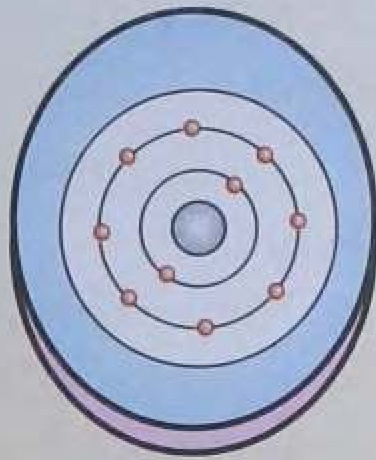
1 STRUCTURE OF ATOM



In This Chapter You Will Learn :

- S.T *Ancient views on atom*
- *Sub-particles of atoms*
- *Discovery of electrons, protons and neutrons*
- *Atomic number, mass number, atomic mass*
- *Arrangement of electrons in an atom*
- *Valency, ions and chemical bonds*
- *Radioactivity*
- *Dalton's atomic theory*
- *Atomic models*

A. Atom and Its Structure

ATOMS : BUILDING BLOCKS OF MATTER

You are aware that anything which occupies space and has mass is matter. But do you know the smallest particle of matter is the **atom**. Atoms are extremely minute particles. They cannot be seen through the naked eye. However there are experimental proofs about the existence of atoms, and they can even be seen through very powerful electron microscopes.

In the ancient times, Indian and Greek philosophers were puzzled about the nature of matter. Gradually the idea developed that all matter must be made of some basic elements.

> In the ancient times water, earth, fire, air and sky were thought to be the five fundamental elements. But we know now that an element is a pure substance made up of one kind of atoms and has definite set of properties.

MAHARISHI KANAD'S VIEWS OF ATOM

Kanad was a great Indian philosopher (600 BC). According to him, "*matter consisted of indestructible particles called paramanus* (*param* means ultimate and *anu* means particle) (now called *atoms*)". A *paramanu* does not exist in free state, rather it combines with other *paramanus* to form a bigger particle called the *anu* (now known as a *molecule*). There are different types of *paramanus*. Each one of them exhibits specific properties.

The Greek philosopher **Democritus** (460 BC – 370 BC) called the *paramanu* as 'atom', which comes from the Greek word *atomos*, meaning *indivisible.*

DALTON'S ATOMIC THEORY

In 1808, **John Dalton**, an English scientist, described the *atom* as the smallest particle exhibiting all the properties of a particular element. According to him, *atoms could not be divided further into smaller particles.*

The fundamentals of Dalton's atomic theory are :

1. Matter consists of very small and indivisible particles called atoms, which can neither be created nor can be destroyed.
2. The atoms of an element are alike in all respects but they differ from the atoms of other elements.
3. *Atoms* of an element combine in small numbers to form *molecules* of the element.
4. Atoms of one element combine with atoms of another element in simple numerical ratio to form molecules of compounds.
5. Atoms are the smallest units of matter that can take part in a chemical reaction.

> **Note :** *The latest research works about atoms have proved that most of Dalton's atomic theory is incorrect. But Dalton was right that atoms take part in chemical reactions.*

SUB-ATOMIC (FUNDAMENTAL) PARTICLES OF ATOMS AND EARLY MODELS OF MATTER

Studies and discoveries in the late nineteenth and the early twentieth centuries showed that atoms are divisible *i.e.* they are composed of still smaller particles. The three main particles present in an atom are *electrons, protons* and *neutrons*. These particles are also called *fundamental* particles or *sub-atomic* particles.

The existence of the sub-atomic particles was proved by the fact that an atom is electrically neutral but it can be made to gain a positive or a negative charge. This means that an atom must contain tiny particles each carrying either a positive or a negative charge. These opposing charges balance each other under ordinary conditions to make an atom electrically neutral.

DISCOVERY OF ELECTRONS (e^-)

Electrons were discovered in 1878 by **William Crooks**, a British scientist, who performed an experiment to study the phenomenon of electric discharge through gases.

He observed that when an electric current of high voltage was passed through a ***discharge tube*** (a glass tube sealed at both ends with metal plates) containing a gas at very low pressure (0·01 mm of mercury). Rays were emitted from the negative terminal called cathode. He called these rays as the '*cathode rays*'.

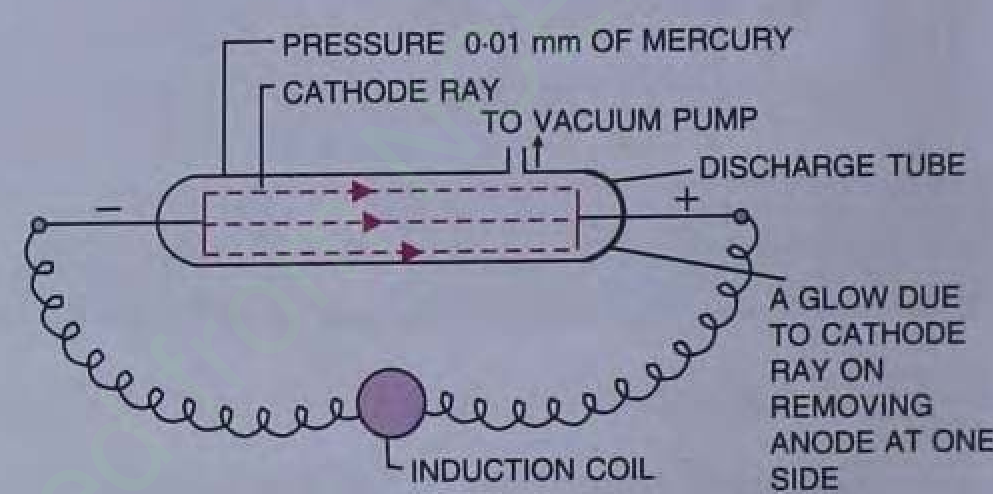


Fig. 1.1 Discharge tube in which electrons are flowing.

J.J. Thomson's work on cathode rays

J.J. Thomson, another British scientist, studied the characteristics and the constituents of the cathode rays and concluded that : *Cathode rays consist of negatively charged particles (now called electrons),* present in atoms of all the elements.

J.J. Thomson's Experiment : Electric field was applied in the path of cathode rays in the discharge tube. It was observed that cathode rays were deflected towards the positive plate of electric field. This showed that cathode rays were negatively charged.

When magnetic field was applied in the

path of cathode rays, they were again deflected in a direction in which moving negative charge would be deflected.

This proved that cathode rays contained negatively charged particles called electrons.

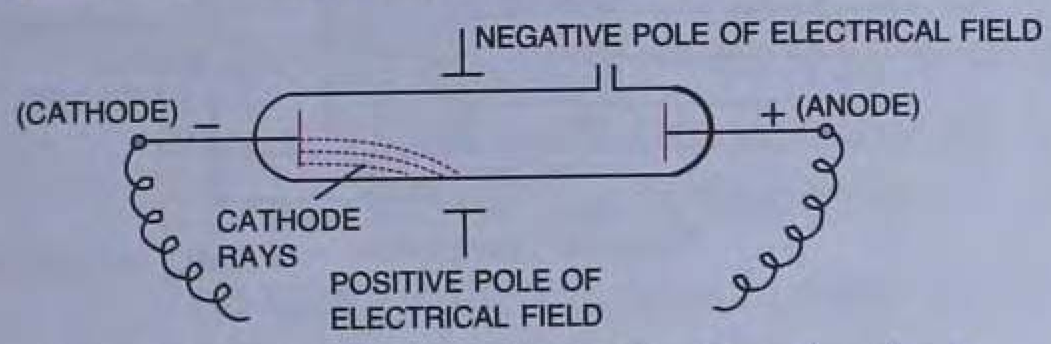


Fig. 1.2 Diagram showing deflection of cathode rays in an electric field

Properties of electrons

1. Electrons are an integral part of all atoms.
2. Its properties are independent of the nature of the gas in the discharge tube.
3. An electron has a definite mass and it carries a definite electric charge.
4. The mass of an electron has been found to be 1/1837 the mass of a hydrogen atom ($9{\cdot}108 \times 10^{-28}$ g)
5. Its charge is one (1) unit negative charge, *i.e.* $1{\cdot}602 \times 10^{-19}$ coulombs.

An ***electron*** is denoted by the symbol $_{-1}e^{0}$. The superscript 0 represents its mass and the subscript –1 represents its electrical charge.

DISCOVERY OF PROTONS (p^+)

The presence of the negatively charged electrons in an atom suggests that it must contain positively charged particles as well, otherwise an atom would not be electrically neutral. These positively charged particles were discovered by *E. Goldstein*, a German scientist, while he was performing an experiment with a discharge tube fitted with a cathode with small holes to allow passage of positive rays (called as perforated cathode) (Fig 1.3). A ray, which was just the opposite to the cathode ray in all respects, was emitted from the anode. This ray was named the *anode ray.* The anode ray consisted of the positively charged particles (now called **protons**).

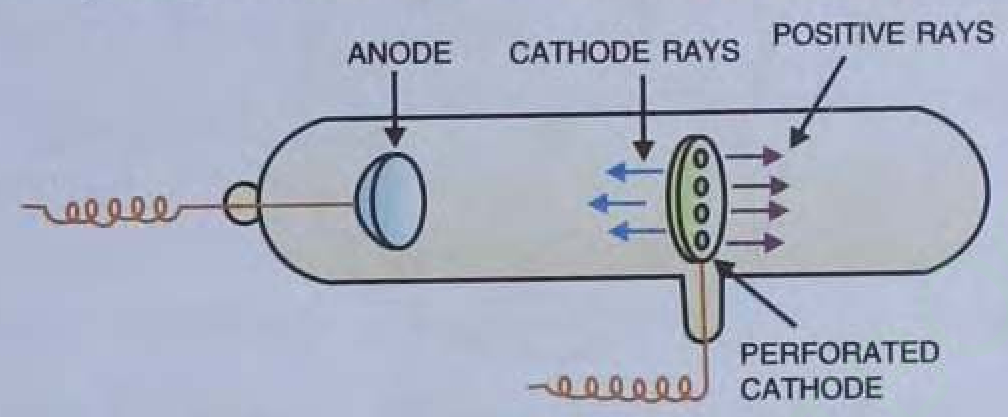


Fig. 1.3 Rays travelling in opposite directions.

Properties of protons

1. The mass of a proton was calculated as being equal to the mass of an atom of hydrogen, *i.e.* $1{\cdot}672 \times 10^{-24}$ g.
2. The positive charge on a proton equalled the negative charge on an electron, *i.e.* $1{\cdot}602 \times 10^{-19}$ coulombs.

Further experiments proved that all elements are composed of electrons and protons. However, no two elements contain the same number of protons in their respective nuclei. *For example*, the atoms of hydrogen, helium, lithium, carbon, nitrogen and oxygen contain 1, 2, 3, 6, 7 and 8 protons respectively. Since an atom is electrically neutral, the number of electrons in an atom is equal to the number of protons in that atom.

Protons are denoted as $_{+1}p^{1}$, where the superscript 1 represents 1 amu mass and the subscript +1 represents one unit positive charge.

THOMSON'S MODEL OF THE ATOM

Now the question arose as to how protons and electrons were arranged in an atom. The first model for an atom was worked out by **J.J. Thomson**. It is known as the *Plum Pudding Model* (Fig. 1.4).

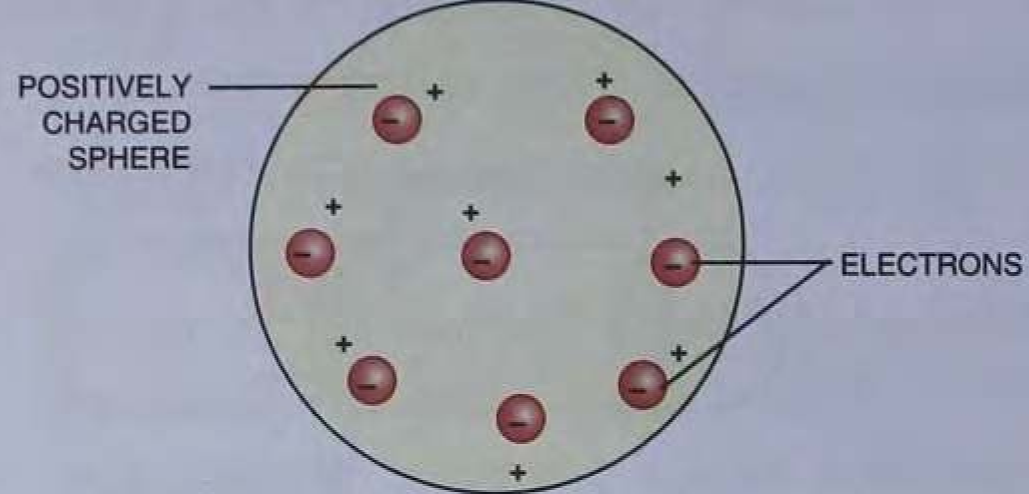


Fig. 1.4 Thomson's Plum Pudding model of the atom

According to this model an atom is a uniform positively charged sphere in which electrons are embedded just like dry fruits in a spherical pudding.

Therefore it is known as **Plum Pudding Model**.

Since the total positive charge of the atom was equal to the total negative charge of its electrons, it followed that an atom would become negatively charged if it gained electrons and positively charged if it lost electrons. However, this model failed to explain many experimental observations about atoms. Thomson's model was not accepted.

DISCOVERY OF THE NUCLEUS

In 1911, **Lord Rutherford**, a scientist from New Zealand, conducted an experiment in order to find the arrangement of electrons and protons in an atom. This experiment led to the discovery of a small, positively charged *nucleus* in the centre of the atom.

Rutherford's alpha particles scattering experiment :- Rutherford bombarded a thin sheet of gold (of 0·00004 cm thickness) with alpha particles* in an evacuated chamber.

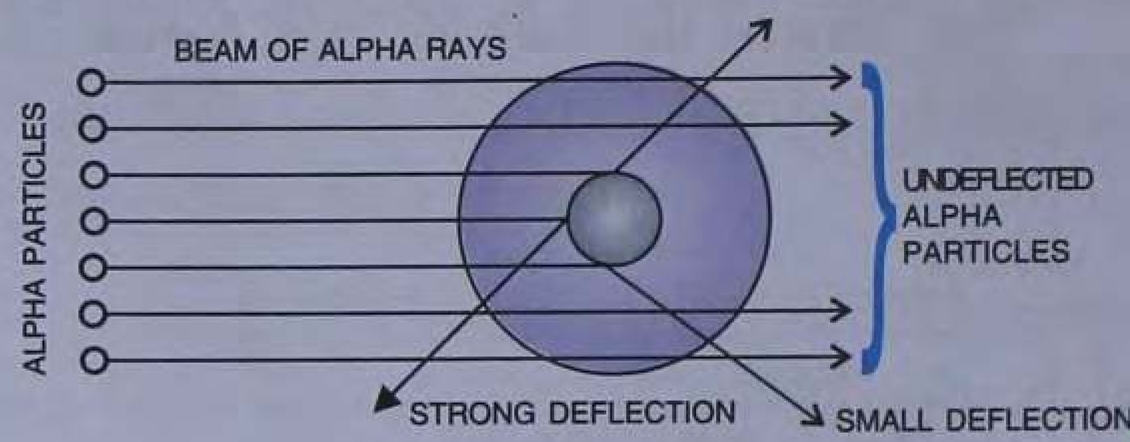


Fig. 1.5 Diagram to show scattering of alpha particles by a single atom

Following were his observations :

- Most of the alpha particles passed straight through the foil without any deflection from their path.
- A small fraction of them were deflected from their original path by small angles.
- Only a few particles bounced back.

On the basis of above observations Rutherford made following conclusions :-

- *Most of the space in an atom was empty* because alpha particles went straight.
- *There was a heavy positively charged mass in the atom* which caused deflection of a small fraction of alpha particles.
- The positively charged mass is very small and is centrally located because only few particles bounced back.

Based on his experiment Rutherford suggested a model for the structure of the atom which is known as *Rutherford's Atomic Model*.

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* *Alpha particles are positively charged particles with two units of positive charge and four units of mass. They are formed by the removal of two electrons from Helium.*

RUTHERFORD'S ATOMIC MODEL

According to this model an atom consists of mainly two parts :

1. *The centrally located nucleus*
   - The nucleus is a centrally located positively charged mass. The entire mass of the atom is concentrated in it. It is the densest part of the atom.
   - The size of the nucleus is very small compared to the size of the atom as a whole.
2. *The outer circular orbits*
   - Electrons revolve in circular orbits (shell) in the space available around the nucleus.
   - An atom is electrically neutral *i.e.* the number of protons and the number of electrons present in an atom are equal.

Thus a model similar to that of the solar system was developed by Rutherford (Fig. 1.6). Just as in the solar system the sun is at the centre and the planets revolve around it, in an atom the electrons revolve around the centrally located nucleus containing protons. **But this model could still not explain the stability of the atom.**

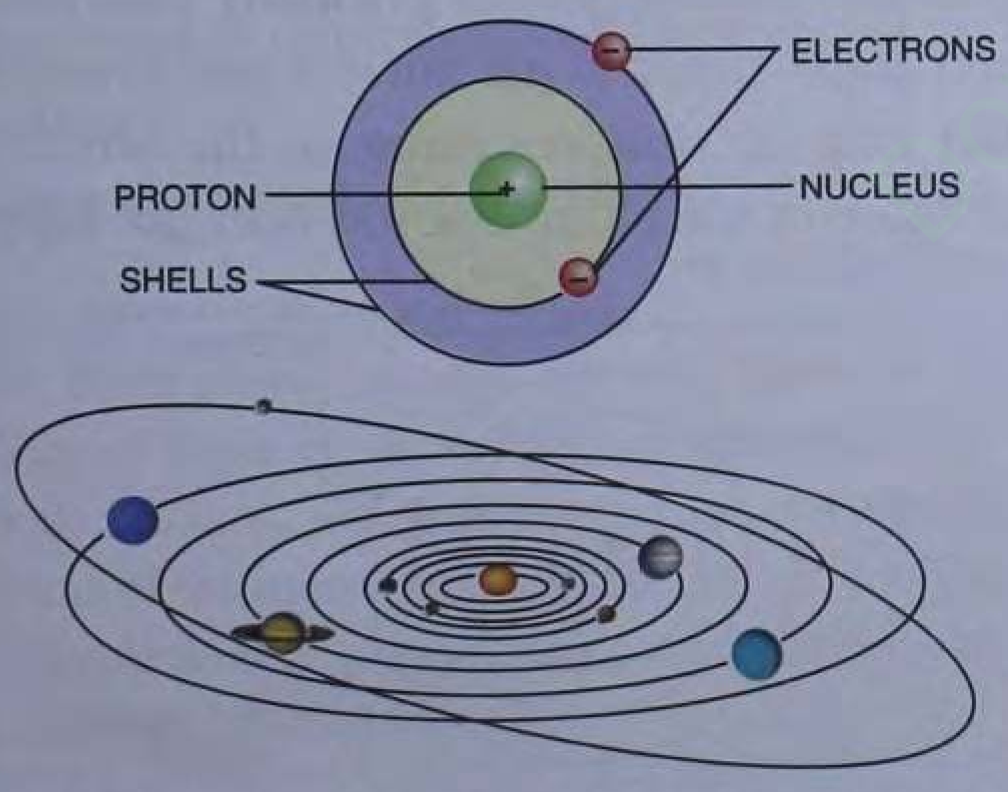


Fig. 1.6 Rutherford's model of the atom was somewhat like that of the solar system

DISCOVERY OF NEUTRONS ($_0n^1$)

The mass of an atom was in fact considered to be entirely concentrated within the nucleus in the form of protons, since electrons were rightly thought to have negligible mass. But when it was discovered that the nucleus had a greater mass than could be accounted for by protons alone, it was realized that there must be a third type of sub-atomic particle, which was present in the nucleus and had neither positive nor negative charge.

In 1932 **James Chadwick** discovered this subatomic particle and called it *neutron*, since it had no charge. Its mass was found to be almost equal to that of a proton, *i.e.* $1{\cdot}672 \times 10^{-24}$ g.

Properties of neutrons

1. The mass of a neutron is slightly more than that of a proton, *i.e.*, $1{\cdot}676 \times 10^{-24}$ g compared to $1{\cdot}672 \times 10^{-24}$ g.
2. Electrically a neutron is neutral, *i.e.*, it has no charge.
3. Atoms of same element may differ in number of neutrons leading to the formation of isotopes.

Table 1.1 : Properties of sub-atomic particles

Particle	*Symbol*	*Charge* $1{\cdot}602\times10^{-19}$C)	*Atomic mass grams*
Electron	$_{-1}e^0$ or e^-	–1	$9{\cdot}1 \times 10^{-28}$ g
Proton	$_{+1}p^1$ or p^+	+1	$1{\cdot}6 \times 10^{-24}$ g
Neutron	$_0n^1$ or n	0	$1{\cdot}6 \times 10^{-24}$ g

MODERN MODEL OF AN ATOM

According to the modern, *standard model of atom* :

1. An atom consists of the sub-atomic particles called electrons, protons and neutrons.
2. There are two structural parts of an atom.
   i) *the nucleus*
   ii) *the orbits* or the *shells* described in the empty space that surrounds the nucleus.
3. The *nucleus* is the positively charged, central part of an atom. It contains protons and neutrons. The protons and neutrons (collectively known as **nucleons**) are held firmly in the nucleus by strong nuclear forces. The entire mass of an atom lies in its nucleus, since electrons have negligible mass. The positive charge of the nucleus is due to the protons present in it. The protons remain unaffected by the neutrons since the latter have no electrical charge.
4. Orbits (or shells) are the imaginary paths traced by the electrons in the empty space surrounding the nucleus. Each orbit is associated with a fixed amount of energy. Therefore these circular orbits are also known as **energy levels** or **energy shells**. Electrons revolve round the nucleus in these orbits. The shell (or the orbit) lying **closest** to the nucleus carries the **lowest amount of energy** and the shell that lies **farthest** from it carries the **highest amount of energy**.
5. An atom is electrically neutral because the number of protons and the number of electrons present in it are the same, thus balancing the charge of the atom.

While the neutral atom of an element has an equal number of protons and electrons, this number itself varies from one element to another. In fact no two elements contain the same number of protons (or electrons), that is why each element differs from the other.

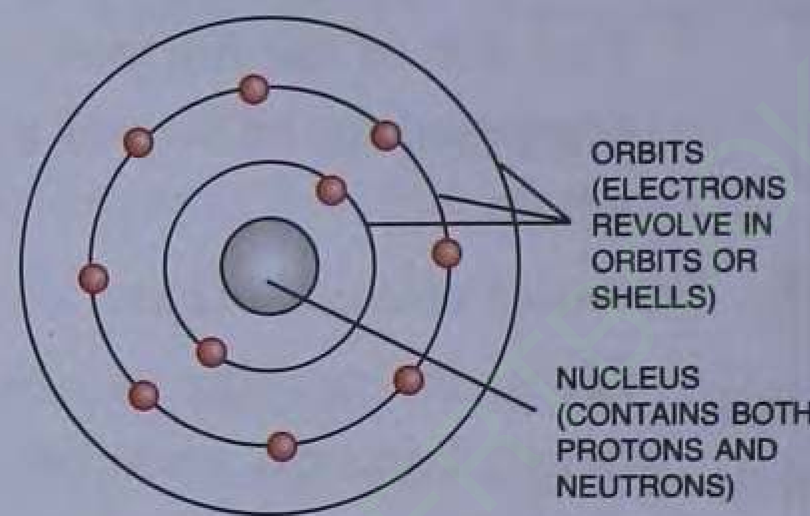


Fig. 1.7 Structure of an atom

STRUCTURAL STABILITY OF AN ATOM

We know that there exists a force of attraction between particles with opposite electrical charges. Thus, there is a force of attraction between the electrons and the protons present within an atom. It is expected that electrons being lighter, charged and in constant motion, would gradually lose energy and come closer to the nucleus and eventually fall into it, thus resulting in the structural collapse of the atom. But this does not happen.

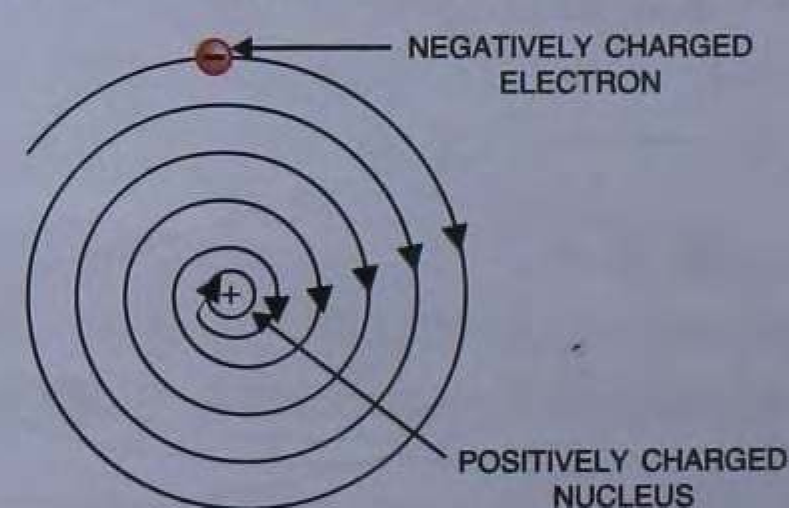


Fig. 1.8 Showing an electron losing energy and eventually falling into the nucleus, but this does not happen.

This is because the electrons revolve in fixed orbits or shells round the nucleus at a very high speed*, with each orbit associated with a fixed amount of energy. The electrons present in these shells neither lose nor gain energy until some external force is applied on it. Thus they maintain their position. As a result the inward force exerted by the nucleus is counterbalanced by the outward force of the moving electrons, thus preventing the electrons from falling into the nucleus and making the atom structurally stable.

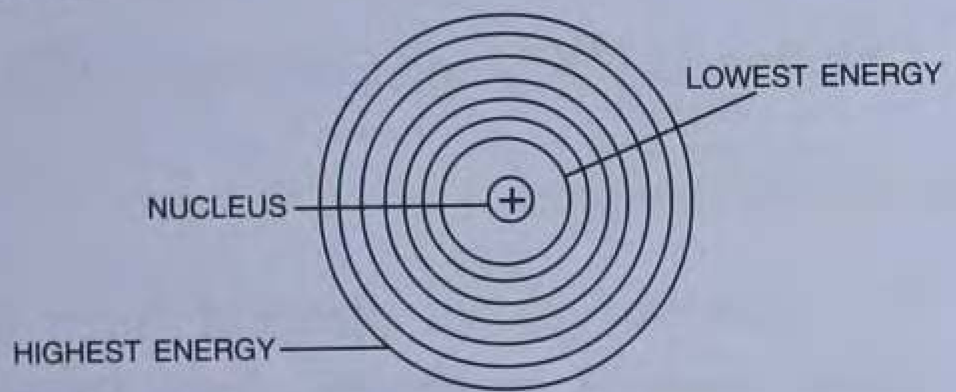


Fig. 1.9 Showing shells or orbits in an atom each with a fixed amount of energy.

ATOMIC NUMBER (Z)

The number of protons present in the nucleus of the atom of an element is called its atomic number, which is denoted by the letter Z.

Since an electrically neutral atom has an equal number of protons and electrons, in such an atom :

Atomic number (Z) = Number of protons
= Number of electrons.

> We have noted already that the atom of an element has a characteristic number of protons in its nucleus, which distinguishes it from the atoms of the other elements. The atomic number of an element never varies and it is a fixed value for a particular element.

* *Velocity of light is 3×10^8 m/sec. The speed of an electron is about 1/10th the speed of light.*

MASS NUMBER (A)

The sum of the number of protons and the number of neutrons present in the nucleus of the atom of an element is called the mass number of that element. It is denoted by the letter A.

Mass number (A) = Number of protons
+
Number of neutrons

Thus, if the atomic number and the mass number of an element are known, one can easily calculate the number of neutrons present in the nucleus of that element.

Number of neutrons = Mass number (A) – Atomic number (Z)

For example, take the *sodium atom*. Its atomic number is 11, and its mass number is 23.

∴ Number of neutrons = A – Z
= 23 – 11 = 12.

Symbolic representation of an element with its atomic number and mass number

Suppose there is an element X with mass number A and atomic number Z. To symbolise this element its mass number should be written as superscript (on top) and its atomic number as subscript (at the bottom), *i.e.* ${}^{A}_{Z}X$ or ${}_{Z}X^{A}$.

Example **:** The symbol of oxygen is O. Its mass number is 16 and its atomic number is 8. Therefore oxygen should be denoted as ${}^{16}_{8}O$ or ${}_{8}O^{16}$.

ISOTOPES

You have learnt that each element has its unique atomic number, *i.e.* each atom of an element has the same number of protons in its nucleus. But the mass number of all the atoms of an element may not be the same. In other words, the nuclei of all the atoms of an element have the same number of protons but some of them have a different number of neutrons.

Therefore we can say that there are some atoms of an element that differ from the other atoms of that element with respect to mass number, not atomic number. **Such atoms are called the isotopes of that element.** Most elements found naturally have two or more isotopes. In fact most elements exist in nature as differing mixtures of their isotopes.

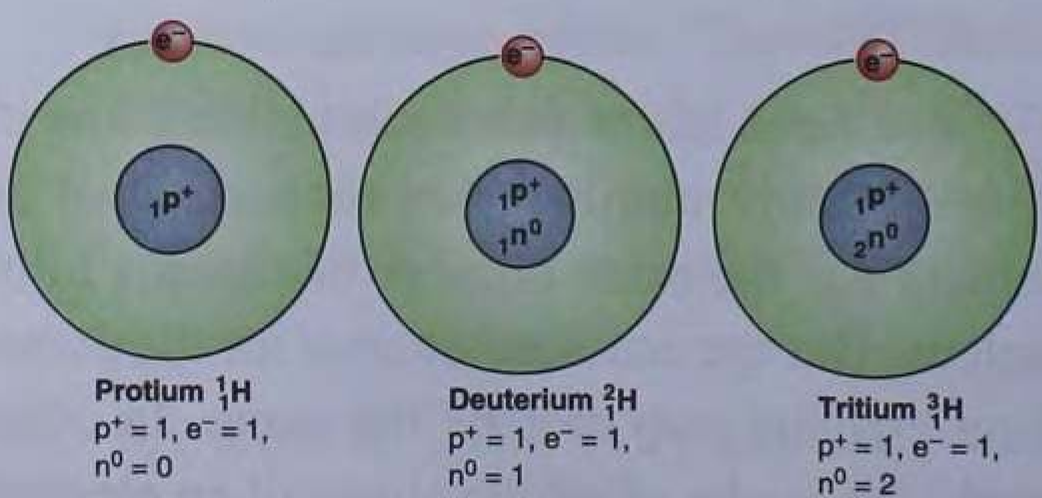
> Isotopes are the atoms of the same element with the same atomic number but a different mass number due to the difference in the number of neutrons.

Example : Hydrogen has three isotopes.

Protium (ordinary hydrogen) ($^{1}_{1}H$) – It has one proton and one electron but no neutron.

Deuterium (heavy hydrogen) ($^{2}_{1}H$) – It has one proton, one neutron and one electron.

Tritium (very heavy hydrogen) ($^{3}_{1}H$) – It has one proton, two neutrons and one electron.



Similarly, carbon has three isotopes, with their mass numbers being 12, 13 and 14 respectively. They are known as :

Carbon–12 [$^{12}_{6}C$]; Carbon–13 [$^{13}_{6}C$] and Carbon–14 [$^{14}_{6}C$].

Oxygen too has *three* isotopes :

Oxygen 16 [$^{16}_{8}O$]; Oxygen 17 [$^{17}_{8}O$] and Oxygen 18 [$^{18}_{8}O$].

But chlorine has only *two* isotopes :

Chlorine 35 [$^{35}_{17}Cl$] and Chlorine 37 [$^{37}_{17}Cl$].

Properties of isotopes

1. The isotopes of an element have the same chemical properties, since there is no difference between their atomic numbers.
2. The isotopes of an element have the same electronic configuration, since they hold the same number of electrons.
3. The isotopes of an element differ from each other only in terms of physical properties, *i.e.* they have different mass, density, melting point, boiling point, *etc.* This is because of the difference in their respective mass numbers.

ARRANGEMENT OF ELECTRONS AROUND THE NUCLEUS OF AN ATOM (ELECTRONIC CONFIGURATION)

The distribution of electrons revolving in different orbits or shells round the nucleus of the atom of an element is called the electronic configuration of that element.

In order to explain the structural stability of an atom ***Niels Bohr***, a Danish scientist, stated that :

1. Electrons revolve round the nucleus in definite orbits or shells, which are labelled as K, L, M, N, and so on, or 1 (or I), 2 (or II), 3 (or III), 4 (or IV), and so on.
2. Each of these shells is associated with a fixed amount of energy, and therefore each is known as an energy level.

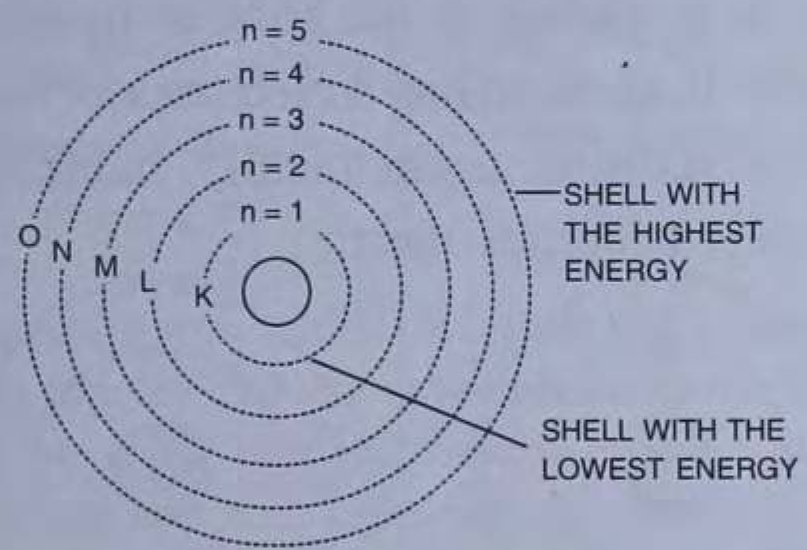


Fig. 1.10 Showing shells or orbits. The greater the number of the shell the greater the energy that it holds.

3. An electron present in the first or the K shell, *i.e.* the one lying nearest to the nucleus, possesses the least amount of energy among all the electrons held by the atom. The second shell (L) has higher energy than has the K shell, and M holds even more than L, and so on. In other words, the greater the distance of a shell from the nucleus the greater is the amount of energy held by it.

Now the problem was to find the number of electrons in each shell of an atom, for which a scheme was proposed by two scientists, Bohr and Bury. Therefore it is known as the *Bohr-Bury Scheme* of electronic configuration.

According to this scheme

(i) The **maximum number of electrons** that can be present in any shell or orbit of an atom is given by the formula $\mathbf{2n^2}$, where **n** is the serial number of the shell. Thus, the first shell (K) can accommodate not more than $2 \times 1^2 = 2$ electrons, the second shell (L) not more than $2 \times 2^2 = 8$ electrons, and so on but it can never exceed 32.

Table 1.2 : Maximum number of electrons that can be present in the successive shells of an atom

Shell	*n*	*Maximum number of electrons*
K	1	$2 \times 1^2 = 2$
L	2	$2 \times 2^2 = 8$
M	3	$2 \times 3^2 = 18$
N	4	$2 \times 4^2 = 32$

(ii) Another rule, known as the **Octet Rule,** determines the **actual number of electrons** present in the outermost shell. It states that "the maximum number of electrons that the outermost shell of an electrically neutral and chemically stable atom can have is 8, except if the atom has only one shell (as it is in the case of hydrogen and helium), which can have only 2 electrons **(duplet)**".

This rule can be understood better by taking up the following examples.

Examples :

(i) The helium atom has 2 electrons which occupy the first and the only shell of the helium atom.

(ii) The lithium atom has 3 electrons. 2 of which occupy the first shell and the 3rd occupies the second shell [2, 1].

(iii) The neon atom has 10 electrons. The first shell takes up 2 electrons and the second shell takes up 8 electrons. Note that the second (II or L) shell cannot occupy more than 8 electrons as per the formula $2n^2$ [2, 8].

(iv) The potassium atom has 19 electrons. The first shell takes up 2 electrons and the second shell takes up 8 electrons. That leaves 9 electrons. According to the formula $2n^2$, all the 9 remaining electrons should occupy the third shell, which can hold up to18 electrons. But, since the outermost shell of an atom cannot have more than 8 electrons, the third shell takes up only 8 electrons and the fourth shell takes 1 electron. Therefore, the electronic configuration of potassium is
K L M N
2, 8, 8, 1.

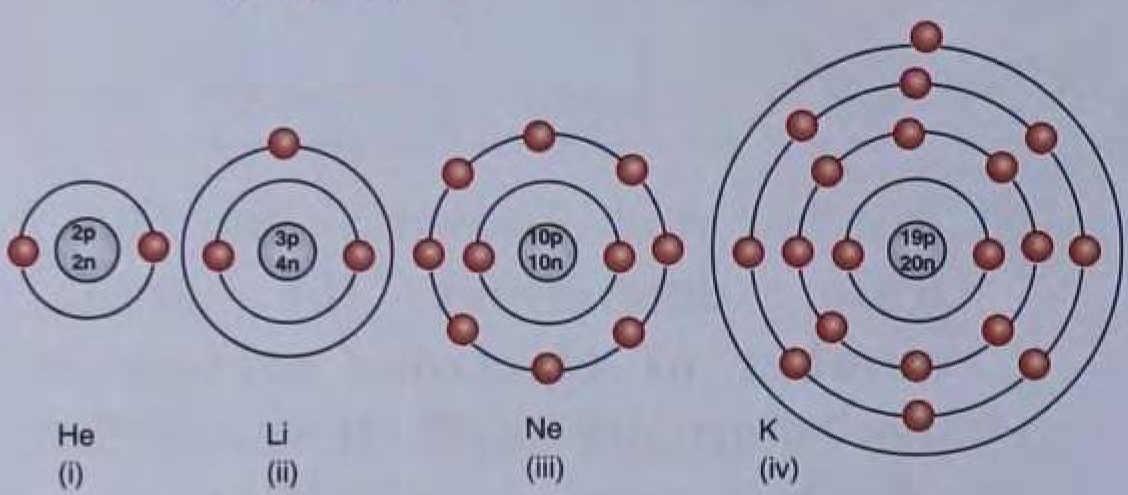


Fig. 1.11 Distribution of electrons in successive shells in He, Li, Ne and K.

VALENCE SHELL, VALENCE ELECTRONS AND VALENCY

Valence shell : The outermost shell of an atom is known as its valence shell or valence orbit.

Valence electrons : The electrons present in the valence shell of an atom are called valence electrons. The number of valence electrons varies from 1 to 8 for the atoms of the different elements. The valence electrons of an atom determine the valency of that element.

Valency : Valency is the combining capacity of an atom with the atoms of other elements so as to form the molecules of compounds. Valency can, therefore be defined in terms of loss or gain of electrons as well.

Why do atoms combine to form the molecules of compounds ?

Atoms tend to combine to attain the electronic configuration of the nearest inert gas. You know that the maximum number of electrons present in the outermost shell of an atom is 8, except in the case of hydrogen and helium. If an atom has 8 electrons in its valence shell it acquires a chemically stable structure and thus becomes inert.

Example **:** All the inert (noble) gases, except helium, have 8 electrons in their respective valence shells. This condition is called *octet.* Helium has 2 electrons only because it has only one orbit, which as per the formula $2n^2$ $(2 \times 1 \times 1 = 2)$ cannot contain more than 2 electrons. This condition is called *duplet.* Both duplet and octet are conditions of chemical stability. Therefore all inert gases are chemically stable and they do not combine with the atoms of any other element.

Therefore anything less than 8 electrons in its outermost shell (except in helium) makes an atom chemically unstable and reactive. However, most of the atoms known to us have electrons less than 8 in their respective valence shells. Therefore they tend to combine with other atoms to complete their octet and attain stability.

During chemical combination one of the atoms donates one or more electrons, which are accepted by another atom to form a *chemical bond* between the two. Sometimes instead of gaining or losing electrons, atoms share their electrons too.

Diagrams of the atoms of the first twenty elements

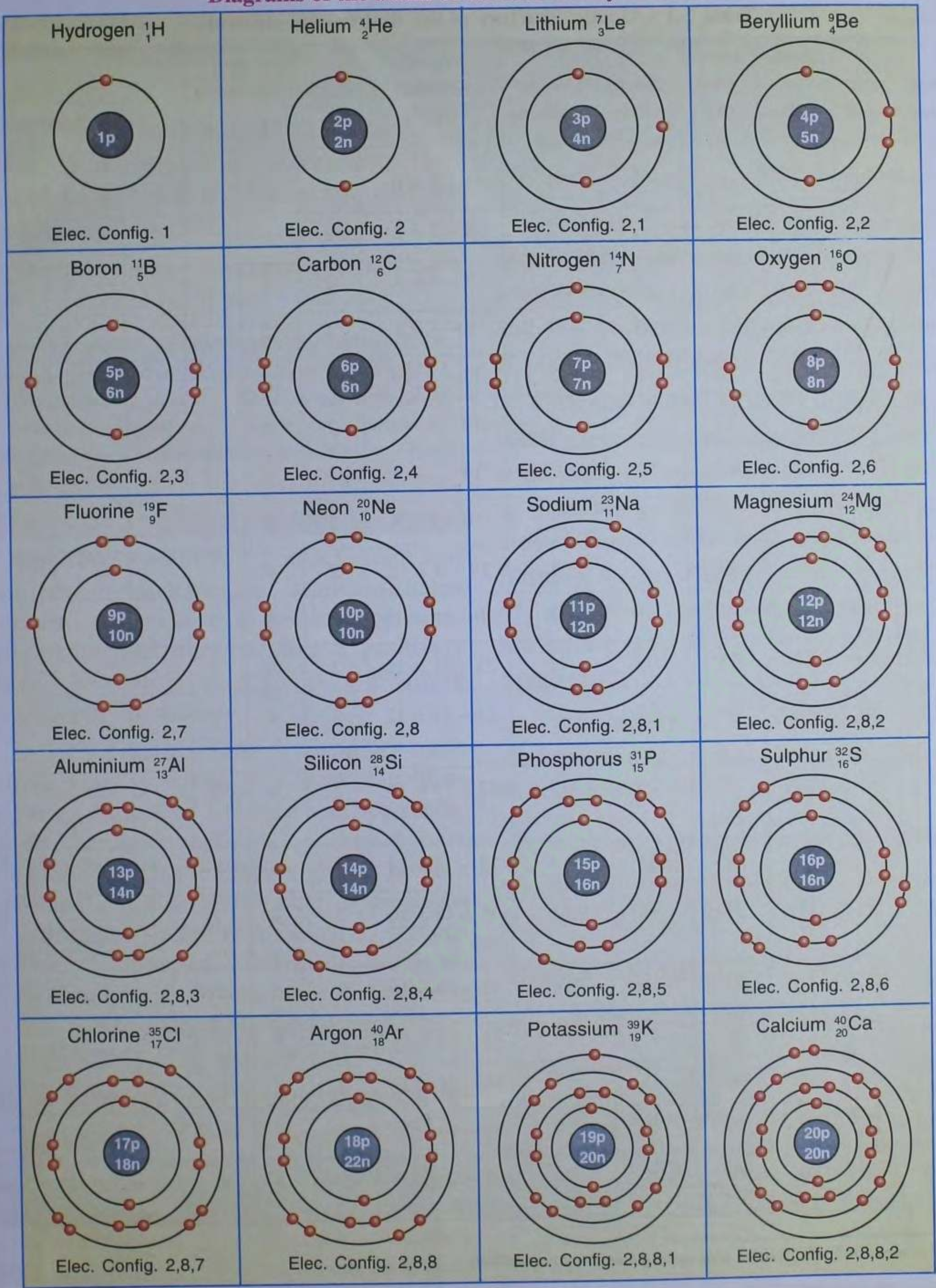


Table 1.3 : Atomic structure of the first twenty elements.

Name of element	Symbol	Atomic No. (Z)	Mass No. (A)	No. of protons	No. of electrons	No. of neutrons (A–Z)	Electronic configuration				Valency
							K	L	M	N	
Hydrogen	H	1	1	1	1	1 – 1 = 0	1				± 1
Helium	He	2	4	2	2	4 – 2 = 2	2				0
Lithium	Li	3	7	3	3	7 – 3 = 4	2	1			+ 1
Beryllium	Be	4	9	4	4	9 – 4 = 5	2	2			+ 2
Boron	B	5	11	5	5	11 – 5 = 6	2	3			+ 3
Carbon	C	6	12	6	6	12 – 6 = 6	2	4			4
Nitrogen	N	7	14	7	7	14 – 7 = 7	2	5			– 3
Oxygen	O	8	16	8	8	16 – 8 = 8	2	6			– 2
Fluorine	F	9	19	9	9	19 – 9 = 10	2	7			– 1
Neon	Ne	10	20	10	10	20 – 10 = 10	2	8			0
Sodium	Na	11	23	11	11	23 – 11 = 12	2	8	1		+ 1
Magnes-ium	Mg	12	24	12	12	24 – 12 = 12	2	8	2		+ 2
Alumi-nium	Al	13	27	13	13	27 – 13 = 14	2	8	3		+ 3
Silicon	Si	14	28	14	14	28 – 14 = 14	2	8	4		4
Phosph-orus	P	15	31	15	15	31 – 15 = 16	2	8	5		– 3
Sulphur	S	16	32	16	16	32 – 16 = 16	2	8	6		– 2
Chlorine	Cl	17	35	17	17	35 – 17 = 18	2	8	7		– 1
Argon	Ar	18	40	18	18	40 – 18 = 22	2	8	8		0
Potassium	K	19	39	19	19	39 – 19 = 20	2	8	8	1	+ 1
Calcium	Ca	20	40	20	20	40 – 20 = 20	2	8	8	2	+ 2

* *+ and – signs indicate positive and negative valency respectively.*

A '*chemical bond*' is the binding force between the two or more atoms of a molecule.

Therefore the valency of an element can be defined as the number of electrons lost, gained or shared by its atom during chemical combination.

The loss or gain of electrons by atoms leads to the transformation of atoms into ions.

An *ion* is a charged particle formed by the loss or the gain of electrons by an atom. Ions are of two types : *cations* and *anions*. A positively charged ion is called a *cation* and a negatively charged ion is called an *anion*. Therefore such valency of an atom is called *electropositive* or *electronegative valency [collectively they are called ionic valency]*.

Positive valency : During chemical combination, when an atom donates electrons, to acquire a stable electronic configuration and thus becomes a positively charged ion, it is said to have positive (electropositive) valency.

All the metals (and hydrogen) have positive valency, since they have electrons numbering from 1 to 3 in their valence shells. During chemical combination they donate these electrons. This results in a greater number of protons and a lesser number of electrons left with them. Therefore these atoms become positively charged, forming *cations*. Depending upon the number of electrons donated, these elements are monovalent (Na^+)* or bivalent (Mg^{2+}) or trivalent (Al^{3+}).

FORMATION OF ELECTROPOSITIVE IONS

***Example* 1 :** $Na \xrightarrow{-1 \text{ electron}} Na^+$

Unstable sodium atom	*Stable sodium ion*
No. of electrons = 11	No. of electrons = 10
Electronic configuration	Electronic configuration
2 (K), 8 (L), 1 (M)	2 (K), 8 (L) (nearest to neon)

***Example* 2 :** $Mg \xrightarrow{-2 \text{ electrons}} Mg^{2+}$

Unstable magnesium atom	*Stable magnesium ion*
No. of electrons = 12	No. of electrons = 10
Electronic configuration	Electronic configuration
2 (K), 8 (L), 2 (M)	2 (K), 8 (L) (nearest to neon)

Negative valency : When in order to acquire stable electronic configuration, an atom accepts electrons during chemical combination and thus becomes a negatively charged ion, it is said to have negative valency.

All non-metals, with 5-7 valence electrons show negative valency. During chemical combination, they accept electrons. This results in an excess of electrons over protons in these atoms. Thus they become negatively charged, forming *anions*. Depending upon the number of electrons accepted, these elements are monovalent (Cl^-)* or bivalent (O^{2-}) or trivalent (N^{3-}).

[Hydrogen is an exception because, though it is a non-metal, it has greater tendency to lose electrons].

Note : Carbon is a non-metal with 4 valence electrons. It neither donates nor accepts electrons. It shares its electrons.

FORMATION OF ELECTRONEGATIVE IONS

***Example* 1 :** $Cl \xrightarrow{+1 \text{ electron}} Cl^-$

Unstable chlorine atom	*Stable chloride ion*
No. of electrons = 17	No. of electrons = 18
Electronic configuration	Electronic configuration
2 (K), 8 (L), 7 (M)	2 (K), 8 (L), 8 (M) (nearest to neon)

* *In the case of monovalency we write only the + or the – sign, not + 1 or – 1.*

Example 2 : $O \xrightarrow{+2\ electrons} O^{2-}$

Unstable oxygen atom	*Stable oxide ion*
No. of electrons = 8	No. of electrons = 10
Electronic configuration	Electronic configuration
2 (K), 6 (L)	2 (K), 8 (L) (nearest to neon)

VARIABLE VALENCY

Some elements exhibit more than one valency. They are said to have *variable valency.*

Examples : Iron, copper, tin, lead, sulphur, phosphorus, *etc.*

(a) In the case of the metals exhibiting variable valency, we represent the lower valency by adding the suffix *ous* to the name of the metal; to represent the higher valency the suffix *ic* is attached to the name of the metal. *For example*, the metal iron has valencies +2 and +3. For the lower valency (+2) we write *ferrous* (Fe^{2+}) and for the higher valency (+3) we write *ferric* (Fe^{3+}). Note that the symbol remains the same but the name changes. In the modern method the variable valency of the element is represented by Roman numbers. Thus ferrous ion is represented as Fe (II) and ferric ion as Fe (III).

The advantage of the modern convention is that neither the name of the element nor its symbol changes.

(b) In the case of a non-metallic atom the number of the other types of atom attached to it determines its valency.

Example : Phosphorus has valencies 3 and 5. With chlorine it forms two compounds, PCl_3 and PCl_5. Therefore the molecule of phosphorus trichloride, which has three chlorine atoms in it, has the lower valency (3), and the molecule of phosphorus pentachloride, which has five chlorine atoms in it, has the higher valency (5) for phosphorus atom.

RADICALS

Two or more non-metals that collectively accept or donate one or more electrons and become negatively or positively charged in the process are called radicals. Radicals behave as a single reactant, though they occur in compound form.

Table 1.5 : Representation of some radicals

Name of radical	*Representation*	*Valency*
Ammonium	NH_4^+	1
Nitrate	NO_3^-	1
Nitrite	NO_2^-	1
Bisulphate	HSO_4^-	1
Bisulphite	HSO_3^-	1
Bicarbonate	HCO_3^-	1
Hydroxide	OH^-	1
Acetate	CH_3COO^-	1
Sulphate	SO_4^{2-}	2
Sulphite	SO_3^{2-}	2
Carbonate	CO_3^{2-}	2
Dichromate	$Cr_2O_7^{2-}$	2
Phosphate	PO_4^{3-}	3

Table 1.4 : Metals with variable valency

Element	*Symbol*	*Lower valency state*	*Higher valency state*
Copper	Cu	Cu^+ or Cu(I) [Cuprous]	Cu^{2+} or Cu (II) [Cupric]
Iron	Fe	Fe^{2+} or Fe (II) [Ferrous]	Fe^{3+} or Fe (III) [Ferric]
Silver	Ag	Ag^+ or Ag (I) [Argentous]	Ag^{2+} or Ag (II) [Argentic]
Lead	Pb	Pb^{2+} or Pb (II) [Plumbous]	Pb^{4+} or Pb (IV) [Plumbic]
Tin	Sn	Sn^{2+} or Sn (II) [Stannous]	Sn^{4+} or Sn (IV) [Stannic]
Mercury	Hg	Hg^+ or Hg (I) [Mercurous]	Hg^{2+} or Hg (II) [Mercuric]

Valency and symbol of some common cations (Positive radicals)

Valency	*Symbol*	*Name*
Monovalent 1	Na^+	Sodium
	K^+	Potassium
	Cu^+	Copper (I) / Cuprous
	Ag^+	Silver (I) / Argentous
	Hg^+	Mercury (I) / Mercurous
	H^+	Hydrogen
	NH_4^+	Ammonium
Bivalent 2	Mg^{2+}	Magnesium
	Ca^{2+}	Calcium
	Ba^{2+}	Barium
	Zn^{2+}	Zinc
	Ni^{2+}	Nickel
	Cu^{2+}	Copper (II) / Cupric
	Fe^{2+}	Iron (II) / Ferrous
	Pb^{2+}	Lead (II) / Plumbous
	Sn^{2+}	Tin (II) / Stannous
	Ag^{2+}	Silver (II) / Argentite
	Hg^{2+}	Mercury (II) / Mercuric
	Mn^{2+}	Manganese (II) / Manganous
Trivalent 3	Al^{3+}	Aluminium
	Fe^{3+}	Iron (III) / Ferric
	Cr^{3+}	Chromium (III)

Valency and symbol of some common anions (Negative radicals)

Valency	*Symbol*	*Name*
Monovalent 1	Cl^-	Chloride
	Br^-	Bromide
	I^-	Iodide
	OH^-	Hydroxide
	NO_2^-	Nitrite
	NO_3^-	Nitrate
	HCO_3^-	Bicarbonate/Hydrogen carbonate
	HSO_3^-	Bisulphite/Hydrogen sulphite
	HSO_4^-	Bisulphate/Hydrogen sulphate
	CH_3COO^-	Acetate
	MnO_4^-	Permanganate
Bivalent 2	O^{2-}	Oxide
	S^{2-}	Sulphide
	SO_3^{2-}	Sulphite
	SO_4^{2-}	Sulphate
	CO_3^{2-}	Carbonate
	CrO_4^{2-}	Chromate
	$Cr_2O_7^{2-}$	Dichromate
	MnO_4^{2-}	Manganate
Trivalent 3	N^{3-}	Nitride
	PO_4^{3-}	Phosphate

EXERCISE – I

1. Fill in the blanks :
   (a) Dalton said that .... could not be divided.
   (b) .... are emitted by radioactive elements.
   (c) An ion which has a positive charge is called a ....
   (d) The outermost shell of an atom is known as ....
   (e) The .... of an atom is very hard and dense.
   (f) Neutrons are .... particles having mass equal to that of protons.
   (g) Isotopes are the atoms of .... element having the same atomic number but a different mass number.

2. Write '*true*' or '*false*' for the following statements:
   (a) An atom on the whole has a positive charge.
   (b) The maximum number of electrons in the first shell can be 8.
   (c) Deuterium is an isotope of hydrogen.
   (d) Non-metals form cations by accepting electrons.
   (e) The central part of an atom is called nucleus.

3. Name the following :
   (a) The sub-atomic particle with negative charge and negligible mass.
   (b) Protons and neutrons present in the nucleus.
   (c) The electrons present in the outermost shell.
   (d) Arrangement of electrons in the shells of an atom.
   (e) The binding force between atoms in a molecule of a compound.
   (f) The number of protons present in the nucleus of an atom.
   (g) The sum of the number of protons and neutrons of an atom.
   (h) Atoms of same element with same atomic number but a different mass number.
   (i) The smallest unit of an element which takes part in a chemical reaction.

4. **Multiple Choice Questions**
   (a) The outermost shell of an atom is known as
      (i) valency (ii) valence electrons
      (iii) nucleus (iv) valence shell
   (b) The number of valence electrons present in magnesium is
      (i) two (ii) three
      (iii) four (iv) five
   (c) The sub atomic particle with negative charge is
      (i) proton (ii) neutron
      (iii) electron (iv) nucleon
   (d) If the atomic number of an atom is 17 and mass number is 35 then number of neutron is
      (i) 35 (ii) 17
      (iii) 18 (iv) 52
   (e) The force of attraction that binds two atoms together, in a molecule, is called
      (i) valency (ii) a chemical bond
      (iii) valence shell (iv) nuclear energy
   (f) The number of electrons in an atom is equal to the number of
      (i) protons in a neutral atom
      (ii) neutrons in a neutral atom
      (iii) nucleons in a neutral atom
      (iv) none of the above
   (g) The sum of number of protons and number of neutrons present in the nucleus of an atom is called its
      (i) mass number (ii) atomic number
      (iii) number of electrons (iv) all of the above

5. Name three fundamental particles of an atom. Give the symbol with charge, on each particle.

6. Define the following terms :
   (a) Valency shell (b) Radioactivity
   (c) Atomic mass (d) Nucleons
   (e) Electronic configuration

7. Mention briefly the salient features of Dalton's atomic theory (five points).

8. (a) What are the two main features of Rutherford's atomic model ?
   (b) State its one drawback.

9. What are the observations of the experiment done by Rutherford in order to determine the structure of an atom ?

10. State the mass number, the atomic number of neutrons and electronic configuration of the following atoms.

    $^{20}_{10}Ne$, $^{24}_{12}Mg$, $^{35}_{17}Cl$ and $^{39}_{19}K$

    Also, draw atomic diagrams for them.

11. Answer the following questions :
    (a) What are isotopes ? How does the existence of isotopes contradict Dalton's theory ?
    (b) What is variable valency ? Name two elements having variable valency and state their valencies.

12. The atomic number and the mass number of sodium are 11 and 23 respectively. What information is conveyed by this statement.

13. Draw the diagrams representing the atomic structures of the following :
    (a) Sodium atom (b) Chlorine atom
    (c) Carbon atom (d) Oxygen atom.

14. Explain the rule according to which electrons are filled in various energy levels.

15. The atom of an element is made up of 4 protons, 5 neutrons and 4 electrons. What is its atomic number and mass number ?

16. In what respects do the three isotopes of hydrogen differ ? Give their structures.

B. Radioactivity

Discovery of radioactivity

Radioactivity means "ray emitting activity". The phenomenon of radioactivity was discovered in 1896 in Paris by Professor **Henry Becquerel**, when he was working on the nature of phosphorescent substances*. He found that **uranium salt** emitted invisible radiations that :

(i) affected a photographic plate.

(ii) penetrated through a metal sheet.

(iii) were unaffected by any chemical change.

(iv) remained unaffected by change in temperature.

Several investigations that followed showed that the emission of such radiations was not the property of uranium salt but of the element uranium. Also, since these radiations were not affected by physical or chemical changes, it was concluded that the phenomenon was rooted in the nucleus of the atom. In other words, *electrons had no role to play in radioactive emissions.*

Later, in 1898, Madam Curie and her husband Pierre Curie found that **pitchblende,** an ore of **uranium,** was more radioactive than **uranium** itself. This was because the ore contained, in addition to uranium, the elements **radium, thorium** and **polonium,** all radioactive elements themselves. This gave support to the view that radioactivity was an elemental property.

* ***Phosphorescent substances contain phosphorus, which causes them to emit light and glow.***

Definition of radioactivity

The phenomenon due to which certain elements spontaneously emit highly penetrating rays made of sub-atomic particles is known as *radioactivity.*

The elements that emit radioactive rays are called *radioactive elements.*

Examples **:** Uranium, thorium, radium, polonium.

Types of radioactive radiations

Rutherford studied the radiations coming out from the nucleus of the radioactive elements and found that these substances emit *three* kinds of radiation :

(i) Alpha (α) rays,

(ii) Beta (β) rays and

(iii) Gamma (γ) rays

(i) α – rays : These rays consist of positively charged particles called α – particles. They are helium nuclei (He^{2+}) each containing two protons and two neutrons, but no electrons, *i.e.,* they have 2 units positive charge and 4 amu mass. The velocity of the α – particles is 1/10th the velocity of light*. The penetrating power of α – particles is not very high. They are only slightly affected by magnetic and electrical fields.

(ii) β – rays : These rays consist of 1 unit negative charge and have mass equivalent to the mass of an electron (negligible mass). The velocity of the β – particles is equal to the velocity of

* ***Velocity of light = 3×10^8 m/sec.***

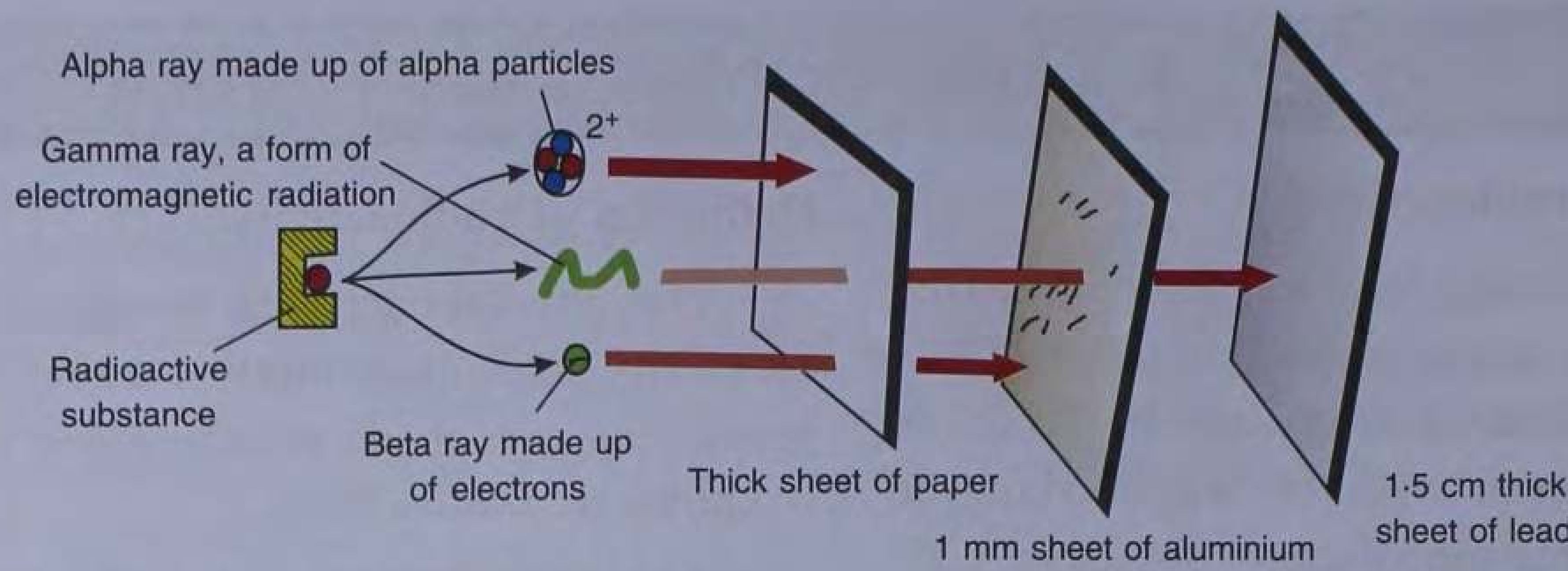


Fig. 1.14 The diagram shows that alpha rays cannot even pass through a sheet of paper, a metal sheet is needed to stop beta rays, but only thick sheet of lead or concrete can stop gamma rays.

light. They have greater penetrating power compared to the α – particles. They are strongly affected by electrical and magnetic fields.

(iii) γ – rays : These are electromagnetic radiations. They have neither mass nor charge. Their velocity equals to that of light. They have very high penetrating power, *i.e.* they can penetrate a 25 mm thick aluminium plate. They are not affected by electrical or magnetic fields.

Cause of radioactivity

The nucleus of an atom contains protons and neutrons (collectively known as nucleons). Two types of force are exerted on the nucleons: the *force of electrostatic repulsion* between the positively charged protons, which tends to move them apart, and the *attractive force between neutrons and protons*, called the **nuclear force,** which tends to bind them together. These two forces balance each other, thereby making the nucleus of an atom stable.

When, under certain conditions, this balance gets disturbed, the nucleus becomes unstable and starts emitting radiation, resulting in the splitting of the nucleus into smaller fragments. Sometimes the smaller unstable nuclei join up to form a large nucleus. The principle behind such nuclear reactions is *the need for atoms to attain chemical stability*. The energy released during this process is enormously large. Thus radioactivity is the property of the nucleus and is exhibited by the elements whose nuclei are unstable.

Radioactive phenomenon is of *two* types

(i) nuclear fission

(ii) nuclear fusion.

NUCLEAR FISSION

Fission means 'breaking up'. A nuclear reaction in which a heavy atomic nucleus breaks up into two smaller nuclei, with the release of a very large amount of energy, is called *nuclear fission*. Fission can be natural and spontaneous, or it may be caused by the man-made bombardment of the nucleus of a radioactive substance with neutrons.

***Example* :** When the isotope of uranium called $^{235}_{92}U$ is bombarded with a neutron, it forms an unstable isotope of uranium, $^{236}_{92}U$, which splits up into two stable nuclei (barium and krypton), three free neutrons and a huge amount of nuclear energy.

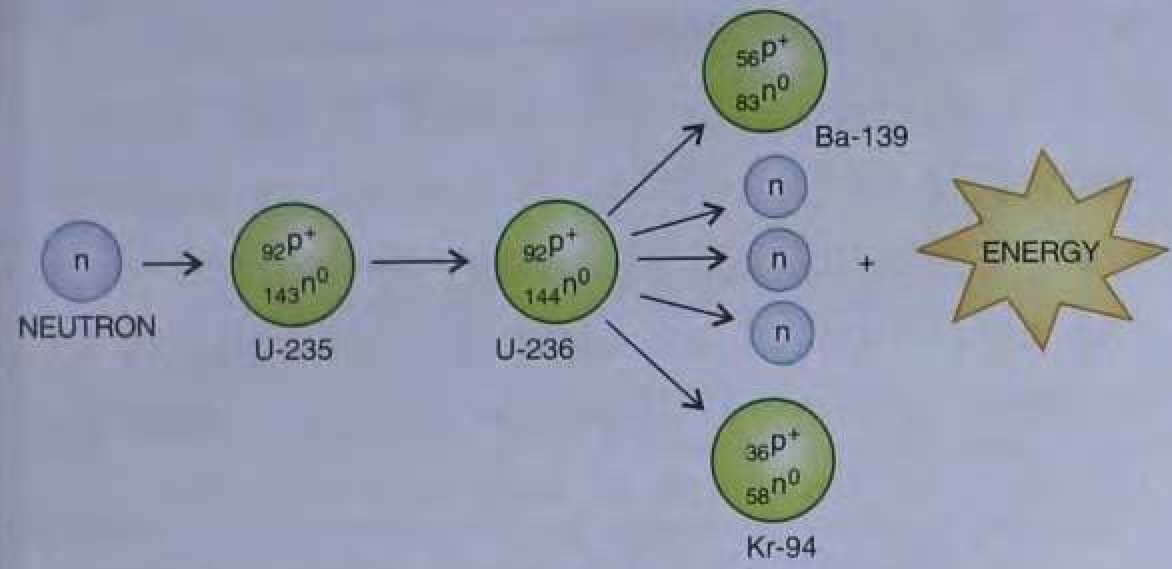


Fig. 1.12 One way in which $^{235}_{92}U$ splits up

This can be represented as :

$$^{235}_{92}U + {_0}n^1 \rightarrow {^{236}_{92}}U \rightarrow {^{139}_{56}}Ba + {^{94}_{36}}Kr + 3{_0}n^1 + Q$$

where Q represents a huge amount of energy.

The three neutrons released during the splitting of the $^{236}_{92}U$ nucleus can be absorbed by the respective nuclei of other U–235 atoms, which too then split up and release energy and 3 neutrons each, and so on. In this way the fission of one uranium atom leads to the fission of another three uranium atoms and a chain of nuclear reactions is set up. The process takes place so fast and is accompanied by the release of such a huge amount of energy that a terrific explosion takes place. This is known as *nuclear reaction (uncontrolled)* and it is this principle that is applied to detonate an atom bomb.

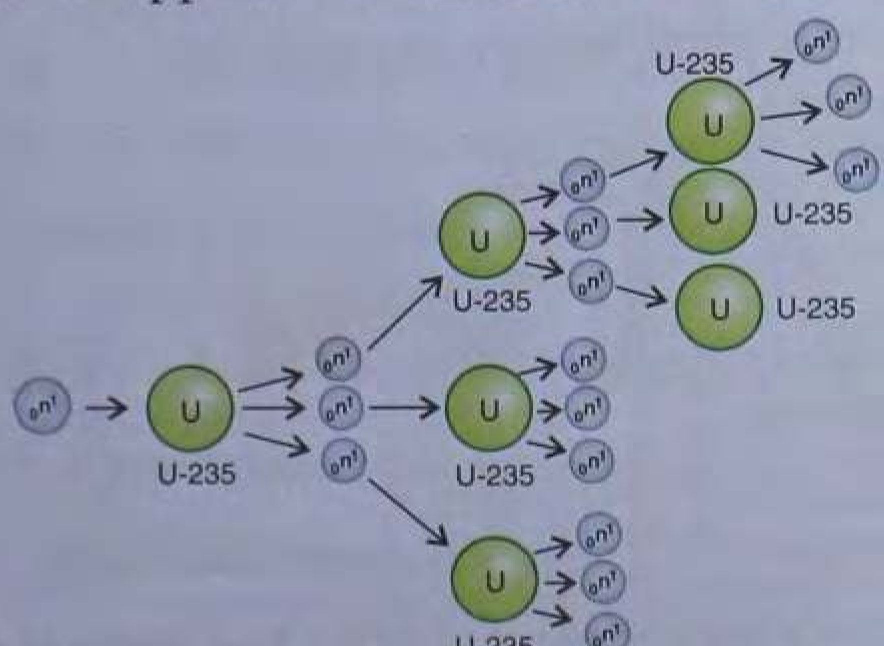


Fig. 1.13 Nuclear fission leading to a nuclear chain-reaction.

However, for peaceful purposes, the uncontrolled reaction has to be brought under control.

NUCLEAR FUSION

Fusion means 'to fuse or to join together'. A nuclear reaction in which the nuclei of light atoms (i.e. elements with small mass numbers) join up to form a heavier nucleus, causing the release of a huge amount of energy, is known as *nuclear fusion*.

***Example* :** Two deuterium (an isotope of hydrogen) nuclei fuse together to give one tritium (another isotope of hydrogen) nucleus, a proton and a huge amount of energy.

$$\underset{\text{(deuterium)}}{^2_1D + {^2_1}D} \rightarrow \underset{\text{(tritium)}}{^3_1T} + \underset{\text{(proton)}}{^1_1H} + \text{Energy}$$

Fusion reactions are the source of the massive energy of the stars, *viz.* the sun. The sun is made up of mostly hydrogen. At the core of the sun, where temperatures reach millions of degrees of centigrade, two hydrogen atoms fuse to form a helium atom. The huge amount of energy released in this process is emitted as heat and light. And this is the energy that sustains life on the earth.

The hydrogen bomb (also called H–bomb or a **thermonuclear device**) works on the principle of nuclear fusion.

Why nuclear fusion cannot be used to generate power ?

Nuclear fusion takes place only at extremely high temperature and pressure. We do not yet have the means to either produce such high temperatures or obtain materials that can withstand such temperatures. This is why nuclear fusion has not been used to generate power. However research is on to find methods to carry out nuclear fusion at room temperature in a controlled and economical manner **(cold fusion)**.

HARMFUL EFFECTS OF RADIO-ACTIVITY

Nuclear radiations are highly penetrating and they can pass through all kinds of living and non-living matter. Of the three kinds of nuclear radiation, γ–rays are the most harmful, since they have the greatest penetrating power. Radioactive radiations can :

(i) cause harmful gene mutation, *i.e.* abnormal change in the genes of living organisms.

(ii) cause skin and other types of cancer.

(iii) lead to the birth of deformed babies.

(iv) cause unmanageable destruction when they are uncontrolled.

(v) cause death when exposed to too much radiation.

USES OF RADIOACTIVE MATERIALS

Under controlled conditions, radioactive radiations emitted from radioactive substances find many applications :

(i) Radioactive materials are used in the treatment of cancer (radiotherapy) because nuclear radiation kills cancer cells. They are also used to detect any disorder in our body system (radio tomography).

(ii) Radioactive rays are used to sterilize food, drugs, *etc*., at normal temperature.

(iii) They are also used to determine the age of rocks, fossils, mineral deposits, historical findings, *etc*.

NUCLEAR ENERGY

The energy that is stored in the atomic nuclei of the elements is known as nuclear energy. [Note that the energy associated with the electrons of an atom is not related to nuclear energy]. Nuclear energy can be obtained in the form of heat and light by :

(i) **the nuclear fission** of heavy elements like uranium, polonium, etc.,

(ii) **the nuclear fusion** of lighter elements like hydrogen.

However, most of the nuclear energy obtained through N-reactions is a product of nuclear fission (controlled). The large amount of energy so obtained is used under controlled conditions to produce steam that powers turbines to produce electricity. Therefore nuclear energy is rightly termed *nuclear fuel.*

Nuclear power plant : Nuclear power plants are set up to generate electricity. Several nuclear power plants are functioning in India. They are at Tarapur, Kalpakkam, Kota, Narora, etc. A nuclear power plant consists of :

(i) a nuclear reactor, where nuclear fission takes place.

(ii) a turbine and a generator for conversion of nuclear energy into mechanical and electrical energy respectively.

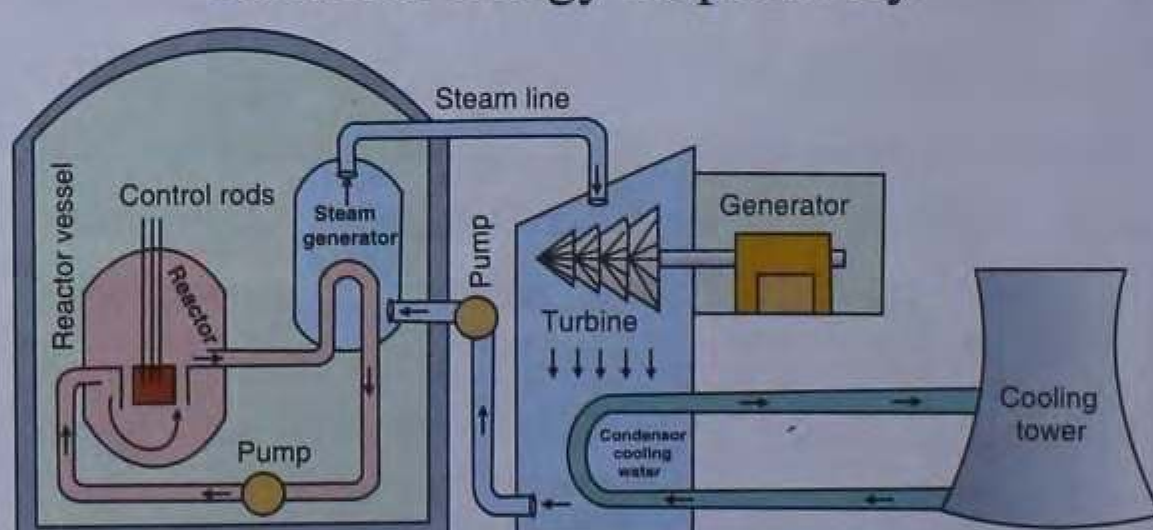


Fig. 1.15 In a nuclear power plant the heat produced by the controlled nuclear fission in the reactor is used to produce steam.

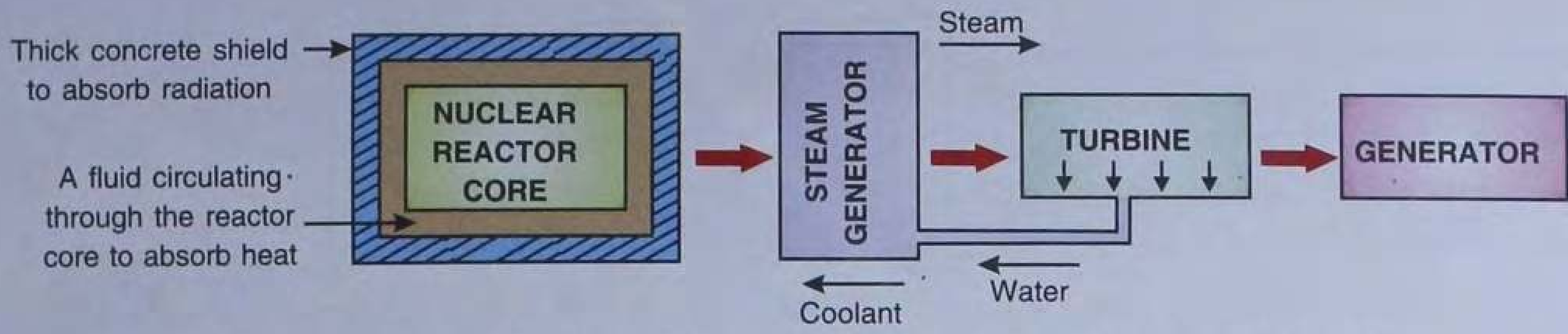


Fig. 1.16 A flow scheme to show a nuclear power plant generating electricity.

Safety requirements at nuclear power plants

1. The nuclear reactor must be embedded (encased) in special concrete walls or in a thick shield of lead so as to prevent leakage of radioactive radiation.
2. The nuclear materials should be kept in either aluminium or stainless steel cans. They should be kept away from each other so that there is no explosion.
3. Workers in a nuclear power plant must wear lead-lined aprons and gloves. They should wear special lead glasses too to protect their eyes from radiation.
4. A periodic medical check-up for workers is a must.
5. If a person is found overexposed to nuclear radiation, he/she should be immediately withdrawn from the power plant and given medical treatment.

EXERCISE – II

1. Fill in the blanks :

(a) The α-particles are emitted from the .... of a radioactive element.

(b) During nuclear fusion .... of lighter elements fuse to form heavy nuclei.

(c) Nuclear reactor works on .... nuclear fission.

(d) Hydrogen bomb is an example of ....

2. Name the following :

(a) a phenomenon due to which heavy nucleus splits into lighter nuclei.

(b) A power plant which uses nuclear energy.

(c) The substance that emits radioactive rays.

3. Multiple Choice Questions

(a) Alpha rays consists of
(i) positively charged hydrogen atom
(ii) helium atom
(iii) positively charged helium atoms
(iv) none

(b) The most penetrating radioactive ray is
(i) alpha ray (ii) beta ray
(iii) gamma ray (iv) none

(c) Nuclear reactor is based upon
(i) nuclear fission (ii) nuclear fusion
(iii) transmutation (iv) chemical bond

(d) Gamma rays can not penetrate through
(i) aluminium (ii) sheet of paper
(iii) lead (iv) iron

(e) An unstable isotope of uranium [$_{92}U^{236}$] splits up to give
(i) a stable barium atom (ii) three neutrons
(iii) a stable krypton atom (iv) all of the above

(f) The attractive force between neutrons and protons is called
(i) electrostatic force (ii) nuclear force
(iii) chemical force (iv) none

4. Answer the following questions :

(a) What are radioactive substances ? Give two examples.

(b) What are the three types of radioactive radiations? Mention two properties for each of them.

(c) What is a nuclear reactor ? State any two precautions taken in running a nuclear reactor.

(d) Why can not nuclear fusion be used to generate electricity ?

(e) What are the harmful effects of radioactivity.

RECAPITULATION

- All matter is made up of elements, which in turn are made of atoms.
- Maharishi Kanad was the first man to give the idea of *paramanu* and *anu*.
- Dalton's atomic theory states that atoms are indivisible.
- Later discoveries led to the modification of Dalton's theory and now it is known that an atom consists of three fundamental particles; electrons, protons and neutrons, *i.e.* atoms are divisible.
- J.J. Thomson put forth the Plum Pudding Model of the atom.
- Rutherford suggested an atomic model on the lines of the solar system.
- According to the modern model of the atom, protons and neutrons are contained in the nucleus while electrons move along only certain fixed orbits or shells each of which is associated with a fixed amount of energy. The energy associated with a shell increases with distance from the nucleus.
- An atom is electrically neutral, *i.e.* the number of protons in an atom is equal to the number of electrons in it.
- The distribution of electrons in the various orbits of the atom of an element is called the electronic configuration of that element. The maximum number of electrons in a shell is given by the formula $2n^2$, where n is the serial number of the shell. But the outermost shell cannot have more than 8 electrons.
- The noble gases (except helium) do not react chemically because they have a stable configuration of 8 electrons in their outermost orbits.
- Elements other than the inert gases are chemically reactive because they need to attain stable electronic configuration by either donating or accepting electrons.
- The number of electrons donated or accepted by an atom during chemical combination is called its valency.
- The force of attraction that binds two atoms together, as in a molecule, is called a chemical bond.
- The charged atoms formed due to the transfer of electrons are called ions. The positively charged ion is called a cation and the negatively charged ion is called an anion.
- The atoms of an element having the same atomic number but different mass number are called the isotopes of that element.
- The number of protons in the nucleus of an atom is called its atomic number (Z), which is equal to the number of electrons in a neutral atom.
- The sum of the number of protons and the number of neutrons present in the nucleus of an atom is called its mass number (A).
- Radioactivity is the phenomenon due to which certain elements give out highly penetrating radiations.
- The elements that emit highly energetic radiations are called radioactive elements.
- Radioactive radiation consists of α, β and γ-rays.
- Nuclear fission is the process in which a heavy nucleus splits up into two smaller nuclei with the release of a large amount of energy.
- Nuclear fusion is the process of the joining together of two light atomic nuclei to form a heavier nucleus, with the release of energy being greater than in the case of fission.
- Radioactivity has some harmful effects; it causes cancer, for instance.
- A nuclear power plant generates nuclear energy under controlled conditions to convert it into electricity.