
of atom.

✍ There is no time delay between
incidence of photon i.e. the electrons are em
as the light falls on metal surfa

✍ If light were wave (not photon
to eject a photoelectron out of t

✍ Doze of X-ray are measured in t
free energy via ionisaiton.

✍ Safe doze for human body per we
Rontgon is the amount of X-rays $\times 10^{4}$ ...
energy through ionization at NTP of 1

✍ The photoelectrons emitted f
have different kinetic energi
photons have same energy. This
electrons do not exist in the sur

Those coming from below the su
in getting themselves free.

✍ Einstein was awarded Nobel p
photoelectric effect.

✍ Uncertainty in the measurem
photon within the nucleus is $\Delta p = \frac{h}{2\pi d}$

where d = diameter of the nucleus, $\Delta x = d$ = uncertainty in the measurement

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