MODERN PHYSICS

1. NUCLEUS

1.1 Isotopes

The atoms of an element, which have the same atomic number but different mass numbers, are called isotopes.

(i) ${}_8O^{16}, {}_8O^{17}, {}_8O^{18}$ (ii) ${}_{17}O^{35}, {}_{17}Cl^{37}$

(iii) ${}_{82}Pb^{206}, {}_{82}Pb^{207}, {}_{82}Pb^{208}$.

1.2 Isotones

The atoms whose nuclei have same number of neutrons are called isotones.

1.3 Isobars

The atoms, which have same mass number but different atomic numbers, are called isobars.

(i) ${}_1H^3$ and ${}_2He^3$ (ii) ${}_3Li^7$ and ${}_4Be^7$

(iii) ${}_{18}Ar^{40}$ and ${}_{20}Ca^{40}$ (iv) Ge^{76} and ${}_{34}Se^{76}$

1.4 Atomic mass unit

The atomic mass unit (a.m.u) is a very small unit of mass and it is found to be very convenient in nuclear physics.

Atomic mass unit is defined as $1/12^{th}$ of the mass of one ${}_6C^{12}$ atom.

According to Avogadro's hypothesis, number of atoms in 12 g of ${}_6C^{12}$ is equal to Avogadro number i.e. 6.023×10^{23}.

Therefore, the mass of one carbon atom (${}_6C^{12}$) is $\frac{12}{6.023\times10^{23}}$ i.e.

1.992678×10^{-26} kg

Therefore, 1 a.m.u. $= \frac{1}{12}\times1.992678\times10^{-26}$ kg

or 1 a.m.u. $= 1.660565 \times 10^{-27}$ kg

1.5 Energy equivalent of atomic mass unit

According to Einstein's mass-energy equivalence relation, the energy equivalent of mass m is given by $E = mc^2$

Where c is speed of light.

Suppose that m = 1 a.m.u = 1.660565×10^{-27} kg

Since, $c = 2.998 \times 10^8\ ms^{-1}$, the energy equivalent of 1 a.m.u is given by 1 a.m.u $= (1.660565 \times 10^{-27}\ kg) \times (2.998 \times 10^8\ ms^{-1})^2$
$= 1.4925 \times 10^{-10}$ J

Since, 1 MeV = 1.602×10^{-13} J, we have $\frac{1.4925\times10^{-10}}{1.602\times10^{-13}}$ eV

Or 1 a.m.u = 931.5 MeV

1.6 Nuclear size

The volume of the nucleus is directly proportional to the number of nucleons (mass number) constituting the nucleus. If R is the radius of the nucleus having mass number A, then

$$\frac{4}{3}\pi R^3 \propto A$$

Or $R \propto A^{1/3}$ Or $R = R_0 A^{1/3}$

1.7 Nuclear density

Mass of the nucleus of the atom of mass number A = A a.m.u $= A \times 1.660565 \times 10^{-27}$ kg. If R is radius of the nucleus, then

Volume of nucleus $= \frac{4}{3}\pi R^3 = \frac{4}{3}\pi (R_0 A^{1/3})^3 = \frac{4}{3}\pi R_0^3 A$

Taking $R_0 = 1.1 \times 10^{-15}$ m, we have

Density of the nucleus, $\rho = \frac{\text{mass of nucleus}}{\text{volume of nucleus}}$

$$= \frac{A\times1.66065\times10^{-27}}{4/3\pi\left(1.1\times10^{-15}\right)^3\times A}$$

$= 2.97 \times 10^{17}\ kg\,m^{-3}$ (independent of A)

Discussion :

- The density of the nuclei of all the atoms is same as it is independent of mass number.
- The high density of the nucleus ($\approx 10^{17}\ kg\ m^{-3}$) suggests the compactness of the nucleus. Such examples of high densities are met in the form of neutron stars.

1.8 Mass defect

The difference between the sum of the masses of the nucleons constituting a nucleus and the rest mass of the nucleus is known as mass defect. It is denoted by Δm.

Let us calculate the mass defect in case of the nucleus of an atom ${}_ZX^A$. The nucleus of the atom contains Z protons and (A–Z) neutrons. Therefore, if $m_N({}_ZX^A)$ is mass of the nucleus of the atom ${}_ZX^A$, then the mass defect is given by

$\Delta m = [Zm_p + (A-Z)m_n - m_N({}_ZX^A)]$

The binding energy of a nucleus may be defined as the energy equivalent to the mass defect of the nucleus. It may be measured as the work required to be done to separate the nucleon an infinite distance apart, so that very no longer intract with each other.

If Δm is mass defect of a nucleus, then according to Einstein's mass-energy relation, binding energy of the nucleus = $\Delta m\ c^2$ (in joule).

Here, mass defect Δm has to be measured in kilogram. In case, mass defect is measured in a.m.u., then

Binding energy of the nucleus = $\Delta m \times 931.5$ (in MeV)

Binding energy = $[Zm_p + (A-Z)m_n - m_N(_ZX^A)] \times 931.5$

1.9 Binding Energy Per Nucleon

The binding energy per nucleon is the average energy required to extract one nucleon from the nucleus.

Thus, binding energy per nucleon $= \frac{\text{binding energy}}{A}$

1.10 Packing Fraction

Packing fraction = (mass defect)/A.

1.11 Natural Radioactivity

The spontaneous transformation of an element into another with the emission of some particle (or particles) or electromagnetic radiation is called natural radioactivity.

1.11.1 Laws of Radioactivity Decay

Rutherford and Soddy studied the phenomenon of radioactivity in details and formulated the following laws, known as the laws of radioactive decay:

1. Radioactivity is a spontaneous phenomenon and one cannot predict, when a particular atom in a given radioactive sample will undergo distintegration.
2. When a radioactive atom disintegrates, either an α-particle (nucleus of helium) or a β-particle (electron) is emitted.
3. The emission of an α-particle by a radioactive atom results in a daughter atom, whose atomic number is 2 units less and mass number is 4 units less than that of the parent atom.

$$_ZX^A \xrightarrow{\alpha-\text{decay}} {}_{Z-2}Y^{A-4}$$

4. The emission of a β-particle by a radioactive atom results in a daughter atom, whose atomic number is 1 unit more but mass number is same as that of the parent atom.

$$_ZX^A \xrightarrow{\beta-\text{decay}} {}_{Z+1}Y^{A}$$

5. The number of atoms disintegrating per second of a radioactive sample at any time is directly proportional to the number of atoms present at that time. The rate of disintegration of the sample cannot be altered by changing the external factors, such as pressure, temperature etc. It is known as radioactive decay law.

According to radioactive decay law, the rate of disintegration at any time t is directly proportional to the number of atoms present at time t i.e. $\frac{dN}{dt} \propto N$ or $\frac{dN}{dt} = -\lambda N$.

Where the constant of proportionally λ is called decay constant of the radioactive sample. It is also known as disintegration constant or transformation constant. Its value depends upon the nature of the radioactive sample. Further, the negative sign indicates that the number of the atoms of the sample decreases with the passage of time.

From equation, we have $\frac{dN}{N} = -\lambda dt$.

Or $\quad \log_e \frac{N}{N_0} = -\lambda t \quad$ Or $\quad \frac{N}{N_0} = e^{-\lambda t}$

Or $\quad N = N_0 e^{-\lambda t}$

1.11.2 Radioactive Decay Constant

According to radioactive decay law, Integrating, we have

$$\frac{dN}{dt} = -\lambda N$$

Or $\quad \boxed{\lambda = \frac{-dN/dt}{N}}$

Hence, radioactive decay constant of a substance (radioactive) may be defined as the ratio of its instantaneous rate of disintegration to the number of atoms present at that time.

Again, $N = N_0 e^{-\lambda t}$

If $t = 1/\lambda$

then, $N = N_0 e^{-\lambda \cdot 1/\lambda} = 1/e\, N_0 = N_0/(2.718) = 0.368\, N_0$

Hence, radioactive decay constant of a substance may also be defined as the reciprocal of the time, after which the number of atoms of a radioactive substance decreases to 0.368 (or 36.8%) of their number present initially.

1.11.3 Half Life

Consider that a radioactive sample contains N_0 atoms at time t = 0. Then, the number of atoms left behind after time t is given by $N = N_0\, e^{-\lambda t}$

From the definition of half life, it follows that when $t = t_{1/2}$, $N = N_0/2$.

Setting the above condition in equation, we have

$$N_0 / 2 = N_0 e^{-\lambda t_{1/2}} = 2$$

Or $e^{-\lambda t_{1/2}} = 1/2$ Or $e^{\lambda t_{1/2}} = 2$

Or $\lambda T = \log_e 2 = 2.303 \log_{10} 2 = 2.303 \times 0.3010 = 0.693$

Or $$\boxed{t_{1/2} = \frac{0.693}{\lambda}}$$

Thus, half life of a radioactive substance is inversely proportional to its decay constant and is characteristic property of its nucleus. It cannot be altered by any known method.

1.11.4 Mean life or average life

The average life of a radioactive substance is defined as the average time for which the nuclei of the atoms of the radioactive substance exist. It is defined by t_{avg}.

$$\boxed{t_{avg} = \frac{1}{\lambda}}$$

1.11.5 Activity of radioactive substance

The activity of a radioactive substance may be defined as the rate at which the nuclei of its atoms in the sample disintegrate.

If a radioactive sample contains N atoms at any time t, then its activity at time t is defined as $A = -\frac{dN}{dt}$.

The negative sign shows that with the passage of time, the activity of the radioactive substance decreases.

Since according to the radioactive decay, law $\frac{dN}{dt} = -\lambda N$ the equation may be expressed as $A = \lambda N$. Since, $N = N_0 e^{-\lambda t}$, we have

Or $$\boxed{\begin{aligned} A &= \lambda N_0 e^{-\lambda t} \\ A &= A_0 e^{-\lambda t} \end{aligned}}$$

Here, $\lambda N_0 = A_0$ is activity of the radioactive sample at time $t = 0$.

1.11.6 Units of activity

The activity of a radioactive sample may be expressed as disintegration per second. The practical unit of activity of a radioactive sample is curie (ci).

The activity of a radioactive sample is called one curie, if it undergoes 3.7×10^{10} disintegrations per second. Thus,

1 curie (ci) = 3.7×10^{10} disintegrations s^{-1}

There is also another unit of radioactivity, called Rutherford (rd).

The activity of a radioactive sample is called one Rutherford, if it undergoes 10^6 disintegration per second.

1 Rutherford (rd) = 10^6 disintegration s^{-1}

1.12 Nuclear fission

The process of splitting of a heavy nucleus into two nuclei of nearly comparable masses with liberation of energy is called nuclear fission.

$$_{92}U^{235} + {_0n^1} \rightarrow [_{92}U^{236}] \rightarrow {_{56}Ba^{141}} + {_{36}Kr^{92}} + 3\,{_0n^1} + Q$$

Neutron reproduction factor is defined as the ratio of the rate of production of neutrons to the rate of loss of neutrons. Thus,

$$k = \frac{\text{rate of production of neutrons}}{\text{rate of loss of neutrons}}$$

A fission reaction will be steady, in case $k = 1$. In case $k > 1$, the fission reaction will accelerate and it will retard, in case $k < 1$.

1.12.1 Nuclear Reactor

Main parts and their functions :-

1. Fuel: It is a fissionable material mostly U^{235}.
2. Moderator: It is used to slow down the neutrons released during the fission. The most common moderators are water, heavy water and graphite.
3. Control Rods: these rods are cadmium or boron, which control the chain reaction by absorbing neutrons.
4. Coolant and Heat Exchange: The coolant takes away heat from the reactor core and in turn heats the water in the heat exchanger to produce steam. The commonly used coolants are liquid sodium and heavy water.
5. Radiation Shielding: These are thick concrete walls, which stop the radiations from going out.

1.12.2 Radiation Hazards

1. The exposure to radioation induces delecterious genetic effects.
2. The strong α-ray exposure can cause lung cancer.
3. The exposure to fast and slow neutrons can cause blindness.
4. The exposure to neutrons, protons and α-particles can cause damage to red blood cells.
5. The exposure to α-particles can cause disastrous effects.
6. The strong exposures to protons and neutrons can cause serious damage to productive organs.

1.12.3 Safety Measures from Radiation Hazards

Following precautions are observed by the workers engaged in this field:

1. The radioisotopes are transferred in thick walled lead containers and are kept in rooms with thick walls of leads.
2. The radioisotopes are handled with the help of remote control devices.
3. The workers are asked to wear lead aprons.
4. The radioactive contamination of the work area is avoided at all costs.

2. CATHODE RAYS

When a potential difference of 10 to 15 kV is applied across the two electrodes of a discharge tube and pressure is reduced to 0.01mm of mercury, the rays known as cathode rays are emitted from the cathode. These rays are independent of the nature of the gas in the discharge tube and their direction of propagation is not affected by the position of the anode.

Properties of Cathode Rays

Cathode rays have the following properties

1. Cathode rays travel along straight lines and cast sharp shadows of the objects placed in their path.
2. Cathode rays are shot out normally from the surface of the cathode.
3. The direction of the cathode rays is not affected by the position of the anode.
4. The cathode rays exert mechanical pressure.
5. The cathode rays produce heat, when they fall upon matter.
6. The cathode rays are deflected by electric and magnetic fields.
7. When cathode rays strike a solid target of high atomic weight such as tungsten, they produce a highly penetrating radiation called the X-rays.
8. Cathode rays ionise the gas through which they pass.
9. Cathode rays can excite fluorescence.
10. Cathode rays can produce chemical changes.
11. Cathode rays can penetrate through thin sheets of matter without puncturing them.
12. Cathode rays are found to have velocity upto one tenth of the velocity of light.

3. FREE ELECTRONS IN METALS

Electron is a fundamental constituent of the atom. A metal contains free electrons, which move about freely through the atomic spaces in a random fashion. But as soon as an electron leaves the metal, immediately an equal positive charge is produced on the surface of the metal. As a result, the electron is pulled back into the metal and hence remains confined to it. The pull on the electrons at the surface is found to depend on the nature of metal surface and is described by a characteristic of the metal, called work function.

Work Function

The minimum energy, which must be supplied to the electron so that it can just come out of the metal surface is called the work function of the metal.

This process is called electron emission and may be achieved in the following ways

(i) Thermoionic emission. In this process of electron emission, the additional energy is supplied in the form of heat. The emitted electrons are known as thermo-electrons.

(ii) Photoelectric emission. In this process, as already discussed, the additional energy is supplied by means of electromagnetic radiation. The emitted electrons are known as photoelectrons.

(iii) Secondary emission. in this process, the fast moving electrons on collision with the metal surface knock out electrons, called the secondary electrons.

(iv) Field emission.

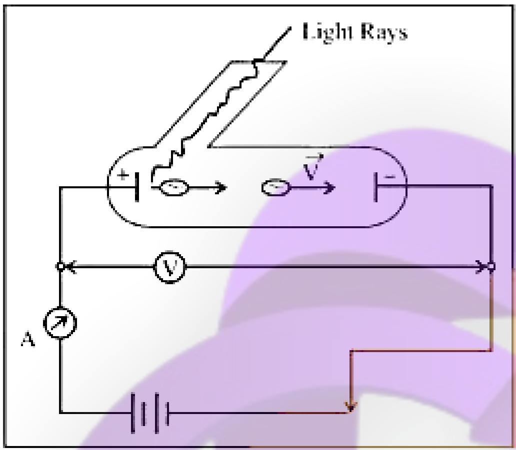
4. PHOTOELECTRIC EFFECT

The phenomenon of ejection from a metal surface, when light of sufficiently high frequency falls upon it is known as the photoelectric effect. The electrons so emitted were called photoelectrons.

Experimental Study of Photoelectric Effect : The apparatus consists of an evacuated glass tube fitted with two electrodes. The electrode E is called emitting electrode and the other electrode C is called collecting electrode.

When a suitable radiation is incident on the electrode E, electrons are ejected from it. The electrons, which have sufficient kinetic energy, reach the electrode C despite its negative polarity. The potential difference between the two electrodes acts as the retarding potential. As the collecting electrode is made more and more negative, fewer and fewer electrons will reach the cathode and the photo-electric current recorded by the ammeter with fall. In case, the retarding potential equals V_0, called the stopping potential, no electron will reach the cathode and the current will become zero. In such a case, the work done by stopping potential is equal to the maximum kinetic energy of the electrons i.e.

$$eV_0 = 1/2\, m v^2_{max}$$



4.1 Laws of Photoelectric Emission

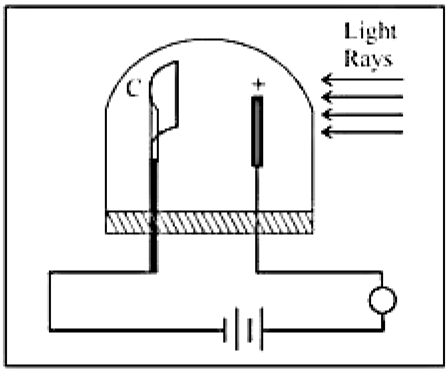
1. The emission of photoelectrons takes place only, when the frequency of the incident radiation is above a certain critical value, characteristic of that metal. The critical value of frequency is known as the threshold frequency for the metal of the emitting electrode.
2. The emission of photoelectrons starts as soon as light falls on metal surface.
3. The maximum kinetic energy with which an electron is emitted from a metal surface is independent of the intensity of the light and depends only upon its frequency.
4. The number of photoelectrons emitted i.e. photoelectric current is independent of the frequency of the incident light and depends only upon its intensity.

4.2 Photoelectric Cell

A photoelectric cell is an arrangement, which converts light energy into electrical energy. Photoelectric cells are of following three types:

1. Photoemissive cells
2. Photovoltaic cells
3. Photoconductive cells

A photo emissive cell may be of vacuum type or gas filled type.



Working - Photoemissive Cells : It consists of two electrodes, a cathode C and anode a enclosed in a highly evacuated glass bulb. The cathode C is a semi-cylindrical plate coated with a photosensitive material, such as a layer. This is called de-Broglie relation of cesium deposited on silver oxide. The anode A is in the form of a wire, so that it does not obstruct the path of the light falling on the cathode.

When light of frequency above the threshold frequency for the cathode surface is incident on the cathode, photoelectrons are emitted. If a potential difference of about 10V is applied between the anode and cathode, the photoelectrons are attracted towards the anode and the microammeter connected in the circuit will record the current.

4.3 Applications of Photoelectric Cells

1. It is used in a television studio to convert the light and shade of the object into electric currents for transmission of picture.
2. It is used in a photographic camera for the automatic adjustment of aperture.
3. It is used for automatic counting of the number of persons entering a hall, a stadium etc.
4. It is used for automatic switching of street lights and traffic signals.
5. It is used for raising a fire alarm in the event of accidental fire in buildings, factories etc.
6. It is used in burglar's alarms for houses, bank and treasuries.

5. DUAL NATURE OF RADIATION

The various phenomena concerning radiation can be divided into three parts:

(i) The phenomena such as interference, diffraction, polarisation etc. in which interaction of radiation takes places with radiation itself. Such phenomena can be explained on the basis of electromagnetic (wave) nature of radiation only.

(ii) The phenomena such as photoelectric effect, compton effect, etc. in which interaction of radiation takes place with matter. Such phenomena can be explained on the basis of quantum (particle) nature of radiation.

(iii) The phenomena such as rectilinear propagation, reflection, refraction, etc. in which neither the interaction of radiation takes place with radiation, nor of radiation with matter. Such phenomena can be explained on the basis of either of the two natures of the radiation.

6. DE-BROGLIE WAVES

Loius-Broglie put forward a bold hypothesis that matter should also possess dual nature.

The following observations led him to the duality hypothesis for matter.

1. The whole energy in this universe is in the form of matter and electromagnetic radiation.
2. The nature loves symmetry. As the radiation has got dual nature, matter should also possess dual nature.

Thus, according to de-Broglie, a wave is associated with every moving particle. These waves are called de-Broglie, waves or matter waves. According to quantum theory of radiation, energy of a photon is given by

$$E = h\upsilon \qquad \ldots(i)$$

Further, the energy of a relativistic particle is given by

$$E = \sqrt{m_0^2c^2 + p^2 + c}$$

Since photon is a particle of zero rest mass, setting $m_0 = 0$ in the above equation, we have

$$E = pc \qquad \ldots(ii)$$

From equation (i) and (ii) we have

$$pc = h\upsilon$$

or $$p = \frac{h\upsilon}{c} = \frac{h\upsilon}{\upsilon\lambda} \qquad (\because c = \upsilon\lambda)$$

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

Therefore, the wavelength of the photon is given by

$$\lambda = \frac{h}{p} \qquad \ldots(iii)$$

Hence, de-Broglie wavelength is given by

$$\lambda = \frac{h}{m\upsilon} \qquad \ldots(iv)$$

This is called de-Broglie relation.

6.1 Conclusion

1. Lighter the particle, greater is its de-Broglie wavelength.
2. The faster the particle moves, smaller is its de-Broglie wavelength.
3. The de-Broglie wavelength of α–particle is independent of the charge or nature of the particle.
4. The matter waves are not electromagnetic in nature. If the velocity of the particle is comparable to the velocity of light, then mass of the particle is given by

$$m = \frac{m_0}{\sqrt{1 - v^2/c^2}}$$

6.2 De-Broglie Wavelength of Electron

Consider that an electron of mass m and charge e is accelerated through a potential difference V. If E is the energy acquired by the particle, then

$$E = eV \qquad \ldots(i)$$

If υ is the velocity of electron, then

$$E = 1/2\, m\upsilon^2 \text{ or } \upsilon = \sqrt{\left(\frac{2E}{m}\right)} \qquad \ldots(ii)$$

Now, de-Broglie wavelength of electron is given by

$$\lambda = \frac{h}{m\upsilon} = \frac{h}{m\sqrt{2E/m}}$$

Or $$\lambda = \frac{h}{\sqrt{2mE}} \qquad \ldots(iii)$$

substituting the value of E, we get

$$\lambda = \frac{h}{\sqrt{2meV}} \qquad \ldots(iv)$$

Setting $m = 9.1 \times 10^{-31}$ kg; $e = 1.6 \times 10^{-19}$ C and $h = 6.62 \times 10^{-34}$ Js, we get

$$\lambda = \frac{12.27}{\sqrt{V}} \times 10^{-10}\text{ m}$$

Or $$\lambda = \frac{12.27}{\sqrt{V}}\text{ Å} \qquad \ldots(v)$$

For example, the de-Broglie wavelength of electrons, when accelerated through a potential difference of 100 volt, will be

$$\lambda = \frac{12.27}{\sqrt{100}} \approx 1.227\text{ Å}$$

Thus, the wavelength of de-Broglie wave associated with 100 eV electrons is of the order of the wavelength of X-rays.

7. THOMSON'S ATOM MODEL

The positive charge is uniformly distributed over the entire sphere and the electrons are embedded in the sphere of positive charges just like seeds in a watermelon or plums in the pudding. For this reason, Thomson's atom model is also known as **plum-pudding model**. The total positive charge inside the atom is equal to the total negative charge carried by electrons, so that every atom is electrically neutral. If the atom gets slightly perturbed, the electrons in the atoms oscillate about their equilibrium position and result in the emission of radiation of definite frequencies in the form of infra-red, visible or ultra-violet light.

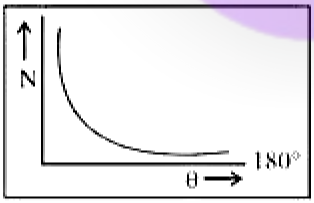
Failure of Thomson's Atom Model

It had to be discarded, because of the following reasons:

1. It could not explain the origin of the spectral lines in the form of series as in case of hydrogen atom.
2. It could not account for the scattering of α-particles through large angles as in case of Rutherford's α-scattering experiment.

8. RUTHERFORD'S ALPHA SCATTERING EXPERIMENT OBSERVATIONS

1. Most of α-particles were found to pass through the fold foil without any appreciable deflection.
2. The different α-particles in passing through the gold foil undergo different amounts of deflections. A large number of α-particles suffer fairly large deflections.
3. A very small number of α-particles (about 1 in 8000) practically retracted their paths or suffered deflection of nearly 180°.
4. The graph between the total number of α–particles $N(\theta)$ scattered through angle θ and the scattering angle θ was found to be as shown in fig.



The experimental observations led Rutherford to the following conclusions:-

1. Since most of the α-particles passed undeviated, the atom has a lot of empty space in it.
2. Since fast and the heavy α-particles could be deflected even through 180°, the whole of the positive charge and practically the entire mass of the atom was confined to an extremely small central core. It was called nucleus. Since 1 in about 8000 α-particles is deflected through 180°, the size of the nucleus is about 1/10000th of the size of the atom.

8.1 Rutherford's Atom Model

On the basis of the results of α-scattering experiment, Rutherford suggested the following picture of the atom:

1. Atom may be regarded as a sphere of diameter 10^{-10} m but whole of the positive charge and almost the entire mass of the atom is concentrated in a small central core called nucleus having diameter of about 10^{-14} m.
2. The nucleus is surrounded by electrons. In other words, the electrons are spread over the remaining part of the atom leaving plenty of empty space in the atom.

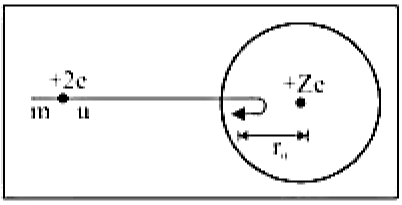
8.2 Drawbacks of Rutherford's Atom Model

1. When the electrons revolve round the nucleus, they are continuously accelerated towards the centre of the nucleus. According to Lorentz, an accelerated charged particle should radiate energy continuously. Therefore, in the atom, a revolving electron should continuously emit energy and hence the radius of its path should go on decreasing and ultimately it should fall into the nucleus. However, electrons revolve round the nucleus without falling into it. Therefore, Rutherford's atom model cannot explain the stability of the atom.
2. If the Rutherford's atom model is true, the electron can revolve in orbits of all possible radii and hence it should emit continuous energy spectrum. However, the atoms like hydrogen possess line spectrum.

8.3 Distance of Closest Approach

Consider the an α-particle of mass m possesses initial velocity u, when it is at a large distance from the nucleus of an atom having atomic number Z. At the distance of closest approach, the kinetic energy of α-particle is completely converted into potential energy. Mathematically,

$$1/2\ mu^2 = -\frac{1}{4\pi\varepsilon_0}\cdot\frac{(2e)(Ze)}{r_0} \qquad \therefore r_0 = \frac{1}{4\pi\varepsilon_0}\cdot\frac{2Ze^2}{1/2\ mu^2}$$

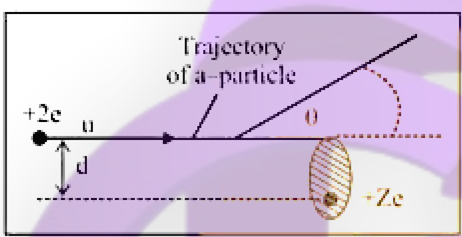


8.4 Impact Parameter

The scattering of an alpha particle from the nucleus of an atom depends upon the impact parameter.

Impact Parameter of the alpha particle is defined as the perpendicular distance of the velocity vector of the alpha particle from the centre of the nucleus, when it is far away from the atom. It is denoted by b.

$$b = \frac{1}{4\pi\varepsilon_0} \cdot \frac{Ze^2 \cot\theta/2}{1/2\, mu^2}$$



8.5 Discussion

The following interference can be drawn from the above equation:

1. If the impact parameter b is large, then cot θ/2 is also large i.e. the angle of scattering θ is small and vice-versa.

   Thus, if an α-particle has large impact parameter, it gets scattered through a very small angle and may practically go undeviated and if the α-particle has small impact parameter, it will be scattered through a large angle.

2. If the impact parameter b is zero, then cot θ/2 = 0 or θ/2 = 90° or θ = 180°.

9. PHOTON

A photon is a packet of energy. It possesses energy given by, $E = h\upsilon$

Where $h = 6.62 \times 10^{-34}$ Js is Plank's constant and υ is frequency of the photon. If λ is wavelength of the photon, then, $c = \upsilon\lambda$.

Hence, $c = 3 \times 10^8\ ms^{-1}$ Js velocity of light. Therefore, $E = h\upsilon = hc/\lambda$.

Energy of a photon is usually expressed in electron volt (eV).

$1eV = 6 \times 10^{-19}$ J

The bigger units are keV and MeV.

$1keV = 1.6 \times 10^{-16}$ and $1\ MeV = 1.6 \times 10^{-13}$ J

10. BOHR ATOMIC MODEL

Bohr adopted Rutherford model of the atom & added some arbitrary conditions. These conditions are known as his postulates :

(i) The electron in a stable orbit does not radiate energy . i.e.

$$\frac{mv^2}{r} = \frac{kze^2}{r^2}$$

(ii) A stable orbit is that in which the angular momentum of the electron about nucleus is an integral (n) multiple of $\frac{h}{2\pi}$. i.e. $mvr = n\frac{h}{2\pi}$; n = 1 , 2 , 3 , ...(n ≠ 0).

(iii) The electron can absorb or radiate energy only if the electron jumps from a lower to a higher orbit or falls from a higher to a lower orbit.

(iv) The energy emitted or absorbed is a light photon of frequency ν and of energy **E = hν**.

10.1 For hydrogen atom : (Z = atomic number = 1)

(i) L_n = angular momentum in the n^{th} orbit $= n\frac{h}{2\pi}$.

(ii) r_n = radius of n^{th} circular orbit $= (0.529\ A^\circ)\, n^2$; $(1A^\circ = 10^{-10}m)$; $r_n \propto n^2$.

(iii) E_n Energy of the electron in the n^{th} orbit $= \frac{-13.6eV}{n^2}$ i.e. $E_n \propto \frac{1}{n^2}$.

Note

Total energy of the electron in an atom is negative, indicating that it is bound.

Binding Energy $(BE)_n = -E_n = \frac{13.6V}{n^2}$.

(iv) $E_{n_2} - E_{n_1}$ = Energy emitted when an electron jumps from n_2^{th} orbit to n_1^{th} orbit $(n_2 > n_1)$.

$$\Delta E = (13.6\,ev)\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right].$$

$\Delta E = h\nu$; ν = frequency of spectral line emitted .

$\frac{1}{\lambda} = \bar{\nu}$ = wave no. [no. of waves in unit length (1m)]

$$= R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right].$$

Where R = Rydberg's constant for hydrogen $= 1.097 \times 10^7\ m^{-1}$.

(v) For hydrogen like atom/species of atomic number Z :

$$r_{nz} = \frac{\text{Bohr radius}}{Z}\, n^2 = (0.529\ A^\circ)\frac{n^2}{Z} ;$$

$$E_{nz} = (-13.6)\ \frac{Z^2}{n^2}\, ev$$

$R_z = RZ^2$ – Rydberg's constant for element of atomic no. Z .

Note...

If motion of the nucleus is also considered, then m is replaced by μ.

Where μ = reduced mass of electron – nucleus system = mM/(m+M).

In this case $E_n = (-13.6\ ev)\ \frac{Z^2}{n^2} \cdot \frac{\mu}{m_e}$

10.2 Spectral Series

(i) **Lyman Series :** (Landing orbit n = 1) .

Ultraviolet region $\bar{v} = R\left[\frac{1}{1^2} - \frac{1}{n_2^2}\right]$; $n_2 > 1$

(ii) **Balmer Series :** (Landing orbit n = 2)

Visible region $\bar{v} = R\left[\frac{1}{2^2} - \frac{1}{n_2^2}\right]$; $n_2 > 2$

(iii) **Paschan Series :** (Landing orbit n = 3)

In the near infrared region $\bar{v} = R\left[\frac{1}{3^2} - \frac{1}{n_2^2}\right]$; $n_2 > 3$

(iv) **Bracket Series :** (Landing orbit n = 4)

In the mid infrared region $\bar{v} = R\left[\frac{1}{4^2} - \frac{1}{n_2^2}\right]$; $n_2 > 4$

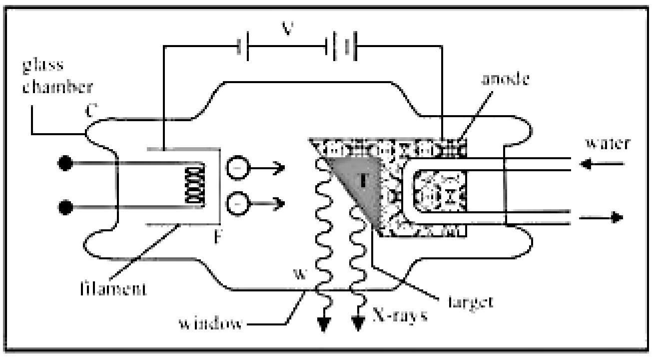
(v) **Pfund Series :** (Landing orbit n = 5)

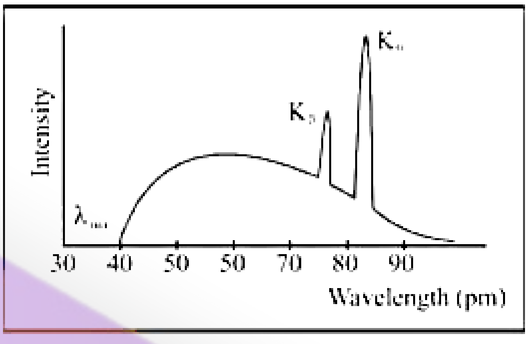
In far infrared region $\bar{v} = R\left[\frac{1}{5^2} - \frac{1}{n_2^2}\right]$; $n_2 > 5$

In all these series n_2 = $n_1 + 1$ is the α line
= $n_1 + 2$ is the β line
= $n_1 + 3$ is the γ line .... etc.

where n_1 = Landing orbit

11. X-RAYS

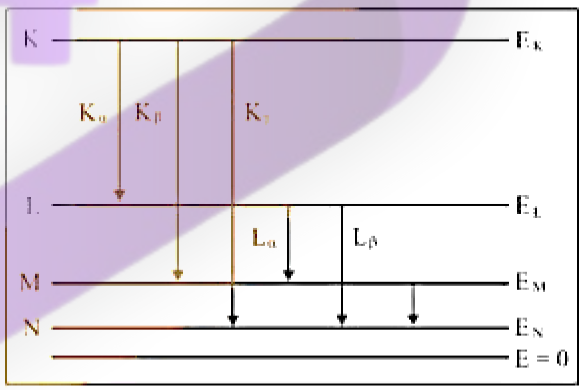




That there is a minimum wavelength below which no X–ray is emitted. This is called the cutoff wavelength or the threshold wavelength.

Certain sharply defined wavelengths, the intensity of X–rays is very large as marked K_α, K_β. These X–rays are known as characteristics X–rays. Other wavelengths the intensity varies gradually and these X-rays are called continuous x-rays.

$$\lambda = \frac{hc}{E} \Rightarrow \lambda_{min} = \frac{hc}{eV}$$



$$\lambda = \frac{hc}{E_K - E_L} \text{ for } K_\alpha$$

$\Rightarrow$ $\lambda = \frac{hc}{E_K - E_M}$ for K_β, $\Rightarrow$ $\lambda = \frac{hc}{E_L - E_M}$ for K_α.