CHAPTER # 2
ATOMIC STRUCTURE

Q1. Summarize the modification of Daltonian concept of the atom.

Ans: Modification of Daltonian Concept of the Atom:

A series of discoveries beginning during the later part of 19th century have modified the Daltonian concept of the atom by demonstrating that an atom is a complex unit made up of similar discrete arts. Atoms are not simple, compact bodies as supposed by Dalton but are complex systems composed of several fundamental particles of matter. The modern theories have proved that an atom is made up of about 100 particles out of which electrons, protons and neutrons are whole time existing and important particles.

Knowledge of the structure of atom has made it possible for the facts of the chemistry to be systematized in such a way that the subject is easier to understand and remember. Chemical reactions that occur between atoms and the force that holds atoms together can be explained in terms of atomic structure.

It is essential to study the details of these sub-atomic particles.

Q2. List the main sub-atomic particles.

Ans: Main sub-atomic Particles:

There are about 100 particles in an atom; about 36 are oftenly seen like electrons, protons, neutrons, electrino, antielectrino, protino, antiprotino, neutrino, antineutrino, mesons and positrons. But first 3 particles are permanently present in an atom i.e. electrons, protons and neutrons.

Q3. How electrons were discovered by discharge tube experiment?

Ans: Discovery of the Electron:

The electrons were first identified by cathode ray tube (or electric discharge tube) by J.J. Thomson in 1887. Many other scientists like Faraday, Crooks and Goldstein studied the effects of passing electric current through a gas. As a result a sub-atomic particle electron with a negative charge was discovered.

Working of Discharge Tube:

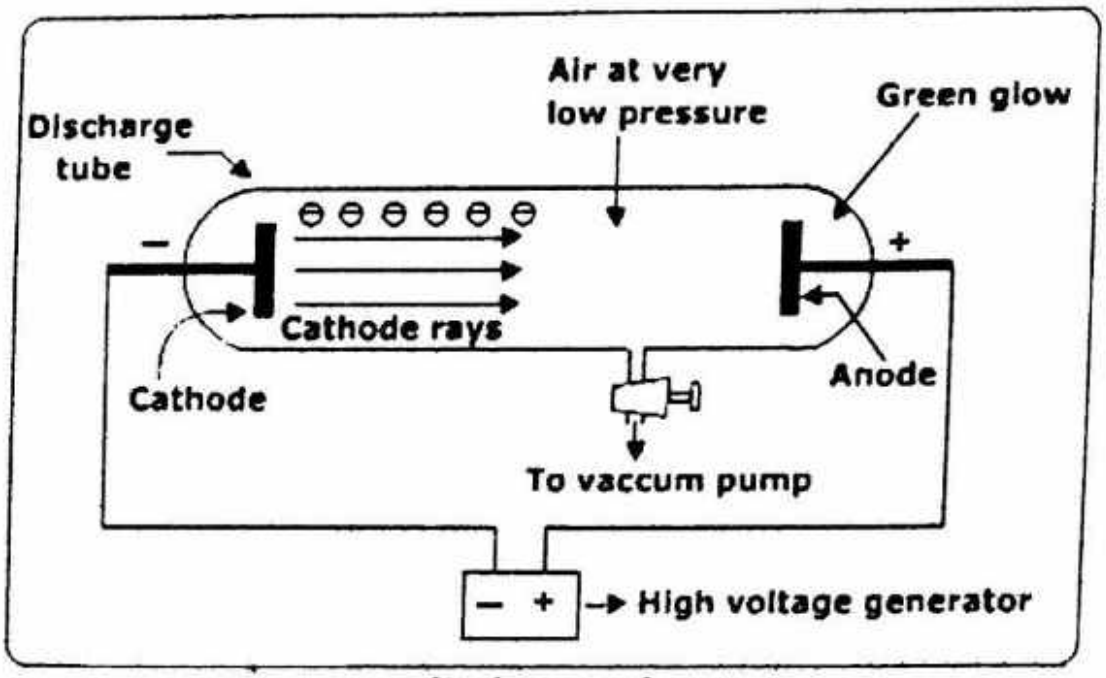
In the beginning, an electric current was passed through the gas in the discharge tube at ordinary pressure. The gas in the tube was not affected even at high potential of 5000 volts.

Low pressure is necessary to get cathode rays in the discharged tube:

Then the gas was discharged at a low pressure of 0.01 Torr, and given high voltage of 5000 -10,000 volts. It was observed that the original glow disappeared, the gas became conductor, current started to flow and the gas started to emit light (example of discharge tube is a road neon sign).

Emission of cathode rays:

When the pressure is reduced further, emission of light by the gas ceases. Certain rays were given out from cathode and travel towards anode. The rays emitted were called cathode rays because they originated from cathode.



A discharge tube

Q4. Describe the Some systematic properties of cathode rays.

Ans: Properties of cathode rays:

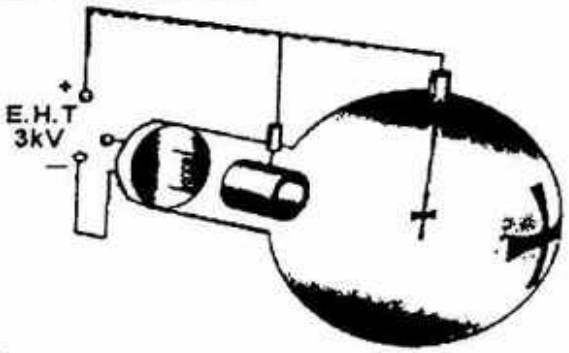
Some systematic studies were made by certain scientists in order to investigate the properties of cathode rays. These properties are mentioned below.

Cathode rays are negatively charged particles:

Cathode rays are negatively charged particles. J-Perrin (1895) showed that cathode rays are deflected in a magnetic field. J.J. Thomson (1897) proved that these rays can be deflected towards anode showing that they are negatively charged. They produce a greenish fluorescence on striking the walls of the glass tube.

Cathode rays cast a sharp shadow:

Hittorf (1869) proved that cathode rays cast a sharp shadow when an opaque object is placed in their path. This proves that they travel in straight line perpendicular to the surface of cathode.



Cathode rays casting shadow of an opaque object

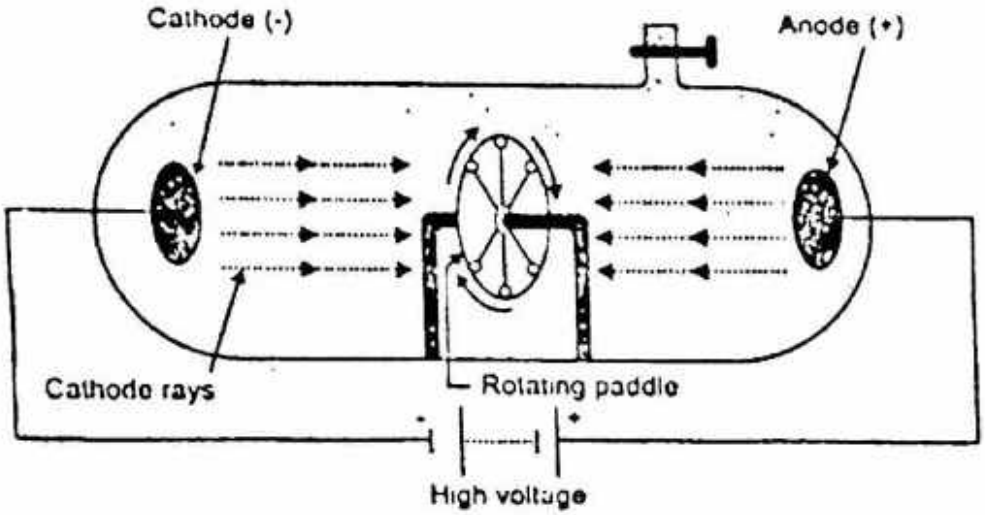
Cathode rays are material particles:

Cathode rays can drive a small paddle wheel placed in their path. This verifies that they are material particles and have certain momentum also.

Cathode rays can produce X-rays:

Cathode rays can produce x-rays when they strike on an anode, particularly with large atomic mass. They produce heat when they fall on a platinum foil and foil

begins to glow. They can ionize gases. They can cause a chemical change in a material on which they fall. They are capable of penetration in metallic sheets like of Aluminium or Gold.



Cathode rays moving a small pedal wheel

$\frac{e}{m}$ Value of an electron:

J.J. Thomson determined $\frac{e}{m}$ value of an electron. He concluded that all atoms contain electrons. The value of $\frac{e}{m}$ is 1.7588×10^{11} coulombs Kg^{-1}.

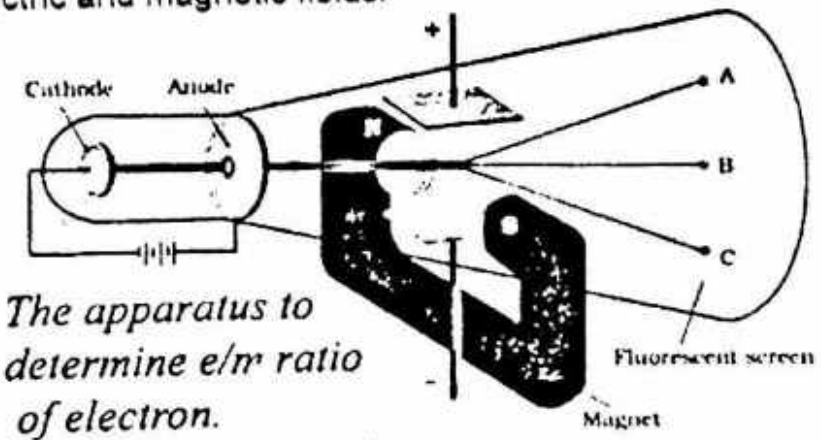
Electrons are fundamental particles of all atoms:

Whatever the gases and the vapour in the discharge tube, the cathode rays and the electrons are always the same. This proves that electrons are fundamental particles of all atoms.

Q5. Explain measurement of $\frac{e}{m}$ and charge of an electron.

Ans: Measurement of $\frac{e}{m}$ and charge of an electron:

J. J. Thomson subjected a beam of cathode rays (electron particles) to see the effects of electric and magnetic fields.



The apparatus to determine e/m ratio of electron.

Cathode rays in electric and magnetic rays

J. J. Thomson Experiment:

i. In the beginning, in absence of any electric or magnetic field, the electrons from cathode rays struck the fluorescent screen at B.

ii. Then under the effect of electric field, they strike at point A.

iii. Similarly they strike at point C under the influence of magnetic field only. Now electric and magnetic fields were adjusted in such a way, that the electron again strike at point B

Conclusion:

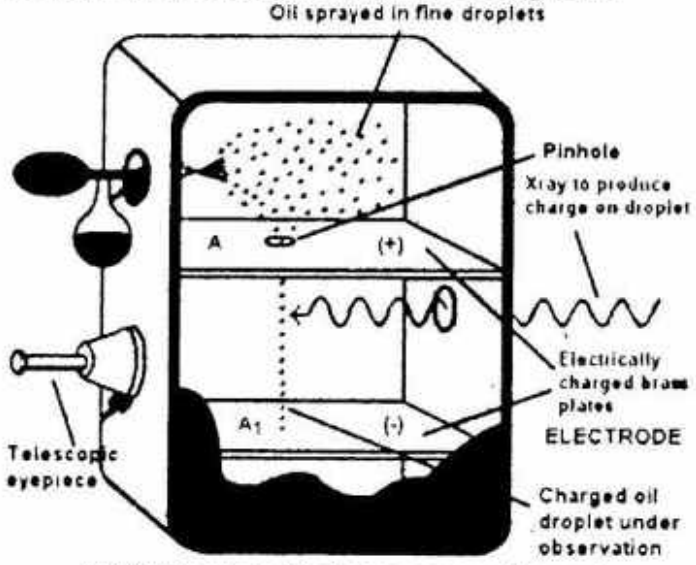
In this way by comparing the strength of the two fields, he determined the $\frac{e}{m}$ value of an electron which is 1.7588×10^{11} coulombs kg^{-1} This means that 1 kg of electrons have 1.7588×10^{11} coulombs of charge

Q6. Explain Millikan's oil drop experiment to determine the charge of an electron.

Ans: Determination of charge of Electron:

Instrumentation:

Millikan constructed a box which consisted of two chambers. The upper chamber was filled with air whose pressure was adjusted by a vacuum pump. There were installed two electrodes A and A_1. The electrodes were attached with electricity to generate an electric field in the space between the electrodes. The upper electrode had a hole in that as shown in the diagram.



Millikan's oil drop experiment

Spray of oil droplets:

A fine spray of oil droplets was created by an atomizer. Few droplets entered the hole. Then the hole was closed.

Use of an arc lamp:

An arc lamp was used to illuminate the space between the electrodes. The droplet fell under the force of gravity. The velocity (V_1) of the droplet was determined depending upon its weight.

$$V_1 \propto m \times g \quad \text{---------- (i)}$$

Where m is mass of particle and g is acceleration due to gravity.

Application of battery:

After that the air between the electrodes was ionized by X-rays. The droplet under observation took up an electron and got charged. Then A and A_1 were connected to a battery which generated an electric field having a strength H. The droplet moved upwards against gravitational force with a velocity V_2.

i.e. $V_2 \propto E \times e - m \times g$ ---------- (ii)

Where E is strength of electric field and e is charge on electron.

Conclusion:

Dividing Eq.(ii) by Eq.(i) $\frac{v_1}{v_2} = \frac{m \times g}{E \times e - mg}$

If V_1, V_2, g and E are known, mass of an electron can be determined by varying the electric field in such a way that the droplet is suspended in the chamber. Hence "e" can be calculated which is 1.6022×10^{-19} coulombs.

Charge of an electron:

Millikan further confirmed the charge of an electron. This charge can also be deduced from the known values of Faraday's constant and Avogadro's Number.

Q7. How Faraday's law of electrolysis help us to calculate charge on electron?

Ans: Faraday's Method to calculate charge on electron:

According to the Faraday's Laws of electrolysis, one Faraday = 9.65×10^4 coulombs mol^{-1}. Also one Faraday is the charge carried by 1 mole of electrons. Which is equal to 6.02×10^{23} electrons $mole^{-1}$ called Avogadro's number.

So, 6.02×10^{23} electron $mole^{-1} = 9.65 \times 10^4$ Coulomb $mole^{-1}$.

One electron $mole^{-1} = \frac{9.65 \times 10^4}{6.02 \times 10^{23}} \frac{\text{Coul mole}^{-1}}{\text{electron mole}^{-1}} = 1.6022 \times 10^{-19}$ **Coulomb per electron.**

Q8. How can we calculate the mass of an electron by using e/m ratio?

Ans: Determination of Mass of an Electron:

We calculate the mass of an electron by using e/m ratio.

We know that $\frac{e}{m} = 1.7588 \times 10^{11}$ Coulomb kg^{-1}

but $e = 1.6022 \times 10^{-19}$ Coulomb

$$\frac{1.60 \times 10^{-19} C}{m} = \frac{1.7588 \times 10^{11} C kg^{-1}}{1}$$

or $m \times 1.7588 \times 10^{11}$ C $kg^{-1} = 1.60 \times 10^{-19}$ C

$$m = \frac{1.60 \times 10^{-19} C}{1.7588 \times 10^{11} C kg^{-1}} = 9.1095 \times 10^{-31} kg$$

Mass of electron, compared with the mass of H-atom is much less which is

Mass of H-atom $= \frac{1.008 \times 10^{-3} \text{ kg mole}^{-1}}{6.02 \times 10^{23} \text{ atom mole}^{-1}} = 1.67 \times 10^{-27}$ kg $atom^{-1}$

Example 1: How much heavier is the H-atom as compared to an electron?

Solution: As we know that

Mass of H atom = 1.67×10^{-27}kg Mass of electron = 9.11×10^{-31}kg

$$\frac{\text{Mass of H-atom}}{\text{Mass of electron}} = \frac{1.67 \times 10^{-27} \text{ kg/H-atom}}{9.11 \times 10^{-31} \text{ kg/electron}} = \frac{1833}{1}$$

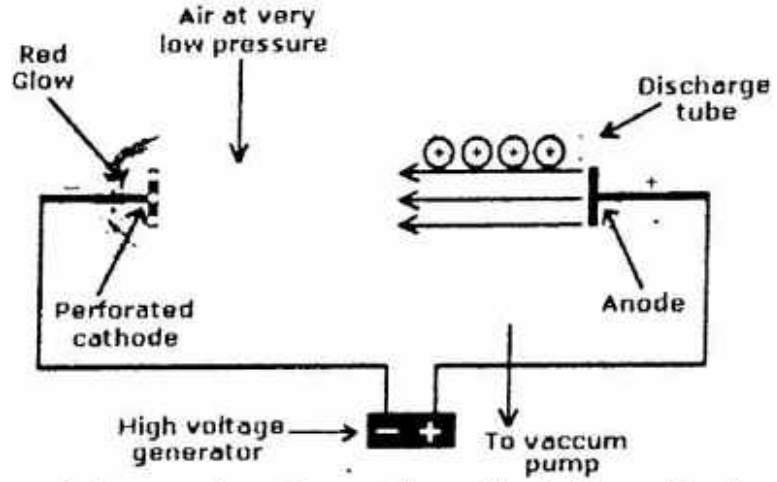
Hence Hydrogen atom is 1833 times heavier than an electron.

Q9. Discuss Goldstein experiment for the discovery of positive rays or canal rays.

Ans: Positive Rays or Canal Rays:

(Discovery of Proton by Goldstein, a German Physicist 1886):

In a discharge tube, atoms or molecules lose electrons forming positive ions. Typical example is of ionization of Neon gas. ($Ne - e \rightarrow Ne^{+1}$). It is observed that the positive ions move towards cathode in a discharge tube.



Positive particles moving towards cathode in a discharge tube.

Construction and Working:

About one metre long tube was taken which was provided with a perforated cathode as shown in the diagram. The electrodes were connected to a high voltage battery.

Atom being electrically neutral must contain equal number of positive and negative particles. When electric current was passed through the gas under reduced pressure, some rays are produced from cathode which travelled away from cathode. Such rays ionize the gas in the middle of the discharge tube. They knocked out electron from the gas molecules. As a result positive ions were produced, which start moving towards the perforated cathode.

$$M \xrightarrow{e^-} M^{+1}$$

$$He \xrightarrow{2e^-} He^{+2}$$

Conclusion:

Since these rays passed through the canals (small holes) of cathode so they were also called as "Canal rays". Later on they were called Positive rays because they carried positive charge.

Q10. List the properties of positive rays or canal rays.

Ans: Properties of Positive Rays:

Positive rays have the following properties:

i) They travel in straight line perpendicular to the anode surface.

ii) They can be deflected in electric field.

iii) Their deflection is towards cathode showing that they are positively charged.

iv) They produce flashes on ZnS plate.

v) Their $\frac{e}{m}$ ratio is smaller than that of an electron.

vi) The $\frac{e}{m}$ ratio depends upon the nature of the gas. The highest $\frac{e}{m}$ is obtained if Hydrogen gas is present in the tube.

vii) The mass of a +ve particle is never less than that of a proton.

viii) The positive particle obtained from H_2 gas is the lightest among all the positive particles.

ix) A particle obtained from positive rays is called proton, a name suggested by Rutherford.

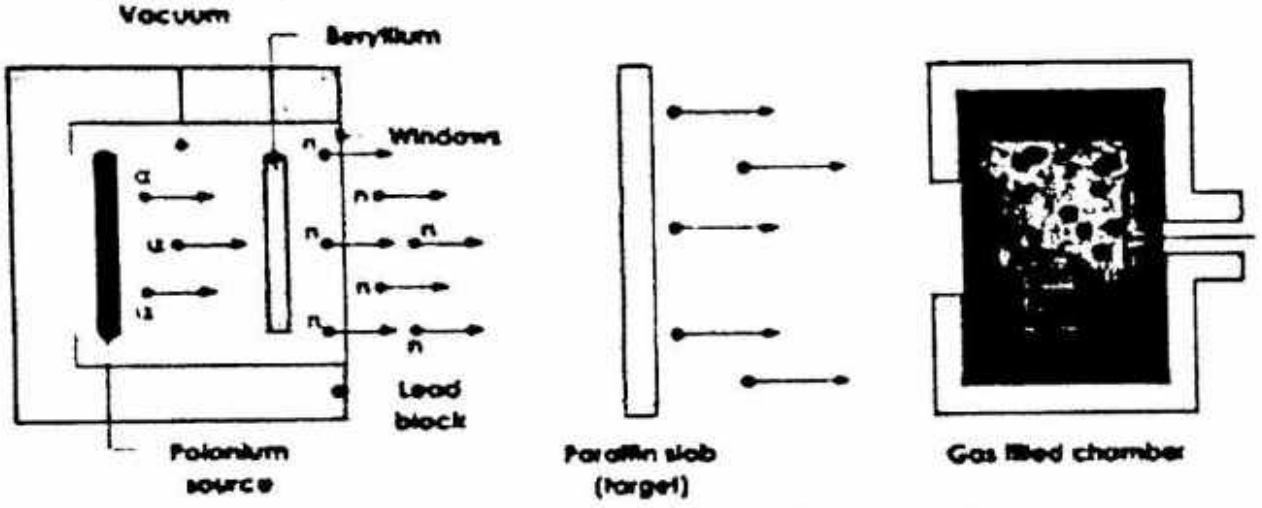
x) The mass of a proton is 1836 times more than that of an electron.
As proton is present in all the atoms therefore proton is a common constituent of all matter.

Q11. Discuss discovery of neutrons by James Chadwick.

Ans: Discovery of Neutrons (by James Chadwick 1932):

Experiment by James Chadwick:

A stream of α-particles produced from Polonium (Po) was directed at target metal foil ${}_4Be^9$.



α – rays bombarded on Beryllium sheet

It was noticed that some penetrating radiations were produced. These radiations were called neutrons, because the charge detector showed them to be neutral.

Nuclear reaction:

The nuclear reaction is as follows:

${}_4Be^9 + {}_2He^4$ (α-particles) $\longrightarrow {}_6C^{12} + {}_0n^1$ (neutron).

Q12. Highlight the properties of neutron.

Ans: Properties of neutrons:

Neutrons have the following properties,

i. Free neutron decays into a proton with the emission of electron and neutrino.

ii. ${}_0n^{1*} \longrightarrow {}_1p^1 + {}_1e^0 + {}_0n^0$ (neutrino, particle of a small mass).

iii. They cannot ionize gases.

iv. They are highly penetrating particles.

v. When neutrons travel with energy 1.2 Mev or more, they are called Fast Neutrons. And when have energy below 1 e.v., they are called slow neutrons.

vi. They are not deflected in electric and magnetic fields. Hence they are neutral in nature.

vii. They can knockout high speed protons from paraffins, water, paper and cellulose.

viii. Slow neutrons are more effective than the fast ones for the fission purposes.

ix. When neutrons are used as projectile, they can carry out the nuclear reactions.

e.g. $N_7^{14} + n_0^1 \longrightarrow B_5^{11} + He_2^4$

When slow moving neutrons hit the Cu metal, β – radiations are emitted.

$$^{65}_{29}Cu + {}^{1}_{0}n \longrightarrow {}^{66}_{29}Cu + h\upsilon$$

$$^{66}_{29}Cu \longrightarrow {}^{66}_{30}Zn + {}^{0}_{-1}e \ (\beta - \text{radiations}).$$

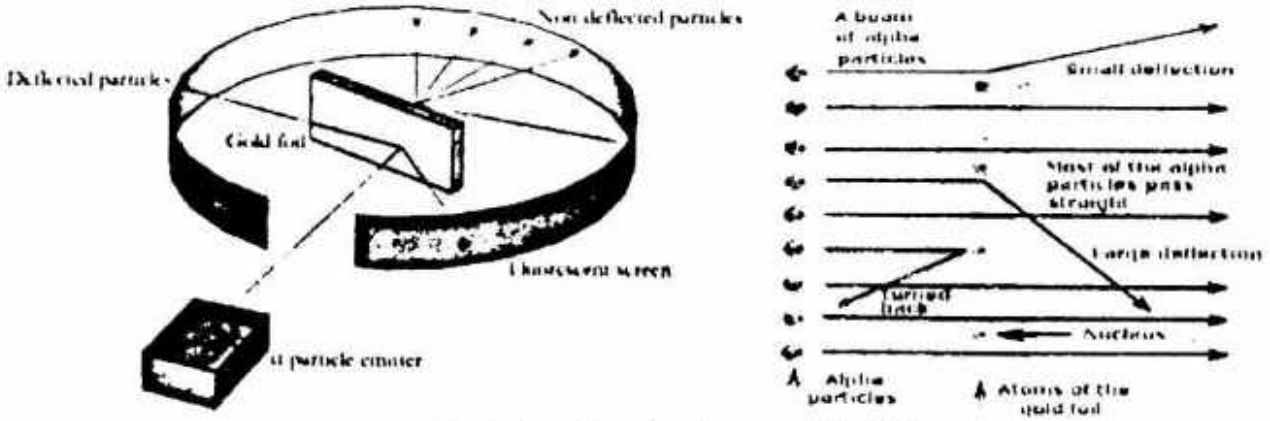
Because of their intense biological effects, they are used in the treatment of cancer.

Note: one a.m.u (atomic mass unit) = 1.6×10^{-27} kg.

Q13. Explain the discovery of nucleus by Rutherford's experiment.

Ans: The Discovery of Nucleus (Rutherford's Experiment, 1910 – 11):

After the discovery of electron, proton and neutron in an atom, the next problem was to locate their positions. Rutherford in 1910 performed an experiment by bombarding α – particles ($_2He^4$) from a radioactive element (R_a or P_o) on a thin metallic foil (0.0004 cm thick). He observed that the α - particles were scattered in all the directions as seen by ZnS detector. A few were deflected through various angles, so much so that some of these particles were deflected in backward direction.



α – rays bombarded on gold foil

Rutherford's Conclusions (Rutherford's Atomic Model):

1. An atom consists of a small heavy positively charged portion called Nucleus.

2. There is a negatively charged portion which surround the nucleus containing electrons called extra – nuclear portion or planetary.

3. The number of protons in the nucleus are equal to the number of electrons in the planetary.

4. The electrons revolve around the nucleus.

5. The centripetal force is equal to the electrostatic force.

6. Only a very small volume is occupied by the nucleus.

Q14. Compare the properties of three fundamental particles.

Ans: Properties of three Fundamental Particles:

Particle	Charge/ Coulomb	Relative charge	Mass/Kg	Mass(a.m.u)	Where found
Proton	$+ 1.6022 \times 10^{-19}$	+ 1	1.6727×10^{-27}	1.0073	In the nucleus
Neutron	0	0	1.6750×10^{-27}	1.0087	In the nucleus
Electron	$- 1.6022 \times 10^{-19}$	-1	9.1095×10^{-31}	5.4858×10^{-4}	Outside nucleus

Q15. Explain the defects of Rutherford's atomic model.

Ans: According to the Rutherford's atomic model the structure of atom was like a planet. It was defective because the revolving electron around nucleus had to lose energy. As a result the electron would be accelerated to the nucleus and the radius of orbit become smaller and smaller and ultimately should fall in to the nucleus. Therefore the atomic structure would collapse.

Q16. Discuss the Bohr's atomic model.

Ans: Bohr's Atomic Model and Its Applications:

Neil Bohr (1913), an English scientist, removed these defects and proposed another possible structure of atom called as the Bohr's atomic model. ***According to this model,***

i. Electrons revolve around the nucleus in definite energy levels called orbits or shells.

ii. As long as an electron remain in a shell it never gains or losses energy.

iii. The gain or loss of energy occurs within orbits only due to jumping of electrons from one energy level to another energy level.

iv. Angular momentum (**mvr**) of an electron is equal to $\frac{nh}{2\pi}$.

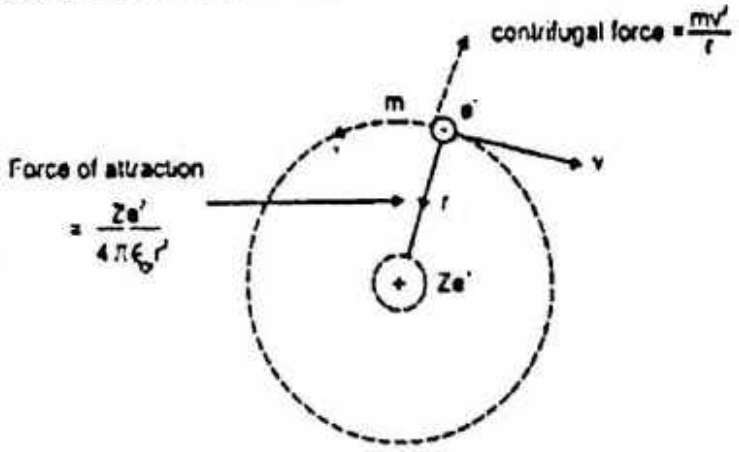
The angular momentum of an orbit depends upon its quantum number and it is an integral multiple of the factor $\frac{h}{2\pi}$.

i.e. $mvr = \frac{nh}{2\pi}$ Where n = 1, 2, 3, ...

Q17. Derive the equation for the radius of n^{th} orbit of hydrogen atom using Bohr's atomic model also calculate radius of first and second orbit.

Ans: Derivation of Radius of an Orbit of an Atom:

Let us consider an atom having an electron $\bar{e}$ moving around the nucleus having charge Ze, where Z is the Atomic No. Let m be the mass, r the radius of the orbit and v, the velocity of the revolving electron.



Now electrostatic force or Coulomb's force of attraction = $\frac{ze^+ \times e^-}{4\pi\varepsilon_o r^2} = \frac{ze^2}{4\pi\varepsilon_o r^2}$

Where ε_o is the permittivity constant with a value 8.84×10^{-12} C^2 J^{-1} m^{-1} and centrifugal force acting on the moving electron = $\frac{mv^2}{r}$

These two forces are equal and opposite and balance each other. So,

$$\frac{mv^2}{r} = \frac{ze^2}{4\pi\varepsilon_o r^2} \quad \text{..... (1)}$$

$$mv^2 = \frac{ze^2}{4\pi\varepsilon_o r}$$

$$r = \frac{ze^2}{4\pi\varepsilon_o mv^2} \quad \text{..... (2)}$$

Thus we conclude that the radius of a moving electron is inversely proportional to the square of its velocity.

Now we consider angular momentum. According to Neil Bohr,

$$mvr = \frac{nh}{2\pi} \quad \text{..... (3)}$$

$$v = \frac{nh}{2\pi mr}$$

Taking square on both sides,

$$v^2 = \frac{n^2h^2}{4\pi^2m^2r^2} \quad \text{..... (4)}$$

Putting this value of v^2 in (2),

$$r = \frac{ze^2}{4\pi\varepsilon_o m} \times \frac{4\pi^2m^2r^2}{n^2h^2}$$

$$\frac{1}{1} = \frac{Ze^2\pi mr}{\varepsilon_o n^2h^2}$$

or $Ze^2\pi\, mr = \varepsilon_o n^2h^2$

$$r = \frac{\varepsilon_o n^2h^2}{Ze^2m\pi} \quad \text{..... (5)}$$

For hydrogen, $Z = 1$

So, $$r = \frac{\varepsilon_o n^2h^2}{\pi me^2} \quad \text{..... (6)}$$

or $r = n^2\, a^\circ$

where $a^\circ = \frac{\varepsilon_o h^2}{\pi me^2}$, a constant quantity having a value of:

0.529×10^{-10} m = 0.529 A° = 10^{-10} m (1 angstrom = 1A° = 1.0×10^{-10} meters)

so, $r = n^2 \times 0.529\ A^0$

Therefore radius of orbits having n = 1, 2,----- are as follows.

When n = 1, $r = 1^2 \times 0.529A^\circ = 0.529A^\circ$

When n = 2, $r = 2^2 \times 0.529A^\circ = 4 \times 0.529\ A^\circ = 2.116\ A^\circ$

Q18. Derive the formula for calculating the energy of an electron in n^{th} orbit using Bohr's model. And Calculate the energy of an electron upto fifth energy level.

Ans: Derivation of Energy of an Orbit:

The energy of an electron in an orbit is the sum of its potential energy and kinetic energy.

$$E_{Total} = K.E + P.E.$$

$$= \frac{1}{2}mv^2 + \left(-\frac{ze^2}{4\pi\varepsilon_o r}\right) \quad \ldots\ldots\ldots\ldots (i)$$

$$E_{total} = \frac{1}{2}mv^2 - \frac{ze^2}{4\pi\varepsilon_o r}$$

This potential energy is governed by the coulomb's Law of Electrostatic force.

Putting the value of $mv^2 = \frac{ze^2}{4\pi\varepsilon_o r}$ into eq. (i) we get

$$E_n = \frac{1}{2}\left[\frac{ze^2}{4\pi\varepsilon_o r}\right] - \frac{ze^2}{4\pi\varepsilon_o r}$$

$$= \frac{ze^2}{4\pi\varepsilon_o r}\left[\frac{1}{2} - \frac{1}{1}\right] = \frac{ze^2}{4\pi\varepsilon_o r}\left[-\frac{1}{2}\right]$$

$$= -\frac{ze^2}{8\pi\varepsilon_o} \quad \ldots\ldots\ldots\ldots (ii)$$

Now putting the value of $r = \frac{\varepsilon_o n^2 h^2}{Ze^2 m\pi}$ in to eq. (ii)

$$E_n = \frac{1}{2}\left[\frac{ze^2}{4\pi\varepsilon_o r}\right] - \frac{ze^2}{4\pi\varepsilon_o r}$$

$$E_n = -\frac{ze^2}{8\pi\varepsilon_o} \times \left[\frac{\pi m z e^2}{\varepsilon_o n^2 h^2}\right]$$

$$= -\frac{mz^2e^2}{8\varepsilon_o^2 n^2 h^2} \quad \ldots\ldots\ldots\ldots (iii)$$

For Hydrogen atom; $Z = 1$

$$\therefore \quad E_n = -\frac{me^4}{8\varepsilon_o^2 n^2 h^2}$$

$$= -\frac{me^4}{8\varepsilon_o^2 h^2}\left[\frac{1}{n^2}\right]$$

But $$\frac{me^4}{8\varepsilon_o^2 h^2} = 2.178 \times 10^{-18}\ J$$

This value is obtained by putting the values of constants.

$$E_n = -2.178 \times 10^{-18}\left[\frac{1}{n^2}\right] J \quad \ldots\ldots\ldots\ldots (iv)$$

$$= -\frac{k}{n^2} \text{ where } k = 2.178 \times 10^{-18}.$$

The negative sign indicates decrease in energy of the electron.

Energy of ground state and excited state:

The value of energy obtained is in Joules/atom. If this quantity is multiplied by Avogadro's Number and divided by 1000, the value of E_n becomes.

$$E_n = -\frac{1313.315}{n^2} \text{ KJ / mole.}$$

This energy is associated with 1.008 gram-atoms of hydrogen.

If n = 1, 2, 3 4, 5.....

then

$$E_1 = -\frac{1313.31}{1^2} = -1331.31 \text{KJ mole}^{-1}$$

$$E_2 = -\frac{1313.31}{2^2} = -328.32 \text{ KJ mole}^{-1}$$

$$E_3 = -\frac{1313.31}{3^2} = -145.92 \text{ kJ mole}^{-1}$$

$$E_4 = -\frac{1313.31}{4^2} = -82.05 \text{ kJ mole}^{-1}$$

$$E_5 = -\frac{1313.31}{5^2} = -52.53 \text{ kJ mole}^{-1}$$

The first energy level when n = 1 is known as the ground state of the Hydrogen atom. All other energy levels are known as excited states.

Q19. Calculate the energy difference between two levels n_1 and n_2.

Ans: Energy difference between two levels n_1 and n_2:

According to Eq. (iii) $\quad E = -\frac{mZ^2e^4}{8\varepsilon_0^2 n^2 h^2}$

Let E_1 be the energy of the orbit n_1 and E_2 that of n_2.

Then $\quad \Delta E = E_2 - E_1$

$$= \frac{mZ^2e^4}{8\varepsilon_0^2 n_2^2 h^2} - \frac{mZ^2e^4}{8\varepsilon_0^2 n_1^2 h^2} = \frac{mZ^2e^4}{8\varepsilon_0^2 n_1^2 h^2} - \frac{mZ^2e^4}{8\varepsilon_0^2 n_2^2 h^2}$$

$$= \frac{mZ^2e^4}{8\varepsilon_0^2 h^2}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

For Hydrogen, Z = 1

$$\therefore \Delta E = \frac{me^4}{8\varepsilon_0^2 h^2}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right] \quad \text{..... (v)}$$

Here, $\quad \frac{me^4}{8\varepsilon_0^2 h^2} = 2.18 \times 10^{-18} \text{ J.}$

$$\Delta E = 2.18 \times 10^{-18} \text{ J}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right] \quad \text{..... (vi)}$$

Q20. Derive frequency of photon emitted when an electron jumps from n_2 to n_1.

Ans: Derivation of frequency (υ):

According to Plank's Quantum theory,

$$\Delta E = h\nu$$

$$h\nu = 2.18 \times 10^{-18}\ J \times \left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right].$$

Again $$h\nu = \frac{me^4}{8\varepsilon_0^2 h^2}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

or $$\nu = \frac{me^4}{8\varepsilon_0^2 h^2}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]\ \text{Hz or cycles sec}^{-1}$$

Q21. Derive wave number of photon emitted when an electron jumps from n_2 to n_1.

Ans: Derivation of Wave Number ($\bar{\upsilon}$):

The relationship between frequency (ν) and wave number ($\bar{\upsilon}$) is

$$\nu = \bar{\upsilon} c \quad \ldots\ldots\ldots\ldots\ldots\ldots\ (i)$$

Where c is the velocity of light.

Putting the value of $\nu = \frac{me^4}{8\varepsilon_0^2 h^2}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$ in eq. (i)

$$\bar{\upsilon} c = \frac{Z^2 me^4}{8\varepsilon_0^2 h^3}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

or $$\bar{\upsilon} = \frac{Z^2 me^4}{8\varepsilon_0^2 h^3 C}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

Putting values of constants, $\frac{me^4}{8\varepsilon_0^2 h^3 C} = R = 1.09678 \times 10^7\ m^{-1}$,

A factor called Rydberg's constant, R.

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

$$\bar{\upsilon} = 1.09678 \times 10^7\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right] m^{-1}$$

Example 2: Calculate the value of a_o of H – atom.

Solution: We know that $a_0 = \frac{\varepsilon_o h^2 n^2}{\pi m e^2}$

The values of the constant are:

$\varepsilon_o = 8.854 \times 10^{-12}\ c^2\ J^{-1}\ m^{-1}$ $\quad$ $h = 6.626 \times 10^{-34}$ J sec.

$\pi = 3.142$ $\quad$ $m = 9.11 \times 10^{-31}$ kg

$e = 1.60 \times 10^{-19}$ C. $\quad$ $n = 1$ (For H)

Putting these values in equation, $a_o = \frac{\varepsilon_o h^2 n^2}{\pi m e^2}$

$$a_o = \frac{8.854\times10^{-12}C^2J^{-1}m^{-1}\times(6.626\times10^{-34})^2 kgm^2s^{-2}.S}{3.142\times9.11\times10^{-31}kg\times(1.60\times10^{-19})^2} = 5.29\times10^{-11}m = 0.529A^\circ$$

Example 3: Calculate the radius of 3rd orbit of electron in H-atom.

Solution: $r_n = a_o n^2$

As $a_o = 5.29\times10^{-11}$ m. and $n = 3$

$\therefore r^3 = (3)^2 \times 5.29 \times 10^{-11}m = 9 \times 5.29 \times 10^{-11}m$

$= 47.61\times10^{-11}m = 4.761\ A^\circ$

Example 4: Calculate the value of k in the expression $k = \frac{e^4m^2}{8\varepsilon_o^2h^2}$

Solution: $k = \frac{e^4m^2}{8\varepsilon_o^2h^2}$

where, $e = 1.60\times10^{-19}C$. $m = 9.11\times10^{-31}Kg$

$\varepsilon_o = 8.854\times10^{-12}\ C^2\ J^{-1}\ m^{-1}$ $h = 6.626\times10^{-34}$ Js.

Putting these values in above eq.

$$k = \frac{(1.60\times10^{19})^4\times C^4\times9.11\times10^{-31}kg}{(8.854\times10^{-12})^2C^4J^{-2}m^{-2}\times(6.626\times10^{-34})^2J^2S^2}$$

$= 2.17\times10^{-18}$J, 1J = $kgm^2\ S^{-2}$

$$k = \frac{(1.60\times10^{-19})^4\times9.11\times10^{-31}.C^4}{(8.854\times10^{-12})^2\times(6.626\times10^{-34})^2m^2S^{-2}\times J^2S^2\times C^4J^{-2}m^{-2}J}$$

$= 2.17\times10^{-18}$

Example 5: Calculate energies of n_1 for (i) He^+ (ii) $_3Li^{+2}$

Solution: $E_n = -\frac{k}{n^2}$ where $k = \frac{e^4m^2}{8\varepsilon_o^2h^2}$

(i) $Z = 2$ for $_2He^+$,

Then $E_{He^+} = -\frac{(2)^2k}{1^2}$

or $E_{He^+} = -\frac{4\times2.179\times10^{-18}}{1} = -8.716\times10^{-18}$J.

(ii) $Z = 3$ for $_3Li^{+2}$

$$E_{Li^{+2}} = -\frac{(3)^2k}{1^2} \qquad E_{Li^{+2}} = -\frac{9\times2.179\times10^{-18}J}{1}$$

$= -1.961\times10^{-19}$ J.

Example 6: How much energy is required to make electron of H-atom to jump from n = 2 to n = 4.

Solution: $\Delta E = E_{Final} - E_{initial}$

Here $n = 2$, (Initial) & $n = 4$ (Final)

So $\Delta E = k\left[\frac{1}{n_2^2} - \frac{1}{n_4^2}\right] = k\left[\frac{1}{4} - \frac{1}{16}\right]$

$$= k\frac{4-1}{16} = k\frac{3}{16}$$

But $k = 2.179 \times 10^{-18} J$

$$\Delta E = 2.179 \times 10^{-18} \times \frac{3}{16} J = 4.086 \times 10^{19} J$$

Activity for Students

(a) Calculate how much energy is required in order to remove electron of hydrogen atom.

(b) (Hint consider $n_1 = 1, n_2 = \infty$)

Convert this energy into ν and $\bar{\nu}$

Solution:

(a) *In this case* $n_1 = 1$, $n_2 = \infty$

$$\Delta E = k \times \left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right] = 2.18 \times 10^{-18} J \times \left[\frac{1}{1^2} - \frac{1}{\infty^2}\right] = 2.18 \times 10^{-18} J \times [1 - 0]$$

$$\Delta E = 2.18 \times 10^{-18} J$$

(b) As we know:

Since, $\Delta E = h\upsilon$

$$\upsilon = \frac{\Delta E}{h} = \frac{2.18 \times 10^{-18}}{6.625 \times 10^{-34}} = 0.3288 \times 10^{16} s^{-1} = 3.288 \times 10^{15} s^{-1}$$

As, $\lambda = \frac{c}{\upsilon} = \frac{3 \times 10^8}{3.288 \times 10^{15}} = 0.9124 \times 10^{-7} m = 9.124 \times 10^{-8} m$

$$Hence \quad \bar{\upsilon} = \frac{1}{\lambda} = \frac{1}{9.124 \times 10^{-8}} = 0.1096 \times 10^8 m^{-1} = 1.096 \times 10^7 m^{-1}$$

Q22. What is spectrum? Describe its types.

Ans: Spectrum:

The visual display or dispersion of the components of visible light when it is passed through a prism is called spectrum.

Continuous spectrum:

When the boundary lines between the colours cannot be marked, it is called continuous spectrum.

Line spectrum:

When the boundary lines between the colours can be marked, it is called line spectrum.

Q23. Briefly describe the origin of hydrogen spectrum.

Ans: Origin of Hydrogen Spectrum:

When Hydrogen is enclosed in a container and heated there are emitted radiations. These radiations are actually emitted due to excitation and de-excitation of electron of hydrogen.

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

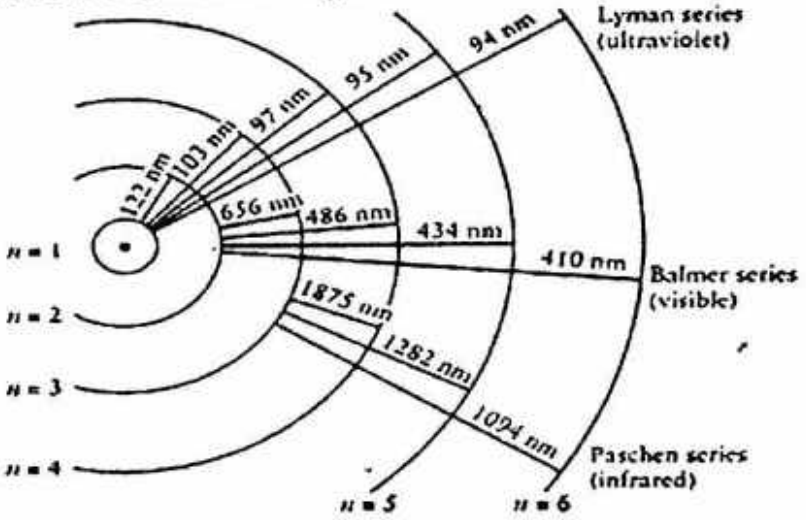
This equation agrees with the original Balmer equation.

With these equations Bohr was able to predict the wave length in the hydrogen emission spectrum and the electron transition (changes of energy levels) that occur in hydrogen atom.

The wave number of different spectral lines can be calculated corresponding to the values of n_1 and n_2. In the hydrogen spectrum, different series of lines have been identified for the n_1 and n_2 values. These series are,

Lyman series	$n_1 = 1$	$n_2 = 2,3,4,5 \ldots$
Balmer series	$n_1 = 2$	$n_2 = 3,4,5,6 \ldots$
Paschen series	$n_1 = 3$	$n_2 = 4,5,6,7$
Bracket series	$n_1 = 4$	$n_2 = 5,6,7,8$
Pfund series	$n_1 = 5$	$n_2 = 6,7,8,9 \ldots$

Only the Balmer series was observed in the visible part of the spectrum. Lyman series lie in the in the ultraviolet region while the Paschen and Bracket series have been observed in the infrared region.



Spectrum of hydrogen atom showing electronic transition to give different series

Q24. Explain hydrogen spectrum on the basis of Bohr's theory. And by using Bohr's equation of wave number find the wave number of all the series.

Ans: Explanation of Hydrogen Spectrum on the Basis of Bohr's Theory:

When current is passed through the hydrogen gas in the discharge tube at low pressure, the molecules of hydrogen break in to atoms.

These excited electrons being unstable come back to one of the lower energy levels. The electrons may come to the lowest energy levels. In this way they emit energy, they had absorbed. Lymen series is produced when the electrons jump from n=2,3,4,5,6...etc to n=1.In balmer series the electrons from n=3,4,5,6....come back to n=2.

Bohr's equation of wave number:

Let us calculate the various lines of Lymen series, Balmer series, Paschen series, Bracket series and Pfund series from Bohr's equation of wave number.

$$\bar{\nu} = \frac{Z^2 me^4}{8\epsilon_0^2 h^3 c}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]^{m-1}$$

Since $\frac{me^4}{8\epsilon_0^2 h^3 c} = 1.09678\times10^{+7}\ m^{-1}$ (when Z=1 for H atom)

$$\bar{\nu} = 1.09678\times10^{+7}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right] m^{-1}$$

The value 1.09678×10^7 is called Rydberg constant.

Lymen Series:

The various lines in Lymen series got their explanation by considering that the electron of hydrogen atom fall back to n=1 from higher levels. The higher levels occupied by the electrons due to the electric spark.

First line: $n_1 = 1$ $n_2 = 2$

$$\bar{\nu} = 1.09687 \times 10^{+7}\left(\frac{1}{1^2} - \frac{1}{2^2}\right) m^{-1} = 82.26\times10^5\ m^{-1}$$

Second line: $n_1 = 1$ $n_2 = 3$

$$\bar{\nu} = 1.09678 \times 10^{+7}\left(\frac{1}{1^2} - \frac{1}{3^2}\right) m^{-1} = 97.60\times10^5\ m^{-1}$$

Third line: $n_1 = 1$ $n_2 = 4$

$$\bar{\nu} = 1.09678 \times 10^{+7}\left(\frac{1}{1^2} - \frac{1}{4^2}\right) m^{-1} = 102.70\times10^5\ m^{-1}$$

Limiting line: $n_1 = 1$ $n_2 = \infty$

$$\bar{\nu} = 1.09678 \times 10^{+7}\left(\frac{1}{1^2} - \frac{1}{\infty^2}\right) m^{-1} = 109.678\times10^5\ m^{-1}$$

This limiting line shows that the energy difference between the first level and the infinite level is the ionization energy of the hydrogen atom. All these lines of Lymen series have close values. They appear in the form of a group. These values of wave numbers lie in the UV region of the spectrum.

Balmer series: In this series the electrons fall back to n=2.

First line(Hα line): $n_1 = 2$ $n_2 = 3$

$$\bar{\nu} = 1.09687\times10^{+7}\left(\frac{1}{2^2} - \frac{1}{3^2}\right) m^{-1} = 15.234\times10^5\ m^{-1}$$

Second line(Hβ line): $n_1 = 2$ $n_2 = 4$

$$\bar{\nu} = 1.09678\times10^{+7}\left(\frac{1}{2^2} - \frac{1}{4^2}\right) m^{-1} = 20.566\times10^5\ m^{-1}$$

Third line(Hγ line): $n_1 = 2$ $n_2 = 5$

$$\bar{\nu} = 1.09678\times10^{+7}\left(\frac{1}{2^2} - \frac{1}{5^2}\right) m^{-1} = 23.05\times10^5\ m^{-1}$$

Limiting line: $n_1 = 2$ $n_2 = \infty$

$$\bar{\nu} = 1.09678\times10^{+7}\left(\frac{1}{2^2} - \frac{1}{\infty^2}\right) m^{-1} = 27.421\times10^5\ m^{-1}$$

All these lines of Balmer series are very close to each other and appear in the form of group of lines. These lines lie in the visible region of the spectrum.

Paschen Series:

The electrons from higher levels fall back to n = 3.

First line: $n_1 = 3$ $n_2 = 4$

$$\bar{\nu} = 1.09687\times10^{+7}\left(\frac{1}{3^2} - \frac{1}{4^2}\right) m^{-1} = 5.3310\times10^5\ m^{-1}$$

Second line: $n_1 = 3$ $n_2 = 5$

$$\bar{\nu} = 1.09678\times10^{+7}\left(\frac{1}{3^2} - \frac{1}{5^2}\right) m^{-1} = 7.799\times10^5\ m^{-1}$$

Limiting line: $n_1 = 3$ $n_2 = \infty$

$$\bar{\nu} = 1.09678\times10^{+7}\left(\frac{1}{3^2} - \frac{1}{\infty^2}\right) m^{-1} = 12.187\times10^5\ m^{-1}$$

These are the again the groups of lines close to each other and appear in ***IR*** region.

Brackett series:

The electrons from higher levels fall back to n = 4.

First line: $n_1 = 4$ $n_2 = 5$ $\bar{\nu} = 2.45\times10^5\ m^{-1}$

Second line: $n_1 = 4$ $n2 = 6$ $\bar{\nu} = 3.808\times10^5\ m^{-1}$

Limiting line: $n_1 = 4$ $n_2 = \infty$ $\bar{\nu} = 6.855\times10^5\ m^{-1}$

Pfund series: The electrons from higher energy levels fall back to n = 5.

First line: $n_1 = 1$ $n_2 = 6$ $\bar{\nu} = 1.340\times10^5\ m^{-1}$

Second line: $n_1 = 1$ $n_2 = 7$ $\bar{\nu} = 2.148\times10^5\ m^{-1}$

Limiting line: $n_1 = 1$ $n_2 = \infty$ $\bar{\nu} = 4.387\times10^5\ m^{-1}$

Q25. Briefly explain Plank's quantum theory.

Ans: Plank's Quantum Theory:

Max Plank (1900) proposed a theory about nature of light. According to this theory,

Postulate:

(a) Energy is not emitted or absorbed continuously but in form of wave packets or quanta. In case of light the quantum of energy is often called photon.

(b) The amount of energy associated with quantum of radiation is directly proportional to the frequency (ν) of radiation. i.e.

$E \alpha \nu$ or $E = h\nu$ ..... (1)

where h = Plank's constant and has a value of 6.625×10^{-34} Joules sec.

(c) A body can emit or absorb energy only in terms of integral multiple of a quantum.

$E = nh\upsilon$ where n = 1, 2, 3

Now $\nu \alpha\ 1/\lambda$ or $\nu = c/\lambda$

Where "λ" is wave length and "c" is the velocity of light, a constant quantity.

Putting the value of ν in eq. (1), we get

$E = h\,c/\lambda$ ..... (2)

Thus greater the value of λ, smaller will be the energy.

Now $\bar{\nu} = 1/\lambda$ (3)

Where $\bar{\nu}$ = wave number.

Putting the value of $1/\lambda$ in eq. (2), we get,

$E = hc\bar{\nu}$

Thus energy of radiation is directly proportional to the frequency.

Frequency (υ):

The number of waves passing through a point per second is called Frequency.

Wavelength (λ):

The distance between two adjacent crests or troughs is called wavelength. It is expressed in ^{0}A (Where ^{0}A is an angstrom and one Angstrom = 10^{-10} m) or in nanometers (1 nanometre = 10^{-9} m).

Wave number ($\bar{\upsilon}$):

The number of wave cycles per unit distance for awave of a given wavelength.

$$\bar{\upsilon} = \frac{1}{\lambda}$$

Example 7:

A photon of light with energy 10^{-19} J is emitted by a source of light.

a) Convert this light in to the wave length, frequency and wave number of the photon in terms of meters, Hertz and m^{-1}, respectively.

b) Convert this energy of photon into ergs and calculate the wavelength in cm, frequency in Hz and wave number in cm^{-1}.

Solution: (a)

Data:

Energy of photon = 10^{-19} J

Wavelength λ = ?

Frequency ν = ?

Wave number $\bar{\nu}$ = ?

First of all we calculate ν

Formula applied: $E = h\nu$

and $\nu = \frac{E}{h}$

$h = 6.625\times10^{-34}$ Js

Putting the values of E and h

$$\nu = \frac{10^{-19}J}{6.625\times10^{-34}Js} = 0.151\times10^{+15}s^{-1}$$

$$= 1.51\times10^{+14}s^{-1}$$

From we can calculate wavelength λ

Formula applied: $\nu = \frac{c}{\lambda}$

So, wavelength $\lambda = \frac{c}{\nu} = \frac{3\times10^{+8}ms^{-1}}{1.51\times10^{+14}s^{-1}}$

$\lambda = 1.98\times10^{-6}$m

From λ we can calculate wave number

Formula applied: Wave number $\bar{\nu} = \frac{1}{\lambda}$

Putting these values

$$\bar{\nu} = \frac{1}{1.98\times10^{-6}m} = 0.50\times10^{6}m^{-1} = 5\times10^{+5}m^{-1}$$

(b) Now we convert energy of the photon from joules into ergs. For this we can use conversion factor

Conversion factor:

$1J = 10^{+7}$erg

So $E = 10^{-19}\times10^{+7}$erg $= 10^{-12}$ergs

$h = 6.625\times10^{-27}$ergs

Now calculate frequency in Hz

Formula applied: $\nu = \frac{E}{h}$

Putting the values $\nu = \frac{10^{-12}ergs}{6.625\times10^{-27}ergs} = 0.151\times10^{+15}s^{-1}$

$= 1.51\times10^{+14}s^{-1}$

Now we can calculate wavelength in cm

Formula applied: $\lambda = \frac{c}{\nu}$

Putting the values $\lambda = \frac{3\times10^{10}cms^{-1}}{1.51\times10^{+14}s^{-1}} = 1.98\times10^{-4}$cm

Now calculate wave number in cm^{-1}

Formula applied: $\nu = \frac{1}{\lambda}$

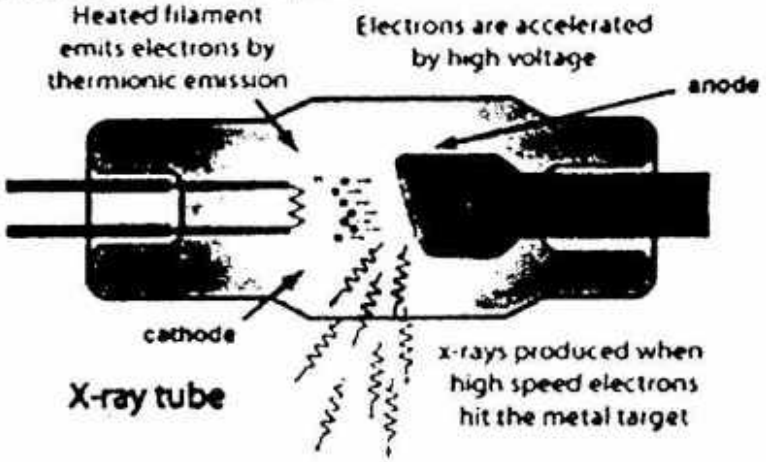
$\nu = \frac{1.51 \times 10^{+14} s^{-1}}{1.98 \times 10^{-4} cm} = 5 \times 10^{-3} cm$

Q26. What are X-rays? What is their origin?

Ans: X-Rays:

Discovery:

Wilhelm Roentgen (1895) accidentally discovered that if cathode rays are pointed to fall on a heavy metal target, there are produced some penetrating short wave length rays. He called them the X-rays. The X-rays are electromagnetic radiations of very high frequency depending upon the nature of anode. Oftenly a tungsten filament is used for this purpose.



Cathode rays pointed at heavy metal (W, Cu etc.)

X-rays are emitted from the target in all directions. A small portion of them is used for useful purpose through the windows. The wavelength of X-rays produced depends upon the nature of target metal. Every metal has its own characteristic $X - rays$.

Q27. How was the idea of atomic number derived from the discovery of X-rays? Explain it with the help of Moseley law.

Ans: Atomic Number and X-rays:

Moseley undertook a systematic and comprehensive study of X-rays in 1913. His researches covered a range of wavelengths 0.04 – 0.08 A°.

Moseley proved that the frequencies of X-rays increase in a regular manner from one element to the other in the Periodic Table. He further suggested that the frequencies of these rays are directly proportional to the no of protons in the nucleus. The no of protons in the nucleus are called "Atomic Number"

Moseley conclusions:

Moseley draw the following conclusions from the detailed analysis of spectral lines which he obtained from 38 different elements. (from Al to Au) as targets in X-rays tube.

(a) The spectral lines could be classified into two distinct groups. One, which belongs to shorter wavelength, called k-series and the other with larger wavelength called as L-series.

(b) If the target element is of higher at no., the wave-length of X-rays becomes shorter.

(c) Moseley Law:

A relationship between frequency (ν) and atomic number (Z) of the elements is given as. $\sqrt{\nu} = a(Z - b)$

This is called Moseley Law. Where a and b are called constant quantities. This law states that the frequency of a spectral line in x-ray spectrum varies as the square of atomic number of an element emitting it.

Q28. Explain the production of X-rays.

Ans: X-Rays, Atomic Numbers and Orbital Structure:

In 1913 Henry G. J. Moseley, a student of Rutherford, used the technique of X-rays spectroscopy (just discovered by Max von Laue) to determine the atomic numbers of the elements. X-rays are produced in a cathode-ray tube when the electron beam (cathode ray) falls on a metal target.

Production of X-rays:

The explanation for the production of X-rays is as follows:

When an electron in the cathode ray hits a metal atom in the target, it can (if it has sufficient energy) knock out an electron from an inner shell of the atom. This produces a metal ion with an electron missing from an inner orbital. The electron configuration is unstable, and an electron from an orbital of higher energy drops in to the half-filled orbital and a photon is emitted. The photon corresponds to electromagnetic radiations in the x-ray region.

Q29. List the uses of X-rays.

Ans: Uses of X-Rays:

X-rays can be used to photograph interior of objects. Roentgen's original announcement of X-rays was made on December 28, 1895. On January 20th, 1896, in Dartmouth, New Hampshire, X-rays were used to assist in setting a person's broken arm. This was something of a record time for turning a scientific discovery in to practical application.

Laue pattern of a substance:

The layers of the closely packed particles in a crystal constitute planes.

In 1912 Max von Laue in Germany suggested that the particles and the planes of a crystal might be separated by distances that are of the same order of magnitude as the wavelength of X-rays. Therefore a beam of X-rays should be diffracted by a crystal. The suggestion was quickly verified experimentally and the highly symmetrical diffraction pattern that appears on a photographic film is known as the Laue pattern of a substance.

X-ray diffraction technique:

In England in 1913 William Bragg and Lawrence Bragg devised a simpler apparatus to determine the internal structure of a crystal, which is called X-ray diffraction technique.

Q30. Briefly describe Schrodinger equation.

Ans: Schrodinger equation:

Schrodinger in 1926 gave an equation in which electrons are treated as moving with wave like mption in the three dimensional space around the nucleus. It differs from Bohr's atomic model in the sense that the electrons move in orbits. It also specifies the distance between the electron and the nucleus.

Schrodinger wave equation in three dimensions is:

$$\nabla^2 \psi + 8 \pi^2 m/h^2 (E - V) \psi = 0$$

Where
- h = Plank's constant.
- m = mass of the electron
- ψ (Psi) = wave function
- V = Potential Energy
- E = Total energy of electron in one dimension.
- ∇ (Nabla) = Laplacian operator

Q31. Highlight the consequences of the quantum mechanical treatment of atom.

Ans: Consequences of the Quantum Mechanical Treatment of atom are as follows,

(a) The energy of electrons in atoms is quantized.

(b) Electrons with different energies are to be found in different regions.

(c) The position and momentum of an electron cannot be determined at the same time.

Q32. Define the term orbital.

Ans: Orbital:

The region or space around the nucleus in which the probability of finding the electron is maximum is called an atomic orbital which are denoted as s, p, d and f.

Q33. What are quantum numbers discuss their significance.

Ans: Quantum number:

The solution of Schrodinger's wave equation gives certain mathematical integers. These sets of numerical values, which give the acceptable picture of an atom, are called Quantum Number.

Types of Quantum numbers: Quantum numbers are of four types:

i. Principal Quantum Number. (n):

It gives us all the information about shells.

It determines the size of the orbit and the distance from the nucleus. Greater the distance from the nucleus, larger will be the size of the orbit. The shells are named as,

If
- n = 1 — K shell.
- n = 2 — L shell.
- n = 3 — M shell.
- n = 4 — N shell.

The number of electrons accommodated in various orbits are as follows,

K = 2, L = 8, M = 18, N = 32.

The higher the value of n, the higher will be the energy of the electron and space around the nucleus.

ii. The Azimuthal Quantum Number (l):

It gives us all the information about sub-shells. It was to explain the fine structure of spectral lines. It depends upon the value of principle quantum number. It describes the shape of an orbital. Its value is always one less than that of value of n. The various energy sub-levels (l) are s, p, d, f having at the most 2, 6, 10 and 14 electrons in them respectively. They are designated as ***s*** for sharp, ***p*** for principal, ***d***

for diffused and *f* for fundamental The relationship between n and l is given below.

$l = n - 1$

If, n = (K), l = 0 (s) and e = 2

n = 2 (L), l = 0 (s) and 1 (p) and e = 2, 6

n = 3 (M), l = 0 (s), 1 (p) and 2 (d) and e = 2, 6, 10

n = 4 (N), l = 0 (s), 1 (p), 2 (d) and 3 (f) and e = 2, 6, 10, 14

From here we conclude that the number of orbit gives the number of orbitals.

i.e. n = 1 (K) orbital = 1 s

n = 2 (L) orbitals = 2s, 2p

n = 3 (M) orbitals = 3s, 3 p, 3 d

n = 4 (N) orbitals = 4s, 4p, 4d, 4f.

The shapes of orbitals described by Azimuthal Quantum number are s = spherical, p = dumbbell, d = sausage and f = complicated.

iii. Magnetic Quantum Number (m):

It gives us all the information about orbitals. It was represented to explain Zeeman's effect. Its value depend upon Azimathul quantum number. It explains the effect of an orbital in the magnetic field. It is related with Azimuthal Quantum number as follows:

$$m = +l \longrightarrow 0 \longrightarrow -l$$

If l = 0 (s), m = 0. It means that an s – orbital is spherical in shape because it is not deflected in any particular direction on placing in an electric field.

If l = 1 (p), m = + 1, 0, –1. It means that a p–orbital can be deflected in three directions on placing in a magnetic field. i.e. a p splits in to three degenerate orbitals in a magnetic field.

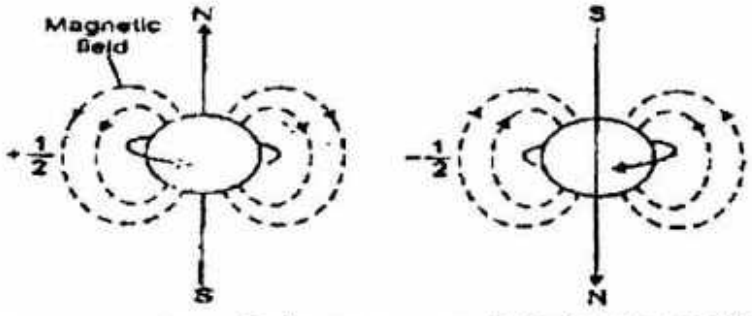
If l = 2 (d), then m = +2, + 1, 0, –1, –2. It means that a d–orbital can be deflected in 5–directions on placing in a magnetic field.

If l = 3 (f), then, m = + 3, + 2, +1, 0, –1, – 2, –3. i.e. an f–orbital can be deflected in 7–direction in a magnetic field.

The whole discussion shows that magnetic quantum number determines the orientation of orbital.

iv. Spin Quantum Number (s):

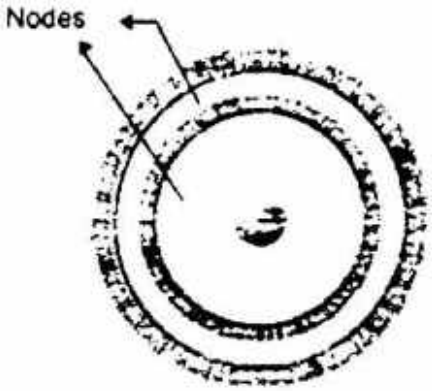
It describes the direction of spin of an orbital. In 1925 Goudsmit suggested that an electron while moving in an orbital around the nucleus also rotates or spins about its own axis either in a clockwise or anti-clockwise direction. It may be 50% clockwise $\left(+\frac{1}{2}\right)$ (↑) and 50% anti-clockwise $\left(-\frac{1}{2}\right)$.



Two different spins of electrons and their magnetic fields

This is also called self-rotation. This spinning of electron is associated with a magnetic field and hence a magnetic moment.

The circular path of an electron around the nucleus is called an orbit. The orbits or shells are denoted by K, L, M, N etc. The orbits of an atom can be shown as the following diagram.



Shapes of orbits or shells

Electron Cloud:

A cloud showing the probability of finding the electron in terms of charged cloud around the nucleus is called Electron Cloud.

Q34. Define shells and sub-shells or orbitals.

Ans: Shells or Orbits:

The circular paths in which electrons revolve around the nucleus are called orbits or shells.

Orbitals or Sub-Shells:

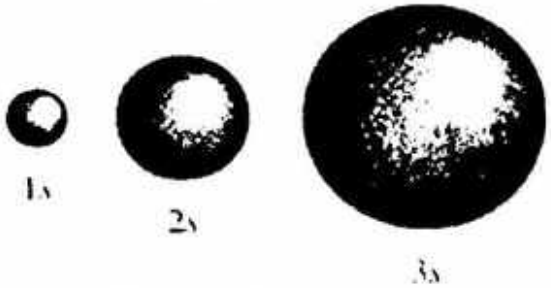
An orbit or a shell consists of the orbitals or sub-shells.

Q35. Briefly explain the different shapes of orbitals or sub-shells.

Ans: Shapes of orbitals:

i. s -orbital:

An s-orbital is spherical and symmetrical in shape.



Shapes of s – orbitals

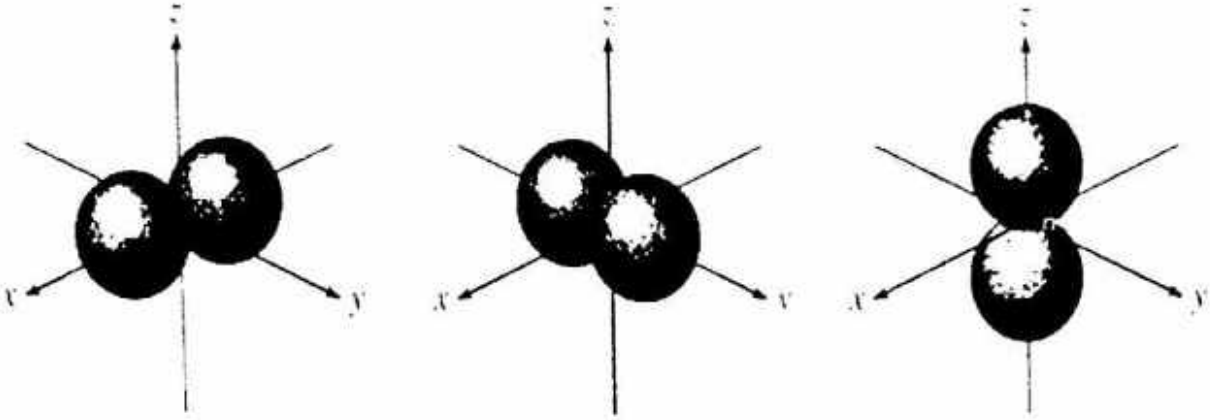
With the increase of value of n, the size of s-orbital increases e.g. 2s orbital is larger in size than 1s – orbital.

Nodal plane or Nodal surface:

The probability of finding the electron is zero between two orbitals. This plane is called nodal plane or nodal surface.

ii. p-orbitals:

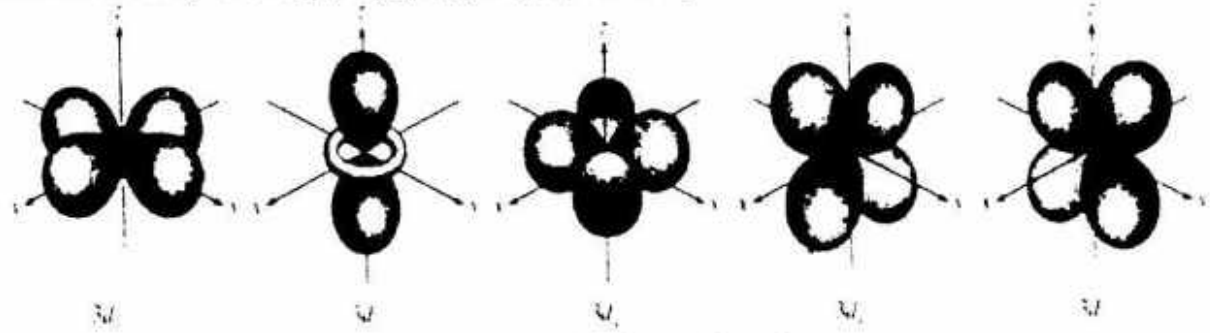
A p-orbital is dumbbell in shape and has three directions in space. Such orbitals which have different directions but equal energy are called "Degenerate Orbitals"



Shapes of p – orbitals

iii. d – orbitals:

These orbitals have dumbbell like structures and can move in the 5-directions. They are d_{xy} , d_{yz} , d_{xz}, $d_{x^2-y^2}$ and d_{z^2}



Shapes of d – orbitals

In the absence of magnetic field all the five d-orbitals are degenerate.

iv. f-orbitals:

It has seven directions in space on placing in a magnetic field, which are very complicated to draw.

Example 8: Describe the allowed combinations of the n, l and m quantum numbers when n = 4.

Solution: The allowed combinations are

n	l	m						
4	0	0						
	1	–1,	0,	+1				
	2	–2,	–1,	0,	+1,	+ 2		
	3	–3,	–2,	–1,	0,	+1,	+2,	+3

Q36. What is understand by electronic configuration?

Ans: Electronic Configuration:

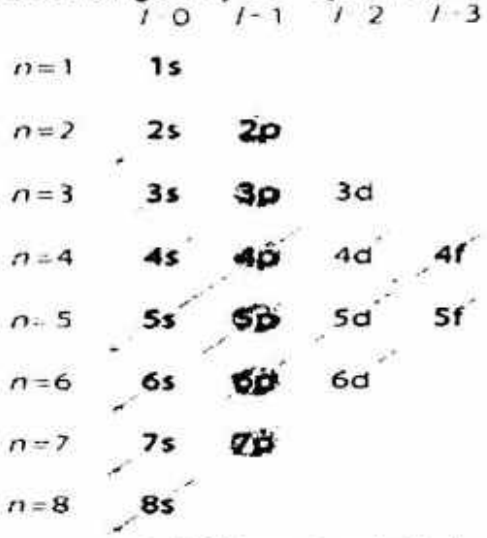
The representation of filling of electrons in different orbitals of an atom is called its electronic configuration.

Q37. Briefly describe the relative energies of atomic orbitals.

Ans: The Relative Energies of Atomic Orbitals:

The relative energies depend upon the size of the orbitals and therefore, according to the *Principal Quantum Number (n)*, an s–orbital has the lowest energy and increases as follows. $s < p < d < f$

The relative energies can be arranged by the figure, given below:



Energy sequence of different orbitals of an atom

Q38. Describe the facts must be observed before writing the electronic configuration of an atom.

Ans: The following facts must be observed before writing the electronic configuration of an atom.

(a) An orbital like s, px, py, pz, dxy etc. can have maximum two electrons.

(b) **The energy order of an orbital is governed by "$n + l$" rule, (where l-value is the value of Azimuthal Quantum number).** This states that an added electron will always enter the level with lower $n + l$ value. Then the next electron will go into that level which has lower value of n.

e.g For the orbital 2s, n = 2, $l = 0$, $n + l = 2$

3d, n = 3, $l = 2$, $n + l = 5$

So, 2s – orbital is filled first because it has lower value of $n + l$ than that for 3d orbital.

Similarly for 4p, n = 4, $l = 1$, n + 1 = 5

But here $3d$ orbital is filled first because the value of n for d is smaller than that of p. If $n + l$ values of two orbitals are same then the orbital with lower n value has lower energy and electron will be added to that orbital.

For example: N = 7 $(1s, 2s, 2px, 2py, 2pz)$

Ne = 10 $(1s, 2s, 2px, 2py, 2pz)$

Q39. List the rules for distribution of electrons in different orbitals.

Ans: Rules for Distribution of Electrons in Different Orbitals:

i. Auf-Bau's Principle

ii. Pauli's Exclusion Principle

iii. Hund's Rule

Q40. Describe Auf-Bau's principle for distribution of an electron in different orbitals.

Ans: Auf-Bau's Principle:

The electrons are placed in energy sub-levels in the order of increasing energy values of sub-levels.

Example:

O = 8 $(1s^{\uparrow\downarrow}, 2s^{\uparrow\downarrow}, 2p_x^{\uparrow}, 2p_y^{\uparrow}, 2p_z^{\uparrow})$

N = 7 $(1s^{\uparrow\downarrow}, 2s^{\uparrow\downarrow}, 2p_x^{\uparrow}, 2p_y^{\uparrow}, 2p_z^{\uparrow})$

Ne = 10 $(1s^{\uparrow\downarrow}, 2s^{\uparrow\downarrow}, 2p_x^{\uparrow\downarrow}, 2p_y^{\uparrow\downarrow}, 2p_z^{\uparrow\downarrow})$

Q41. Describe Pauli's Exclusion principle for distribution of an electron in different orbitals.

Ans: Pauli's Exclusion Principle:

According to it "No two electrons in the same orbital can have the same values of four Quantum numbers.

Let us take the example of an orbital having two electrons.

For First electron: n = 1, $l = 0$, m = 0, $s = +\frac{1}{2}$ ($\uparrow$)

For second electron n = 1, $l = 0$, m = 0, $s = -\frac{1}{2}$ ($\downarrow$)

So this orbital will have a maximum no. of two electrons with opposite spin i.e. ($\uparrow\downarrow$). Such on orbital is said to be completely filled and may contain a single electron in it, called as un-paired electron.

Q42. Describe Hund's rule for distribution of an electron in different orbitals.

Ans: Hund's Rule:

If we have two orbitals of same energy (degenerate orbitals like p_x, p_y, p_z) and we want to introduce more than one electrons in them, then they should be placed in separate orbitals with the same spin, rather than putting in the same orbital with opposite spin. It means that the arrangement ⊙⊙ will be more stable than the arrangement⊙◯, provided the two circles represent the orbitals of equal energies.

The Hund's rule can be applied to predict the valency of an element because the numbers of unpaired electrons give the valency of that element. The rule is equally applicable in case of **hybridized orbitals** and **molecular orbitals** which are degenerate.

e.g. **O = 8** $(1s^{\uparrow\downarrow}, 2s^{\uparrow\downarrow}, 2p_x^{\uparrow}, 2p_y^{\uparrow}, 2p_z^{\uparrow})$ Divalent

N = 7 $(1s^{\uparrow\downarrow}, 2s^{\uparrow\downarrow}, 2p_x^{\uparrow}, 2p_y^{\uparrow}, 2p_z^{\uparrow})$ Trivalent

Ne = 10 $(1s^{\uparrow\downarrow}, 2s^{\uparrow\downarrow}, 2p_x^{\uparrow\downarrow}, 2p_y^{\uparrow\downarrow}, 2p_z^{\uparrow\downarrow})$ No valency or zero valency.

But in case of carbon

C = 6 $(1s, 2s, 2px, 2py, 2pz)$

It looks divalent but actually it is tetravalent.

Example 9: Pick the orbital with the lower energy from each of the given pairs.

(a) 3d, 4s, **(b)** 2p, 3s, **(c)** 3d, 4s **(d)** 3d, 4p

Solution: We apply $n + l$ rule here.

(a) For 3d, $n = 3$, $l = 2$, $n + l = 5$

For 4s $n = 4$, $l = 0$, $n + l = 5$

So, 4s–orbital will be filled first because it has lower energy than that of 3d.

(b) For 2P, $n = 2$, $l = 1$, $n + l = 3$

3S, $n = 3$, $l = 0$, $n + l = 3$

As the values of n + l are equal in both the cases, therefore, 2P will filled first than 3s, as the former has lower n value than the later.

(c) 3d, $n = 3$, $l = 2$, $n + l = 5$

4p, $n = 4$, $l = 1$, $n + l = 5$

3d is filled first than 4p.

Example 10: Write the electronic configuration of $_{19}K$ and $_{20}Ca$.

Solution: $_{19}K$ = $1s^2, 2s^2 2p^6, 3s^2 3p^6, 4s^1$ or [Ar] $4s^1$

$_{20}Ca$ = $1s^2, 2s^2 2p^6, 3s^2 3p^6, 4s^2$ or [Ar] $4s^2$

Example 11: Write the electronic configuration of $_{21}Sc$, $_{25}Mn$, $_{30}Zn$.

Solution: $_{21}Sc$ = $1s^2, 2s^2 2P^6, 3s^2 3p^6, 4s^2, 3d^1$ or [Ar] $4s^2 3d^1$

$_{25}Mn$ = $1s^2, 2s^2 2p^6, 3s^2 3p^6 4s^2 3d^5$ or [Ar] $4s^2 3d^5$

$_{30}Zn$ = $1s^2, 2s^2 2p^6, 3s^2 3p^6 4s^2 3d^{10}$ or [Ar] $4s^2 3d^{10}$

Example 12: From the following symbols
Pick the impossible cases.
$6s^2, 6p^8, 6s^7, 3d^{11}$

Solutions: s contains maximum 2 electrons
p contains maximum 6 electrons
d contains maximum 10 electrons
The impossible cases are
$6p^8, 6s^7, 3d^{11}$

Activity for Students

Write the electronic configuration of following elements and ions:

(i) $_{20}Ca^{40}$ (ii) $_{17}Cl^{35}$ (iii) $_{13}Al^{27}$

Predict the valences of the element in activity 4 using Hund's rule.

Solution:

(i) $_{20}Ca^{40}$ = $1s^2, 2s^2 2P^6, 3s^2 3p^6, 4s^2$ or [Ar] $4s^2$ Valancy = 2

(ii) $_{17}Cl^{35}$ = $1s^2, 2s^2 2P^6, 3s^2 3p^5$ or [Ne] $3s^2 3p^5$ Valancy = 1

(iii) $_{13}Al^{27}$ = $1s^2, 2s^2 2P^6, 3s^2 3p^1$ or [Ne] $3s^2 3p^1$ Valancy = 3

Q43. Differentiate between Para-magnetic and diamagnetic substances.

Ans: Para-magnetic substances:

Those substances, which are attracted by the magnetic field, are called para-magnetic substances. Such substances contain unpaired electrons.

e.g. Na, H, Fe, O_2 etc.

Diamagnetic substances:

The substances, which are not attracted by the magnetic field or weakly repelled by the magnetic field, are called diamagnetic substances. Such substances contain paired electrons e.g. He. Actually when two electrons occupy the same orbital, they have spin in opposite directions. As a result the paramagnetism of one electron is cancelled by the paramagnetism of the second electron.

Q44. What is the difference between fast moving and slow moving neutron?

Ans: Difference between fast moving and slow moving neutron:

Fast moving neutron	Slow moving neutron
i. When neutrons travel with energy 1.2 Mev or more, they are called Fast Neutrons.	**i.** When they have energy below 1 e.v., they are called slow neutrons.
ii. The fast neutron are less effective in fission reaction.	**ii.** Slow neutrons are more effective in fission.
iii. They produce $\alpha - Particles$ **Example:** $N_7^{14} + n_0^1 \longrightarrow B_5^{11} + He_2^4$	**iii.** They produce $\beta - Particles$ **Example:** When slow moving neutrons hit the Cu metal, β – radiations are emitted. $^{65}_{29}Cu + {}^{1}_{0}n \longrightarrow {}^{66}_{29}Cu + h\upsilon$ ${}^{66}_{29}Cu \longrightarrow {}^{66}_{30}Zn + {}^{0}_{-1}e$ (β – radiations).

EXERCISE

MULTIPLE CHOICE QUESTIONS

1. Choose the correct answer (MCQ_s).

i. Wave mechanical model of the atom depends upon

(a) De-Broglie's concept of duality.
(b) Uncertainty Principle.
(c) Schrodinger's wave equation
(d) All of the above

ii. For which species Bohr's theory does not apply

(a) H **(b)** He^+ **(c)** Li^{2+} **(d)** Be

iii. From the discharge tube experiment, it is concluded that

(a) Mass of a proton is in fraction.
(b) Matter contained electrons.
(c) Nucleus contains positive change.
(d) Positive rays are heavier than protons.

iv. When an electron of charge 'e' and mass 'm' moves with velocity 'v' about the nuclear change Ze in the circular orbit of radius 'r', the P.E of electron is given by

(a) Ze^2/r **(b)** $-Ze^2/r$ **(c)** Ze^2/r^2 **(d)** mv^2/r

v. Which of following quantum numbers is not obtained from Schrodinger wave equalier?

(a) Principal quantum number, n
(b) Azimuthal quantum number, l
(c) Magnetic quantum number, m
(d) Spin quantum number, s

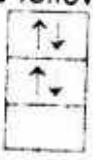
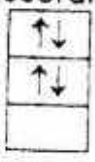
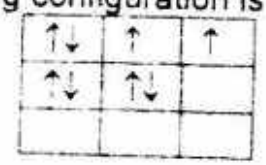
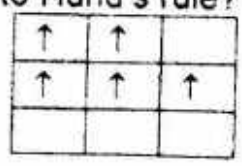
vi. Electronic configuration of species M^{2+} is $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^6$ and its atomic weight is 56 number of neutrons in the nuclears of species M is

(a) 20 **(b)** 26 **(c)** 28 **(d)** 30

vii. The energy of an electromagnetic radiation is 3×10^{-12} ergs. What is its wave-length in nano meters?

(a) 400 **(b)** 228.3 **(c)** 3000 **(d)** 662.5

viii. Which of the following configuration is not correct according to Hund's rule?

(a) 
(b) 
(c) 
(d) 

ix. Which one of the following statement is not correct?

(a) Rydberg's constant and wave number have same unit.

(b) Lyman series of hydrogen spectrum occurs in the ultraviolet region.

(c) The angular movement of the electron in the ground state of hydrogen atom is equal to $h/2\pi$.

(d) The radius of first Bohr orbit of hydrogen atom is 2.116×10^{-8} cm.

x. Which one of the following is not isoelectronic pair

(a) Mg^{2+}, Be^{2+} **(b)** N^{3-}, O^{2-} **(c)** N^{2-}, O^{2-} **(d)** F^-, Al^{3+}

xi. The third line in Balmer series corresponds to an electronic transfer between which Bohr's orbit in hydrogen.

(a) $5 \longrightarrow 3$ **(b)** $5 \longrightarrow 2$

(c) $4 \longrightarrow 3$ **(d)** $4 \longrightarrow 2$.

Answers

i. d	**ii. d**	**iii. b**	**iv. b**	**v. d**	**vi. d**
vii. d	**viii. c**	**ix. d**	**x. a ,c**	**xi. b**	

2. Short questions and answers:

i. How mass of electron can be calculated from e/m ratio and charge?

Ans: Mass of electron = ?

Charge to mass ratio of electron = $\frac{e}{m} = 1.7588 \times 10^{11}$ Coulomb kg^{-1}

Charge on 1 electron = e $= 1.6022 \times 10^{-19}$ Coulomb

$$\frac{1.60\times10^{-19}C}{m} = \frac{1.7588\times10^{11}Ckg^{-1}}{1}$$

or $m \times 1.7588 \times 10^{11}$ C $kg^{-1} = 1.60 \times 10^{-19}$ C

$$m = \frac{1.60\times10^{-19}C}{1.7588\times10^{11}Ckg^{-1}}$$

$$m = 9.1095\times10^{-31}\,kg$$

Ii. How does Mosley's Law help in the production of X-rays?

Ans: A relationship between frequency (v) and atomic number (Z) of the elements is given as: $\sqrt{\nu} = a(Z - b)$

This is called Moseley Law. Where a and b are called constant quantities. This law states that the frequency of a spectral line in x-ray spectrum varies as the square of atomic number of an element emitting it.

X-rays produce when an inner electron is removed and electrons from higher energy levels fill the vacancy. The X-ray series are labeled according to the level in which the original vacancy was created.

Mosley showed that the K-alpha x-rays followed a straight line when the atomic number Z versus the square root of frequency was plotted.

$$\sqrt{\nu} = a(Z - b)$$

This law states that the frequency of a spectral line in x-ray spectrum varies as the square of atomic number of an element emitting it.

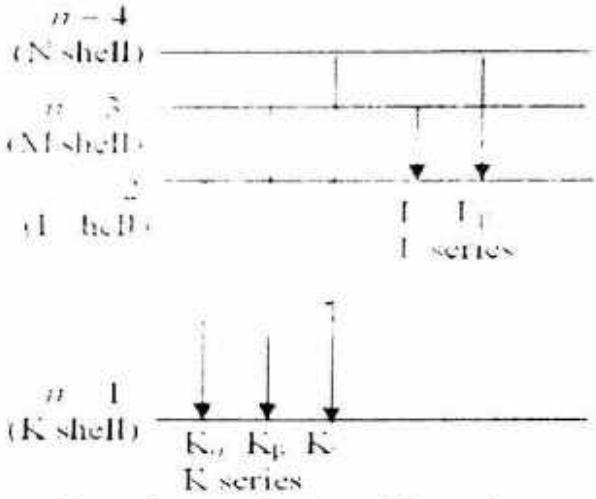


Fig: shows the K and L series.

iii. Which quantum number is also called sub-shell quantum number?

Ans: The Azimuthal Quantum Number (l) is called sub-shell quantum number.

Azimuthal Quantum Number (l)/ Secondary Quantum Number:

The Azimuthal quantum number, l divides the shells up into smaller groups of subshells called orbitals. The value of n determines the possible values for l. For any given shell the number of subshells can be found by $l = n - 1$. This means that for $n = 1$, the first shell, there is only $l = 1 - 1 = 0$ subshells. i.e. the shell and subshell are identical. When $n = 2$ there are two sets of subshells; $l = 1$ and $l = 0$. A number could be used to identify the subshell however to avoid confusion between the numerical values of n and those of l the l values are given a letter code.

value of l	0	1	2	3	4	.....
letter designation	s	p	d	f	g	

iv. What is the difference between orbit and orbital?

Ans: Difference between Orbit and Orbital:

Orbit	Orbital or Sub-shell
i. It is well-defined circular path followed by electron around nucleus.	**i.** It is a region of space around the nucleus where the probability of finding an electron is maximum.
ii. It represents two dimensional motion of electron around nucleus.	**ii.** It represents three dimensional motion of electron around nucleus.
iii. The maximum number of electrons in an orbit is $2n^2$.	**iii.** The maximum number of electrons in an orbital is 2.
iv. Orbit is circular in shape.	**iv.** Orbitals have different shapes.
v. Orbit shows certainty about the position of an electron.	**v.** Orbital shows uncertainty about the position of an electron.
vi. Bhor provided this concept	**vi.** This concept was given by modern techniques (Schrodinger)
vii. They cannot be degenerate	**vii.** The can be degenerate e.g. P_x, P_y, P_z
viii. Explained by principle quantum number	**viii.** Explained by magnetic quantum number.

v. What is the relationship between?

(a) energy and wavelength

(b) frequency and wavelength

Ans: (a) Relation between energy and wavelength:

According to de Broglie equation $E = \frac{hc}{\lambda}$

$$E \propto \frac{1}{\lambda}$$

Thus greater the value of λ, smaller will be the energy.

Where E = Energy, c = Velocity of light, λ = wavelength

h = Plank's constant = $6.625 \times 10^{-34}\ Js$

(b) Relation between frequency and wavelength:

$\nu \propto 1/\lambda$ or $\nu = c/\lambda$

Thus greater the value of λ, smaller will be the frequency.

λ = wavelength, υ = frequency, c = speed of light

vi. What species are formed by the decay of neutron.

Ans: A Free neutron decays into a proton with the emission of electron and neutrino.

$_0n^{1+} \longrightarrow {}_1p^1 + {}_1e^0 + {}_0n^0$ (neutrino, particle of a small mass).

Free neutron decays into a proton ($_1p^1$) with the emission of an electron ($_1e^0$) and a neutrino ($_0n^0$).

vii. Hydrogen atom and He^+ are mono electronic system, but the size of He^+ is much smaller than H, why?

Ans: In hydrogen atom there are one electron and one proton whereas in He atom there are two electrons and two protons. In case of H^+ ion there is one proton but in He^{+1} there are two protons and one electron. These two proton exert more force of attraction on one electron as a result electron comes more close to the nucleus so size of He^+ is decreases.

OR

H-atom and He^+ are monoelectronic system. It means both H-atom and He^+ have one electron in the valence shell. H-atom has one proton in the nucleus whereas He^+ has two proton in the nucleus. So, the force of attraction between two protons and one electron is greater than one proton and one electron. Hence, the size of He^+ is much smaller than H-atom.

viii. How the wavelength of moving particles are related to the momentum of electron.

Ans: According to Louis de-Broglie an electron is a solid particle which moves in form but the wavelength of an electron decreases with the increase in momentum of electron. Mathematically,

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

Where, λ **= Wavelength,** $h = Plank's\ constant$

$m = mass\ of\ electron$, $v = velocity\ of\ electron$

$mv = momentum\ of\ electron$

According to this relation, the wavelength (λ) of the moving particle or electron is inversely proportional to its momentum (p).

ix. State Heisenburg's uncertainty principle.

Ans: According to this principle position and momentum of an electron cannot be determined simultaneously In an atom if we use the photons of longer wavelength to avoid the change of momentum of electron the determination of position of electron is impossible.

Mathematical, $\Delta x . \Delta p \geq \frac{h}{4\pi}$

Where Δx = Uncertainty to measure the position of electron

Δp = uncertainty in the measurement of momentum of an electron

This relationship is called uncertainty principle.

x. Why is 4s orbital lower in energy than 3d orbital?

Ans: According to Wiswessel's rule $(n + l)$ For 3d, $n + l = 3 + 2 = 5$ and for 4s, $n + l = 4 + 0 = 4$. Therefore 4s orbital lower in energy than 3d orbital.

xi. Write electronic configuration of $_{25}Mn^{2+}$, $_{30}Zn^{2+}$, $_{64}Cd^{3+}$ and $_{13}Al^{3+}$.

Ans: $_{25}Mn^{2+} = 1s^2, 2s^2 2p^6, 3s^2 3p^6 4s^2 3d^3$

$_{30}Zn^{2+} = 1s^2, 2s^2 2p^6, 3s^2 3p^6 4s^2 3d^8$

$_{64}Cd^{3+} = 1s^2, 2s^2 2p^6, 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^7$

$_{13}Al^{3+} = 1s^2, 2s^2 2p^6$

xii. What is $(n + l)$ rule?

Ans: This rule says that sub–shells are arranged in the increasing order of $(n + l)$ values and if any two sub–shells have the same $(n + l)$ values, then the sub–shell is filled first whose n values is smaller.

This is also called Wis-Wesser's rule. According to this rule "when electrons are filled in different orbitals of an atom, the electrons go first in orbital having lower value of $n + l$. But when two orbitals have same value of $n + l$, the electrons will go first in the orbital having lower value of $n + l$ where n = number of shell

Example 1:

1s	2s
1+0	2+0
1	2

So electrons will go first in 1s, then

Example 2:

3d	4p
3 + d	4+1
5	5

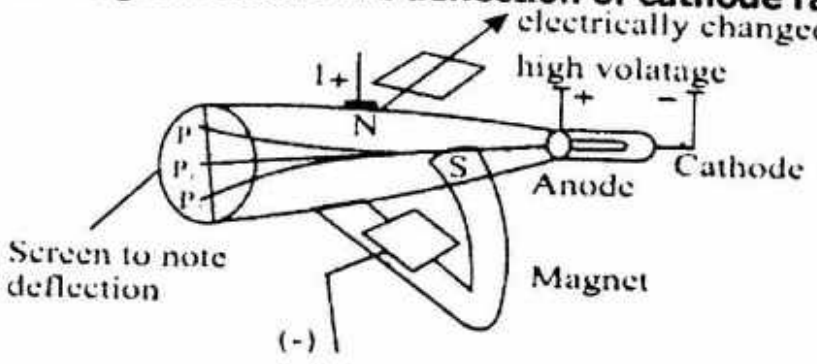
Here Values of $n + l$ are same

But n value of 3d = 3

And n value of 4p = 4

So, Electrons will go first in 3d then in 4p.

xiii. The given diagram shows the deflection of cathode rays.



What do you understand when cathode rays strikes at

(a) at point P_3 (b) at point P_2 (c) at point P_1

Ans: (a) at point P_3

The electrons from cathode rays strike at point P_3 under the influence of electric field only.

When cathode rays strike on point P_3 it means cathode rays which have negative charge have been attracted by positive plate of anode.

(b) at point P_2

The electrons from cathode rays strike at point P_2 under the influence of magnetic field only.

When cathode rays strike at point P_2 this indicates that cathode rays having negative charge are repelled.

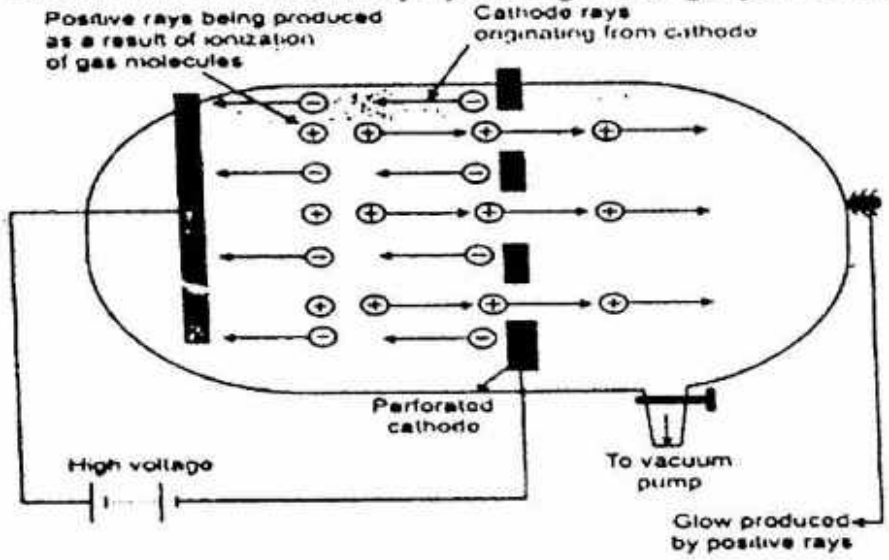
(c) at point P_1

The electrons from cathode rays strike at point P_1 under two conditions:

(i) In the absence of any electric and magnetic field.

(ii) When both electric and magnetic field are adjusted (balanced) and applied.

xiv. Diagram shows the canal rays passing through perforated cathode



(a) Name of apparatus and its use

(b) How much voltage is required to follow current through the gas?

(c) What is the function of vacuum pump?

Ans: (a) Name of the apparatus: Discharge tube.

Use of Discharge tube:

It is used to study ionization of gases at low pressure and high temperature.

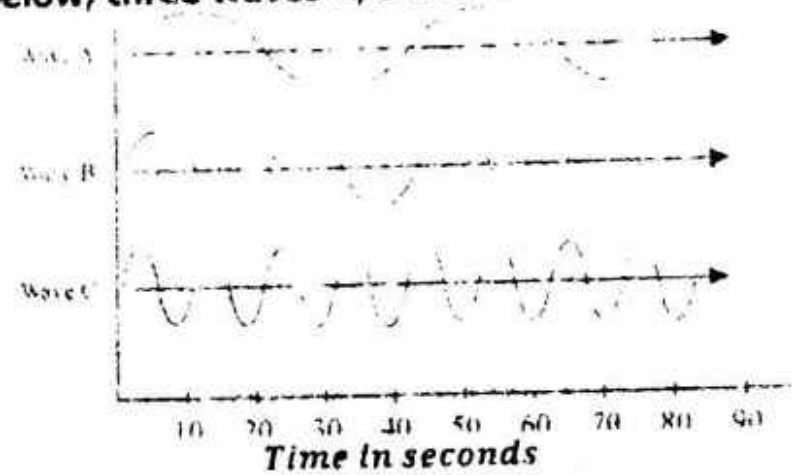
This discharge tube is used to generate cathode and anode rays.

(b) 5,000 - 10,000 volts

(c) Function of vacuum pump:

The function of vacuum pump is to reduced or change the pressure inside the tube. Function of vacuum pump is to decrease pressure in discharge tube by removing the gas. As a result a uniform glow inside the tube appears. When the pressure is reduced to about 0.01 torr the original glow disappears.

xv. In fig. Below, three waves A, B and C has shown.



(a) Which wave has higher frequency?
(b) Which wave has longest wavelength.
(c) Define the following term.
(i) Frequency (ii) Wavelength
(d) What is the frequency of wave B as compound to wave C?

Ans: **(a)** Wave C has the highest frequency because it has shortest wavelength ($\nu \propto \frac{1}{\lambda}$)

(b) Wave A has longest wavelength because its frequency is lowest ($\nu \propto \frac{1}{\lambda}$).

(c) **(i) Frequency:**
The number of waves passing through a point per second is called its frequency. Its symbol is ν. Its units are hertz, cycle/sec, rev/sec.

$$\nu \propto \frac{1}{\lambda}$$

(ii) Wavelength:
The distance between the adjacent crests or troughs is called wavelength. Its units are A^o, nm or pm. Its symbol is lambda. (λ)

$$\lambda \propto \frac{1}{\nu}$$

(d) Frequency of wave B is half than that of C because wavelength of B is longer than wavelength of wave C.

$$\nu \propto \frac{1}{\lambda}$$

xvi. Point out the defects of Bohr's Model. How these defects are partially covered by dual nature of electron and Heisenberg's uncertainty principle.

Ans: Defects of Bohr's Atomic Model:

Spectrum of multi electrons or poly-electron system:

Bohr's theory cannot explain the origin of the spectrum of multi electrons or poly-electron system like He, Li, Be etc.

Motion of electron:

Bohr suggested circular orbits of electrons around the nucleus. But it is proved that motion of electron is not in a single plane but takes place in three-dimensional space.

Zeeman Effect:

When the excited atom of hydrogen giving atomic emission spectrum is placed in a magnetic field, its spectral lines further split up into closely spaced lines. This type of splitting up of spectral lines is called *Zeeman Effect.*

Stark's effect:

Similarly when the excited hydrogen atom is placed in a strong electrical field, then similar more splitting of spectral lines takes place which is called *"Stark Effect".*

Bohr's theory does not explain either *Zeeman or Stark's effect.*

Motion of electrons:

When a spectrum of Hydrogen gas is seen through a powerful spectrometer, the original spectral lines are replaced by several very fine lines. i.e. original lines are divided into other fine lines. Bohr suggested circular orbits of electrons around the nucleus of H-atom. But it is proved that the motion of electron is not in a single plane, but takes place in three-dimensional space.

Dissatisfaction of Heisenberg's uncertainty Principle:

Following the Heisenberg's uncertainty Principle, Bohr's picture of an atom is not satisfactory. In Bohr's atom, the electrons are moving in orbits with specific velocities in specific radii. But according to uncertainty principle, both of these quantities cannot be measured experimentally.

Schrodinger wave equation:

In order to solve this difficulty, Schrodinger gave a wave equation for hydrogen atom. According to him, although the position of an electron cannot be found exactly, the probability of finding an electron can be ascertained. The maximum probability is at a distance of 0.053 nm.

xvii. Calculate the energy of electron of a hydrogen atom in the orbit for which the value of n = 3. Ans. $E_3 = -145.92$ KJ mole^{-1}.

Solution: $E_n = \frac{1313.315}{n^2}\ kJmol^{-1}$

For 3rd orbit, n = 3. Putting the value of 'n' in above equation, we have:

$$E_3 = \frac{1313.315}{3^2} = -145.92\ kJmol^{-1}$$

$$OR(Second\ Method)$$

Energy of an electron can be determined using the following relation

$$E_n = -k\left(\frac{Z^2}{n^2}\right) Joules$$

$$E_n = -2.18 \times 10^{-18} \times \frac{Z^2}{n^2}\ Joules$$

$$Where\quad Z = atomic\ number,\quad n = number\ of\ shell$$

$$Here\quad Z = 1,\quad n = 3$$

$$E_3 = -2.18 \times 10^{-18} \times \frac{(1)^2}{(3)^2}\ Joules = -0.242 \times 10^{-18}\ Joules$$

$$E_3 = -2.42 \times 10^{-19}\ Joules$$

xviii. A proton of light with energy 10^{-16} J is emitted by a source of light.

(a) Convert this energy into the wavelength, frequency and wave number of the photon in terms of meters, hertz and m^{-1} respectively.

(b) Convert this energy of the photons into ergs and calculate the wave length in cm, frequency in Hz and wave number in cm^{-1}.

Solution:

(a) $E = 10^{-16} J$

$h = 6.625 \times 10^{-34} Js$

$c = 3 \times 10^{8} m/s$

$\upsilon = ?$, $\lambda = ?$, $\bar{\upsilon} = ?$

$Since \ E = h\upsilon$

$$\upsilon = \frac{E}{h} = \frac{10^{-16}}{6.625 \times 10^{-34}} = 1.509 \times 10^{18} s^{-1}$$

$Since \ \lambda = \frac{c}{\upsilon}$

$$\lambda = \frac{c}{\upsilon} = \frac{3 \times 10^{8}}{1.509 \times 10^{18}} = 1.988 \times 10^{-10} m$$

$Since \ \bar{\upsilon} = \frac{1}{\lambda}$

$$\bar{\upsilon} = \frac{1}{\lambda} = \frac{1}{1.988 \times 10^{-10}} = 5.030 \times 10^{9} m^{-1}$$

(b) Convert this energy of the photons into ergs and calculate the wave length in cm, frequency in Hz and wave number in cm^{-1}.

$h = 6.625 \times 10^{-34} Js$

$c = 3 \times 10^{8} m/s$

$E = 10^{-19} J = 10^{-19} \times 10^{7} = 10^{-12} erg$ $(\because 1 J = 10^{7} erg)$

$h = 6.625 \times 10^{-34} Js = 6.625 \times 10^{-34} \times 10^{7} = 6.625 \times 10^{-27} erg$

$1m = 100 cm$

$\upsilon = ?$, $\lambda = ?$, $\bar{\upsilon} = ?$

$$\upsilon = \frac{E}{h} = \frac{10^{-12}}{6.625 \times 10^{-27}} = 1.509 \times 10^{14} s^{-1}$$

$Since \ \lambda = \frac{c}{\upsilon}$

$$\lambda = \frac{c}{\upsilon} = \frac{3 \times 10^{10}}{1.509 \times 10^{14}} = 1.988 \times 10^{-4} cm$$

$$Since \ \bar{\upsilon} = \frac{1}{\lambda} = \frac{1}{1.988 \times 10^{-4}} = 5.030 \times 10^{3} cm^{-1}$$

xix. Bohr's equation for the radius of nth orbit of electron in the hydrogen atom is $r_n = \frac{\varepsilon_0 h^2 n^2}{\pi e^2 m}$

(a) When the electron moves from n = 1 to n = 2, how much does the radius change?

(b) What is the distance travelled by the electron when it goes from (i) n = 8 to n = 3?

Solution: (a) $r_n = \frac{\varepsilon_o h^2 n^2}{\pi e^2 m}$ ..... (i)

$$Since, \quad \frac{\varepsilon_o h^2}{\pi e^2 m} = 0.529\ A^o$$

Therefore (i) *becomes,* $r_n = 0.529\ A^o(n^2)$

$$r_1 = 0.529\ A^o(1^2) = 0.529\ A^o$$

$$r_2 = 0.529 \times (2)^2 = 2.1164\ A^o$$

$$increase\ in\ radius = r_2 - r_1 = 2.116 - 0.529 = 1.587\ A^o$$

(b) $r_8 = 0.529 \times (8)^2 = 33.856\ A^o$

$r_3 = 0.529 \times (3)^2 = 4.734\ A^o$

$$increase\ in\ radius = r_8 - r_3 = 33.856 - 4.734 = 29.122\ A^o$$