UNIT 5

Atomic Structure

EVZ9I1

Learning Objectives

At the end of this unit you will be able to

- state and illustrate the laws of multiple proportion, reciprocal proportion and law of combining volumes
- solve simple numerical problems based on the above laws
- to understand Rutherford's gold foil experiment
- conclude the presence of nucleus in an atom.
- to identify the limitations of Rutherford's model
- compare the charge and mass of sub-atomic particles
- calculate number of protons, neutrons and electrons in a given atomic number and mass number of an element
- differentiate isotopes, isobars and isotones
- explain the main postulates of Bohr's atomic model
- draw the atomic structure of first 20 elements
- recognize the significance of quantum numbers.
- assign valency of various elements based on the number of valence electrons

Introduction

We already know that anything that has definite mass and occupies space is known as matter.

Let us quickly recall
What is matter?
What are the different states of matter?
Is matter continuous or particulate in nature?

If somehow we could go on dividing any piece of matter we will get smaller and smaller particles until we reach the smallest particle of it which cannot be divided further. These smallest particles can be atoms, molecules or ions.

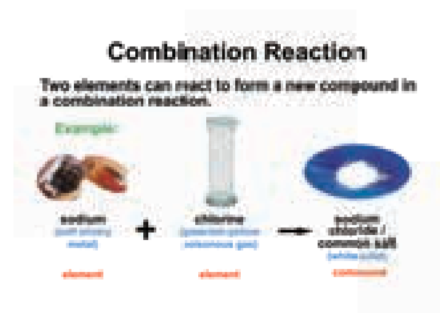
Atoms are the building blocks of matter. Every substance is made up of atoms in one form or other. Different kinds of atoms have different properties (both physical and chemical).

You already know that atoms combine together to form molecules. This combination is called a chemical reaction which can be represented symbolically by balanced chemical equations.

Now look at the following equation. What do you understand?

We can say that Sodium and Chlorine combine to form Sodium Chloride.

$$2Na + Cl_2 \longrightarrow 2NaCl$$



What is a combination reaction?

Combination reaction is a reaction where two or more substances combine to form a single substance. The combination of different elements to form a compound is governed by certain basic rules. These rules are known as Laws of chemical combination.

5.1 Laws of Chemical combination

Out of these five laws you already know the first two laws. Let us see the next three laws in detail in this chapter.

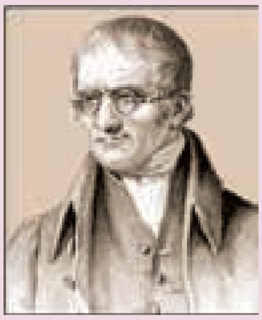
More to Know

- Kanada, the Indian philosopher of 6th century put forward the theory that everything in the universe was made of minute particles called "Paramanu"
- In fourth century BC, the Greek philosophers Leucippus and Democritus suggested that the universe was formed by very tiny particles named atoms.
- Ancient Indian philosophers said that Universe is formed from five basic elements, air, water, fire, soil, and space. Greek philosopher Plato argued that the Universe is formed of four elements soil, air, water & fire.

5.1.1 Law of multiple proportions

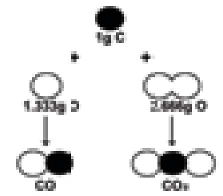
This law was proposed by **John Dalton in 1804**.

When two elements A and B combine together to form more than one compound, then masses of A which separately combines with a fixed mass of B are in simple ratio.



To illustrate the law let us consider the following example.

Carbon combines with oxygen to form two different oxides, carbon monoxide(CO) and carbon dioxide (CO_2).



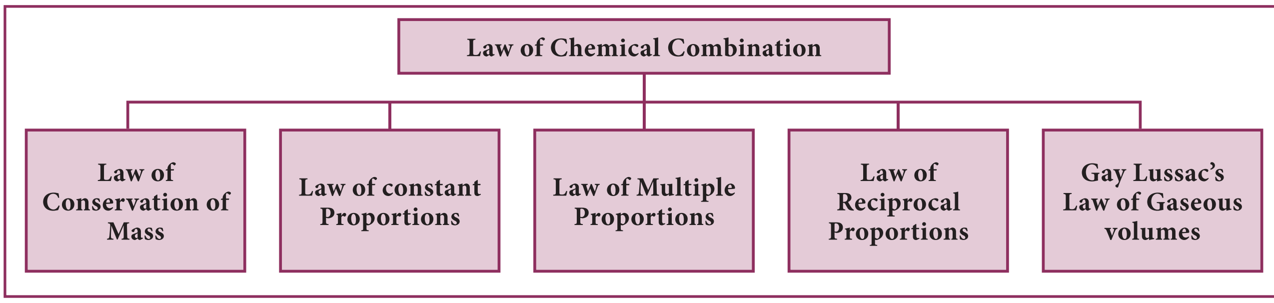
The ratio of masses of oxygen in CO and CO_2 for fixed mass of carbon is 1: 2. Isn't this a simple ratio? Let us take one more example. Sulphur combines with oxygen to form sulphur dioxide and sulphur trioxide. The ratio of masses of oxygen in SO_2 and SO_3 for fixed mass of Sulphur is 2:3.

Test Yourself

Tabulate the composition by mass of oxides of nitrogen with the fixed weight of nitrogen in the following table

What do you conclude?

Compound	N_2O	NO_2	N_2O_4	N_2O_5
Ratio of the molar masses N : O				



S. No	Compound	No. of atoms/g of carbon	No atoms/g of Oxygen	Ratio of masses C : O
1.	CO	One -12g	One-16g	12:16 or 1: 1.333g
2.	CO_2	One-12g	Two- 32g	12:32 or 1: 2.666g

Compound	N_2O	NO_2	N_2O_4	N_2O_5
Grams of oxygen combining with 1 gm of Nitrogen				
Simple O : N ratio				

Sample Problem(Solved)

Iron forms two different chlorides, namely ferrous and ferric chlorides. Each of these chlorides was prepared from 2 gram of iron. It was found that 4.538 gram ferrous chloride and 5.804 gram ferric chloride were produced. Show that these observations are according to the law of multiple proportions.

Solution:

Here iron is forms different chlorides. The weight of iron taken in both cases is the same. i.e. 2.0 g. Therefore, we have

	Ferrous chloride (A)	Ferric chloride (B)
Weight of chloride	4.538 g	5.804 g

	Ferrous chloride (A)	Ferric chloride (B)
Weight of iron	2.000 g	2.000 g
Weight of chlorine	2.538 g	3.804 g

The proportion of chlorine in this compound is

Ferrous chloride	:	Ferric chloride
2.538	:	3.804
1	:	1.5 or 2: 3

The proportion by weight of chlorine is indicated by a simple ratio. Thus Law of multiple proportions is verified

Activity 1

Lead forms three oxides A, B and C. The quantity of oxygen in each of the oxides A, B and C is 7.143%, 10.345% and 13.133% respectively. Show that the law of multiple proportions is obeyed.

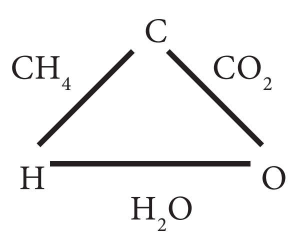
5.2 Law of Reciprocal Proportions

The **law of reciprocal proportions** was proposed by Jeremias Ritcher in 1792.

Jeremias Ritcher

It states that, "If two different elements combine separately with the same weight of a third element, the ratios of the masses in which they do so are either the same or a simple multiple of the mass ratio in which they combine."

Let us study the following example Here carbon combines with hydrogen and oxygen to form Methane (CH_4) and CO_2 (carbon dioxide) respectively. Hydrogen and oxygen combine to form water.



Sr. No	Compounds	Combining elements		Combining weights	
1	CH_4	C	H	12	4
2	CO_2	C	O	12	32

It is seen that in CH_4 the ratio of masses C : H = 3:1

In CO_2 the ratio of masses of C : O = 3:8

Here hydrogen and oxygen combine with the same mass of carbon. They also combine with each other to form water (H_2O)

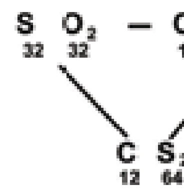
What is the ratio of masses of H and O in H_2O?

It is 2: 16 or 1:8 which is same as 4:32, which is the ratio of the different masses of hydrogen and oxygen combining with the same mass of carbon.

This illustrates the law of reciprocal proportions.

Let us consider one more example.

Sulphur combines with oxygen to form sulphur dioxide, carbon combines with oxygen to form carbon dioxide and carbon combines with sulphur to form carbon disulphide



The ratio of masses of carbon and sulphur which combine with fixed mass (32 parts) of oxygen is

12:32 or 3:8 ...(1)

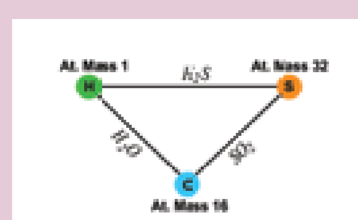
In CS_2 ratio of masses of carbon and sulphur is in the ratio

12:64 or 3:16 ...(2)

The two ratios (1) and (2) are related to each other by $\frac{3}{8}:\frac{3}{16}$ or **2:1**

Activity 2

Illustrate the given diagram of law of reciprocal proportion



Solved problem

Hydrogen sulphide (H_2S) contains 94.11% sulphur, water (H_2O) contains 11.11% hydrogen and sulphur dioxide (SO_2) contains 50% of oxygen. Show that the results are in agreement with the law of reciprocal proportions.

Solution

In 100g of water, the weight of hydrogen	=	11.11 g
The weight of oxygen	=	100 – 11.11 = 88.89 g
In 100g of sulphur dioxide, the weight of sulphur	=	50 g
Weight of oxygen	=	100 – 50 = 50 g

The ratio between the weight of oxygen and Hydrogen is 88.89:11.11 i.e. 8:1 (1)

In hydrogen sulphide, the weight of sulphur = 94.11 g

The weight of hydrogen = 100 – 94.11 = 5.89 g

The ratio between the weight of sulphur and hydrogen is 94.11: 5.89 ie. 16: 1 … (2)

The two ratios 1 and 2 are related as 8/1: 16/1 (or) **1 : 2**

These are simple multiples of each other. The ratio between the weight of sulphur (32) and oxygen (16) which combine separately with the weight of Hydrogen (2) supports **the law of reciprocal proportions.**

Activity 3

1 gram of hydrogen combines with 15.88 gram of sulphur. 1 gram of hydrogen combines with 7.92 gram of oxygen. 8 gram of sulphur combines with 7.92 gram of oxygen. Show that these data illustrate the law of reciprocal proportions.

5.2.1 Gay Lussac's law of Combining Volumes

Whenever gases react together, the volumes of the reacting gases as well as the products bear a simple whole number ratio, provided all the volumes are measured under similar conditions of temperature and pressure

Step 1: Hydrogen combines with oxygen to form water (word equation)

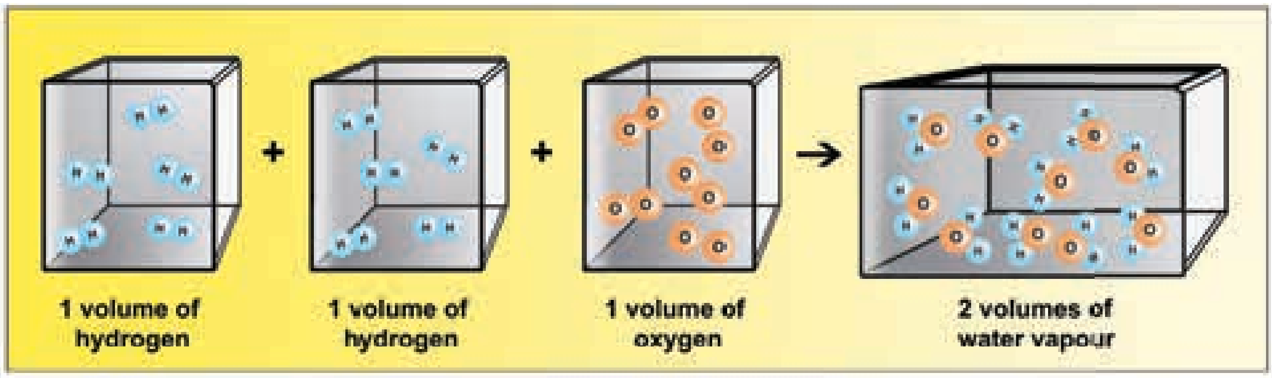
Step2: H_2 + ½ $O_2 \rightarrow$ H_2O (skeletal equation)

Step3: $2H_{2(g)} + O_{2(g)} \rightarrow 2H_20$ (g) (balanced equation)

(2 Volumes) + (1 Volume)→(2 Volumes) **(2:1:2)**

i.e. two volumes of hydrogen react with 1 volume of oxygen to form two volumes of water vapour. i.e. the ratio by volume which gases bears is **2:1:2** which is a simple whole number ratio.

It follows that at a given temperature and pressure the volumes of all gaseous reactants and products bear a simple whole number ratio to each other.



Two volumes of hydrogen react with One volume of oxygen to give Two volumes of water vapour

Let us consider one more example:

Step 1: Hydrogen combines with chlorine to form hydrogen chloride

Step2: $H_2 + Cl_2 \rightarrow 2HCl$

Step 3: $H_{2(g)}$ + $Cl_{2(g)}$ → $2HCl_{(g)}$

1volume 1volume 2volumes

[1 : 1 : 2]

i.e. one volume of hydrogen reacts with one volume of chlorine to form two volumes of HCl gas. i.e. the ratio by volume which gases bears is **1:1:2** which is a simple whole number ratio.

Activity 4

Nitrogen combines with hydrogen to form ammonia (NH_3). Illustrate Gay Lussac's law using this example.

Solved Problem

Methane burns in oxygen to form carbon dioxide and water vapour as given by the equation

$$CH_{4(g)} + 2O_{2(g)} \rightarrow CO_{2(g)+} 2H_2O_{(g)}$$

Calculate: (i) the volume of oxygen needed to burn completely 50 cm^3 of methane and (ii) the volume of carbon dioxide formed in this case.

Solution:

$CH_{4(g)}$	$+2O_{2(g)}$	$\rightarrow CO_{2(g)}$	$+2H_2O_{(g)}$
1 volume	2 volumes	1 volume	2 volumes
1 x 50 cm^3	2 x 50 cm^3	1 x 50 cm^3	2 x 50 cm^3
50 cm^3	100 cm^3	50 cm^3	100 cm^3

Volume of oxygen used = 100 cm^3

Volume of carbondioxide formed = 50 cm^3

Activity 5

100 cm^3 of propane (C_3H_8) was burnt in excess oxygen to form carbon dioxide and water. Calculate (i) the volume of oxygen used up (ii) the volume of carbon dioxide formed.

[Hint: $C_3H_8(g) + 5O_{2(g)} \rightarrow 3CO_{2(g)} + 4H_2O(l)$]

More about of structure of atoms

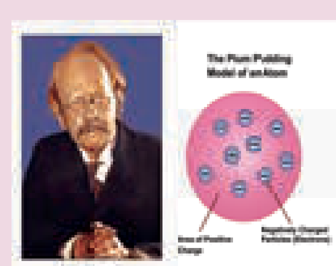
Know your Scientist

John Dalton FRS was an English chemist, physicist, and meteorologist. He is best known for proposing the modern atomic theory and for his research into colour blindness, sometimes referred to as Daltonism in his honour.

You already have a basic idea of Dalton's atomic theory, J. J. Thomson's Cathode ray experiments, and limitations of Thomson's model of atom.

Let us recall:

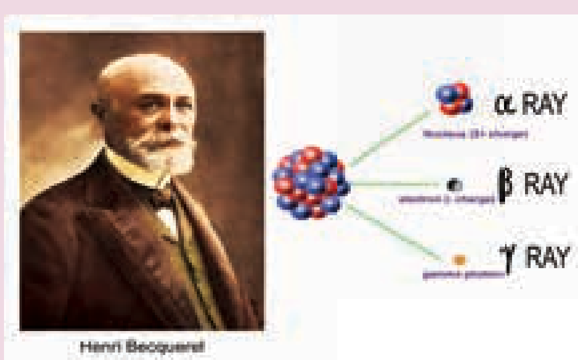
According to John Dalton: Matter consists of very small and indivisible particles called atoms. Atoms can neither be created nor be destroyed. The atoms of an element are alike in all respects but they differ from the atoms of other elements. Atoms of an element combine in small whole numbers to form molecules.



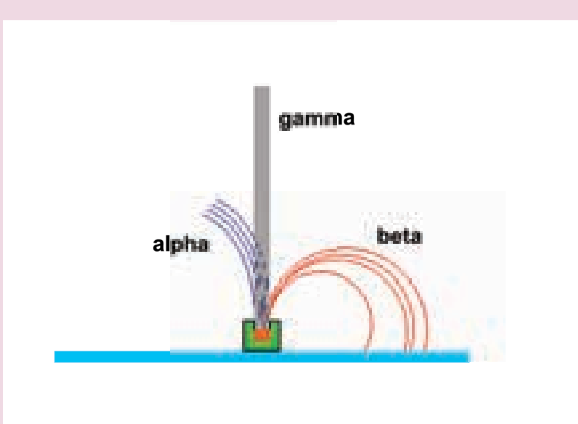
J J Thomson said that like plums in pudding the negatively charged electrons are dotted here and there in a positively charged sphere. According to this 'plum pudding' model, an atom is considered to be a sphere of uniform positive charge and electrons are embedded into it.

MORE TO KNOW: RADIOACTIVITY

In 1896, Henri Becquerel arranged in his cupboard, a packet of uranium salt beside an unexposed photographic plate. Several days later, he took out the plate and developed it. To his surprise, he noticed that the photographic plate had been exposed without having been exposed to the light. Having repeated this experiment, he concluded that some stream of particles came out from Uranium. Today we call them as alpha particle.



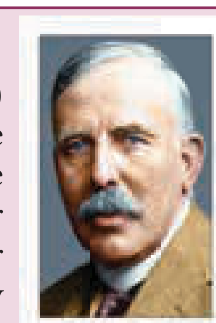
Henri Becquerel



Alpha (α), beta (β) and gamma(γ) rays are emitted during the radioactive decay of an atom. The alpha and beta rays consist of actual matter form, while *gamma rays* are electromagnetic waves. The alpha particles which are the main constituent of the alpha radiation are made up of two protons and two neutrons. An alpha particle is identical with a Helium nucleus. Hence it is positively charged and has mass equal to a Helium atom.(He^{2+}). Beta particle is negatively charged and is identical with electron. Gamma rays have no charge. Rutherford used a stream of alpha particles for his experiment which is discussed below.

5.3 Discovery of Nucleus

Know your Scientist

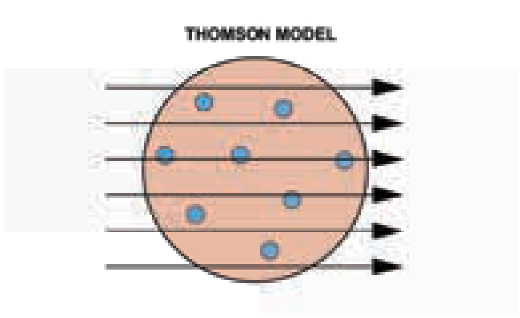

Ernest Rutherford

E. Rutherford (1871-1937) was born at Spring Grove on 30th August 1871. He was the 'Father' of nuclear physics. He is famous for his work on radioactivity and the discovery of the nucleus of an atom with the gold foil experiment. He got the Nobel Prize in chemistry in 1908. He was the first to produce Tritium in 1934.

Thomson's model of atoms is a conceptual representation like many other models in science. Scientists test scientific models by doing experiments to find out if they were wrong. The model proposed by Thomson was conceptual. Scientists were eager to test it by doing an experiment. How would you test if the model is correct or wrong? They are so small that even a powerful microscope is useless in peering inside an atom.

In 1905, Ernest Rutherford along with his scholars Hans Geiger and Ernest Marsden came up with an interesting idea to test the Thomson's model. In Thomson's model recall that the charges are symmetrically distributed. Suppose you shoot a highly energetic positively charged particle smaller than an atom, to collide at an atom, what do you expect? As the incoming particle is positive, it should be repelled by the positive atom. This is because you know that ″like charges repel each other.″ If according to plum pudding model, the positive charge of atoms is evenly distributed; it should be very small at each point inside the atom. But as the energy of the incoming particle is higher than the repulsion at the point of contact, the particle should overcome the repulsion and penetrate the atom.

Once it is inside the atom, the positively charged particle is repulsed on all sides with the same force. Assuming that atom is a uniformly positively charged mass with random moving electrons, the particle should come out of the other end of the atom almost undeflected. Some of the electrons inside the atom could attract the positively charged particle and make small change in the path. Therefore it can be predicted that deviation if any, be less than a small fraction of a degree and is negligible.

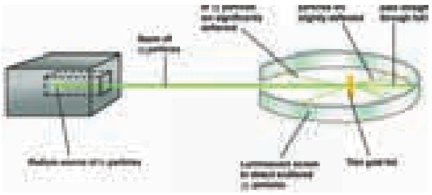


5.3.1 Rutherford's α–ray scattering experiment

Alpha particles are positively charged it possess adequate energy to overcome the repulsive force of positive charge, if the charge is evenly distributed in an atom. As you probably know, according to Coulomb's law, the less concentrated a sphere of electric charge is, the weaker is its electric field at its surface.

Atoms are so small that you cannot pick them one by one to be kept as a target and shoot alpha particles. Gold as you may know is a highly malleable metal and can be made in to a very thin layer.

They arranged an experimental set up. A natural radioactive source that emitted highly energetic alpha particles was chosen. The source was kept inside a lead box with a small hole in it. Alpha particles came out of the source in all directions. Those particles which hit the walls of the box were absorbed by it. Only those alpha particles that were emitted in the direction of the hole could escape. These rays of alpha particles followed a straight line.



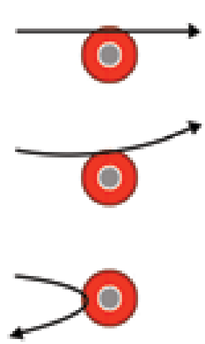
A thin gold foil, about 400 atoms thick, was kept on the path of the alpha particle. They also kept a circular screen coated with zinc sulphide surrounding the foil. When an alpha particle hit the screen, it would produce fluorescence glow in the point where they struck the screen. From the point on the screen, one can infer the path taken by the alpha particle after penetrating the gold foil. The whole set up was kept inside a vacuum glass chamber, to avoid alpha particles from interacting and getting scattered by air molecules.

The experiments were repeated for reproducibility. Each time when the experiment was conducted, they computed and tabulated the angle of the rays of alpha particle after it hits the gold foil. They observed the following.

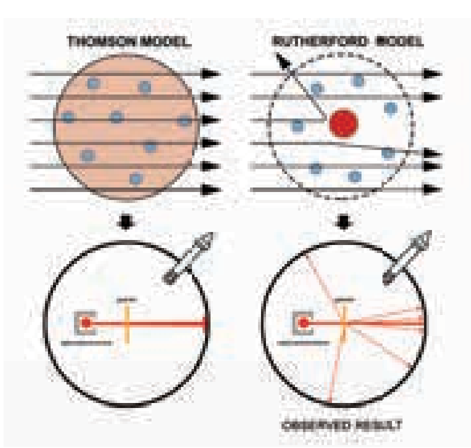
(i) Most of the fast moving α-particles passed straight through the gold foil.

(ii) Some α particles were deflected by small angles and a few by large angles.

(iii) Surprisingly very few α particles completely rebounded.



The experiments showed that most of the alpha particles behaved as expected, but there was a small discrepancy. Out of every 2000 particles that got scattered, just one was deflected by a full 180°. That is, they simply retraced their path after hitting the gold foil. You know that change of direction is possible only if a strong enough force acted against the direction of the motion of the particle.



Based on the plum pudding model of the atom, it was assumed that there was nothing dense or heavy enough inside the gold atoms to deflect the massive alpha particles from their paths. However, what Rutherford actually observed did not match his prediction. These observations indicated that a new model is needed to account for the evidences gathered in the experiment.

Rebound of alpha particle was impossible under the Thomson model. The alpha particle could have been deflected at 180° only if the positive charge was concentrated at a point rather than dispersed throughout the atom. If all the positive charge of the atom was concentrated at a small area inside the atom, only then, the electrostatic repulsion would be strong enough to bounce them back at 180°.

Now two observational evidence were before Rutherford and his team

1) Most of the particles passed are not deviated as there was no obstruction to their path: This should imply that most part of the atom is empty

2) Some alpha particle was deflected right back; implying that the positive charge should be concentrated at the centre of atom.

To be sure that their findings were really correct, the team performed the same type of experiments with many other materials including gases between the period 1908 and 1913.

Based upon these evidences, Rutherford rejected the Thomson's idea and proposed that all the positive charges are concentrated in the central region of the atom called 'nucleus', and electrons orbit the nucleus at a distance. Further he stated that in between the nucleus and electron inside an atom there existed a void. This came to be called as planetary model of atom.

5.3.2 Rutherford's model of an atom- salient features

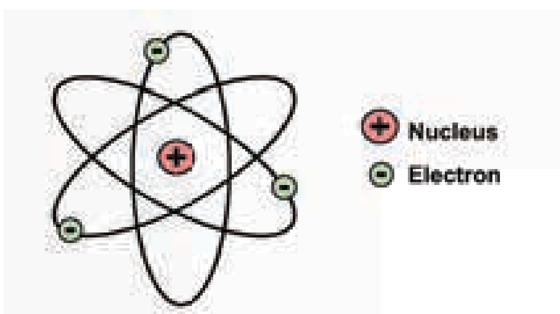
(i) Atom has a very small nucleus at the centre.

(ii) There is large empty space around the nucleus.

(iii) Entire mass of an atom is concentrated in a very small positively charged region which is called the nucleus.

(iv) Electrons are distributed in the vacant space around the nucleus.

(v) The electrons move in circular paths around the nucleus.

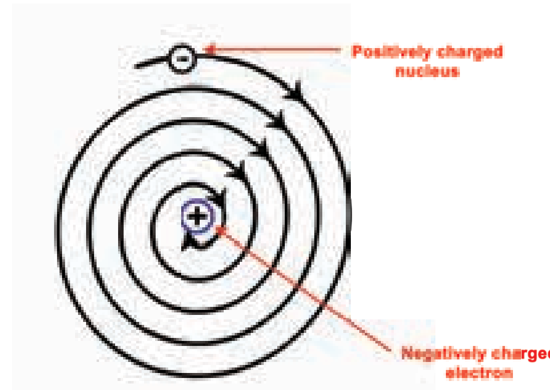


Rutherford Model of the Atom

5.3.3 Limitations in Rutherford's model

Although the model suggested by Rutherford went beyond the one by Thomson and explained the behaviour of alpha particles, it also left a few questions unanswered. Planets can go around the Sun under the gravitational attraction. But negatively charged electron should be attracted by the positively charged nucleus, since opposite charges attract. But it does not happen that way.

It was shown by Clark Maxwell that a charged body moving under the influence of attractive force loses energy continuously in the form of electromagnetic radiation. Thus unlike a planet the electron is a charged body and it emits radiations while revolving around the nucleus. As a result, the electron should lose energy at every turn and move closer and closer to the nucleus following a spiral path consequently the orbit will become smaller and smaller and finally the electron will fall into the nucleus. In other words, the atom should collapse. However, this never happens and atoms are stable.



Thus the stability of the atom could not be explained by Rutherford Model. There were also a few more objections to his model. This led on to more research and evolving better models of atomic structure.

5.3.4 Bohr's model of an atom

Know your Scientist

Niels Bohr was born on October 7, 1885 in Copenhagen, Denmark. He was also an outstanding soccer player. He worked with Rutherford at the university of Manchester. Bohr received the Nobel Prize for Physics in 1922.

A new model of atom was needed because Rutherford model could not explain the stability of atom. Neils Bohr developed a successful model of hydrogen atom. In order to justify the stability of an atom Neils Bohr made some improvements on Rutherford's model. The main postulates are:

i. In atoms, electrons revolve around the nucleus in certain special or permissible orbits known as discrete orbits or shells or energy levels

ii. While revolving in these discrete orbits the electrons do not radiate energy.

iii. The circular orbits are numbered as 1, 2, 3, 4,… or designated as K, L, M, N, shells. These numbers are referred to as principal quantum numbers (n).

iv. K shell (n=1) is closest to the nucleus and is associated with lowest energy.

L, M, N, …. etc are the next higher energy levels. As the distance from the nucleus increases the energy of the shells also increases.

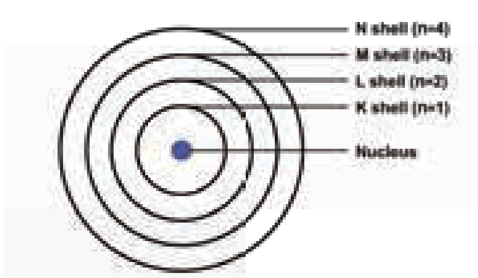
v. The energy of each orbit or shell is a fixed quantity and the energy is quantized.

vi. As the distance from the nucleus increases, the size of the orbits also increases.

vii. Maximum number of electrons that can be accommodated in an energy level is given by $2n^2$ where n is the principal quantum number of the orbit.

viii. When an electron absorbs energy, it jumps from lower energy level to higher energy level.

ix. When an electron returns from higher energy level to lower energy level, it gives off energy.



DO YOU KNOW?

How big are atoms?

Very small! An average atom is 0.000,000,001 metre. (one millionth of 1 mm) across. Blow up a balloon, It seems to contain nothing and weight almost nothing. But it contains about one hundred billion billion atoms which make up the gases in the air.

5.3.5 Limitations of Bohr's model

Many arguments were raised against Bohr's model of an atom. One main limitation was that his model was applicable only to Hydrogen. It could not be extended to multi electron atoms. Hence more research and deeper study of atoms became necessary. A detailed study of these aspects will be done in higher classes.

Orbit or shell:

Orbit is defined as the path by which electrons revolve around the nucleus.

Illustration:

The number of electrons in the first orbit (K)(n = 1);$2 \times 1^2 = 2$

The number of electrons in the second orbit (L) (n = 2); $2 \times 2^2 = 8$

Activity 6

Calculate the number of electrons present in the third (M) and fourth orbits (N)

5.4 Discovery of Neutrons

In 1932 James Chadwick observed when Beryllium was exposed to alpha particles, particles with about the same mass as protons were emitted.

DO YOU KNOW?

In 1920 Rutherford predicted the presence of another particle in the nucleus as neutral. James Chadwick, the inventor of neutron was student of Rutherford

${}_{4}Be^{8} + \alpha$ rays $\longrightarrow {}_{6}C^{12}$ + Neutron (n)
Beryllium + Alpha rays $\longrightarrow$ carbon + neutron

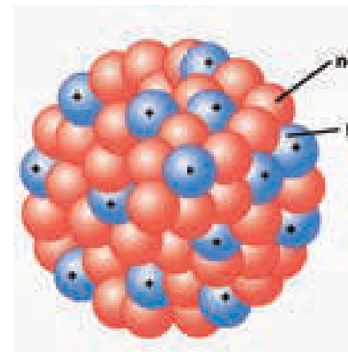
These emitted particles carried no electrical charges. They were called as neutrons. Neutrons present in the nuclei of all the atoms except of hydrogen. The mass of a neutron is almost equal to the mass of proton. Neutron is represented by n.

5.4.1 Composition of nucleus

Electrons have a negligible mass; hence the mass of the atom mainly depends on the mass of the nucleus. Nucleus of an atom consists of two components, they are protons and neutrons.

Protons are positively charged. Protons repel each other because of their like charges. Hence more than one proton cannot be packed in a small volume to form a stable nucleus, unless neutrons are present.

Neutrons reduce the repulsive force between the positively charged protons and contribute to the force that holds the particles in the nucleus together.



DO YOU KNOW? The strong force that binds proton and neutron is more powerful than gravity.

5.4.2 Nucleons

The elementary particles such as protons and neutrons are collectively called as Nucleons. Why are atoms neutral? Because an atom contains the same number of protons and electrons and hence it's neutral.

Characteristics of fundamental particles

The physical and chemical properties of elements and their compounds can be

Particles	Mass	Charge		Location	Mass relative to Hydrogen atom
		Unit	Coulomb		
Electron	9.108×10^{-28}g	−1	-1.602×10^{-19}	Orbit	1/1837
Proton	1.672×10^{-24}g	+1	1.602×10^{-19}	Nucleus	1
Neutron	1.674×10^{-24} g	0	-	Nucleus	1

Activity 7

Complete the following table:

Particles	Mass	Charge	Location	Scientist who discovered
Electron	?	−1	?	J.J. Thomson
Proton	1.672×10^{-24}gm	?	Nucleus	?
Neutron	?	0	?	James Chadwick

explained by the fundamental particles of an atom. The fundamental particles are proton, neutron and electron.

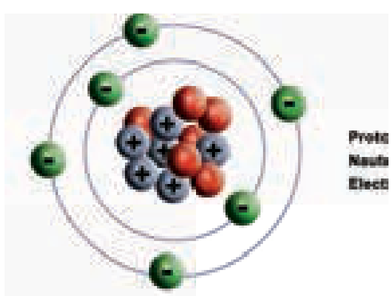
> **DO YOU KNOW?** Besides the fundamental particles like protons, electrons and neutrons some more particles are discovered in the nucleus of an atom. They include mesons, neutrino, antineutrino, positrons etc.

Terminology

Atomic Number (Z)

The figure shown here represents an atom.

Using the colour code given below



	Proton	?
	Neutron	6
	Electron	?

Count the number of protons, electrons and complete the table. Are the number of protons and electrons the same?

An atom of an element has its own characteristic number of protons in its nucleus, which distinguishes it from the atoms of other elements. Hence proton is considered to be the finger print of an atom.

This characteristic number (Number of protons) is called the atomic number of the element. Atomic number is denoted by Z.

What is the Atomic number of the above element?

Since there are 6 protons, the atomic number = 6.

The number of electrons = 6, which is the same as the atomic number.

Atomic number of an atom is therefore equal to the number of protons and it is also equal to the number of electrons present.

> In a neutral atom
>
> Atomic Number = Number of protons = Number of electrons

Illustration:

An atom has 11 protons, 11 electrons and 12 neutrons. What is the atomic number and the name of the element?

Atomic number = Number of protons = Number of electrons

Number of protons = Number of electrons = 11

∴ Atomic number = 11

Name of the element is Sodium.

> **Test Yourself**
>
> An atom 'A' has 7 protons, 7 neutrons and 7 electrons. Atom 'B' has 9 protons, 9 electrons and 10 neutrons. Identify the Atomic number and names of A and B

Mass Number:(A)

From Rutherford's experiment it was clear that the mass of the atom is concentrated in the nucleus. This means that mass of an atom is practically due to protons and neutrons which are present in the nucleus. Protons and neutrons together are also called nucleons.

Mass number of the element is the total number of protons and neutrons present in the nucleus.

Mass number is denoted by A

Mass number = Number of protons + Number of neutrons

For example if an atom has 3 protons, 3 electrons and 4 neutrons, then its mass number will be equal to 7 (3 protons+ 4 neutrons)

Test Yourself

An atom has 15 protons, 15 electrons and 16 neutrons. What is the mass number?

Symbolic representation of an atom using Atomic Number and Mass Number

An atom can be represented by its symbol with atomic number as subscript and mass number as superscript.

Mass Number		A
	Symbol of element	X
Atomic Number		Z

For example, nitrogen is written as $^{14}_{7}N$

Here **7** is its atomic number and **14** is its mass number.

Activity 8

Symbolically represent the following atoms using atomic number and mass number.

a) Carbon b) Oxygen c) Silicon d) Beryllium

Relationship between Mass Number and Atomic Number:

Mass Number (A) = Atomic Number (z) + Number of Neutrons(n)

Atomic Number (Z) = Number of Protons or Number of Electrons

$$A = Z + n$$

DO YOU KNOW?

Atomic number designated as Z why?

Z stands for Zahl, which means NUMBER in German.

Z can be called Atomzahl or atomic number

A is the symbol recommened in the ACS style guide instead of M (massenzahl in German)

Sample Problem (solved):

Calculate the atomic number of an element whose mass number is 39 and number of neutrons is 20. Also find the name of the element.

Solution:

Mass Number = Atomic Number + Number of neutrons

Atomic Number = Mass Number – Number of neutrons

= 39 – 20

Atomic Number = 19

Element having Atomic Number 19 is Potassium (K)

Complete the following table: Pair work

Elements	Atomic Number	Mass number	No. of protons	No. of electrons	No. of Neutrons
Beryllium	?	9	4	4	?
Oxygen	8	?	?	8	8
Magnesium	12	24	?	?	12
Aluminum	?	27	13	?	?

Do It Yourself

Calculate the atomic number of the element whose mass number 31 number of neutron is 16 and find the name of the element.

DO YOU KNOW? **Chlorine got from natural resources (Sea water) has fractional atomic mass. Why is it so?**

This is due to the presence of isotopes.

An atom can have a fractional atomic mass (Relative atomic mass) For example:

Chlorine has fractional atomic mass.

Chlorine – 35 exists by 75% Chlorine – 37 exists by 25%

$$35 \times \frac{75}{100} + 37 \times \frac{25}{100} = 35.5 \text{ amu}$$

Fractional atomic mass of Chlorine is [(75/100)x 35] + [(25/100)x37] = 35.5

5.5 Isotopes (Iso – same, topo – place, Isotope – same place

5.5.1 ISOTOPES

Find below three different atoms. Count the different subatomic particles and fill in the table.

More to Know

Thumb rule for isotopes and isobars. Remember **t** for top and **b** for bottom.
Isotope: Top value changes – atomic mass
Isobars: Bottom value changes – atomic number

What do you observe in the above atoms?

Which is same and what is different in them?

All of them have the same number of protons and electrons but different number of neutrons.

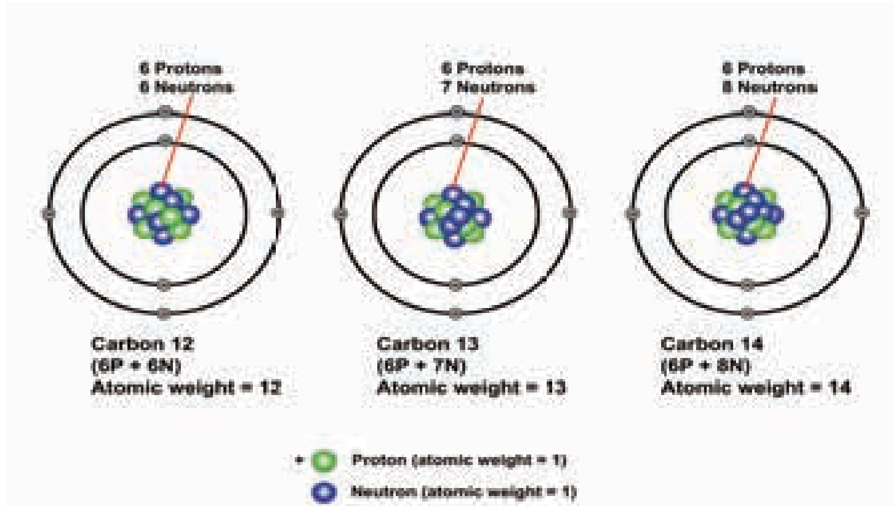
What will they have in common?

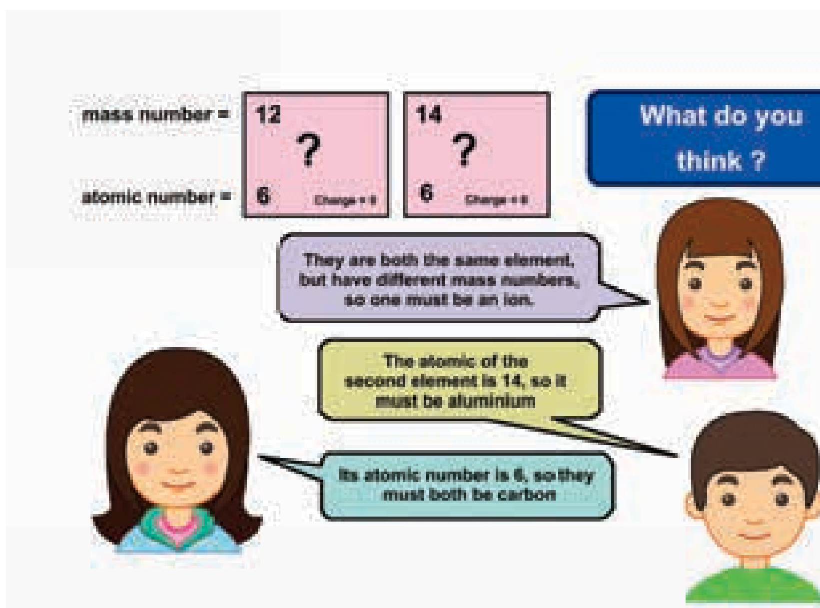
All the three structures have same atomic number but different mass numbers. They have the same number of electrons also. Such atoms of the same element are called isotopes.

Isotopes are atoms of the same element having same atomic number but different mass numbers.

This is due to the difference in the number of neutrons in the nucleus. Isotopes differ in few physical properties such as density, boiling point etc. Physical properties depend upon mass number. Isotopes have different mass numbers. So they differ in physical properties.

DO YOU KNOW? Lightning can trigger nuclear reaction, creating rare atomic isotopes.





Example: Isotopes of carbon

Activity 9

Draw the structures of the isotopes of oxygen O^{16} and O^{18}

Atomic number of oxygen = 8

Why do some isotopes show radioactivity?

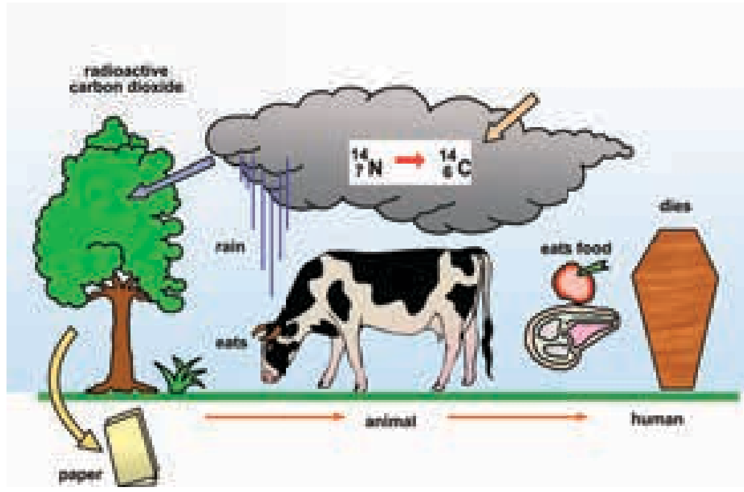
When the number of neutrons exceeds the number of protons in the nucleus of atoms, some nuclei become unstable. These unstable nuclei break up spontaneously emitting certain type of radiations. They are known as radioactive isotopes. Examples: $H^3$and C^{14}

Many elements have isotopes of which some of them are radioactive isotopes.

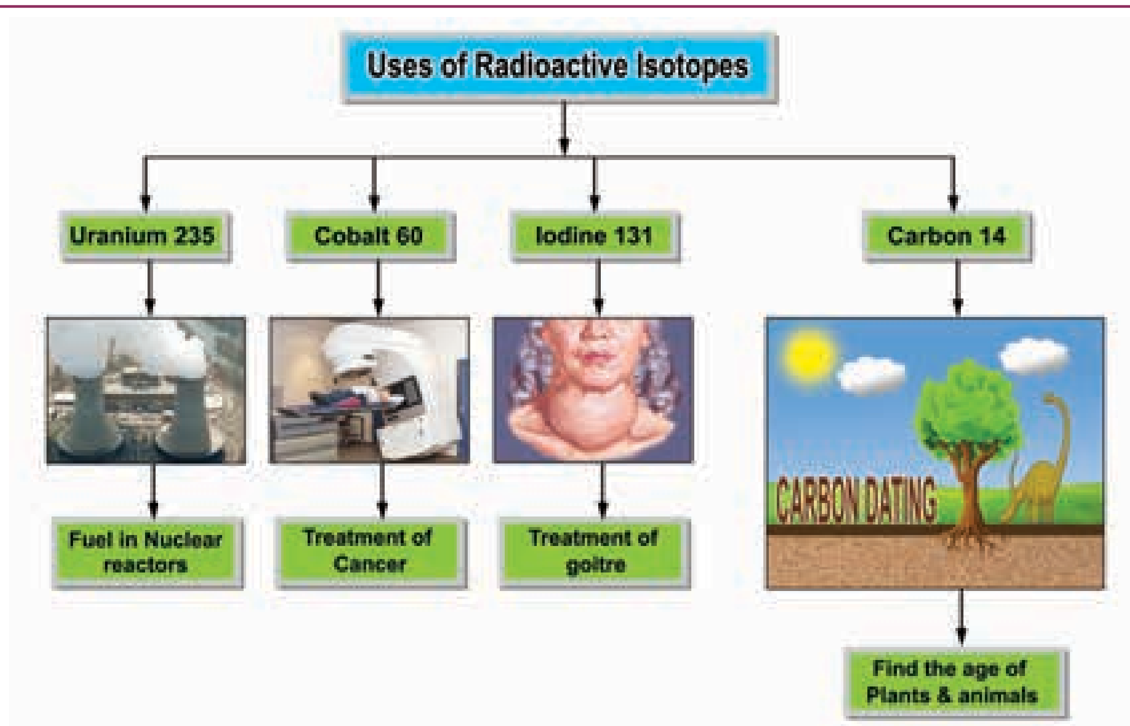
Uses of radioactive isotopes

Radioactivity prevails around us. The food we eat, the air we breathe, the buildings we live in, all contain small amounts of radioactive materials. This radiation will be present always.

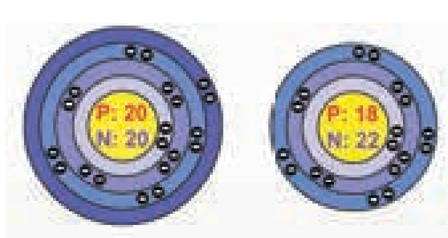
Thus there are a lot of low level natural radioactivity around us. For example, our bodies contain radioisotopes, such as potassium-40, which continuously emit radiation, but the level is so low that this does not harm us.The picture below shows us how radioactive carbon(C^{14}) is all around us.



But the special properties of radioactive isotopes make them useful to us in various fields.



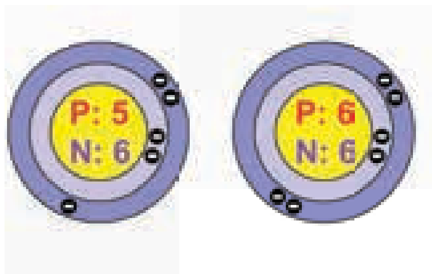
5.5.2 Isobars



What is the difference between these two atoms?

The above two elements calcium and argon have atomic number 20 and atomic number 18 respectively. This means they have different number of protons and electrons. But the mass number of both these elements is 40. It follows that the total number of nucleons in both of them are the same. Atoms of different elements with different atomic numbers, which have the same mass number, are known as isobars.

5.5.3 Isotones



The above pair of elements Boron and Carbon has the same number of neutrons but different number of protons and hence different atomic numbers. Atoms of different elements with different atomic numbers and different mass numbers, but with the same number of neutrons are called isotones.

Activity 10

Draw the model of the following pairs of isotones:

Fluorine & Neon (ii) Sodium & Magnesium (iii) Aluminum and Silicon

How are electrons arranged around the nucleus in an atom?

So far we have been discussing about the nucleus of an atom and the protons and neutrons which constitute the nucleus. We also saw that electrons are extra nuclear particles and they revolve around the nucleus in fixed trajectories or orbits. Let us now see how electrons are arranged in different orbits. The systematic arrangement of electrons in various shells or orbits in an atom is called the electronic configuration.

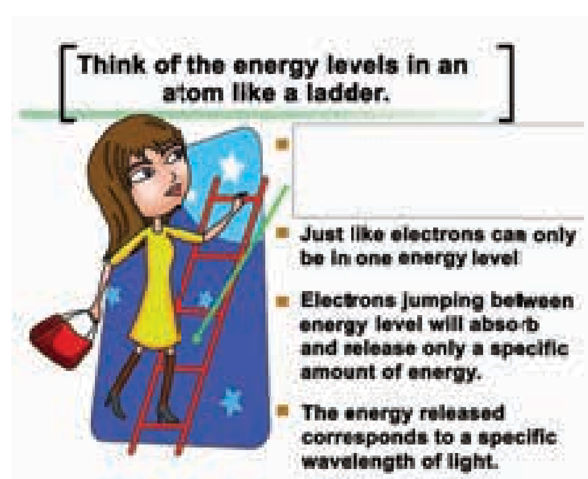
Electronic configuration of atoms:

You already know that electrons occupy different energy levels called orbits or shells.The distribution of electrons in these orbits of an atom is governed by certain rules or conditions. These are known as **Bohr and Bury Rules of electronic configuration.**

Bohr and Bury simultaneously proposed the following rules for the distribution of electrons in different shells.

- **Rule 1:** The maximum number of electrons that can be accommodated in a shell is equal to $2n^2$ where 'n' is the quantum number of the shell (i.e., the serial number of the shell from the nucleus).

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



- **Rule 2:** Shells are filled in a **stepwise manner** in the increasing order of energy.
- **Rule 3:** The outermost shell cannot have more than 8 electrons and the next inner, i.e., the penultimate shell cannot have more than 18 electrons.

Illustration:

Structure of Aluminium atom: (13 electrons)
K shell = 2 electron, L shell = 8, M Shell – 3
So its electronic configuration is 2, 8, 3

DO YOU KNOW?

Atoms are so tiny their mass number cannot be expressed in grams but expressed in amu (atomic mass unit). New unit is U Size of an atom can be measured in nano metre (1nm=10^{-9m})Even though atom is an invisible tiny particle now-a-days atoms can be viewed through SEM that is Scanning Electron Microscope.

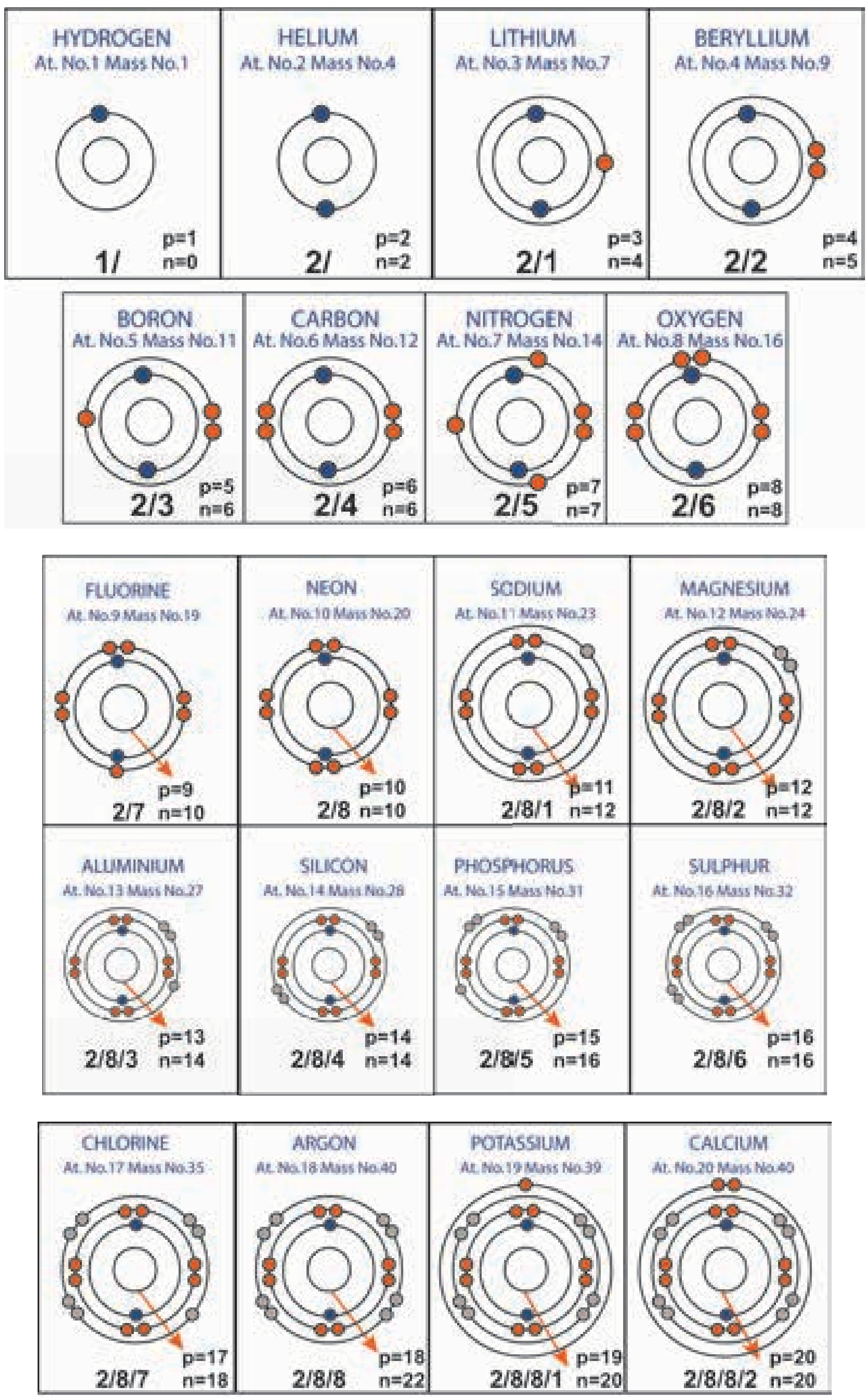
EH95JN

Electronic configuration of first 20 elements

Element	Symbol	Atomic Number	Electronic configuration or Electron distribution			
			K	L	M	N
Hydrogen	H	1	1			
Helium	He	2	2			
Lithium	Li	3	2	1		
Beryllium	Be	4	2	2		
Boron	B	5	2	3		
Carbon	C	6	2	4		
Nitrogen	N	7	2	5		
Fluorine	F	9	2	7		
Neon	Ne	10	2	8		
Sodium	Na	11	2	8	1	
Magnesium	Mg	12	2	8	2	
Aluminium	Al	13	2	8	3	
Silicon	Si	14	2	8	4	
Phosphorus	P	15	2	8	5	
Sulphur	S	16	2	8	6	
Chlorine	Cl	17	2	8	7	
Argon	Ar	18	2	8	8	
Potassium	K	19	2	8	8	1
Calcium	Ca	20	2	8	8	2

For getting a basic idea about the electron distribution around the nucleus we can draw schematic diagrams as shown below. As you learn more about atomic structure you will come to know that the real picture of electron distribution is entirely different from what we have shown here.

Schematic diagrams for Atomic Structure of Elements (first 20)



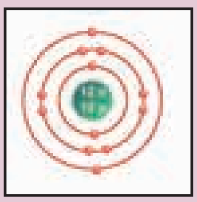
Activity 11

Look at the model given below. Make groups of five. Each group can make models of 4 elements by using available materials like balls, beads, string etc.

Activity 12

Electronic configuration of some elements are given below. Elements follow the sequence of their atomic numbers.

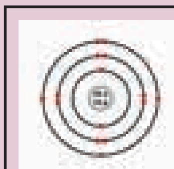
Complete the blank spaces.



?

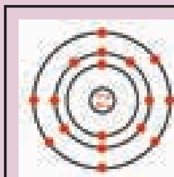
Aluminium

Silicon



?

Sulphur



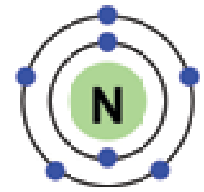
?

Argon

Potassium

5.5.4 Valence electrons

How many electrons are in the outermost shell? 5



The outermost shell of an atom is called its valence shell and the electrons present in the valence shell are known as valence electrons.

Hydrogen atom has only one electron in its valence shell. Hence it has **one** valence electron. Similarly carbon has 4 electrons in the outermost shell and so it has **4 valence electrons.**

The chemical properties of elements are decided by these valence electrons, since they are the ones that take part in chemical reaction.

The elements with same number of electrons in the valence shell show similar properties and those with different number of valence electrons show different chemical properties. Elements, which have valence electrons 1 or 2 or 3 (except Hydrogen) are **metals.**

These elements can lose electrons to form ions which are positively charged and are called **cations**.

Eg: $Na - e^- \rightarrow Na^+$
2, 8, 1 → 2, 8

Elements with 4 to 7 electrons in their valence shells are **non-metals.**

These elements can gain electrons to form ions which are negatively charged and are called **anions**.

Eg: $Cl + e^- \rightarrow Cl^-$ (Chlorine has valence electrons 7)
2, 8, 7 → 2,8,8

5.5.5 Valency

Valency of an element is the combining capacity of the element with other elements and is equal to the number of electrons that take part in a chemical reaction. Valency of the elements having valence electrons 1, 2, 3, 4 is 1, 2, 3, 4 respectively.

While valency of an element with 5, 6 &7 valence electrons is 3, 2 and 1 (8–valence electrons) respectively, where 8 is the number of electrons required by an element to attain stable electronic configuration. Elements having completely filled outermost shell show **Zero valency**.

For example: The electronic configuration of Neon is 2,8 (completely filled). So valency is **0**.

Illustration:

Assign the valency of Magnesium & Sulphur

Electronic configuration of magnesium is 2, 8, 2. So valency is 2.

Electronic configuration of sulphur is 2, 8, 6. So valency is 2 i.e.(8 – 6)

Activity 13

Assign the valency for Phosphorus, Chlorine, Silicon and Argon

Introduction to Quantum Numbers

We have learnt to designate orbits (shells) by K,L,M, N …., and orbitals (sub shells) as s, p, d and f. We have seen that electrons are filled in to these orbitals according to certain rules. Can we now designate an electron in an atom in a manner in which it gets a unique identity? Each electron inside of an atom has its own 'identity' which is given by **four quantum numbers** that communicate a great deal of information about that electron.

The numbers which designate and distinguish various atomic orbitals and electrons present in an atom are called quantum numbers.

How would you describe to someone exactly where you live? I guess you would start with your address. (similar to the identity fo an electron).

When you specify the location of a building, you usually list which country it is in, which state and city it is in that country, then the area and the street and the door number.

Just like no two buildings have the exact same address, no two electrons can have the same set of **quantum numbers**.

A **quantum number** describes a specific aspect of an electron. Just like we have four ways of defining the location of a building (country, state, city, and street address), we have four ways of defining the properties of an electron, i.e.**four quantum numbers.**

These quantum numbers tell us

- how far is the electron from the nucleus,- **(Principal Quantum number)**
- which orbital does it occupy and what is its shape **(Azimuthal Quantum number)**
- how this orbital is oriented in space **(Magnetic Quantum number)**
- what kind of spin the electron has. **(Spin Quantum number)**:

Quantum Number	Symbol	Information conveyed
Principal quantum number	n	Main energy level
Azimuthal quantum number	l	Sub shell/ shape of orbital
Magnetic quantum number	m	Orientation of orbitals
Spin quantum number	s	Spin of the electron

You will learn more details about this in higher classes.

Key words

Atomic number	Isobars	Valency
Mass number	Isotones	Orbit
Nucleons	Electronic configuration	Orbital
Isotopes	Valence electrons	Quantum numbers

Points to Remember

- Rutherford's alpha-particle scattering experiment led to the discovery of the atomic nucleus.
- Rutherford's Planetary model of an atom proposed that nucleus of an atom is in the centre and electrons revolve around this nucleus.
- Neils Bohr's atomic model explained the stability of an atom.
- J.Chadwick discovered presence of neutrons in the nucleus.
- The atomic number of an element is the number of protons or electrons in an atom.
- Mass number of an element is the total number of protons & neutrons.
- Valence electrons are the electrons in the outermost orbit.
- Valency is the combining capacity of an atom.
- Isotopes are atoms of the same element, which have same atomic number but different mass numbers.
- Isobars are the atoms of the different element of same mass number but different atomic number.
- Isotones are the different element having same number of neutron but different atomic number and mass number.
- Simple diagrammatic representation may be used to depict electronic configuration of various elements.
- Quantum numbers designate an electron in an orbital.

A-Z GLOSSARY

1. **Atom** the smallest component of an element, and is also a nucleus with neutrons, protons and electrons.
2. **Atomic mass** the mass of an atom of a chemical element expressed in atomic mass units. It is approximately equivalent to the number of protons and neutrons in the atom (the mass number) or to the average number allowing for the relative abundances of different isotopes.
3. **Atomic number** the number of protons in the nucleus of an atom, which is characteristic of a chemical element and determines its place in the periodic table.
4. **Electron** a stable subatomic particle with a charge of negative electricity, found in all atoms and acting as the primary carrier of electricity in solids.

5. **Isotope** each of two or more forms of the same element that contain equal numbers of protons but different numbers of neutrons in their nuclei, and hence differ in relative atomic mass but not in chemical properties; "some elements have only one stable radioactive isotope".
6. **Isobar** each of two or more isotopes of different elements, with the same atomic weight.
7. **Isotone** one of two or more atoms having an equal number of neutrons but different atomic numbers.
8. **Mass number** the total number of protons and neutrons in a nucleus.
9. **Neutron** a subatomic particle of about the same mass as a proton but without an electric charge, present in all atomic nuclei except those of ordinary hydrogen.
10. **Orbitals** Atomic orbitals are regions of space around the nucleus of an atom where an electron is likely to be found. Atomic orbitals allow atoms to make covalent bonds. The most commonly filled orbitals are s, p, d, and f.
11. **Proton** a stable subatomic particle occurring in all atomic nuclei, with a positive electric charge equal in magnitude to that of an electron.
12. **Quantum number** a number which occurs in the theoretical expression for the value of some quantized property of a subatomic particle, atom, or molecule and can only have certain integral or half-integral values.
13. **Radical** molecule that contains at least one unpaired electron. Most molecules contain even numbers of electrons, and the covalent chemical bonds holding the atoms together within a molecule normally consist of pairs of electrons jointly shared by the atoms.
14. **Valency**: the property of an element that determines the number of other atoms with which an atom of that element can combine.

ICT CORNER

ATOMIC STRUCTURE

Atoms are building blocks. They are made of neutrons, protons and electrons.

This activity help the students to explore more about atoms and its components.

Step 1. Type the following URL in the browser or scan the QR code from your mobile.You can see on the screen. Click that.

Step 2. Select atom. Atomic orbit you can see with multiple options. Select protons, neutrons and electrons to their respective places. According to their numbers name of the elements appear on the periodic table. You can also find out whether the selected element is neutral or charged(ions)

Step 3. click"**symbol**"now. When you arrange electrons, neutrons and protons on the orbits you can see the name of the element, it's atomic number, atomic mass and number of electrons.

Step 4. Third option is games. It's an evaluation one to test your understanding

B121_9_SCI_EM

https://phet.colorado.edu/sims/html/build-an-atom/latest/build-an-atom_en.html

EXERCISE

EHI1LB

I. Multiple Choice Questions

1. Among the following the odd pair is
   a) $^{18}_{8}O$, $^{37}_{17}Cl$ b) $^{40}_{18}Ar$, $^{14}_{7}N$
   c) $^{30}_{14}Si$, $^{31}_{15}P$ d) $^{54}_{24}Cr$, $^{39}_{19}K$
2. Change in the number of neutrons in an atom changes it to
   a) an ion. b) an isotope.
   c) an isobar. d) another element.
3. The term nucleons refer to
   a) Protons and electrons
   b) only Neutrons
   c) electrons and neutrons
   d) Protons and neutrons
4. The number of protons, neutrons and electrons present respectively in $^{80}_{35}Br$
   a) 80, 80, 35 b) 35, 55,80
   c) 35, 35, 80 d) 35, 45, 35
5. The correct electronic configuration of potassium is
   a) 2,8,9 b) 2,8,1
   c) 2,8,8,1 d) 2,8,8,3

II. True or false/if false give the correct answer

1. In an atom, electrons revolve around the nucleus in fixed orbits
2. Isotopes of an element have the different atomic numbers
3. Electrons have negligible mass and charge.
4. Smaller the size of the orbit, lower is the energy of the orbit.
5. The maximum number of electron in L Shell is 10

III. Fill in the Blanks:-

1. Calcium and Argon are examples of a pair of __________________
2. Total Number of electrons that can be accommodated in an orbit is given by _______________
3. ______________ isotope is used in the treatment of goiter
4. The number of neutrons present in $^{7}_{3}Li$ is ____________
5. The valency of Argon is ____________

IV. Match the following

i)

a) Dalton	1. Hydrogen atom model
b) Thomson	2. Planetary model
c) Rutherford	3. First atomic theory
d) Neils Bohr	4. Plum pudding model
	5. Discovery of neutrons

ii)

a) Mass of proton	1) 1.6 X 10^{-19} C
b) Mass of electron	2) -1.6 X 10^{-19} C
c) Charge of electron	3) 9.31 X 10^{-28} g
d) Charge of proton	4) 1.67 X 10^{-24} g

V. Complete the following table

Atomic Number	Mass Number	Number of Neutrons	Number of Protons	Number of Electrons	Name of the Element
9	-	10	-	-	-
16	-	16	-	-	-
-	24	-	-	12	Magnesium
-	2	-	1	-	-
-	1	0	1	1	-

VI. Arrange the following in the increasing order of atomic number

Calcium, Silicon, Boron, Magnesium, Oxygen, Helium, Neon, Sulphur, Fluorine and Sodium

VII. (a) Cross word puzzle

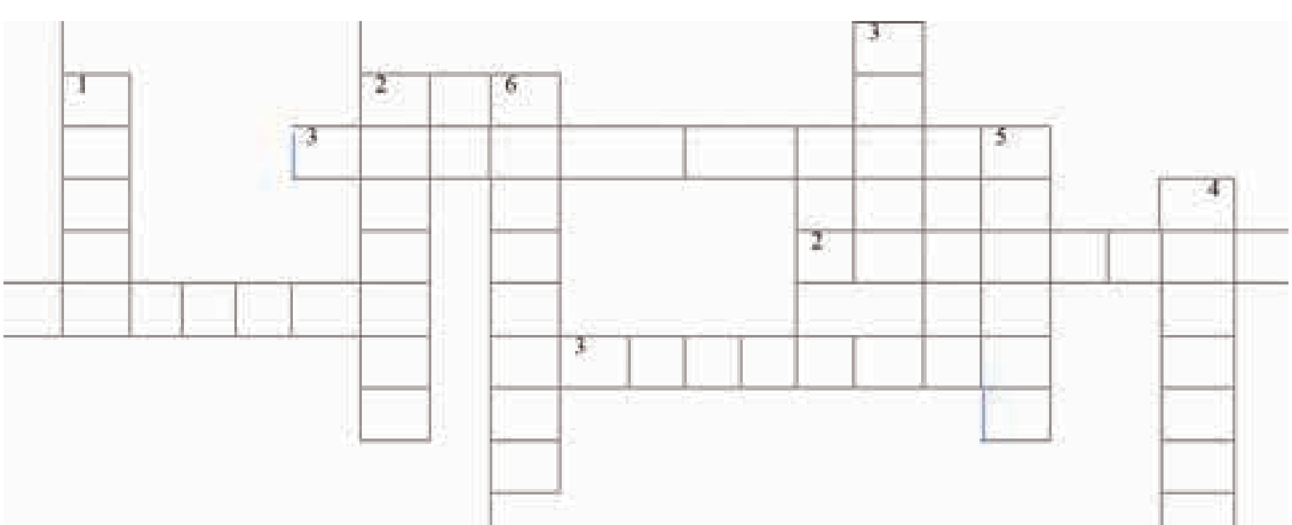
Clues:

Down:

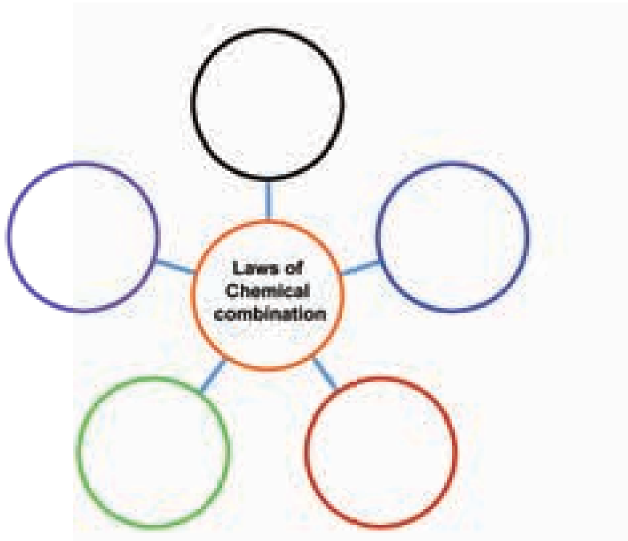
1. Helium Nuclei (Particle)
2. Positive Charge mass at the core of the atom
3. An atom whose valency is zero
4. One or two electrons in the outermost shell of atoms of elements are called as _______________ electrons.
5. $^{14}_{6}C$ is used for carbon dating
6. Discovery of neutron

Across:

1. Electrons present in the outermost shell
2. This pair of atoms $^{40}_{20}Ca$, $^{40}_{18}Ar$ are ____
3. An atom that does not have neutron
4. Scattering of α particles in the gold foil experiment



b) Copy the following and write the names of the laws and their simple definitions in the space provided.



VIII. Very short answer

1. Name an element which has the same number of electrons in its first and second shell.
2. Write the electronic configuration of K^+ and Cl^-
3. Compare the charge and mass of protons and electrons.
4. For an atom 'X', K, L and M shells are completely filled. How many electrons will be present in it?
5. Ca^{2+} has completely filled outer shell. Justify your answer.

IX. Short answer

1. State the law of multiple proportion.
2. List the uses of isotopes?
3. What is isotone? Give an example
4. Draw the structure of oxygen and sulphur atoms.
5. Calculate the number of neutrons, protons and electrons (i) atomic number 3 and mass number 7 (ii)atomic number 92 and mass number238

X. Numerical problem

1. Calculate the volume of oxygen required for the complete combustion of 20 cm^3 of methane[$CH_{4(g)}$ $+2O_2 \rightarrow$ $CO_{2(g)}$ $+2H_2O_{(g)}$]
2. A metal combines with oxygen to form two oxides having the following composition

   i) 0.398 gram of metal oxide I contains 0.318 gram of metal

   ii) 0.716 gram of metal oxide II contains 0.636 gram of metal. So that the above data agrees with the law of multiple proportions.
3. Calculate the mass of a proton, given its charge = $+ 1.60 \times 10^{-19}$ C

   charge / mass = 9.58×10^7 C kg^{-1}

XI. Long answer

1. What conclusions were made from the observations of Gold foil experiment?
2. Explain the postulates of Bohr's atomic model.

3. State the Gay Lussac's law of combining volumes, explain with an illustration.

XII. Get connected

Health

1. Discuss the uses of radio-active isotopes in Medicine.

Art

1. Make the model of different atoms by using the materials like card boards, colour beads and strings.
2. Draw the time line of history of atomic model

Language

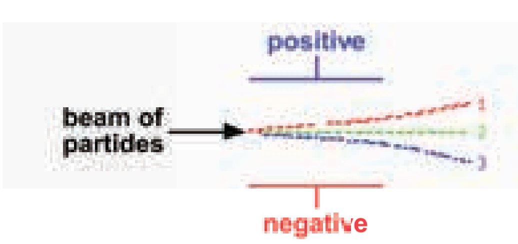
1.Write (in about 200 words) about Homi J Bhabha who was the father of **Indian Nuclear programme**

XIII. Get Together and Do

1. Prepare a science magazine including photos, profiles and contribution of philosophers and scientists related to the history of atom
2. Prepare a display board chart illustrating the electronic configuration and valency of elements with atomic number 1 – 20.

XIV. Unlock

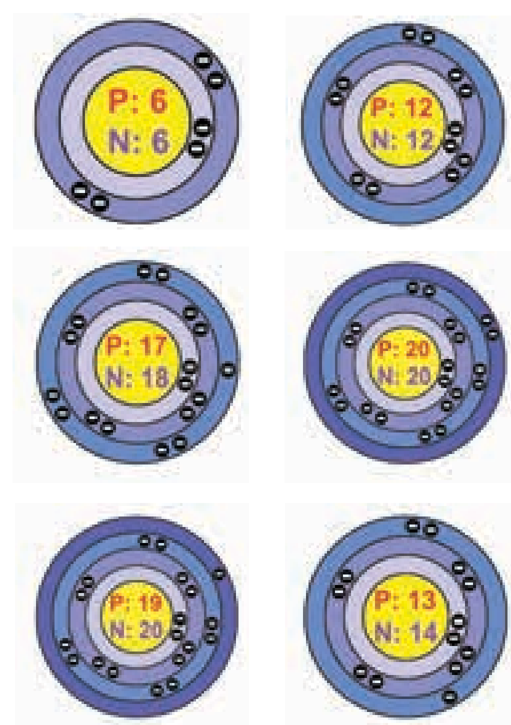
1.



The particles represented above are

	1	2	3
a.	electrons	protons	neutrons.
b.	protons	electrons	neutrons
c.	neutrons.	protons	electrons
d.	electrons	neutrons.	protons

2. From the structures given below, Tabulate the following:
   1. Valence electron
   2. Valency
   3. Atomic Number
   4. Mass number
   5. Electronic configuration



3. The correct numbers of protons and neutrons present in $^{23}_{11}Na^{+}$ are

	protons	neutrons
a.	11	23
b.	10	12
c.	11	12
d.	11	22

REFERENCE

1. Atomic Structure Rebecca L. Johnson Twenty-First Century Books ISBN-13: 978-0-8225-6602-1.
2. Atomic structure and Periodicity Jack Barrett. Royal Society of Chemistry. ISBN 0-85404-657-7.
3. Chemistry for Degree Students (B.Sc. Sem.-I, As per CBCS) R L Madan ISBN: 9789352533039. S. Chand Publishing

INTERNET RESOURCES

Electronic configuration

https://www.youtube.com/watch?v=t4xgvlNFQ3c

https://www.youtube.com/watch?v=P6DMEgE8CK8

https://www.youtube.com/watch?v=YURReI6OJsg