

STRUCTURE OF ATOMS

CONCEPTUAL LINKAGE

Before reading this chapter, the student must know the:

- Basics of Atom.
- Basics of sub atomic particles
- Properties of charged particles

TIME ALLOCATION

Teaching periods	= 16
Assessment periods	= 03
Weightage	= 14%



LEARNING OUTCOMES

After reading this chapter, the Student will be able to:

- Describe the contribution that Rutherford made to the development of the atomic theory. (Applying)
- Describe the contribution of Bohr made in development of atomic structure. (Applying)
- Explain how Bohr's theory differs from Rutherford's theory. (Analyzing)
- Describe the structure of an atom including the location of the proton, electron and neutron. (Understanding)
- Define isotope. (Remembering)
- Compare isotopes of an atom. (Analyzing)
- Draw the structures of different isotopes from mass number and atomic number. (Applying)
- State the importance of isotopes in various fields of life. (Remembering)
- Describe the presence of sub shells in a shell. (Understanding)
- Distinguish between shells and sub shells. (Understanding)
- Write electronic configuration of first 18 elements in the Periodic table. (Applying)

2.0 Introduction

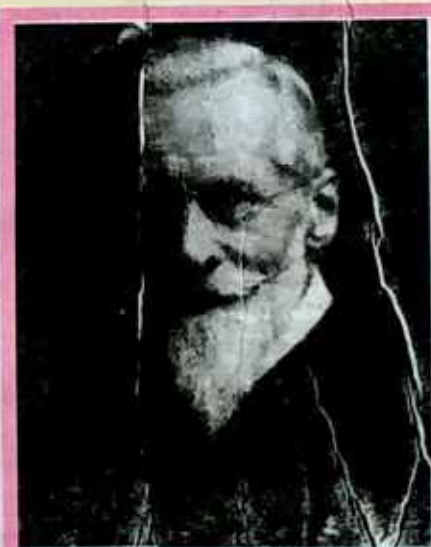
Atoms which are the building blocks of matter are very important to understand in Chemistry which is the science of matter. As already describe that the name atom is derived from the Greek word Atomos which means "indivisible", this initial concept of atom is believed to be given by the Greek philosopher Democritus (400BC) who suggested that matter is composed of tiny indivisible particles.

But with the advancement of science they are no more indivisible now, and can be easily broken into smaller particles. These particles are called subatomic particles. The important subatomic particles are the Electrons, protons and the neutrons. In the subsequent pages you will learn about the structure of atom, the arrangement of subatomic particles and discovery of these subatomic particles.

2.1 Theories and Experiments Related to Atomic Structure

Although, the Scientists from the ancient eras were trying to understand the atomic structure, but the important success in understanding this was made in and after the mid of eighteenth century, after the advent of cathode ray tube by William Crook.

A cathode ray tube is a glass tube linked with high voltage source of current at its two electrodes, the air pressure in the tube is reduced by using vacuum pump, William Crook observed that at ordinary pressure, when electricity is passed through this tube, nothing happens, but at reduced pressure 0.01 torr high voltage produces a beam of radiation which cause fluorescence on striking with some fluorescent material.



William Crook
(British)
Born 182—Died 1919

The structure of this cathode ray tube is shown in figure 2.1.

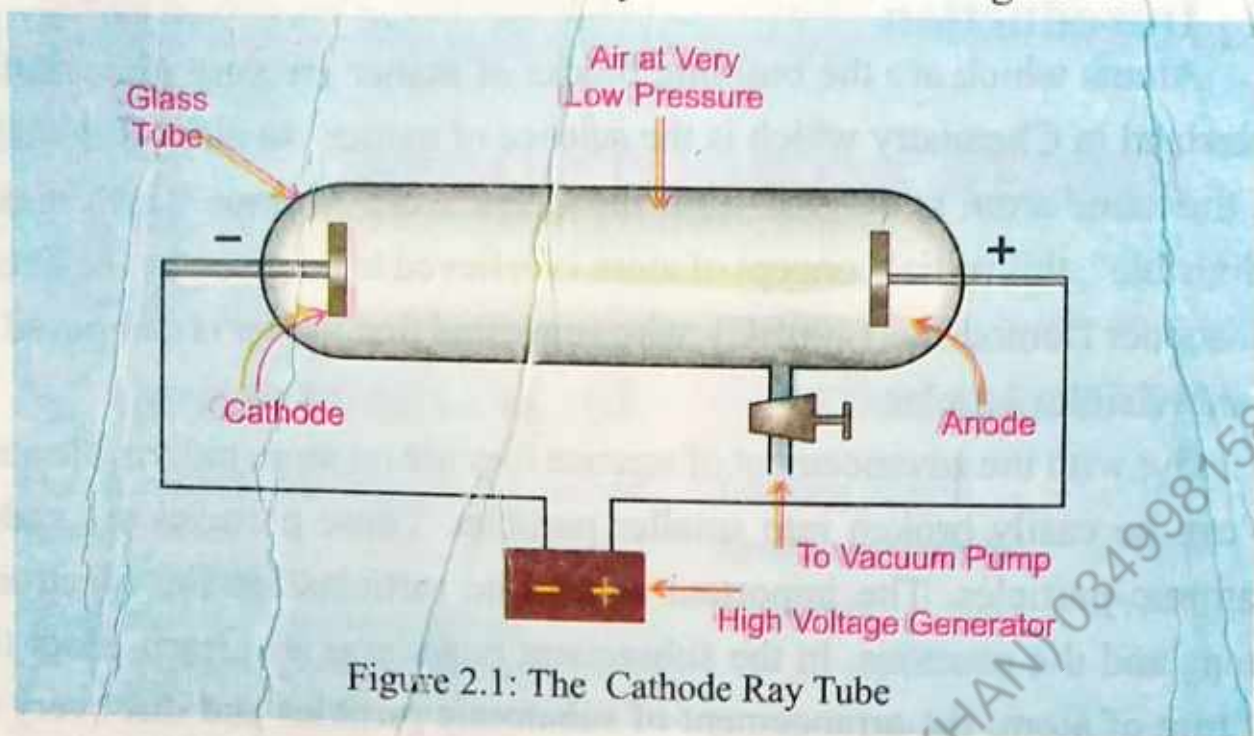


Figure 2.1: The Cathode Ray Tube

Discovery of Electron

It was observed that when high voltage current is passed through this tube at a very low pressure 0.01 torr then a beam of ray is produced. The direction of these rays is from cathode to anode, hence they originate from the cathode electrode, so are called cathode rays, fig 2.2.

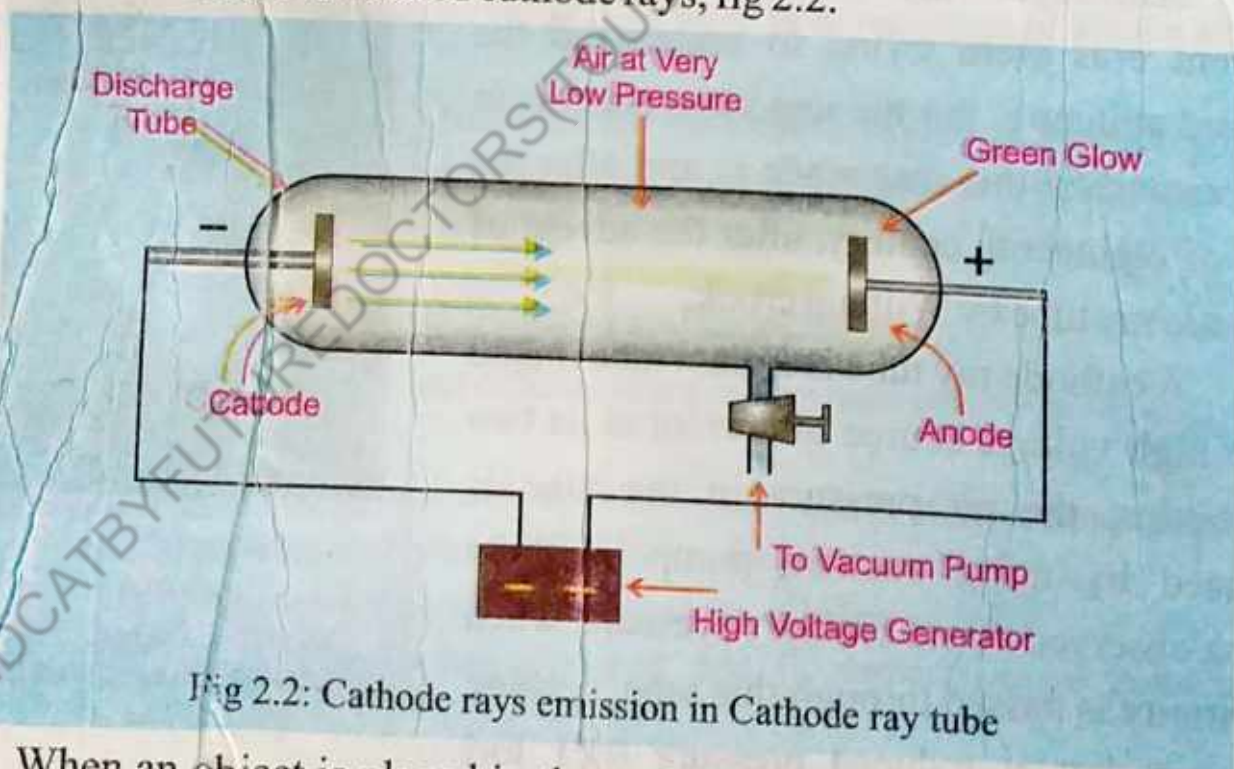


Fig 2.2: Cathode rays emission in Cathode ray tube

When an object is placed in the path of these rays, it is observed that they cast a sharp shadow; it means that they travel in straight line. (Figure 2.3)

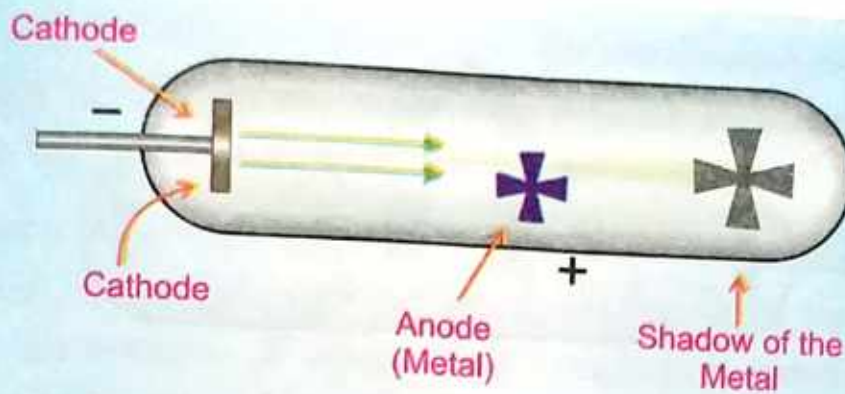


Fig 2.3: Experiment showing that cathode rays cast shadow

When a flywheel of mica is placed in their path it is moved showing that these rays are actually particle in nature, (Figure 2.4)

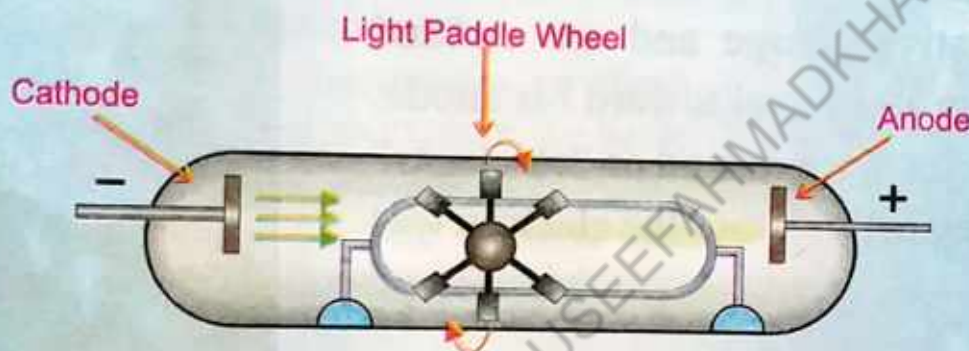


Fig 2.4: Experiment showing that cathode rays move fly wheel

When these rays are subjected to electric or magnetic fields, they were deflected towards the positive plate showing their negative nature. (Figure 2.5 and 2.6)

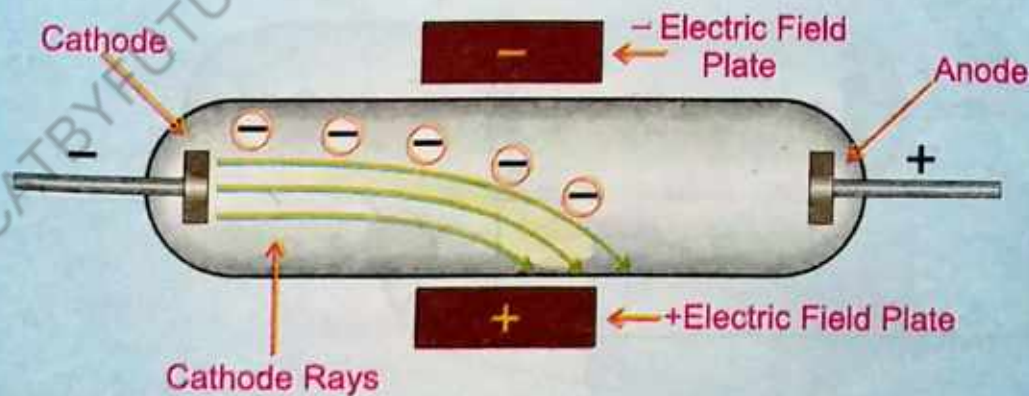


Fig 2.5: Experiment showing that cathode rays bent towards positive plate

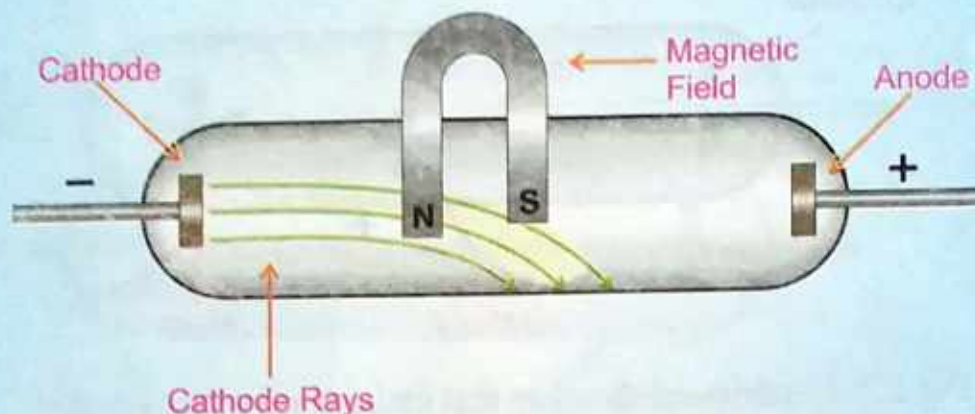


Fig 2.6: Experiment showing that cathode rays bent perpendicular in magnetic field

These experiments proved that cathode rays are actually tiny particles having negative charge and are emitted from cathode and travel toward his anode. These particles were named as “electrons” by G.J Stoney in 1891, thus the electron was discovered.

Discovery of Proton

In 1886 Gold Stein observed that glow appeared in the discharge tube at opposite end of anode at back of cathode if a perforated cathode is used (see figure 2.7).



Goldstein
(German Physicists)
1850—1930

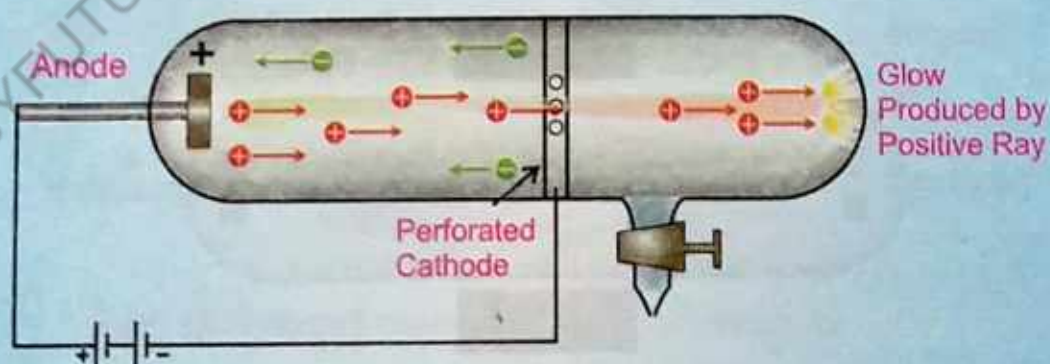


Fig 2.7: Canal rays produce by anode in cathode ray tube

The rays that form from the gas inside the discharge tube.

Further investigations showed that these rays have positive charge, have momentum. They were named Proton.

The Discovery of Neutron

In 1920, Ernest Rutherford postulated that there were neutral, massive particles in the nucleus of atoms. This conclusion arose from the disparity between an element's atomic number (protons = electrons) and its atomic mass (which is in excess of the mass of the known protons present). James Chadwick proved the existence of these particles in 1930 and he received the

Noble prize in 1935 for his success.

Thus all the basic fundamental sub atomic particles were discovered.

Soon after the discoveries of these particles Scientists tried to explain the basic structure of atom by their models.

The important atomic models are discussed here in the following sections.

2.1.1 Rutherford's Atomic Model

In 1910 (note that at this time only proton and electrons were known) Rutherford bombarded a thin gold foil (4×10^{-7} m) and observed that:



Rutherford
(New Zealand)
Noble Laureate
Chemistry,
Born 1871, Died 1937

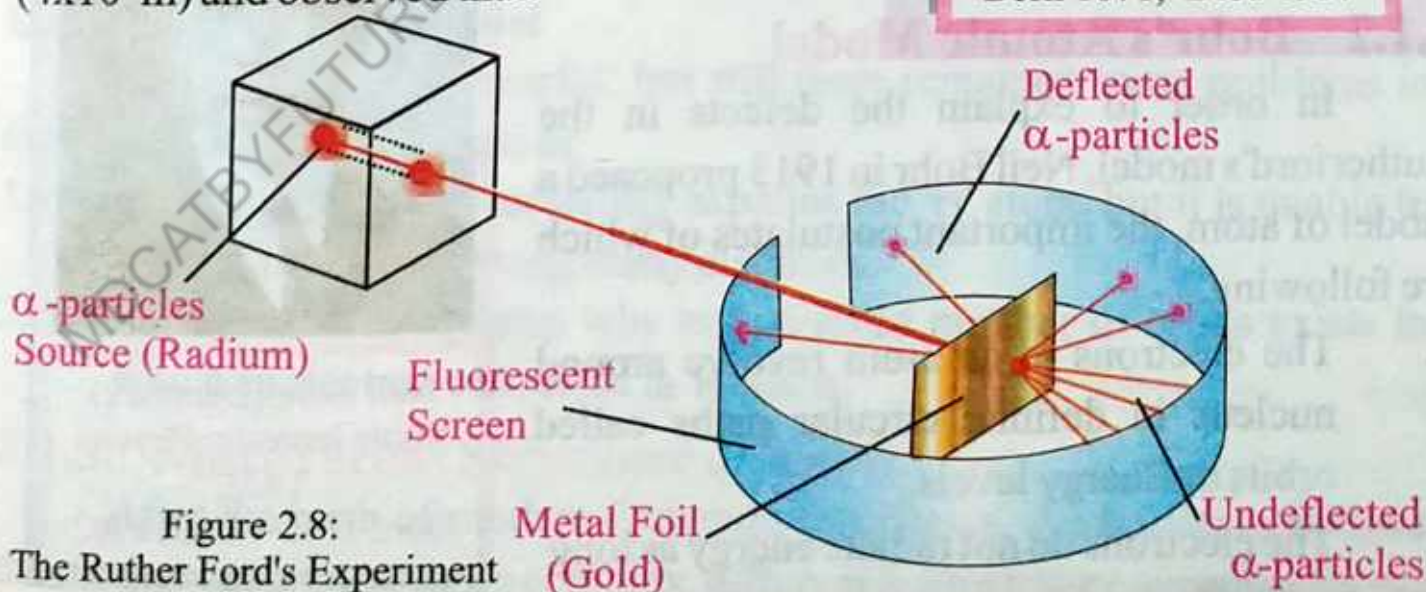


Figure 2.8:
The Rutherford's Experiment

Most of the alpha ray particles passed through foil. Some particles deflected (one in 20,000) at various angles. Very few deflected back. Rutherford concluded that, as most of the α -ray particles passed through foil without any resistance, so most of area in atom is empty. Some particles deflected so in the atom there is a very small area of positive charge with the mass of whole atom in their.

He named the positive centre of atom as Nucleus of atom.

On the basis of his experiment, Rutherford developed a model for atomic structure, **which has following important postulates.**

- An atom has a positive centre called nucleus.
- Around this nucleus the electrons revolve.
- The number of electrons are equal to positive particles so atom as a whole is neutral.

This model is just like the solar system where the centre is sun around which planets move. Rutherford's model gave the basic idea for structure of atom, although there were some problems. e.g why electrons do not fall in nucleus, as by classical mechanics a charged particle moving should radiate energy, and when all energy is lost by electron, it should fall in nucleus. Moreover due to radiating electron, a continuous spectra should be observed, but this is not the case.

Recent studies show that nucleus is about 10^{-15} m in diameter and atom has about 10^{-10} m diameter, (See figure 1.5).

2.1.2 Bohr's Atomic Model

In order to explain the defects in the Rutherford's model, Neil Bohr in 1913 proposed a model of atom, the important postulates of which are following.

1. The electrons in an atom revolve around nucleus in definite circular paths called orbits or Energy levels.
2. The electrons do not radiate energy as long



Neil Bohr (Denmark)
Noble laureate Physics
1922,
Born 1885—Died 1962

as they remain in an orbit.

3. For electrons only that orbit is allowed for which the angular momentum, (mvr) of electron is equal to integral multiple of $\frac{h}{2\pi}$.
4. The electron jumps to higher energy level or emits energy coming to lower energy level by absorbing or emitting energy respectively.
5. This energy is quantized and is given by: $E = h\nu$

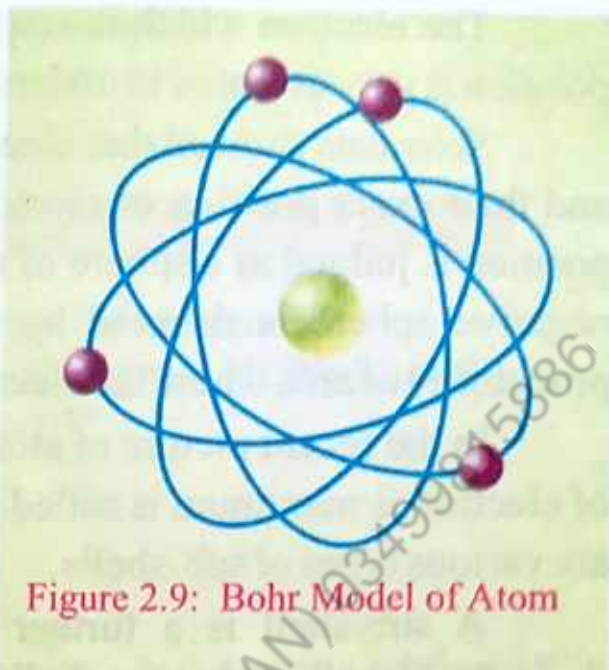


Figure 2.9: Bohr Model of Atom

Where h = Planck's constant and
where ν (spelled as nu) is the frequency of radiation.

The Bohr model has following merits over classical models:

1. Bohr model was a successful approach in explaining many basic characteristics of atomic structure.
2. His theory was conflicting with classical mechanics, and thus he started modern mechanics.
3. He told that the principles at macroscopic level do not apply on microscopic level.
4. Bohr explained the spectral lines of 'H' atom successfully.
5. He calculated Radius and energy of electron in an orbit successfully

Limitations Of Bohr Model

Although very successful, but still there remained some problems in the Bohr atomic model, such as

1. The Bohr model successfully explains the 'H' atom, but it is unable to explain the atoms having many electrons.
2. It also do not explains why only a fixed number of orbits exists in which an electron can reside in 'H' atom.

2.1.3 More recent Structure of Atom

After the birth of modern Quantum mechanics, the scientists believe the structure of atom as more complex, different from earlier concepts.

The electron which is responsible for the properties of atoms and its position is very essential to understand.

Scientists showed that electron behaves as a particle as well as a wave, and their exact position of electron is very hard to determine. Although its position is judged as a sphere of negative charge cloud around nucleus. This negative sphere is denoted by the dots and density of dots show more probability of area where the electrons are located.

In the recent picture of atom the areas where the probability of finding of electron is maximum is called the Sub-shell or orbital and in an atom there are various types of sub-shells.

A sub-shell is a further division of shell, and as the shell number increases, the size of shell also increases and more orbitals are included in this, this is explained in the following table 2.1.

No of shell	Shell name	Sub-shells
1	K	s
2	L	s,p
3	M	s,p,d
4	N	s,p,d,f

Table 2.1: Table showing number of shell, name of shell and the sub shells that it contains.

The orbitals grow towards more complexity as their number increases, e.g the s orbital is spherical in shape and is directionless, while p orbital is dumbbell in shape and are located in 3 directions, i.e. along x-axis, y-axis, and z-axis. (d) sub-shell have 5 orbitals and (f) sub-shell have 7 orbitals.

2.2 The Electronic Configuration

The position of electrons in an atom is called its electronic configuration. In order to calculate electronic configuration it is kept in mind that electrons will fill that orbitals first whose energy is least, The filling of orbitals is easily calculated by following figure 2.10, the arrow sign shows the filling of electrons in specific sub shells.

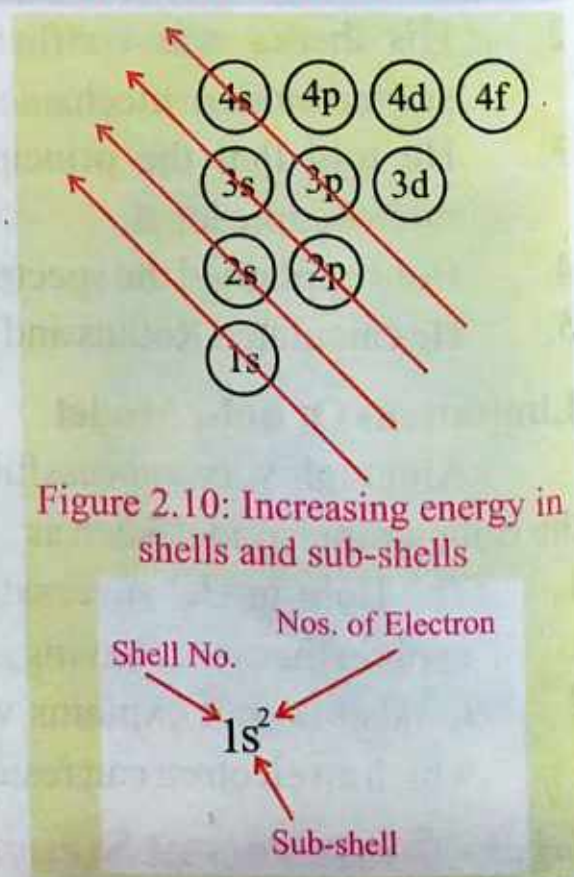


Figure 2.10: Increasing energy in shells and sub-shells

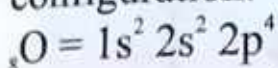
This is further explained by the following examples:

Example:

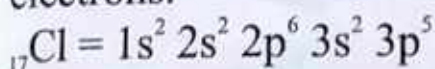
Write down the electronic configuration of 'O' and 'Cl'.

Solution

O having 8 electrons has electronic configuration.



Cl has 17 atomic number so it has 17 electrons.



Activity: 2.1

Draw the electronic configuration of "N=7" and "P=15".

Following table 2.2 that shows the electronic configuration of first 18 elements.

Atomic No.	Symbol	Electronic Configuration	Atomic No.	Symbol	Electronic Configuration
1	H	$1s^1$	10	Ne	$1s^2 2s^2 2p^6$
2	He	$1s^2$	11	Na	$1s^2 2s^2 2p^6 3s^1$
3	Li	$1s^2 2s^1$	12	Mg	$1s^2 2s^2 2p^6 3s^2$
4	Be	$1s^2 2s^2$	13	Al	$1s^2 2s^2 2p^6 3s^2 3p^1$
5	B	$1s^2 2s^2 2p^1$	14	Si	$1s^2 2s^2 2p^6 3s^2 3p^2$
6	C	$1s^2 2s^2 2p^2$	15	P	$1s^2 2s^2 2p^6 3s^2 3p^3$
7	N	$1s^2 2s^2 2p^3$	16	S	$1s^2 2s^2 2p^6 3s^2 3p^4$
8	O	$1s^2 2s^2 2p^4$	17	Cl	$1s^2 2s^2 2p^6 3s^2 3p^5$
9	F	$1s^2 2s^2 2p^5$	18	Ar	$1s^2 2s^2 2p^6 3s^2 3p^6$

Table 2.2: Electronic configuration of first 18 elements

2.3 Isotopes

The term isotope has been originated from two words, 'iso' that means same, and 'topes' (from topos) which means place.

The isotopes are the atoms forms of same element that have same

atomic number but different atomic masses. e.g hydrogen has three isotopic forms i.e Protium (${}_1\text{H}^1$) deuterium (${}_1\text{D}^2 / {}_1\text{H}^2$) and Tritium (${}_1\text{T}^3 / {}_1\text{H}^3$).

These isotopes of hydrogen are drawn in the figure 2.11.

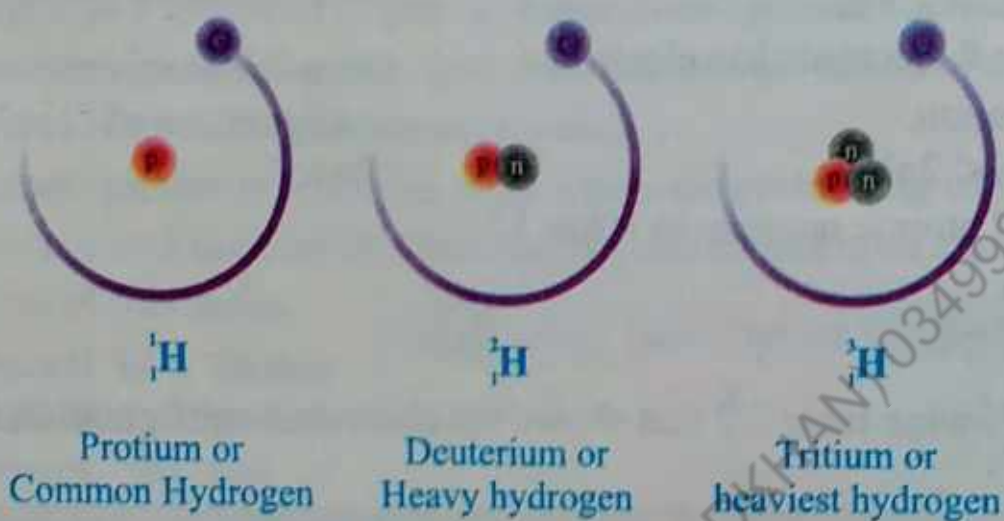


Figure 2.11: Isotopes of Hydrogen

Similarly the Carbon also has 3 isotopic forms, which are drawn in figure 2.12.

Carbon-12

Carbon-13

Carbon-14

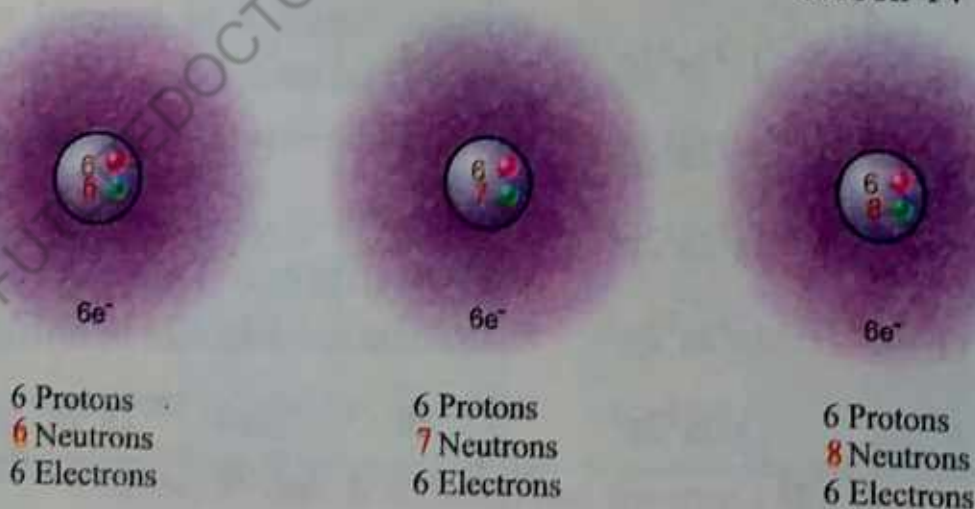


Figure 2.12: Isotopes of Carbon

Almost all of the elements form isotopes, in the following table 2.3 shows isotopes of some elements and their percentage in nature.

TABLE OF ISOTOPES

Element	Protons	Mass Number	Symbol	Abundance %
H	1	1	${}_1\text{H}^1$	99.985
	1	2	${}_1\text{D}^2$	0.015
	1	3	${}_1\text{T}^3$	Trace
C	6	12	${}_6\text{C}^{12}$	98.90
	6	13	${}_6\text{C}^{13}$	1.10
	6	14	${}_6\text{C}^{14}$	Trace
Cl	17	35	${}_{17}\text{Cl}^{35}$	75.77
	17	36	${}_{17}\text{Cl}^{36}$	Trace
	17	37	${}_{17}\text{Cl}^{37}$	24.23
U	92	233	${}_{92}\text{U}^{233}$	Trace
	92	234	${}_{92}\text{U}^{234}$	0.0055
	92	235	${}_{92}\text{U}^{235}$	0.7200
	92	238	${}_{92}\text{U}^{238}$	99.2745

Table: 2.3: Table of some isotopes

Activity: 2.2

Using the data given in the table 2.3 draw the structures of Chlorine isotopes.

2.3.1: Uses of Isotopes

The isotopes are used in many fields of life, e.g.

- 1- They are used in isotopic labeling, normally, atoms of a given element are indistinguishable from each other. However, by using isotopes of different masses, they can be distinguished by mass spectrometry or infrared spectroscopy.

- 2- As tracers or markers in chemical reactions, this technique is called radio isotopic labeling. If radioactive isotopes are used in chemical reactions, they can be detected by the radiation they emit, and thus mechanisms of different reactions can be understood quite easily.
- 3- The isotopes are also used to understand the mechanisms of various natural processes like photosynthesis.
- 4- A technique similar to radio isotopic labeling is radiometric dating; using the known half-life of an unstable element we can calculate the amount of time that has elapsed since a known level of isotope existed. The most widely known example is radiocarbon dating used to determine the age of carbonaceous materials.
- 5- Several forms of spectroscopy rely on the unique nuclear properties of specific isotopes. For example, nuclear magnetic resonance (NMR) spectroscopy can be used only for isotopes with a non zero nuclear spin.
- 6- The isotopes also used for the treatment of different types of cancers in the body, the cancerous cells are killed by using radio active rays of radio isotopes. This process is called radiotherapy.
7. Isotopes are also used for the investigation of different diseases, e.g. in order to determine the efficiency of kidneys heavy water (D_2O) is past in the body and its traveling is monitored. The malfunctioning kidney does not passes water, so the relative functioning of each kidney is determined.
8. The isotopes are also used to generate electricity. This is because of the tendency of radio isotopes to emit radioactive rays, these rays are also a good source of energy and this energy is carefully used to run turbines. In Pakistan Kanupp (Karachi), Nilore (Islamabad) and Chashma Nuclear Energy centers produce electricity based on this method.

SUMMARY OF THE CHAPTER

- ❖ **Atoms** are the building blocks of matter; they are the smallest particle of matter having all the characteristics of their element.
- ❖ The electron and proton, two important sub atomic particles of atoms were discovered by the series of experiments with **cathode ray tubes**.
- ❖ Rutherford discovered the **nucleus** of atom, and proposed the basic structure of atom.
- ❖ Bohr told that electron revolve in fixed paths around nucleus called **orbits**, during revolving around the nucleus the electrons do not radiate energy in normal circumstances. Bohr told that in special cases, electron absorb energy and get excited, jump to higher energy level (or orbit.), but as the normal conditions reach, these excited electron release their extra energy and come back in previous energy level.
- ❖ The Bohr energy levels or orbits were later named as **shells** and they are further divided into **sub shells** (orbitals). In an atom different types of sub shells are found, they are named, s, p, d, f.
- ❖ The electrons in an atom are filled in the increasing order of energy, i.e. the orbital with least energy is filled first.
- ❖ Filling of electrons in an atom is called its **electronic configuration**. The electronic configuration plays an important role in predicting the properties of atoms.

EXERCISE

Q1. Fill in the blanks with suitable words.

- i) Experiments with tube helped a lot in understanding the nature of sub atomic particles.
- ii) According to Bohr the angular momentum is of $h/2\pi$.
- iii) The most stable isotope of C has mass
- iv) Rutherford bombarded the gold foil with
- v) Cathode rays were given the name of electron by in

1891.

- vi) Nucleus was discovered by
- vii) The presence of neutron was confirmed by in 1930.
- viii) Electrons radiate energy when jumps from to energy levels.
- ix) The modern research showed that electron behaves both as a --- and a particle.
- x) Number of neutrons in the atom of $_{17}\text{Cl}^{35}$ are

Q2. Choose the correct answer.

- i) Structure determination helps to determine the:
 - (a) Physical characters
 - (b) Chemical characters
 - (c) Both physical and Chemical characters
 - (d) Does not helps in any way
- ii) Recent Studies shows that atom has an average size of:
 - (a) 10^{-10} meters
 - (b) 10^{-8} meters
 - (c) 10^{-15} meters
 - (d) 10^{-12} meters
- iii) 1 angstrom is equal to the:
 - (a) 10^{-10} meters
 - (b) 10^{-12} meters
 - (c) 10^{-15} meters
 - (d) 10^{10} meters
- iv) Neil Bohr mainly concentrated upon:
 - (a) Nucleus of atom
 - (b) Behavior of electrons
 - (c) protons
 - (d) Neutrons
- v) Electronic configuration tells about the:
 - (a) Number of sub-shells
 - (b) Number of shells
 - (c) Valency
 - (d) All sub-shell, shell and valency

Q3. Answer the following questions in short.

- i) Describe the structure of cathode ray tube.
- ii) Do you agree that atoms are indivisible?
- iii) Write a note on discovery of neutrons.
- iv) Why position of electrons is hard to know?

- v) Discuss the shape of 's' and 'p' orbitals.
- vi) What is the role of electronic configuration in determining the chemical nature of an element.
- vii) Write electronic configuration of Na and Na^+ .
- viii) What do you know about shells of atoms?
- ix) Describe division of shells into sub shells?
- x) Why Rutherford used α -rays and not γ -rays.

Q4. Answer the following question with reasoning.

- i) Can you explain the experiment that lead to the development that e^- has negative charge and proton has the +ve charge?
- ii) Why Rutherford used gold foil instead of any other metal foil?
- iii) Why scientist concluded that electrons revolve around nucleus and not neutrons?
- iv) Why Tritium, is not found in larger quantities in nature.
- v) Can you explain why in the cathode ray tube pressure is reduced?

Q5. Discuss various experiments that lead to establish the Atomic structure?

Q6. Can you describe the experiment and result deduced by Rutherford for explaining atomic structure?

Q7. Explain how Bohr helped in understanding the structure of atoms?

Q8. What do you understand by the term "isotopes"? Explain with examples.

Q9. Discuss use of isotopes in medical science?