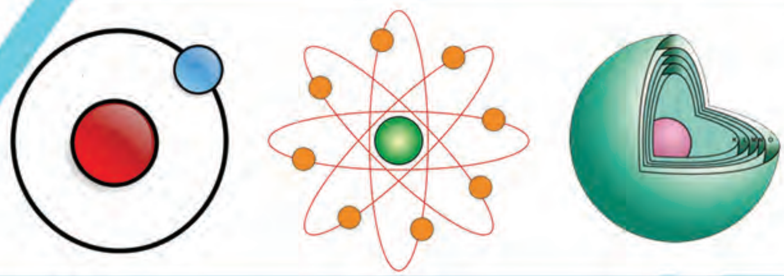
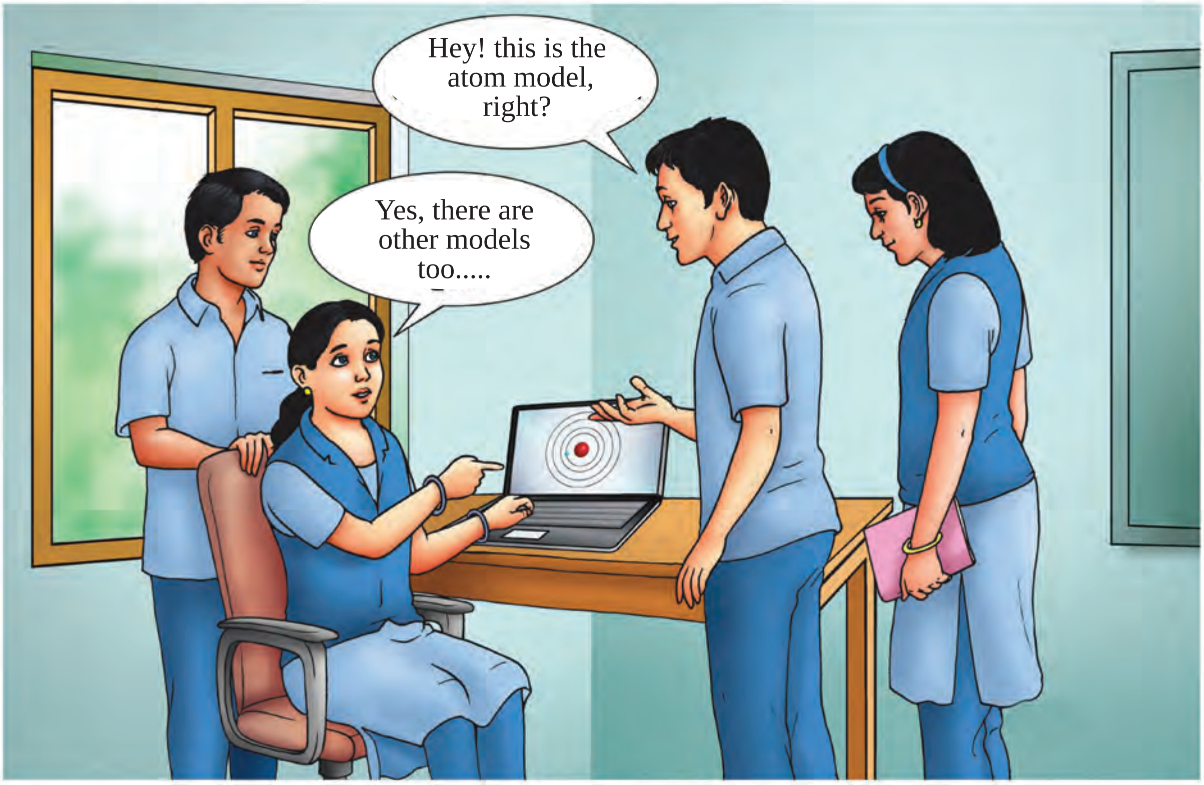


1 Structure of Atom



Look at the picture. Here the students are discussing the structure of atoms. Can you identify the atoms in the substances that are familiar to you?

Analyse Table 1.1

Substance	Constituent elements	Chemical formula of the molecule	Ratio of number of atoms
Sugar	Carbon, Hydrogen, Oxygen	$C_{12}H_{22}O_{11}$	12:22:11
Glucose	Carbon, Hydrogen, Oxygen	$C_6H_{12}O_6$	1:2:1
Water	Hydrogen, Oxygen	H_2O	2:1

Table 1.1

You have seen that the molecules of each substance contain atoms combined in a particular ratio. Molecules are particles which show all the properties of the substance and have a free existence.

How do molecules of different substances differ?

- The constituent elements of the molecules.
- The ratio of the number of constituent atoms in them.

You have understood that the molecules are formed by atoms.

You have learnt that atoms contain particles smaller than them. What are the important particles in an atom?

- Electron
- ....
- ....

These are known as subatomic particles. Let us learn more about these particles in this unit.

William Crookes
1832 - 1919

Discharge Tube Experiments and Discovery of Electrons

In 1875 William Crookes, the physicist conducted experiments by passing electricity at high voltage through a glass tube in which both sides are fixed with metal plates as electrodes (Figure 1.1).

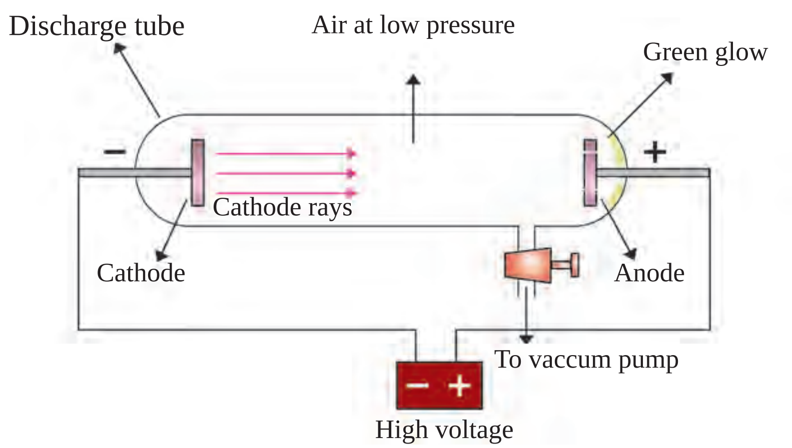


Fig. 1.1

As air is an insulator, electricity does not pass through the air in the tube at normal pressure. But, when the tube was evacuated gradually, it was seen that electricity passed through it (electric discharge). When a perforated positive electrode (anode) was used, a light green glow was observed on the zinc sulphide coated glass wall behind it. The glow is due to the rays emitted from the cathode. These rays came to be known as cathode rays. Scientists conducted more experiments on cathode rays and identified their various characteristics.

Discovery of Cathode Rays

In the first half of the 19th century itself, it was found that gases conduct electricity at low pressure. Michael Faraday studied the changes that occur when electricity passes through gases at low pressure. But the studies became very complicated due to the lack of efficient suction pumps and the difficulty in arranging the evacuated glass tubes. In 1854, Henrich Giesler developed discharge tubes and suction pumps. When modified Giesler tubes became available, Julius Plucker conducted various experiments using them. He found out that when electricity passes through the tube, a glow is formed on the opposite side of the cathode and the position of this glow can be changed in the presence of a magnet.

Later, the scientists Johan Williams Hittorff (1869) and Eugen Goldstein (1876) continued these experiments. They discovered that some rays originating from the cathode were responsible for this glow.

Main characteristics of cathode rays

- Cathode rays cast shadows of opaque objects placed in its path indicating that cathode rays travel in straight lines (Figure 1.2).

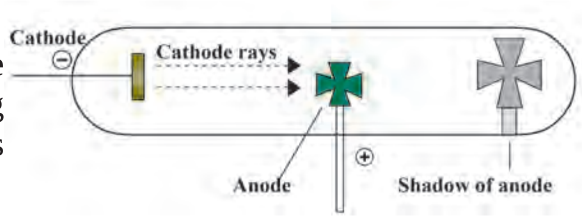


Fig. 1.2

- If a small paddle wheel is placed in the path of the cathode rays, it rotates. Thus we can understand that particles in the cathode rays have mass (Figure 1.3).

Fig. 1.3

- When an electric field is applied on both sides of the rays, they are found to be attracted towards the positive side.

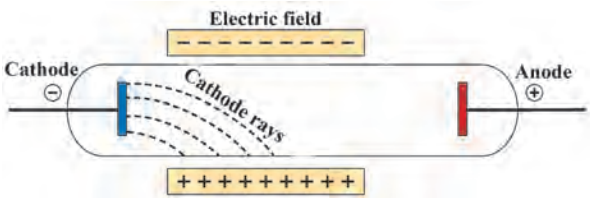


Fig. 1.4

From this we can infer that cathode rays have negative charge (Figure 1.4).

- The path of the cathode rays gets deflected in the magnetic field also.

J. J. Thomson
1856 - 1940

The properties of the cathode rays do not change on changing the gas inside the tube or the metals with which the electrodes are made. This indicates that the particles in the cathode rays are present in all substances. These particles are electrons.

The ratio of electrical charge to mass of an electron (e/m ratio) was determined by J. J. Thomson. When scientists accepted the studies done by Thomson on cathode rays, it was proved that there were particles smaller than atoms. In 1906, he received the Nobel prize in physics for the discharge tube experiments and the discoveries that followed.

The mass of electron

The e/m ratio of an electron is 1.76×10^{11}C/kg. But J. J. Thomson was unable to find out the charge and mass separately. Later, Robert Millikan, through his famous oil drop experiment, found out that electron has 1.6×10^{-19}C negative charge and from this, he calculated the mass of electron as 9.1×10^{-31}kg. (C = coulomb)

?

- How was it proved that electrons have mass?
- Cathode rays, cast shadows of opaque objects placed in their path. What can be inferred from this?

Proton

Eugen Goldstein
1850 - 1930

In 1886 Eugen Goldstein, the German scientist conducted discharge tube experiments with perforated cathode and he discovered rays known as canal rays. As they originated from the metal placed at the positive side (anode), they were known as Anode rays. He studied the characteristics of these rays and identified the presence of positive charge in them. The behaviour of these canal rays varied with the nature of gases taken in the discharge tubes. The smallest and lightest positive particles in the canal rays were obtained when the discharge tube was filled with hydrogen. It was Earnest Rutherford who discovered that this was a subatomic particle and named it proton.

Plum Pudding Model of the Atom

J. J. Thomson proposed his plum pudding model when the presence of negative particles were identified in atoms (Figure 1.5). According to this model, negatively charged electrons are embedded in a positively charged sphere. The total number of positive charges and negative charges in the sphere will be equal. So, an atom is electrically neutral. But Thomson model failed to explain the results of several experiments. Hence this model was rejected.

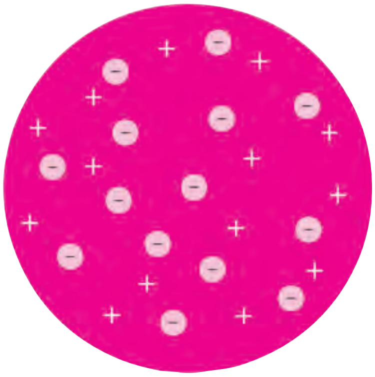


Fig. 1.5
Plum pudding model

Radioactivity

Radioactivity is a phenomenon in which certain elements like uranium and thorium emit radiations on their own. It was discovered by Henry Bequerel in 1896. Mainly three types of radiations are emitted as a result of radioactivity. They are alpha (α) rays with positive charge and mass, beta (β) rays with negative charge and gamma (γ) rays with no charge and no mass.

Rutherford's Gold Foil Experiment

Earnest Rutherford
1871 - 1937

In 1911, under the leadership of Earnest Rutherford, Hans Geiger and Earnest Marsden conducted experiments by bombarding alpha rays on a very thin gold foil. These experiments helped in bringing more clarity about the structure of atom. Rutherford bombarded a very thin gold foil with the alpha rays which originated from radioactive substances and tried to find out the deflections that occurred in their path. The alpha particles which passed through the gold foil were made to strike on the photographic film arranged around it. He made the following observations (Figure 1.6).

- Most of the alpha particles passed through the gold foil undeflected.
- Some of the alpha particles deflected by a small angle from the straight line when they hit the gold foil.
- A very few alpha particles (approximately 1 in 20000) bounced back. i.e., deflected by 180°.

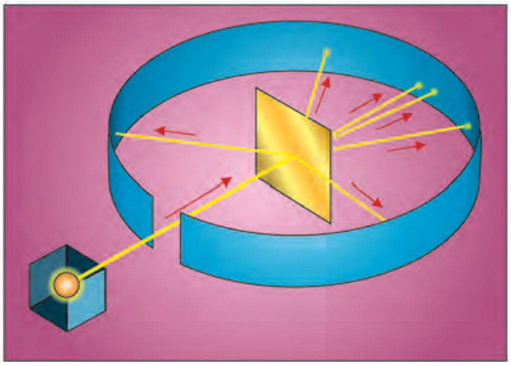


Fig. 1.6
Gold foil experiment diagram

He arrived at the following assumptions from these observations.

- Majority of the alpha particles passed through the foil undeflected since most part of the atom was empty.
- Some of the alpha particles got deflected by a small angle due to the repulsion caused when they passed by the positively charged region inside the atom.
- The entire positive charge of an atom is concentrated in a very small volume at the centre of the atom. This centre is extremely small when compared to the size of the atom. The alpha particles which bounced back were those that were directed to this centre. He called this centre nucleus.

Rutherford atom model can be briefed as follows:

- Atom has a centre called nucleus.
- The size of the nucleus is extremely small when compared to the size of the atom.
- The entire positive charge and most of the mass of the atom are concentrated in the nucleus.
- Electrons revolve very fast around the nucleus in circular paths or orbits.

This model is known as the planetary model of an atom.

Limitations of Rutherford's atom model

According to the electromagnetic theory, a charged body in motion should continuously emit energy. Hence, negatively charged electrons revolving around the nucleus should continuously lose energy and collapse into the nucleus. But this does not happen. Therefore Rutherford atom model failed to explain the stability of an atom.

Neutron

James Chadwick
1891 - 1974

The real mass of the nucleus was found to be very much greater than that calculated by Rutherford on the basis of the number of protons. But he failed to prove this discrepancy through experiments. Later, in 1932, James Chadwick found out that there are some neutral particles in the nucleus and that they have mass approximately equal to that of a hydrogen atom. He named them neutrons since they were chargeless.

Niels Bohr Atom Model

Niels Bohr
1885 - 1962

To overcome the limitations of Rutherford atom model, the Danish scientist Niels Bohr proposed his atom model in 1913.

The main concepts of Bohr Atom model:

- Electrons revolve around the nucleus of an atom in fixed orbits.
- Electrons in each orbit have a definite energy. So orbits are also known as energy levels.
- As long as the electrons revolve in a particular orbit their energy does not change. So, the orbits are known as stationary energy levels.
- The energy of the orbit increases as the distance from the nucleus increases.
- Energy is emitted when the electrons shift from orbits of higher energy to orbits of lower energy. Energy is absorbed when the electrons shift from orbits of lower energy to orbits of higher energy.
- Orbits can be represented by giving numbers 1, 2, 3, 4, 5.... etc.

In the studies that followed, orbits were also called shells.

The energy levels 1, 2, 3, 4...... etc., can be considered as shells K, L, M, N... etc., respectively (Figure 1.7).

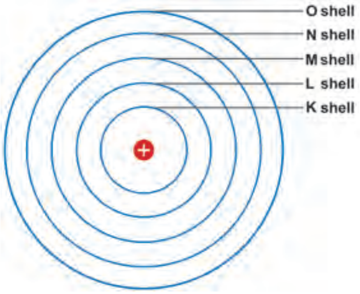


Fig. 1.7
Energy level

Some properties of the subatomic particles like electron, proton and neutron are given in Table 1.2. Complete the following table and record it in your science diary.

Name of particle	Position in atom	Charge	Mass	Mass in practical use
Proton	....	....	1.00727 u	1 u
Electron	....	....	0.000548 u	0
....	Nucleus	....	1.00866 u	1 u

Mass of the atoms is stated in unified atomic mass unit (u).

Table 1.2

- The mass of an electron is $\frac{1}{1837}$ part of the mass of a proton.

You are now familiar with different models of the atom. These models have helped to simplify many concepts in chemistry. Later, scientists proposed many more atom models. We can learn more about these models in higher classes.

- Some statements are given. Which of them are related to J. J. Thomson?

  a) Proposed the idea of the orbit.
  b) Conducted discharge tube experiments.
  c) Discovered neutron.
  d) Discovered electron.
  e) Proposed the plum pudding model.

- Prepare a questionnaire about the scientists who conducted research on atomic structure and their contributions. Conduct a quiz programme in your classroom based on this.

Atomic Number and Mass Number

The number of protons is very important in the case of an atom. It is the number of protons in an atom that determines the element to which the atom belongs. The total number of protons in an atom is known as its atomic number. This is represented using the letter Z.

Atomic number = number of protons
= number of electrons

- What are the particles in the nucleus of an atom?

....

The total number of protons and neutrons in an atom is known as its mass number. This is represented using the letter A.

- What is the mass number of an atom having 2 protons and 2 neutrons?

....

Mass number = number of protons + number of neutrons
= atomic number + number of neutrons

Number of neutrons = mass number - number of protons
= mass number - atomic number = (A-Z)

Elementary Particles

You know that an atom can be divided and that it contains the particles electron, proton and neutron. Can these be divided again? As an electron cannot be divided further, it is an elementary particle. But, protons and neutrons are formed by the combination of three quarks each. Hence, they are not considered elementary particles.

When we represent an atom using its symbol, we write mass number and atomic number on the top left and the bottom left respectively.

e.g. $^{35}_{17}Cl$, $^{40}_{20}Ca$

- Find the number of protons, electrons and neutrons in chlorine and calcium atoms.

$^{35}_{17}Cl$
Proton : ....
Electron : ....
Neutron : ....

$^{40}_{20}Ca$
Proton : ....
Electron : ....
Neutron : ....

- Complete the table given below and record it in your science diary.

Symbol	Atomic number	Mass number	Number of protons	Number of electrons	Number of neutrons
$^{1}_{1}H$					
$^{7}_{3}Li$					
$^{16}_{8}O$					
$^{23}_{11}Na$					
$^{20}_{10}Ne$					
$^{48}_{22}Ti$					
$^{235}_{92}U$					
$^{232}_{90}Th$					
$^{65}_{30}Zn$					

Electron Configuration in an Atom

- According to the Bohr atom model, where is the electron situated in an atom?

....

- What are the symbols given to the energy levels 1, 2, 3 and 4?

....

The arrangement of electrons in an atom is done in accordance with certain laws.

1. The maximum number of electrons that can be accommodated in any orbit is $2n^2$ (n=orbit number).

Orbit number (n)	Name	Maximum number of electrons that can be accommodated ($2n^2$)
1	K	$2\times 1^2 = 2$
2	L	$2\times 2^2 = 8$
3	M	....
4	N	....

Table 1.3

2. Normally, filling up of electrons in higher energy orbits will take place only after the lower energy orbits are filled.
3. The maximum number of electrons that can be accommodated in the outermost orbit of an atom is 8.

Electron configuration is the representation of the filling of electrons in the orbits.

Let us write the electron configuration of some elements. Complete Table 1.4 and record it in your science diary.

Element	Atomic number	Number of electrons	Electron configuration		
			K	L	M
H	1		1		
He	2		2		
Li	3		2	1	
Be	4				
B	5				
C	6				
N		7			
O	8				
F		9			
Ne	10				
Na		11			
Mg	12				
Al	13		2	8	3
Si		14			
P		15			
S		16			
Cl		17			
Ar	18		2	8	8

Table 1.4

Only the electron configuration of elements from atomic number 1 to 18 can be written accurately in this way. Writing electron configuration of elements with atomic number greater than 18 can be learned in higher classes.

Orbit Electron Configuration-Diagrammatic Representation

See the orbit electron configuration of hydrogen given below (Figure 1.8).

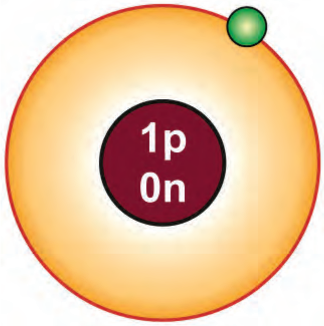


Fig. 1.8

The number of electrons in hydrogen atom = 1

See the orbit electron configuration of boron, having atomic number 5 and mass number 11 given below (Figure 1.9).

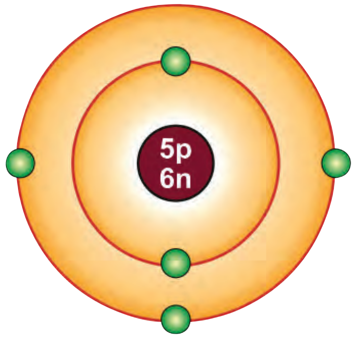
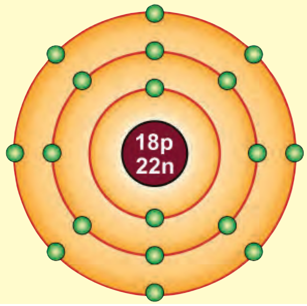


Fig. 1.9

- Diagrammatically represent the orbit electron configuration of ${}^{27}_{13}Al$.
- The orbit electron configuration of an atom is given.



Analyse the figure and find the following.

Atomic number.........................Mass number..........

Number of protons...................Number of neutrons...................

Electron configuration.................

- Write the electron configuration of elements from atomic number 1 to 18 and represent their shell electron configuration in the science diary.

Isotopes

The number of which subatomic particle determines an element? (proton/neutron)

See Figure 1.10 given below.

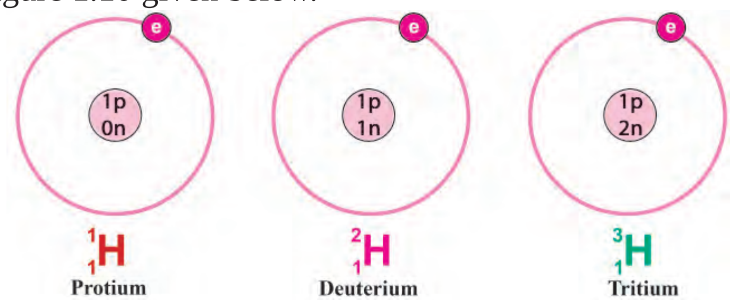


Fig. 1.10

Complete Table 1.5 regarding these atoms.

Name of atom	Proton	Neutron	Electron	Atomic number	Mass number
Protium	1	....	....	....	....
Deuterium	....	1	....	....	....
Tritium	....	....	1	....	....

Table 1.5

- What is the atomic number of these atoms?

  ....

- Which is the element having atomic number 1?

  ....

Then, all these three are hydrogen atoms.

- In the number of which particle do these atoms differ?

  ....

- Are the mass numbers of these atoms same?

  ....

- Which of them has no neutron in the nucleus?

  ....

- These are the isotopes of hydrogen. Can you define an isotope?

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

Isotopes exhibit the same chemical properties. But they show slight variations in physical properties.

Heavy water is the oxide of deuterium, an isotope of hydrogen. Heavy water is used in nuclear reactors.

Let us see whether hydrogen alone has isotopes. See the Figure 1.11 given below.

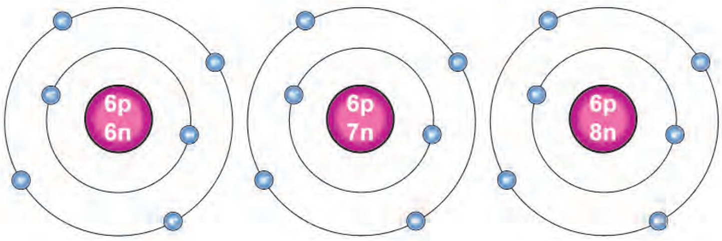


Fig. 1.11

..... Proton	..... Proton	..... Proton
..... Electron	..... Electron	..... Electron
..... Neutron	..... Neutron	..... Neutron

^{12}C, ^{13}C and ^{14}C are the natural isotopes of carbon. The most stable and the most abundant isotope of carbon is ^{12}C. Now, you have understood that carbon also has isotopes.

The amount of ^{13}C among the isotopes of carbon is approximately 1.1 %. This isotope is used to study the metabolic processes in plants and animals. ^{14}C is a radioactive isotope. This is used to determine the age of fossils. You have noticed that only the isotopes of hydrogen have specific names.

Some other isotopes and their uses are given in Table 1.6.

Isotope	Uses
Iodine-131	To study the functioning of Thyroid gland and in its treatment
Uranium-235	Fuel in nuclear reactors
Cobalt-60	Cancer treatment
Sodium -24	To detect the leakage in industrial pipelines
Iron-59	To diagnose Anaemia

Table 1.6

Isobars

Orbit electron configuration of argon (Ar), potassium (K) and calcium (Ca) is given below (Figure 1.12).

Analyse the figure and complete Table 1.7. Record it in your science diary.

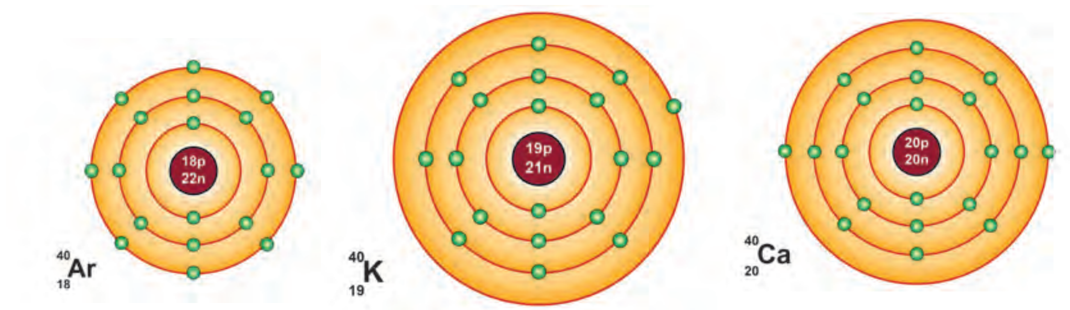


Fig. 1.12

Element	Proton	Electron	Neutron	Atomic number	Mass number
Ar	18				
K		19			
Ca			20		

Table 1.7

- What is the peculiarity of the mass numbers of these elements?

  ....

- Are the atomic numbers the same?

  ....

These atoms are known as isobars.

Isobars are atoms having the same mass number and different atomic numbers.

They are atoms of different elements in which the number of nucleons (proton + neutron) are equal.

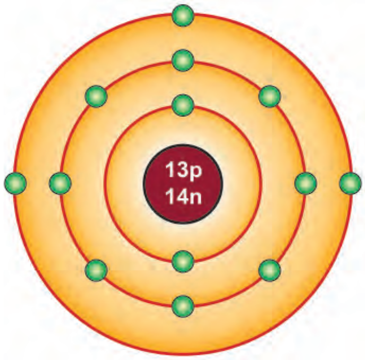
Isotones

Atoms in which the number of neutrons is equal are known as isotones

e.g. $^{15}_{7}N$, $^{14}_{6}C$

Let's Assess

1. Some observations related to experiments on cathode rays are given. Write the inference based on each observation.
    a. A paddle wheel placed in the path of cathode rays rotates.
    b. A shadow is formed if an object is placed in the path of cathode rays.
    c. When an electric field is applied perpendicular to the path of cathode rays, the rays deflect towards the positive plate.
2. The atomic number of an atom is 16 and mass number is 32.
    a. How many electrons, protons and neutrons are present in this atom?
    b. Write the electron configuration of this atom.
    c. Draw the orbit electron configuration of this atom.
3. Electrons are present in the K, L and M shells of an atom.
    a. Which of these shells has the highest energy?
    b. If M shell contains only 3 electrons, write the atomic number of this atom.
    c. What is the number of electrons in this atom?
    d. If the nucleus of this atom contains 16 neutrons, what is its mass number?
4. The orbit electron configuration of an atom is given below.



    a. What is the mass number of this atom?
    b. Write its electron configuration.
5. The symbols of some elements are given.

$$^{24}_{12}Mg, \quad ^{12}_{6}C, \quad ^{15}_{7}N, \quad ^{14}_{6}C, \quad ^{24}_{11}Na$$

a. Select a pair of isotopes from the given elements. Write the reason for selecting it.

b. Select a pair of isobars from the given elements.

6. Match the items in column A & B suitably.

A	B
Plum pudding model	James Chadwick
Planetary model of atom	Goldstein
Canal rays	J. J. Thomson
Neutron	Rutherford

7. The atomic number and mass number of an element are 15 and 31 respectively.
   a. What is the number of valence electrons in this atom?
   b. How many neutrons are present in this atom?
   c. Draw the orbit electron configuration of this atom.

8. Isotope of an element is used to determine the age of fossils.
   a. Which is this isotope?
   b. Which are the other two main isotopes of this element?
   c. Write the number of neutrons in each isotope.

Extended Activities

1. Prepare a presentation on scientists connected to the history of atom and their contributions and present it in the classroom.

2. Prepare a timeline chart on the main events that led to the discovery of different subatomic particles.

3. You have learned about isotopes. Find more examples for radio isotopes. Prepare an article on the uses of each radio isotope and publish it in the science magazine. Use word processor for this work.

4. If you get a chance to conduct an interview with Rutherford, what questions would you ask him? Prepare a questionnaire.