11. ATOMIC PHYSICS

Synopsis: CATHODE RAYS

1. The word 'atom' derived from Greek word which literally means indivisible.
2. In 1803 'Dalton' put forward his atomic theory according to which 'atom' was indivisible neutral particle.
3. Michael Faraday studied the passage of electricity through liquid solutions.
4. In 1870 William Crookes did experiments about discharge of electricity through gases which led to the discovery of cathode rays.
5. Under normal conditions of atmospheric pressure and temperature, gases are good insulators. A very large electric field is required to produce a discharge. (About 3×10^5 volt/metre for air).
6. By creating low pressure and applying high potential, conduction of current through gases is made easy.
7. The minimum potential difference that causes a spark between two electrodes separated by 1 cm is called **sparking potential (V).**
8. The pressure at which sparking potential is minimum for a given gas and electrode separation is called **critical pressure**.
9. A high potential is obtained by induction coil.
10. Low pressures are measured by **Mcleod gauge**.
11. **Paschen's law :** The sparking potential (V) is directly proportional to the gas pressure (P) and directly proportional to the distance between the electrodes (d) i.e., $V \alpha Pd$.
12. The sparking potential is independent of the nature of the metal of which the electrodes are made.
13. Discharge tube is used to investigate the passage of electricity through rarefied gases.
14. **Discharge through gases**:
    i) Conduction in a discharge tube starts at about 10 mm of Hg pressure with crackling noise and streaks of light jumping between the electrodes.
    ii) At 4 mm of Hg pressure, the discharge broadens out and the whole tube is filled with bright light which is called **positive column** or **Geissler discharge**. It extends from cathode to anode.
    iii) At 1.65 mm of Hg pressure, the positive column detaches from the cathode and a blue luminous intensity appear around the cathode. This is called **negative glow**. The dark space between the negative glow and the positive column is called **Faraday's dark space**.
    iv) At 0.8 mm of Hg pressure, the negative glow detaches from the cathode and a dark space is formed between the cathode and the negative glow. This dark space is called **Crooke's dark space**. The length of the positive column is further reduced and a very small glow is produced at the cathode, known as **cathode glow**.
    v) At a pressure of 0.37 mm of Hg, the positive column breaks up into bands called **striations.**
    vi) Cathode rays are produced when the pressure in the discharge tube is 0.01 mm of Hg. When cathode rays fall on the walls of the tube, glowing of walls can be seen due to fluorescence. The colour of the glow depends upon the nature of the glass. e.g. yellowish green for soda glass and greyish blue for lead glass.
    vii) If the pressure is less than 0.001 mm of Hg, cathode rays can not be produced.
15. Cathode rays were discovered by Plucker.

16. **Plucker** noticed the existence of cathode rays first. Cathode rays are found to be streams of negatively charged particles whose nature is independent of the nature of the gas or material of the electrode.

    Stoney named them “electrons”.

    J.J.Thomson discovered them for which he was awarded Noble prize.

    Hitroff proved that they travel in straight lines.

    Jein Perin found that they possess –ve charge

    Millikan determined the charge of the electron.

    Crookes proved that they possess momentum and energy

    Hertz showed that they penetrate through matter.

17. **Properties of cathode rays**

    i) They travel in straight lines.

    ii) They shoot out normally from the cathode irrespective of the position of the anode.

    iii) They are fast moving electrons.

    iv) They are deflected by electric and magnetic fields.

    v) They ionise the gases through which they pass.

    vi) They possess mechanical energy.

    vii) They produce heat in a body on which they fall.

    viii)They cause fluorescence in substances like zinc sulphide and barium platino cyanide .

    ix) They effect photographic plates.

    x) They produce X-rays when they bombard heavy targets.

18. **Applications of cathode ray discharge tube :**

    i) Mercury and sodium vapour lamps.

    ii) As Geissler tubes to study the characteristic spectrum of different gases.

    iii) They are used as beacon lights, lending lights, boundary lights and wind deflection indicators in air fields.

19. **A charged particle in an electric field :**

    a) The force experienced by a charge (q) placed in a uniform electric field of intensity E is given by F = qE.

    b) If the charge is +ve, the force will be in the same direction as that of the field.

    c) If the charge is –ve, it will be in the direction opposite to the field.

    The acceleration produced a = Eq/m. Where m is the mass of electron.

    d) If an electron enters in the perpendicular direction into an electric field, then it moves in a parabolic path. $y = \left(\frac{eE}{2mv^2}\right)x^2$. Where x is the distance travelled along x-axis direction and v is its velocity. y is displacement along y axis.

20. **Electron in a uniform magnetic field :**

    Whenever an electron enters into a uniform magnetic field of induction B, it experiences a force F= B. ev. Sinθ. Where v is its velocity and θ is the angle with the field. The direction of the force is given by Fleming Left hand rule.

    a) If it enters in a direction parallel (θ = 0°) or antiparallel (θ = 180°) to the magnetic field F =0 and the path is a straight line.

b) If it enters in a direction perpendicular of the field, it describes a circular path whose plane is perpendicular to the direction of the field. The radius of the circular path is $r = \frac{mv}{Be}$.

c) If it enters in a direction different from 0° or 90° or 180°, the path is helical (spiral).

21. The velocity of an electron when it is subjected to mutually perpendicular electric field ($\vec{E}$) and magnetic field ($\vec{B}$) at right angles to the path of a beam of electrons and when the electron goes without any deviation is given by v = E/B.

$\frac{e}{m} = \frac{E^2}{2VB^2}$ where V is the potential difference between anode and cathode.

22. **e/m Thomson's method :**

i) e/m is called specific charge of the electron. A beam of cathode rays is subjected to simultaneous electric and magnetic field which are mutually perpendicular and also perpendicular to the beam. Such fields are called *crossed fields*.

ii) The condition for the null deviation of the beam is v = E/B.

iii) When the magnetic field alone is applied, disconnecting the electric field, $\frac{e}{m} = \frac{E}{rB^2} = \frac{V}{rB^2 d}$. Where r is the radius of curvature of the path, v is the P.D. between the condenser plates and d is their distance of separation.

23. e/m was found to be 1.76×10^{11} c/kg. Its value decrease with the increases of velocity of the electron because the mass of the electron m varies with its velocity v, as $m = \frac{m}{\sqrt{1 - \frac{V^2}{C^2}}}$, where C is the velocity of light and m_0 is the rest mass of the electron.

24. **Determination of e/m of electron – Thomson's method :**

i) A narrow beam of cathode rays coming out of a small hole in the anode moves towards a distant fluorescent screen and produces a bright spot.

ii) The cathode ray beam is made to pass through a region where there are electric and magnetic fields perpendicular to each other and perpendicular to the direction of motion of cathode rays.

iii) If the electric and magnetic fields are chosen so that the cathode ray beam remains un deflected, then

Force due to magnetic field = force due to electric field

iv) Bev = eE $\Rightarrow$ v = E/B………(1)

Here 'v' is the velocity and 'e' is the charge of the cathode ray particle, 'B' is the induction of the magnetic field and 'E' is the electric field strength.

v) If 'V' s the potential difference between the cathode and anode, through which the cathode ray particles each of mass 'm' are accelerated, they by work energy theorem,

$V \times e = \frac{1}{2}mv^2$ …………..(2)

vi) Combining the two equations, we get

$$\frac{e}{m} = \frac{E^2}{2VB^2}$$

25. Thomson found that cathode rays are nothing but electrons. Thomson studied the properties of cathode rays.

26. The properties of cathode rays are independent of the nature of the gas in the discharge tube and the nature of the material of the electrodes.

27. a) Thomson discovered electron.
    b) Johnson Stoney gave the name electron.
    c) The ratio of the charge to the mass of a particle is called specific charge.

28. Thomson determined the specific charge (e/m) of cathode rays as 1.77×10^{11} C/kg. The accurate value of e/m of electron as determined with more advanced apparatus is 1.759×10^{11} C/kg.

29. **Mallikan's oil drop experiment :**
    a) This method is based on the measurement of the terminal velocity of the charged oil droplet under the action of gravity and under the combined action of gravity as well as an electric field opposite to it.
    b) When no electric field is applied, the oil drop moves down due to gravity.

    Effective weight of the drop

    = True weight – Buoyancy acting upwards

    $= \frac{4}{3}\pi a^3 \rho g - \frac{4}{3}\pi a^3 g\sigma g$

    $\Rightarrow$ Effective weight = $\frac{4}{3}\pi a^3(\rho-\sigma)g$

    Here a is radius of the drop , ρ is density of oil

    σ is density of air

    c) The upward viscous drag on the oil drop is $6\pi\eta\nu$. When $\nu = \nu_1$ which is known as terminal velocity, the resultant force on the drop is zero. Then effective gravitational force on the oil drop is equal to upward viscous drag.

    $\Rightarrow \frac{4}{3}\pi a^3(\rho-\sigma)g = 6\pi\eta a\nu_1$

    Radius of the oil drop, $a = \left(\frac{9\eta\nu_1}{2(\rho-\sigma)g}\right)^{1/2}$

    Mass of the oil drop, $m = \frac{4}{3}\pi\rho\left(\frac{9\eta\nu_1}{2(\rho-\sigma)g}\right)^{3/2}$

    Here η is coefficient of viscosity of air.

    If the buoyancy on the drop is negligible, then $a = \left(\frac{9\eta\nu_1}{2\rho p}\right)^{1/2}$ and $m = \frac{4}{3}\pi\rho\left(\frac{9\eta\nu_1}{2\rho g}\right)^{3/2}$

    d) When electric field is applied, the force on the charged oil drop = Eq.

    If the drop moves up with a terminal velocity ν_2,

    $Eq = \frac{4}{3}\pi a^3(\rho-\sigma)g + 6\pi\eta a\nu_2$

    $\Rightarrow Eq = 6\pi\eta a(\nu_1 + \nu_2)$

    $\Rightarrow q = \frac{6\pi\eta a}{E}(\nu_1+\nu_2)$

    $\Rightarrow q = \frac{6\pi\eta(\nu_1+\nu_2)}{E}\left(\frac{9\eta\nu_1}{2(\rho-\sigma)g}\right)^{1/2}$

    Here 'q' is the charge on the drop.

e) If the same drop moves up with terminal velocity v_2^1 after picking up additional charge due to X-rays, the difference in the charge possessed by the drop is proportional to $\left(v_2^1 - v_2\right)$.

$\Rightarrow (q^1 - q) \propto \left(\left(V_2^1 - V_2\right)\right.$

f) When the charged oil drop is at rest in uniform electric field, then

Eq = mg $\Rightarrow$ q = mg /E

As $E = \frac{V}{d}$, $q = \frac{mgd}{V} \Rightarrow q \propto \frac{1}{V}$

If the same oil drop is kept stationary when it is made to pick up different charges by ionizing the space between the plates continuously,

$q_1 : q_2 : q_3 .... = \frac{1}{V_1} : \frac{1}{V_2} : \frac{1}{V_3} :............$

g) i) In Millikan's experiment the drop falls freely under gravity with a terminal velocity V. It is held floating in air in an electric field when it has a charge q_1. After picking up some more charge it moves up with a terminal velocity ν. If q_2 is final charge,

$mg = Eq_1 = 6\pi\eta a\nu$

$Eq_2 = 6\pi\eta a\nu + mg = 2mg$

$\Rightarrow q_2 = 2q_1$

Excess charge acquired = $(q_2 - q_1) = q_1$

ii) If it moves up with a terminal velocity $K\nu$ after picking up some more charge,

$Eq_2 = 6\pi\eta aK\nu + mg = (K+1)\, mg$

$\Rightarrow q_2 = (K + 1)q_1$

Excess charge acquired = $(q_2 - q_1) = Kq_1$

h) From Millikan's experiment, charge, radius and mass of electron can be determined. Quantisation of charge is established from the experiment.

30. **Importance of Millikan oil drop method :**

i) The charge 'e' on the electron is the smallest possible charge

ii) The total charge on a body can be only an integral multiple of 'e' or q = ne. Where n =1, 2,3,…….n, an integer only. That means charge is quantized.

iii) The specific charge of an electron was determined by J.J. Thomson as 'e/m'=1.76×10^{11}C.Kg^{-1}. Using Millikan's value of charge of an electron the mass of the electron can be determined as 9.1×10^{-31} Kg.

31. **Methods of producing electrons :**

i) By **discharge through** gases, electrons can be produced and these are known as cathode rays.

ii) When a tungsten filament is heated, electrons are emitted. This process is known **as thermionic emission** and these electrons are called **thermions.** This phenomenon was discovered by **Edison**.

iii) When light is incident on metals like potassium and caesium, electrons are liberated. They are called *photoelectrons.*

iv) In the case of natural radioactive substances, fast moving electrons are emitted from the nucleus. These are called β *-rays.*

v) By applying a high intensity electric field on a suitable substance, electrons can be obtained. This phenomenon is known as field emission or *cold cathode electron emission.*

32. Whatever may be the method of producing electrons, they all have the same charge and mass.

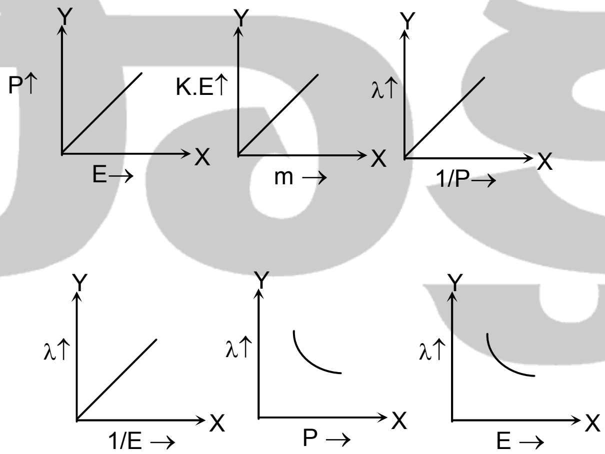
33. In atomic physics, the energy of the fundamental particles is measured in electron volt.

34. An electron volt is the energy acquired by an electron when it is accelerated through a potential difference of 1 volt.
$1\ eV = 1.602 \times 10^{-19}\ J$

PHOTOELECTRIC EFFECT :

35. **Photons** :
 a) Photons are packets of energy which are emitted by source of radiations.
 b) Photons travel in straight line with speed of light (3×10^8 m/s).
 c) Photons are electrically neutral.
 d) Photons are not deflected by electric and magnetic fields.
 e) If the frequency of radiation is ν then energy of photon (E) = $h\nu = \frac{hc}{\lambda}$

 where c = velocity of light
 λ = wavelength of radiation
 h = Planck's constant = 6.6×10^{-34} J.s.
 f) The number of photons of wavelength λ emitted in t sec. from a lamp of power p is given by n = $\frac{Pt\lambda}{hc} = \frac{Pt}{h\nu}$



36. a) The emission of electrons from the surface of a metal when exposed to electromagnetic radiation of a suitable frequency is called *photoelectric effect*.
 b) This phenomenon was discovered by Hertz and experimentally verified by Hallwachs, Lenard, J.J.Thomson, R.A.Millikan and others.
 c) The current due to photoelectrons is called photoelectric current. It is independent of frequency of light and energy of incident light. The photoelectric current does not follow the ohm's law.
 d) The photoelectric effect is based on law of conservation of energy
 e) Alkali metals like lithium, sodium, potassium, cesium etc emit electrons with visible light only.

37. **Lenard laws of photoelectric emission**
 i. Photoelectric emission is an instantaneous phenomenon. i.e., there is no time lag between the falling of light and emission of photoelectrons. (time lag is 10^{-9} second).

ii. For every metal surface, there is a limiting frequency below which no photoelectrons are produced. This frequency is called **threshold frequency** (ν_0). Different metals have different threshold frequencies. The corresponding wavelengths are called **threshold wavelengths** (λ_0) or **cut-off wavelengths.**

iii. The rate of emission of photoelectrons from the surface of a metal is directly proportional to the intensity of the light falling on it.

iv. The maximum kinetic energy of the emitted photoelectrons does not depend upon the intensity of the incident radiation.

v. The maximum kinetic energy of the emitted photoelectrons is directly proportional to the frequency of the incident radiation and depends on the nature of metals.

vi. The photoelectric emission is independent of temperature of the cathode.

38. The velocity of electrons ejected from near the surface will be greater than those coming from the interior of the substance.

39. **Work function :** The minimum energy required to remove an electron from the surface of a metal without giving kinetic energy to the electron is called *work function* (W). Its unit is eV.

Metal (in eV)	Work function (in eV)	Work function (Joules)
Sodium	2.3	3.67×10^{-19}
Potassium	2.18	3.48×10^{-19}
Caesium	1.88	3.01×10^{-19}

40. Among the alkali metals (sodium, potassium, rubidium, cesium) cesium is the best metal for photoelectric emission as its work function is the least.

41. As the atomic number of elements increases, the work function will decrease.

42. When the temperature of a metal increases, the work function will decrease.

43. **Threshold frequency (ν_0) :**

i) It is the minimum frequency of the incident radiation below which photo-electrons are not emitted from a metal surface.

ii) The work function, $W = h\nu_0$, where h is Planck's constant.

iii) The threshold frequency of sodium is 5.6×10^{14} Hz., that for potassium 5.26×10^{14} Hz and for Caesium 4.55×10^{14} Hz.

44. **Threshold Wavelength (λ_0):**

i) It is the maximum wavelength of the incident radiation above which there is no photo electric emission from the surface of a metal.

ii) The threshold wavelength for sodium is 5400A°, that for potassium 5700 A° and for Caesium 6590 A°.

iii) The work function , $W = h\nu_0 = \dfrac{hc}{\lambda_0}$

iv) If W is in ev and λ_0 in A°, the above equation can be written as $W = \dfrac{12400}{\lambda_0} eV$.

45. **Stopping potential (V_s) :**

i) The stopping potential is that value of the retarding potential difference to be applied between the surface of a photosensitive plate and the electrode of the collector, which is just sufficient to stop the most energetic photo electrons emitted.

ii) The stopping potential or cut off potential V_s is measure of the maximum K.E. of the emitted photo electrons.

iii) $qV_s = K = \frac{1}{2}mv^2$ Joules

Where q is the charge of the electron in C and V_s is the stopping potential in Volts.

iv) If the maximum K.E. of electron is x eV then the stopping potential is given by $V_s = -x$ volt .

v) Stopping potential (V_s) $\propto$ frequency of incident radiation and $V_s \propto \frac{1}{\text{Work function}}$.

vi) Stopping potential is independent of intensity of incident radiation , power of the source of light and distance between source of light and photometal.

vii) If atomic number of photometal increases then stopping potential also increases because work function decreases.

46. If stopping potentials corresponding to wavelengths λ_1 and λ_2 ($>\lambda_1$) are V_1 and V_2 then work function of metal, $W = \frac{\lambda_1 V_1 - \lambda_2 V_2}{\lambda_2 - \lambda_1}$.

47. If wavelength of incident light is changed from λ_1 to λ_2 ($< \lambda_1$) then the charge in stopping potential, $V_2 - V_1 = \frac{hc}{e}\left(\frac{1}{\lambda_2} - \frac{1}{\lambda_1}\right)$

where e = charge of electron .

48. **Einsteins explanation of photoelectric effect :**

a) Einstein treated photoelectric effect as a collision between a photon and the atom of photometal.

b) When a photon strikes a metal surface, the entire energy of the photon is transferred to a single electron in the emitter. The energy supplied to the electron is used in two ways

   i) Part of the energy is used in ejecting the electron from the metal (work function)

   ii) The remaining energy is used to provide K.E. to the ejected electrons.

c) Einstein's photoelectric equation is given by

$h\nu = W + \frac{1}{2}m\nu^2$ or $h\nu = W + K.E_{max}$

$h\nu = h\nu_0 + \frac{1}{2}m\nu^2$

Here ν is frequency of incident radiation and ν_0 is threshold frequency , $\frac{1}{2}m\nu^2$ is maximum KE of electrons.

K. E_{max} or $\frac{1}{2}m\nu^2 = h(\nu - \nu_0)$

$\Rightarrow \frac{1}{2}m\nu^2 = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right)$

As $K.E_{max} = V_s e$, we can write

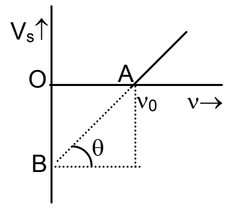
$V_s e = h(\nu - \nu_0)$

$\Rightarrow V_s e = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right)$

49. **Millikan experiment :**

a) R.A. Millikan verfied Einstein's equation experimentally. Millikan measured stopping potential for different frequencies of incident radiation for a given emitter.

b) Einstien photoelectric equations verified by Millikan's for low frequencies of radiations.



c) Millikan plotted a graph between V_s and ν. The graph shape is a straight line as shown in the figure. The slop of the graph =h/e.

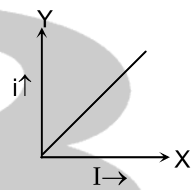
d) Determination of h:

1) $h = \frac{K_2 - K_1}{\nu_2 - \nu_1} = \frac{e(V_{S_2} - V_{S1})}{\nu_2 - \nu_1}$

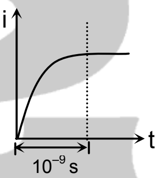
2) $h = \frac{(K_2 - K_1)\lambda_1\lambda_2}{c(\lambda_1 - \lambda_2)}$

50. **Graphs on photoelectric effect :**

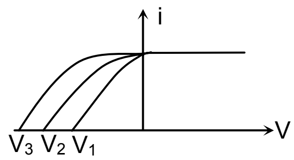
a) Variation of photocurrent with intensity of incident light on the photometal is represented by this graph.
i–photocurrent and
I– intensity of light.



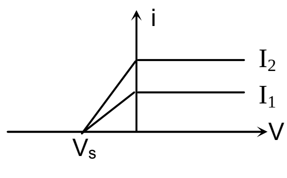
b) Time dependence of photocurrent is represented by this graph. It takes about a nano second for the photocurrent to attain the saturation value.



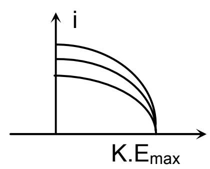
c) Variation of photocurrent with the accelerating potential difference or anode potential for different frequencies is as shown in this graph. Here intensity of each light is same. V_1, V_2 and V_3 are different stopping potentials for different incident frequencies ν_1, ν_2 and ν_3 respectively. ($\nu_3 > \nu_2 > \nu_1$ and $V_3 > V_2 > V_1$). From this graph it is observed that stopping potential or maximum K.E. of photoelectron depends on incident frequency but independent of intensity.



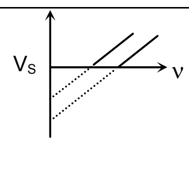
d) Variation of photocurrent with intensity of incident radiation for the same frequency is as shown. As the positive potential increases, the photocurrent reaches a saturation value. If the intensity is increased by keeping the frequency same, photocurrent and saturation current increase. Hence V_s is the negative potential which is stopping potential. V_s is independent of intensity.



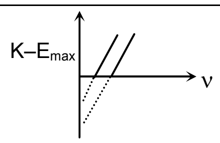
e) For the same frequency, maximum K.E. for different photocurrents or incident intensities varies as shown in this graph.

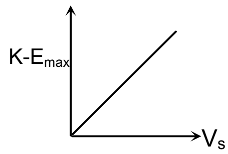


f) The variation of stopping potential with frequency of incident radiation will be as shown in this graph. It is a straight line with slope *h/e.* Intercept on frequency axis gives the threshold frequency of the photometal. Intercept on Y –axis (V_s axis) gives $h\nu_0/e$ when the graphs are drawn for different metals they are parallel straight lines with the same slope *h/e*. Different intercepts on X – axis denote different threshold frequencies for different photometals.



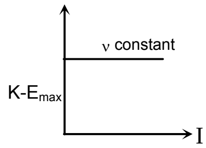
g) The variation of maximum K.E. of photoelectrons with frequency of incident radiation will be as shown in the graph. It is a straight line with slope *h*. Intercept on X-axis gives threshold frequency. Intercept on Y-axis gives work function when the graphs are drawn for different metals, they are parallel straight lines with same slope different intercepts on X-axis denote different threshold frequencies of different photometals.





h) If a graph is drawn by plotting maximum kinetic energy on Y-axis and stopping potential on X-axis it will be a straight line passing through the origin. Slope of the line gives electronic charge 'e'.

i) If a graph is drawn by plotting K.E_{max} or Y-axis and intersity on X-axis, it will be a straight live parallel to X – axis.



51. **Photo electric cell or Photo Cell** :

a) Photocells are the most important devices which are based on application of the photoelectric effect.

b) It is called *magic eye.*

c) There are three kinds of photocells namely photoemissive cell, photovoltaic cell and photoconductive cell.

52. **Photoemissive Cell** :

a) It consists of a glass or quartz bulb whose inner surface is coated with a thin layer of alkali metal such as sodium, cesium etc. This layer acts as cathode.

b) A thin metal ring acts as anode.

c) Photoemissive cell acts as a switch in electric circuits i.e., flow of current can be controlled.

d) These cells are also called as *photoresistive cells.*

e) Photoemissive cells are of two types namely vacuum type photoemissive cell and gas filled photoemissive cell.

f) In *vacuum type cells*, current flows immediately after the light is incident on it and it is proportional to the intensity of incident light. The current output is only a few microampere. These cells are most suitable for photometry and in televisions.

g) In *gas (inert gas) filled type cells*, the current flow is five to ten times more than that of vacuum type due to ionisation of the gas, but it is not proportional to the intensity of light. These cells are used in cinematography and in the recording and reproduction of sound.

53. **Photovoltaic Cell** :

a) photovoltaic cell consists of a copper plate coated with a thin layer of cuprous oxide.

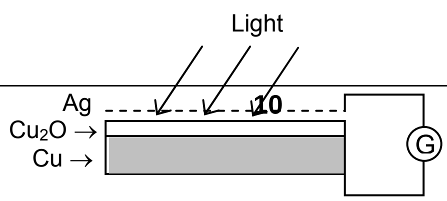
b) A semi-transparent layer of silver is laid on this plate.

c) When external light falls on the oxide layer, the electrons emitted from the layer moves towards the silver layer.

d) Then the silver layer becomes negative and copper plate becomes positively charged.

e) Due to this a potential difference is developed between copper and silver plates and current is set up in the external circuit whose strength is proportional to the intensity of light.

f) These cells supply current without any external source of e.m.f.



54. **Photoconductive Cell** :

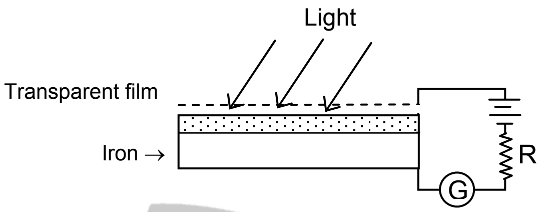
a) Photoconductive cells are based on the principle that when light is incident on some semiconductor like selenium, lead sulphide etc., its electric resistance is reduced.

b) It consists of a thin layer of semiconductor placed between transparent film and iron plate.

c) When the light is incident on the transparent film, the electrical resistance of the semiconductor layer decreases. Hence a current flows from the iron plate to the transparent film in the circuit.

d) The current changes with the change in intensity of light with time gap.

e) The time gap is the main disadvantage in this cell.



55. **Uses of photo electric cells :**

a) Photocells are used as light meters in cameras to measure intensity of light.

b) The photocells inserted in the street light electric circuit are used to switch on and off the street lighting system automatically at dusk and dawn.

c) Photocells are used in the control of a counting device, which records every interruption of the light beam. So photocells help count the persons entering at temple or auditorium.

d) in burglar alarm, ultra violet light is continuously made to fall on photocell installed at the close way. A person entering interrupts the beam, which activates an electric bell to ring. Fire alarms also use photocells. Light from the fire activates the photocell and the current in the circuit causes the siren to whistle.

e) Photocells are used in the reproduce sound in cinematograph and in the television camera for scanning and telecasting scenes.

f) They are also used in automatic opening and closure of doors.

g) Photo voltaic cells are used in solar arrays to generate electricity.

h) They are used in controlling the temperature of furnaces.

i) They are used in industries for detecting minor flaws of holes in metal sheets.

j) They are used for detection of traffic law defaulters.

k) The temperature of celestial bodies is measured and their spectra are studied by photocells.

56. **Photomultiplier :**

i) Device used to amplify very weak light signals. ii) It is also called as electron multiplier.

X-RAYS :

57. X-rays were discovered by **Roentgen** with a plate coated with barium platinocyanide.

58. X-rays are electromagnetic radiations with X-rays are electromagnetic radiations with wavelength in the range 0.1 Å to 100 Å.

59. (i) The frequency of X – rays is 10^{16} Hz to 10^{18} Hz.
    (ii) X-rays of very low wavelength are called hard X-rays.
    (iii) X-rays of large wavelength are called soft X-rays (or) white X-rays.
60. The energy of X-rays is 10^2eV to 10^4 eV.
61. **Production of X-rays :**
    i) High velocity electrons due to collision with the target will loose some amount of kinetic energy and it will be radiated in the form of X-rays.
    ii) X-rays are produced using Coolidge tube. The pressure inside Coolidge tube is almost zero.
    iii) The target in Coolidge tube is made of tungsten (high melting point).
    iv) Accelerated electron beam strikes a target and results X-rays.
    v) Only 2% energy of incident electron beam is used in producing X-rays rest of the energy is converted into heat.
    vi) The intensity of X-rays depends on the number of electrons striking the target or filament current. By increasing the filament current, intensity of the X-rays can be increased.
    vii) the frequency of X-rays depends on the accelerating potential or kinetic energy of electrons striking the target
    $\nu \propto V$ or $\nu \propto K.E.$
    $\lambda \propto \frac{1}{V}$ or $\lambda \propto \frac{1}{K.E}$
    viii) Accelerated or decelerated charges emit electromagnetic radiation which are known as *Bremsstrahlung radiations.*
62. The maximum frequency of X-rays produced is given by formula $\nu_{max} = \frac{Ve}{h}$ where V = the potential of the target.
63. The minimum wavelength or cut-off wavelength is given by $\lambda_{min} = \frac{hc}{eV} = \frac{12400}{V}$ (in Å)
64. **Properties of X-rays**:
    i) They are invisible rays.
    ii) They travel in straight lines with the velocity of light.
    iii) They are not deflected by electric and magnetic fields.
    iv) They emit photoelectrons when they fall on some metals like sodium, potassium, etc.
    v) They can pass through certain substances (like wood, cardboard, flesh, etc.) which are generally opaque for light.
    vi) They effect photographic plates.
    vii) They exhibit reflection, refraction, interference, diffraction and polarisation in crystals.
    viii) They cause fluorescence on ZnS and barium platinocyanide.
65. High energy photons are used for nuclear disintegration which is usually referred to as *photodisintegration*.
66. **Uses of X-rays**:
    i) They are used to study the structure of crystals and the internal arrangement of atoms and molecules.
    ii) They are used to detect tuberculosis and tumours.
    iii) The are used in the treatment of cancer and some skin diseases.

iv) They are used to detect forgery of old paintings and to discriminate between real and artificial diamonds.

v) They are used to detect fractures in bones, location of foreign bodies, stones in kidneys, etc.

vi) They are used to detect flaws in metal castings.

67. **X – rays spectra** :

a) Continuous X-ray spectrum :

i) It is formed due to scattering of high speed electrons that strike the target. When high energy electrons move close to the nucleus of target atom then these get decelerated and X-rays of continuous frequency are emitted.

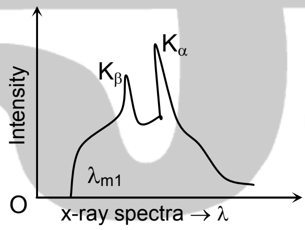
ii) The electron rarely loses whole of its energy in a single collision. Generally it undergoes a sequence of collisions with atoms of the target before coming to rest, thus emitting photons of smaller energies or longer wavelength.

iii) **Duan and Haunt's rule :** Continuous x-ray spectrum suddenly ends at a certain minimum wavelength called limiting wavelength , which decreases with increase of applied voltage $\lambda_{max} \alpha \frac{1}{V}$

$$\lambda_{min} = \frac{hc}{e\nu} = \frac{12400}{V} A°$$

iv) Greater the applied voltage, smaller will be the value of λ_{min}.

v) Continuous x-ray spectrum is superposed by a line spectrum whose wavelengths are characteristic of the target.



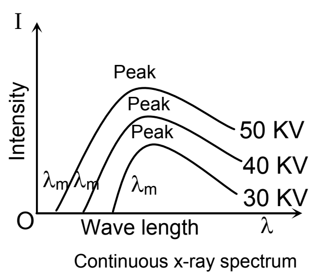
vi) These X –rays do not depend on the atomic number of target element.

vii) When the electron loses the whole of its energy in a single collision with the target atom, then X-ray photon of maximum energy is emitted.

$h\nu_{max} = eV$

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

viii) When the potential applied to the target increases, the limiting wavelength decreases.



Continuous x-ray spectrum

ix) The intensity increases rapidly on the lower wavelength side and falls slowly on the higher wavelength side.

x) When the target potential is increased, the wavelength corresponding to peak of curve decreases.

xi) When the potential applied to the target is increased, the intensity corresponding to every wavelength increases.

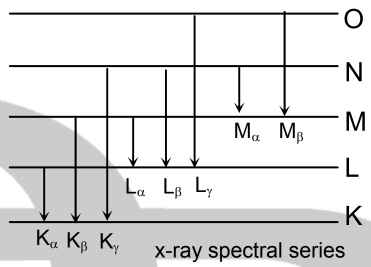
68. **Characteristic X-rays spectrum :**

a) When electron with high energy penetrate atoms, they strike the electrons of inner shells and knock out them from the atoms, then deficiency of electron is created in the inner shell. Electron from higher shell jumps into this shell to fulfill this deficiency. In this process photons with energies equal to difference of energies of initial and final shells are emitted. These are characteristic X-rays.

b) These X-rays depend on the nature of the target.

c) The frequencies of the characteristic X-rays do not depend on the applied potential difference.

Thus a line spectrum in which series of various frequencies or wavelength are obtained.



d) When electron makes transitions from L, M, N…… shells to K shell, then K-series of X-rays is emitted. When electron makes transitions from M, N,…… shells to L shell, L series is emitted.

e) The first liens of the series are called K_α, L_α, M_α-------- similarly the second liens are called K_β, L_β, M_β………

f) Wavelength of K-series are generally less than 1 A° and those of L-series are about 10 times longer.

g) The frequencies of these spectral lines will be 1000 times higher to the frequency of visible light.

h) Energy of K_α line is $h\nu_\alpha = E_L - E_K$

Energy of K_β line is $h\nu_\beta = E_M - E_K$

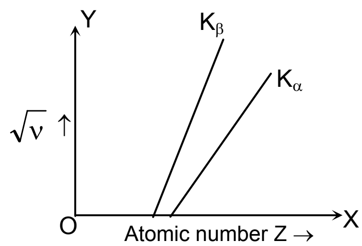
i) This energy spectrum is superimposed over the continuous spectrum.

j) In K series, frequency of $K_{\square}$ is maximum and its wavelength is minimum. Intensity of K_α is maximum.

k) For K-series, $\frac{1}{\lambda} = R(Z-1)^2\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$

l) The wavelength of K_α is greater than that of K_β line.

69. **Moseley's law**:



a) The frequency of a spectral line in the characteristic X-ray spectrum is directly proportional to the square of the atomic number (Z) of the element concerned.

b) $\nu \,\alpha\, Z^2$ or $\sqrt{\nu} = a(Z-b)$ where 'a' is a constant for different series and b is screening constant that varies with series.

c) The slope of the straight line gives the constant 'a' and its intersection with the x-axis gives the constant b.

d) The value of screening constant 'b' is 1 for K_α line and 7.4 for L_α line

70. **Importance of Mosley's law** :

a) According to Mosleys' law, atoms must be arranged in the periodic table by means of their atomic number but not their atomic number but not their atomic weights.

b) Atomic numbers of the rare earth elements could be finalized.

c) Moseley's law led to the discovery of elements like technetium (masurium) (43) hafnium (72), illinium promethium (61), rhenium (75) etc. Moseley justified the ordering of elements Ar, K and Co, Ni and Te, I (Anomalous pairs).

Dual nature of matter : de Broglie's hypothesis :

71. a) In 1924, Louis de Broglie proposed that matter should also possess dual nature as radiation exhibits dual nature.

b) His hypothesis is based on two facts. 1) The whole energy in the universe is in the form of matter and energy i.e.., matter and energy are the manifestations of the same. So these two forms of energy should possess similar characteristics, 2) Nature is symmetrical in many ways. As light has dual nature, matter should also possess dual nature.

c) The wavelength λ of the wave associated with a matter particle of mass m moving with velocity is given by $\lambda = \frac{h}{P} = \frac{h}{mv}$. This relation is known as *de Broglie relation.*

d) de Broglie wavelength of a particle is independent of the nature of the material.

e) de Broglie waves are not electromagnetic waves.

f) They do not move with the velocity of light, and are not produced by charged particles.

g) If a large number of waves of frequencies differing by very small amounts are superimposed, a *wave packet* is formed which will have the same velocity as the particle.

h) A moving particle is always associated with a wave packet rather than a wave.

i) Electromagnetic radiation consists of particle-like discrete bundles of energy called photons or light quanta.

72. **Properties of photon** :

i) The rest mass of a photon is zero while the mass of a moving photon is $\frac{h\nu}{c^2}$ or $\frac{h}{c\lambda}$.

ii) The energy of photon (E) = $h\nu = \frac{hc}{\lambda}$ where

h = Planck's constant.

iii) The momentum of a photon (P) = $\frac{E}{c} = \frac{h\nu}{c} = \frac{h}{\lambda}$.

iv) The effective mass of a photon

(m) = $\frac{E}{c^2} = \frac{h\nu}{c^2} = \frac{h}{\lambda c}$.

v) The intensity of a beam of photons

(I) = $\frac{\text{energy}}{\text{area x time}}$

$= \frac{\text{energy of a photon x number of photons}}{\text{area x time}}$

73. **Broglie wavelength in different forms :**

i) If a material particle is moving with velocity ν and kinetic energy E we have

$$E = \frac{1}{2}m\nu^2 = \frac{P^2}{2m}$$

$$\Rightarrow P = \sqrt{2mE}$$

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

ii) If a charged particle (q) is accelerated by a potential difference of V, then

$$\frac{P^2}{2m} = qV$$

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

iii) de–Broglie's wave lengths associated with different particles :

a) Electron = $\lambda_{electron} = \frac{h}{\sqrt{2mE}} = \frac{h}{\sqrt{2mqV}}$ (or)

$\lambda_{electron} = \frac{12.27}{\sqrt{V}}$ A°

b) Proton : $\lambda_{proton} = \frac{0.286}{\sqrt{V}}$ A°0.

c) Deutron : $\lambda_{deutron} = \frac{0.202}{\sqrt{V}}$ A°

d) α - particle : $\lambda_{\alpha} = \frac{0.101}{\sqrt{V}}$ A°

e) Neutron : $\lambda_{neutron} = \frac{0.286}{\sqrt{E}}$ A°

iv) If a material particle is in thermal equilibrium at temperature T, its kinetic energy is given by

K.E= $\frac{P^2}{2m} = \frac{3}{2}KT \Rightarrow \lambda = \frac{h}{P} = \frac{h}{\sqrt{3mKT}}$

74. **Compton effect :**

a) When a monochromatic beam of X-rays are scattered by a substance, the scattered radiation contains higher wavelength (modified) along with unchanged wavelength (un modified). This phenomenon is known as *Compton effect.*

b) When X-rays fall on matter, a part is scattered without any change in wavelength. This is known as *un modified or coherent or classical* scattering.

c) If the secondary radiation in the previous case contains X-rays of lower frequency or longer wavelength than those of incident beam, it is known as *modified or incoherenet* scattering.

d) In compton scattering an electron is also ejected with an energy depends on its direction. It is known as *compton recoil electron.*

e) Compton effect is due to collision between the incident photon and the free electron in the matter being irradiated. This *collision is elastic.*

f) The energy and momentum carried by the scattered photon and recoiled electron is governed by the laws of conservation of energy and momentum respectively.

h) The kinetic energy of the electron is of same order as the binding energy of it (about 10 keV).

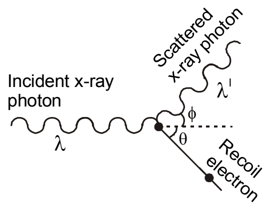
i) As the electron moves with a speed comparable to that of light, its energy and momentum should be considered as per the relativistic equations.

j) If λ is the wavelength of incident radiation and λ^1 is the wavelength of scattered radiation,

$$\lambda^1 - \lambda = \frac{h}{m_0 C}(1-\cos\phi)$$

Here ϕ is scattering angle with respect to the initial direction. m_0 is rest mass of target particle. (generally electron)

Here the particle recoil at an angle θ as shown. The above equation is called Compton equation.



k) Compton shift depends on angle of scattering.

l) Compton shift is independent of the energy of the incident X-ray photon.

m) Compton effect supports quantum nature of light.

n) In Compton effect, the recoil electron has maximum energy when X-ray photon (or radiation) is scattered through 180°.

75. **Compton shift :**

a) The increase in wavelength of incident radiation known as compton shift.

$$\Rightarrow \Delta h = \frac{2h}{m_0 c}\sin^2\left(\frac{\phi}{2}\right)$$

i) If $\phi = 0°$, $\Delta\lambda = 0 \Rightarrow$ no scattering along the direction of incidence. (un modified)

ii) If ϕ = 90° or 270°, $\Delta\lambda = \frac{h}{m_0 c}$ =0.024 A°

iii) If ϕ = 135°, $\Delta\lambda$ = 0.041 A°

iv) If ϕ = 180°, $\Delta\lambda = \frac{2h}{m_0 C}$ =0.048 A°

Here ϕ varies between 0° and 180° and the wavelength of photon varies from λ to $\lambda + \frac{2h}{m_0 c}$

b) Compton wavelength = $\frac{h}{m_0 c}$ =0.024 A°

Maximum compton shift = twice the compton wavelength

c) Compton shift is around 0.04 A°. Hence it can be easily recognised only when the incident radiation is having wavelength less then 1 A° or in that range i.e X –rays and γ - rays etc.

d) Compton shift depends on the scattering angle and the rest mass of the particle with scatters the photon.

e) Compton shift does not depend on the wavelength of incident radiation and on the nature of material in the scattering block.

f) If the electron is free or loosely bound, then photon is scattered by it and m_0 is rest mass of electron. Here compton wavelength and compton shift are considerable.

g) If the electron is rigidly bound in the atom, the atom as a whole recoils. Here m_0 stands for the mass of whole atom. Compton wavelength and compton shift are so small that they cannot be recognised.

h) Compton shift is proportional to $(1-\cos\phi)$, it increases from zero for $\phi = 0$ to $\Delta\lambda=2\lambda$, for $\phi=\pi$.

i) Direction of recoil electron is given by $\tan\theta = \dfrac{\cot\frac{\phi}{2}}{1+\left(\frac{h\nu}{m_0c^2}\right)}$ (or) $\tan\theta = \dfrac{\lambda\sin\phi}{\lambda^1 - \lambda\cos\phi}$

j) K.E of electron = $hc\left[\dfrac{\lambda^1-\lambda}{\lambda\lambda^1}\right]$

76. **Significance of compton effect :**

The compton effect supports

a) Quantum nature of electromagnetic radiation (photo theory)

b) Quantization of momentum of photon.

c) Elastic collisation nature of interaction of EM radiation with matter.