Unit 02

Structure of Atom

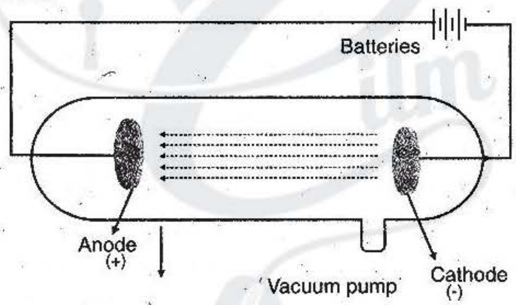
Long Answer Questions

Q1. How are cathode rays produced? What are its major characteristics?

Ans. Cathode rays and Discovery of Electron

In 1895 Sir William Crooks performed experiments by passing electric current through gases in a discharge tube at very low pressure.

He took a glass tube fitted with two metallic electrodes, which were connected to a high voltage battery. The pressure inside the tube was kept 10^{-4} *atm*. When high voltage current was passed through the gas, shiny rays were emitted from the cathode towards the anode as shown in figure. These rays were given the name of 'cathode rays' as these were originated from the cathode.



Characteristics of cathode rays

The major characteristics of cathode rays are given below

i. These rays travel in a straight line perpendicular to the cathode surface.

ii. They can cast a sharp shadow of an opaque object if placed in their path.

iii. They are deflected towards positive plate in an electric field showing that they are negatively charged.

iv. They raise temperature of the body on which they fall.

v. J.J. Thomson discovered their charge/mass (e / m) ratio.

vi. Light is produced when these rays hit the sides of the discharge tube.

Conclusions

i. All these properties suggested that the nature of cathode rays was independent of the nature of the gas present in the discharge tube or material of the cathode.

ii. The fact that they cast the shadow of an opaque object suggested that these are not rays but they are fast moving, material particles. They were given the name electrons.

iii. Since all the materials produce same type of particles, it means all the materials contain electrons.

iv. As we know materials are composed of atoms, hence the electrons are fundamental particles of atoms.

Q2. How it was proved that electrons are fundamental particles of an atom?

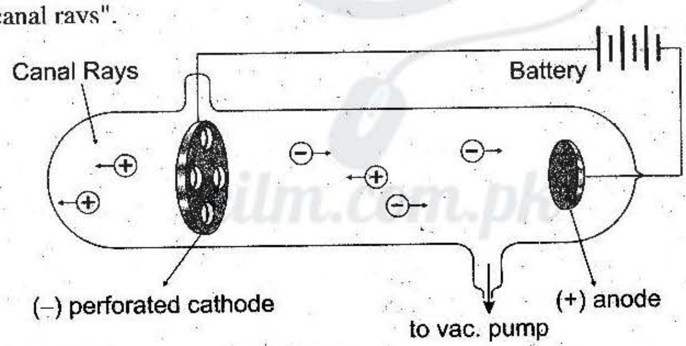
Ans. In 1895, Sir William Crooks performed experiments by passing electric current through gases in a discharge tube at very low pressure. When high voltage current was passed through the gas, shiny rays were emitted from the cathode towards the anode. These rays were given the name cathode rays.

These rays were given the name electrons after finding their e/m ratio which come to be same as electrons that was same of electrons "By changing the material of electrodes, it was proved that always same rays were produced." Hence it was proved that electrons are fundamental particles of an atom.

Q3. Draw a labeled diagram to show the presence of protons in the discharge tube and explain how canal rays were produced.

Ans. Discovery of Proton

In 1886 Goldstein observed that in addition to cathode rays, other rays were also present in the discharge tube. These rays were traveling in opposite direction to cathode rays. He used a discharge tube having perforated cathode as shown in figure. He found that these rays passed through holes present in the cathode and produced a glow on the wall. He called these rays as "canal ravs".



The properties of positive rays or canal rays

i. These rays travel in a straight line in a direction opposite to cathode rays.

ii. Their deflection in electric and magnetic field proved that these were positively charged.

vii. It was found that the same type of rays were emitted no matter which gas and which cathode was used in the discharge tube.

iii. The nature of canal rays depends upon the nature of gas, present in the discharge tube.

iv. These rays do not originate from the anode. In fact these rays are produced when the cathode rays or electrons collide with the residual gas molecules present in the discharge tube and ionize them as follows:

$$M + e^- \rightarrow M^+ + 2e^-$$

v. Mass of these particles was found equal to that of a proton or simple multiple of it. The mass of a proton is 1840 times more than that of an electron.

Results

i. These rays are made up of positively charged particles.

ii. The mass and charge of these particles depend upon the nature of the gas in the discharge tube.

iii. Hence, different gases produce different types of positive rays having particles of different masses and different charges.

iv. Hence particles produced by a gas will be of the same type i.e. positive rays produced by the lightest gas hydrogen contain protons.

Q4. How neutrons were discovered? Write their properties.

Ans. Discovery of Neutron

Rutherford observed that atomic mass of the element could not be explained on the basis of the masses of electron and proton only. He predicted in 1920 that some neutral particle having mass equal to that of proton must be present in an atom. Thus scientists were in search of such a neutral particle. Eventually in 1932 Chadwick discovered neutron, when he bombarded alpha particles on a beryllium target. He observed that highly penetrating radiations were produced.

These radiations were called neutron.

$${}^{9}_{4}Be + {}^{4}_{2}He \longrightarrow {}^{12}_{6}C + {}^{1}_{0}n$$

Properties of neutron

i. Neutrons carry no charge i.e. they are neutral

ii. They are highly penetrating.

iii. Mass of these particles was nearly equal to the mass of a proton.

Q5 How Rutherford discovered that atom has a nucleus located at the centre of an atom?

Ans. Rutherford's Atomic Model

Rutherford performed 'Gold Foil' experiment to understand how negative and positive charges could coexist in an atom. He bombarded *alpha* particles on a 0.00004 *cm* thick gold foil. Alpha particles are emitted by radioactive elements like radium and polonium. These are actually helium nuclei (He^{2+}). They can penetrate through matter to some extent.

He observed the effects of α-particles on a photographic plate or a screen coated with zinc sulphide as shown in figure. He proved that the 'plum-pudding' model of the atom was not correct.

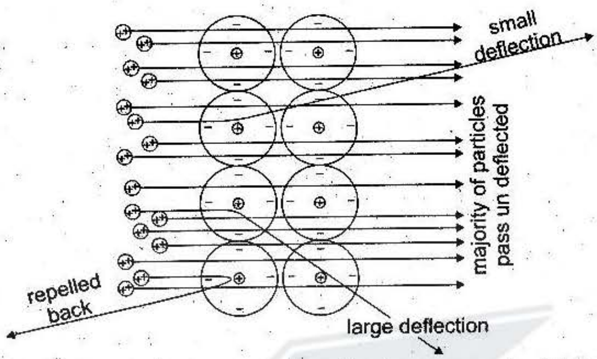


Fig. Scattering of alpha particles by the atoms of gold foil.

Observations

Observations made by Rutherford were as follows:

i. Almost all the particles passed through the foil un-deflected.

ii. Out of 20,000 particles, only a few were deflected at fairly large angles and very few bounced back on hitting the gold foil.

Results of the experiment

Keeping in view the experiment, Rutherford proposed planetary model for an atom and concluded following results:

i. Since most of the particles passed through the foil un-deflected, therefore most of the volume occupied by an atom is empty .

ii. The deflection of a few particles proved that there is a 'center of positive charges' in an atom, which is called 'nucleus' of an atom.

iii. The complete rebounce of a few particles show that the nucleus is very dense and hard.

iv. Since a few particles were deflected it shows that the size of the nucleus is very small as compared to the volume of an atom.

v. The electrons revolve around the nucleus.

vi. An atom as a whole is neutral, therefore the number of electrons in an atom is equal to the number of protons.

vii. Except electrons, all other fundamental particles that lie within a nucleus are known as nucleons

Q6. Write defects of Rutherford's Model.

Ans. Defects in Rutherford's Model

Although Rutherford's experiment proved that the 'plum-pudding' model of an atom was not correct, yet it had following defects:

i. According to classical theory, electrons being the charged particles should release or emit energy continuously and they should ultimately fall into the nucleus.

ii. If the electrons emit energy continuously, they should form a continuous spectrum but in fact, line spectrum was observed.

Although the scientists had objections on the atomic model presented by Rutherford, yet it cultivated thought provoking ideas among them.

Q7. Write postulates of Bohr's Atomic Model.

OR

How did Bohr prove that an atom must exist?

Ans. Bohr's Atomic Theory

Keeping in view the defects in Rutherford's Atomic Model, Neil Bohr presented another model of atom in 1913. The Quantum Theory of Max Planck was used as foundation for this model. According to Bohr's model revolving electron in an atom does not absorb or emit energy continuously. The energy of a revolving electron is 'quantized' as it revolves only in orbits of fixed energy called 'energy levels' by him. The Bohr's atomic model is shown in figure.

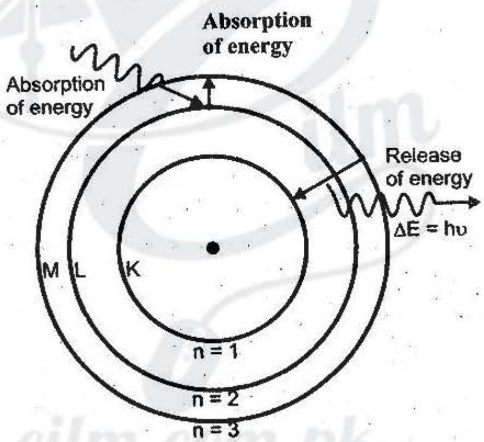


Fig. Bohr's atomic model showing orbits.

The Bohr's atomic model was based upon the following postulates;

1. The hydrogen atom consists of a tiny nucleus and electrons are revolving in one of circular orbits of radius r around the nucleus.
2. Each orbit has a fixed energy that is quantized.
3. As long as electron remains in a particular orbit it does not radiate or absorb energy. The energy is emitted or absorbed only when an electron jumps from one orbit to another.
4. When an electron jumps from lower orbit to higher orbit it absorbs energy and when it jumps back from higher orbit to lower orbit it radiates energy.

This change in energy, ΔE is given by following Planck's equation

$$\Delta E = E_2 - E_1 = h\nu$$

Where h is Planck's constant equal to 6.63×10^{-34} Js, and ν is frequency of light.

5. Electron can revolve only in orbits of a fixed angular moment mvr, given as:

$$mvr = n\frac{h}{2\pi}$$

Where 'n' is the quantum number or orbit number having values 1,2,3 so on.

Q8. Write differences between Rutherford and Bohr's atomic theory.

Ans. Differences between Rutherford and Bohr's theories:

Rutherford's Atomic Theory	Bohr's Atomic Theory
i. It was based on classical theory.	i. It was based upon quantum theory.
ii. Electrons revolve around the nucleus.	ii. Electrons revolve around the nucleus in orbits of fixed energy.
iii. No idea about orbits was introduced.	iii. Orbits had angular momentum.
iv. Atoms should produce continuous spectrum.	iv. Atoms should produce line spectrum.
v. Atoms should collapse.	v. Atoms should exist.

Q9. Write a note on shell and subshell?

Ans. Shell

Shell is the energy level in which electrons revolve around the nucleus e.g. K,L,M etc.

Explanation

Atom consists of a tiny nucleus lying in the center and electrons revolving around the nucleus. The electrons revolve around the nucleus in different energy levels or shells according to their respective energies (potential energy).

Energy levels are represented by 'n' values 1,2,3 and so on. While shells are designated by the alphabets or shells K, L, M and so on. A shell closer to the nucleus is of minimum energy. Since K shell is closest to the nucleus, the energy of shells increases from K shell onwards. Such as:

1st energy level is K shell; it has the lowest energy.

2nd energy level is L shell; it has more energy than K shell.

3rd energy level is M shell; it has more energy than K and L shell.

4th energy level is N shell; it has more energy than K, L and M shell.

In simple words shells are the main energy levels that electrons occupy. Shells are represented by circles around the nucleus. They are counted from the center to outward as shown in the figure. The number of electrons that a shell can accommodate is given by $2n^2$,

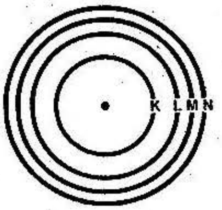


Fig. Showing different energy levels or shells counted from the centre outwards.

Subshell

A shell also consists of subshells or orbitals. Each subshell or orbital is designated by a small alphabetical letter *s, p, d,* f, etc.

i. First energy level or K shell has only one sub-shell called s subshell.

ii. Second energy level or L shell has two subshells *s* and p.

iii. Third energy level M shell has three subshells S, *p* and *d.*

iv. Fourth energy level or N shell has four subshells *s, p, d* and f

n value	Shell	Sub-Shell
1	K	Only s
2	L	s,p
3	M	s,p,d
4	N	s,p,d,f

Q10. What do you mean by electronic configuration? What are basic requirements while writing electronic configuration of an element?

Ans. Electronic Configuration

The distribution of electrons around the nucleus in various shells and subshells according to their increasing energy, is called electronic configuration.

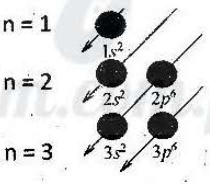


Fig. Filling sequence of electrons in subshells according to energy levels

Rules:

The most stable or ground state electronic configuration of an atom is the one in which electrons are present in the lowest possible energy level. The electrons fill the shells in order of their increasing energy, i.e. lower energy level is occupied first then the higher energy level and so on. The maximum capacity of shells to accommodate the electrons as following:

K shell can accommodate 2 electrons.

L shell can accommodate 8 electrons.

M shell can accommodate 18 electrons.

N shell can accommodate 32 electrons.

As we know there is a slight difference between the energies of the subshells or orbitals within a shell, therefore, filling of electrons in subshells of a shell is such as that " s" subshell is filled first and then its "*p*" subshell and then other subshells are filled.

The maximum capacity of subshells to accommodate electrons is:

i. 's' orbital can accommodate 2 electrons.

ii. 'p' orbital can accommodate 6 electrons.

iii. 'd' orbital can accommodate 10 electrons.

iv. 'f' orbital can accommodate 14 electrons.

While writing the electronic configuration of the elements and their ions. we should know three things:

i. The number of electrons in an atom.

ii. The sequence of shells and sub shells according to the energy levels.

iii. The maximum number of electrons that can be placed in different shells and subshells.

Q11. Draw electronic configuration of first 18 elements.

Ans. The electronic configuration of first 18 elements

The sequence of filling of electrons in different subshells is as following:

$1s^2$, $2s^2$,$2p^6$, $3s^2$, $3p^6$ ……

Where number represents the shell number, while letters (s and *p*) represent subshells. The superscript shows the number of electrons in a subshell. The sum of superscripts number is the total number of electrons in an atom. i.e. atomic number of an element. The electronic configuration of first 18 elements is shown in the Table

Table: Electronic Configuration of First Eighteen Elements

Element	Symbol	Atomic Number	Electronic Configuration
Hydrogen	H	1	$1s^1$
Helium	He	2	$1s^2$
Lithium	Li	3	$1s^2,2s^1$
Beryllium	Be	4	$1s^2$, $2s^2$
Boron	B	5	$1s^2,2s^2,2p^1$
Carbon	C	6	$1s^2,2s^2$,$2p^2$
Nitrogen	N	7	$1s^2,2s^2,2p^3$
Oxygen	O	8	$1s^2,2s^2,2p^4$
Fluorine	F	9	$1s^2,2s^2,2p^5$
Neon	Ne	10	$1s^2,2s^2,2p^6$

Sodium	Na	11	$1s^2,2s^2,2p^6,3s^1$
Magnesium	Mg	12	$1s^2,2s^2,2p^6,3s^2$
Aluminium	Al	13	$1s^2,2s^2,2p^6,3s^2,3p^1$
Silicon	Si	14	$1s^2,2s^2,2p^6,3s^2,3p^2$
Phosphorus	P	15	$1s^2,2s^2,2p^6,3s^2,3p^3$
Sulphur	S	16	$1s^2,2s^2,2p^6,3s^2,3p^4$
Chlorine	Cl	17	$1s^2,2s^2,2p^6,3s^2,3p^5$
Argon	Ar	18	$1s^2,2s^2,2p^6,3s^2,3p^6$

Q12. What is an isotope? Describe the isotope of Hydrogen, Carbon, Chlorine and Uranium.

Ans. Isotopes

Isotopes are defined as the atoms of an element that have same atomic number but different mass numbers.

Properties of Isotopes

i. They have same electronic configuration and number of protons.

ii. They differ in their number of neutrons.

iii. Isotopes have similar chemical properties because these depend upon electronic configuration.

iv. They have different physical properties because these depend upon atomic masses.

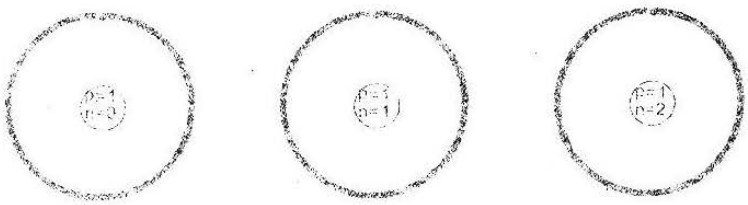
v. All isotopes of an element occupy same position in the periodic table.

Examples

i. Isotopes of Hydrogen

The naturally occurring hydrogen is combination of its three isotopes, present in different abundances. The three isotopes of hydrogen are named as protium (^1_1H), deuterium (^2_1H or D) and tritium (^3_1H or T). Each one of them has 1 proton and 1 electron, but number of neutrons is different.

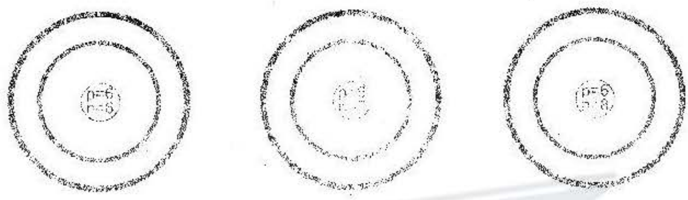
The isotopes are represented as:



protium (^1_1H)   deuterium (^2_1H)   tritium (^3_1H)

ii. Isotopes of Carbon

There are two stable isotopes of carbon ^{12}C, ^{13}C and one radioactive isotope ^{14}C. The isotope ^{12}C is present in abundance of 98.9 %, while ^{13}C and ^{14}C are both present only 1.1 % in nature. All of them have the same number of protons and electrons but differ in number of neutrons. They are represented as follows:



protium (^1_1H) deuterium (^2_1H) tritium (^3_1H)

iii. Isotopes of Chlorine

There are two isotopes of chlorine, $^{35}_{17}Cl$, $^{37}_{17}Cl$

iv) Isotopes of Uranium

There are three isotopes of uranium i.e. $^{234}_{92}U$, $^{235}_{92}U$, $^{238}_{92}U$. The $^{238}_{92}U$ is found in nature nearly 99% pure.

Symbol	*Atomic Number*	*Mass Number*	*No. of proton*	*No. of Neutron*
^1H	1	1	1	0
^2H	1	2	1	1
^3H	1	3	1	2
^{12}C	6	12	6	6
^{13}C	6	13	6	7
^{14}C	6	14	6	8
^{35}Cl	17	35	17	18
^{37}Cl	17	37	17	20
^{234}U	92	234	92	142
^{235}U	92	235	92	143
^{238}U	92	238	92	146

Q13. Write down the uses of radioactive isotopes.

Ans. Uses of radioactive isotopes

With the advancement of the scientific knowledge, the isotopes have found many applications in our lives. Following are the major fields in which isotopes have vast applications:

i. Radiotherapy (Treatment of Cancer)

For the treatment of skin cancer, isotopes like P-32 and Sr-90 are used because they emit less penetrating beta radiations. For cancer, Co-60, affecting within the body, is used because it emits strongly penetrating gamma rays.

ii. Tracer for Diagnosis and Medicine

The radioactive isotopes are used as tracers in medicine to diagnose the presence of tumor in the human body. Isotopes of Iodine-131 are used for diagnosis of goiter in thyroid gland. Similarly technetium is used to monitor the bone growth.

iii. Archaeological and Geological Uses

The radioactive isotopes are used to estimate the age of fossils like dead plants and animals and stones etc. The age determination of very old objects based on the half-lives of the radioactive isotope is called radioactive-isotope dating. An important method of age determination of old carbon containing objects (fossils) by measuring the radioactivity of C-14 in them is called radio-carbon dating or simply carbon dating.

iv. Chemical Reaction and Structure Determination

The radioisotopes are used in a chemical reaction to follow a radioactive element during the reaction and ultimately to determine the structure. For example: C-14 is used to label CO_2. As is used by the plants for photosynthesis to form glucose, its movement is detected through the various intermediate steps up to glucose.

v. Applications in Power Generation

Radioactive isotopes are used to generate electricity by carrying out controlled nuclear fission reactions in nuclear reactors. For example, when U-235 is bombarded with slow moving neutrons, the uranium nucleus breaks up to produce Barium-139 and Krypton-94 and three neutrons.

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{139}_{56}Ba + ^{94}_{36}Kr + 3\,^{1}_{0}n + \text{Energy}$$

A large amount of energy is released which is used to convert water into steam in boilers. The steam then drives the turbines to generate electricity. This is the peaceful use of atomic energy for development of a nation

Q14. Describe the electronic configuration of Na^+, Mg^{2+} and Al^{3+} ion. Do they have the same number of electrons in the outermost shell?

Ans. (i) Na^+

Electronic Configuration

K L

2 8

In terms of sub shells

$1s^2, 2s^2, 2p^6$

(ii) Mg^{2+} Electronic configuration

K L

2 8

In terms of sub shells

$1s^2\ 2s^2\ 2p^6$

(iii) Al^{3+} Electronic configuration

K L

2 8

In terms of sub shells

$1s^2, 2s^2, 2p^6$

It is proved that all have eight electrons in there outermost shell.

Q15. One of the postulates of Bohr's atomic model is that angular momentum of a moving electron is quantized. Explain its meaning and calculate angular momentum of third orbit (i.e n=3).

Ans. **Angular momentum of a moving electron is quantized means that "electron can revolve only in orbits of a fixed angular momentum mvr, given as**

$$\text{Angular momentum } mvr = \frac{nh}{2\pi} \quad \text{———} \quad (1)$$

$n = 3$

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

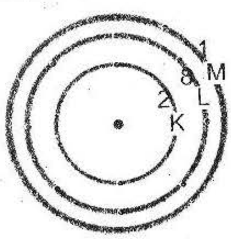
$\pi = 3.14$

Putting values in equation (1)

$$\text{Angular momentum } (mvr) = \frac{3 \times 6.63 \times 10^{-34}\ Js}{2 \times 3.14}$$

$$\text{Angular momentum} = 3.16 \times 10^{-34}\ kgm^2s^{-1}$$

Q16. Write the electronic configuration of an element electrons having 11 electrons.



Solution:

Keep in mind that all the electrons do not have the same energy. Therefore, they are accommodated in shells according to increasing energy and capacity of the shell. First of all, the electrons will .go to K shell which has minimum energy. It can accommodate 2 electrons. After this, electrons will go to L shell that can accommodate 8 electrons. Thus K and L shells have accommodated 10 electrons. The remaining 1 electron will go to M shell, the outermost shell of maximum energy in this case.

The electronic configuration will be written as:

K L M

2, 8, 1,

Therefore, it is simply written as 2,8,and 1. Further distribution of electrons in subshells will be: $1s^2$, $2s^2$,$2p^6$, $3s^1$.

Q17. Write down the electronic configuration of Cl^- ion.

Solution:

We know that chlorine has 17 electrons and chloride ion (Cl^-) has 17 + 1 = 18 electrons. Its electronic configuration will be 2, 8. 8, which is presented in the figure. The further distribution of electrons in subshells will be $1s^2$, $2s^2$, $2p^6$, $3s^1$, $3p^6$.