2

STRUCTURE OF ATOMS

This is a 14 days lesson

After completing this lesson, you will be able to:

- Describe the contribution the Rutherford Atomic Theory in the structure of the atoms.
- Explain how Bohr's Atomic Theory differed from Rutherford's Atomic theory.
- Compare isotopes of an element.
- Describe the structure of an atom including the location of the proton, electron and neutron.
- Describe the contribution that Rutherford made to the development of the atomic theory
- Describe the presence of sub shells in a shell.
- Define isotopes.
- Distinguish between shells and sub shells.
- Discuss the properties of the isotopes of H, C, Cl, U.
- Draw the structures of different isotopes from mass number and atomic number.
- State the importance and uses of isotopes in various fields of life.
- Write the electronic configuration of the first 18 elements in the Periodic Table.

Pre- Reading

The structure of atom tells how the sub-atomic particles are arranged. Atoms are so small that they can only be visualized with a scanning tunneling microscope. See figure 2.1 that shows an image of gold atoms on the surface. In grade VII you have learned about the structure of atom and sub-atomic particles, electrons, protons and neutrons. In this chapter you will learn about the arrangement of these particles in an atom. Atomic structure was formulated from a series of experiments during the later part of nineteenth century and the beginning of the twentieth century. We will discuss contributions of British physicist Rutherford and Danish physicist Neil Bohr for determining the structure of an atom. Bohrs's structure of an atom nicely explains the arrangement of elements in the periodic table and periodicity of properties. How? To understand this you should know the structure of atoms.

Reading

2.1 THEORIES AND EXPERIMENTS RELATED TO ATOMIC STRUCTURE

In grade VII you have learned about the structure of atom and sub-atomic particles. You have also learned the distribution of electrons in shells (KLM only) using $2n^2$ formula. In this section you will learn about theories and experiments related to atomic structure.

2.1.1 Rutherford's Atomic Model

In 1911 Rutherford performed an experiment in order to know the arrangement of electrons and protons in atoms.

2.1.1.1 Rutherford's Experiment

Rutherford bombarded a very thin gold foil about 0.00004cm thickness with α-particles. (figure 2.1). He used α-particles obtained from the disintegration of polonium. α-particles are helium nuclei that are doubly positively charged (He^{++}). Most of these particles passed straight through the foil. Only few particles were slightly deflected. But one in 1 million was deflected through an angle greater than 90^o from their straight paths. Rutherford performed a series of experiments using thin foils of other elements. He observed similar results from these experiments.

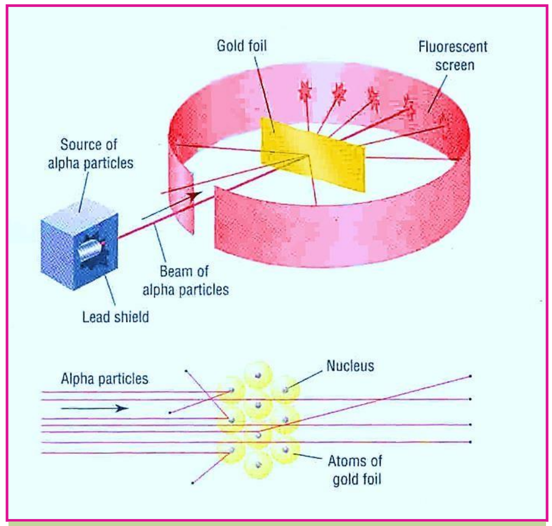

Figure 2.1 Rutherford's Experiment

Rutherford drew the following conclusions:

1. Since majority of the α-particles passed through the foil undeflected, most of the space occupied by an atom must be empty.
2. The deflection of a few α-particles through angles greater than 90^o shows that these particles are deflected by electrostatic repulsion between the positively charged α-particles and the positively charged part of atom.
3. Massive α-particles are not deflected by electrons.

On the basis of conclusions drawn from these experiments, Rutherford proposed a new model for an atom. He proposed a planetary model (similar to the solar system) for an atom. An atom is a neutral particle. The mass of an atom is concentrated in a very small dense positively charged region. He named this region as nucleus. The electrons are revolving around the nucleus in circles. These circles are called orbits. The centripetal force due to the revolution of electrons balances the electrostatic force of attraction between the nucleus and the electrons.

2.1.1.2 Defects in Rutherford's Atomic Model

Rutherford's model of an atom resembles our solar system. It has following defects:

1. Classical physics suggests that electron being charged particle will emit energy continuously while revolving around the nucleus. Thus the orbit of the revolving electron becomes smaller and smaller until it would fall into the nucleus. This would collapse the atomic structure.
2. If revolving electron emits energy continuously it should form a continuous spectrum for an atom but a line spectrum is obtained.

Teacher's Point

Tube light is a discharge tube

Bohr formulated new explanation and a new theory to remove defects from the Rutherford's atomic model.

2.1.2 Bohr's Atomic Theory

In1913 Neil Bohr, proposed a model for an atom that was consistent with Rutherford's model. But it also explains the observed line spectrum of the hydrogen atom. Main postulates of Bohr's atomic theory are as follows:

1. The electron in an atom revolves around the nucleus in one of the circular orbits. Each orbit has a fixed energy. So each orbit is also called energy level.
2. The energy of the electron in an orbit is proportional to its distance from the nucleus. The farther the electron is from the nucleus, the more energy it has.
3. The electron revolves only in those orbits for which the angular momentum of the electron is an integral multiple of $\frac{h}{2\pi}$ where h is Plank's constant (its value is $6.626\text{x}10^{-34}$ J.s).
4. Light is absorbed when an electron jumps to a higher energy orbit and emitted when an electron falls into a lower energy orbit. Electron present in a particular orbit does not radiate energy.

Society, Technology and Science

Rutherford was the first scientist who proposed first atomic model of an atom. He suggested that all of the positive charge and most of the mass of the atom is concentrated in the nucleus. The remaining volume of the atom is occupied by electrons that revolve around the nucleus in circles called orbits. These suggestions remained unchallenged. But his model could not explain the stability of an atom and line spectrum for an atom. Bohr leaped over difficulty by using Quantum Theory of Radiation that was proposed by Max Plank. Bohr proposed that an electron moves around the nucleus in well defined circular paths called orbits. An orbit has fixed energy. Electron present in an orbit does not emit energy. Bohr atomic theory explains nicely the stability of an atom and also explains why an atom gives line spectrum. Development of Bohr's atomic model explains how interpretations of experimental results of other scientists help chemists to formulate new explanations and new theories.

5. The energy of the light emitted is exactly equal to the difference between the energies of the orbits.

$$\Delta E = E_2 - E_1$$

Where ΔE is the energy difference between any two orbits with energies E_1 and E_2

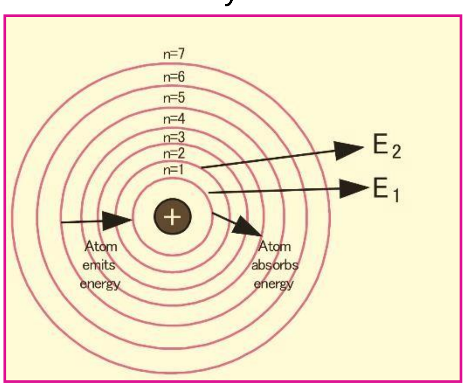

Figure 2.2 Bohr's model of the atom

Self-Assessment Exercise 2.1

Draw Bohr's Model for the following atoms indicating the location for electrons, protons and neutrons,

(a) Carbon (Atomic No. 6, Mass No. 12)

(b) Chlorine(Atomic No. 17, Mass No. 35)

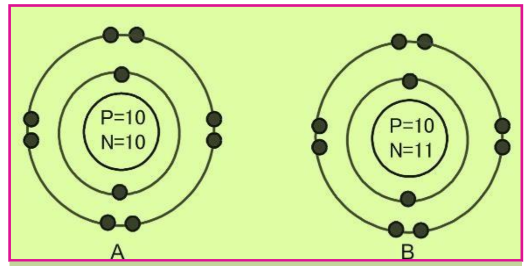

Figure 2.3 Bohr's model for atom A and atom B

Reading

2.2 ISOTOPES

Figure 2.3 shows Bohr's Model for two atoms A and B

Can you identify three similarities and two differences in these atoms?

You will find,

(a) Both the atoms have same number of protons.

(b) Both the atoms have same number of electrons.

(c) Both have same atomic number.

(d) Both have different number of neutrons.

(e) Both differ in total number of protons and neutron. This means they have different mass numbers.

Society, Technology and Science

Dalton's atomic theory explained data from many experiments. So it was widely accepted. Discovery of sub-atomic particles and isotopes proved that some of the Dalton's ideas about atoms were not correct. Scientists did not discard his theory. Instead, they revised the theory to take into account new discoveries. This shows how prevailing theories bring about changes in them.

Since both the atoms have the same atomic number, they must be the atoms of same element and are called isotopes. The word isotope was first used by Soddy. It is a Greek word "isos" means same and "tope" means place.

Isotopes are atoms of an element whose nuclei have the same atomic number but different mass number. This is because atoms of an element can differ in the number of neutrons. Isotopes are chemically alike and differ in their physical properties.

How does the discovery of isotopes contradicted Dalton's atomic theory?

Isotopes of Hydrogen

Hydrogen has three isotopes. Hydrogen –1 (Protium) has no neutron. Almost all the hydrogen is Hydrogen –1. Its symbol is ${}^{1}_{1}H$. Hydrogen – 2 (deuterium) has one neutron and hydrogen –3 (Tritium) has two neutrons. Their symbols are ${}^{2}_{1}H$ and ${}^{3}_{1}H$ respectively Because hydrogen –1 also known as protium has only one proton, adding a neutron doubles it mass.

Protium / Hydrogen is a colourless, odourless, and tasteless gas. It is insoluble in water and is highly inflammable gas. Water that contain hydrogen–2 atoms in place of hydrogen–1 is called heavy water. Table2.1 Shows some physical properties of ordinary water and heavy water.

Table 2.1 - Comparision of ordinary water and heavy water.

Property	Ordinary water	Heavy water
Melting Point	0.00^0C	3.81^0C
Bioling point	100^0C	101.2^0C
Density at 25^0C	0.99701 g/cm^3	1.1044 g/cm^3

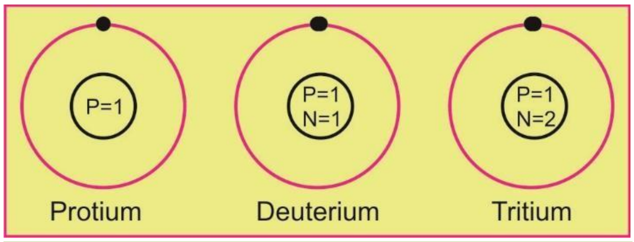

Figure 2.5 Isotopes of hydrogen

At what temperature would a sample of heavy water freeze?

Naturally occurring hydrogen contains 99.99% protium, 0.0015% Deuterium. Tritium is radioactive and is rare. Tritium is not found in naturally occurring hydrogen because its nucleus is unstable.

Isotopes of Carbon

Carbon has three isotopes. Carbon–12, carbon–13 and carbon –14. Almost all the carbon is carbon–12. Its symbol is ${}^{12}_{6}C$. It has six neutrons and six protons. Carbon–13 has symbol ${}^{13}_{6}C$. It has seven neutrons and six protons. Carbon–14 has eight neutrons and six protons. Its symbol is ${}^{14}_{6}C$. Different forms of carbon are black or greyish black solids except diamond. They are odourless and tasteless. They have high melting and boiling points and are insoluble in water.

Activity 2.1

Carbon has three isotopes ${}^{12}_{6}C$, ${}^{13}_{6}C$, ${}^{14}_{6}C$ Figure 2.6 shows incomplete structure of isotopes of carbon. Can you complete it?

Natural abundance of isotopes of carbon is as follows

${}^{12}_{6}C = 98.8\%$, ${}^{13}_{6}C = 1.1\%$, ${}^{14}_{6}C = 0.009\%$

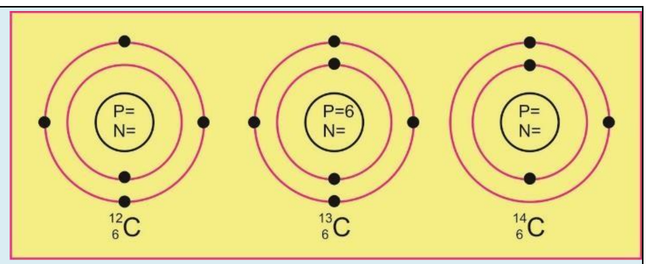

Figure 2.6 Isotopes of Carbon

Isotopes of Chlorine

There are two natural isotopes of chlorine, chlorine–35 and chlorine–37. An atom of chlorine–35 has 17 protons and 18 neutrons. An atom of chlorine–37 has 17 protons and 20 neutrons. Chlorine–35 occurs in nature about 75% and chlorine–37 about 25%. Chlorine is a greyish yellow gas with sharp pungent irritating smell. It is fairly soluble in water.

Activity 2.2

Chlorine has two isotopes. Figure 2.7 shows the structure of isotopes of chlorine. Can you write isotope symbol for each?

Isotope symbols:	________	________
Natural abundance	75.77%	24.23%

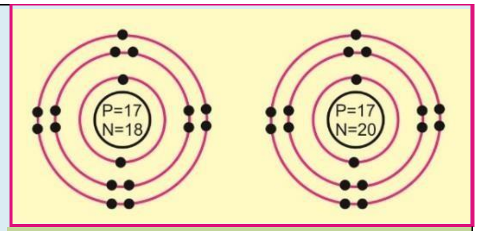

Figure 2.7 Isotopes of chlorine

Isotopes of Uranium

Activity 2.3

Uranium has three isotopes with mass number 234, 235 and 238 respectively.

$$^{234}_{92}U,\ ^{235}_{92}U,\ ^{238}_{92}U$$

The $^{235}_{92}U$ isotope is used in nuclear reactors and atomic bombs, whereas the $^{238}_{92}U$ isotope lacks the properties necessary for these applications. $^{234}_{92}U$ is rare. Natural abundance of Uranium isotopes is as follows:

$$^{234}_{92}U = 0.006\%,\ ^{235}_{92}U = 0.72\%,\ ^{238}_{92}U = 99.27\%$$

Fill in the blanks?

$^{234}_{92}U$ has____protons,____electrons and____neutrons

$^{235}_{92}U$ has____protons,____electrons and____neutrons

$^{238}_{92}U$ has_protons,_electrons and_ neutrons

When uranium–238 decays into thorium–234, it emits alpha particle. An alpha particle is doubly positively charged helium nucleus.

$$^{238}_{92}U \rightarrow\ ^{234}_{90}Th +\ ^{4}_{2}He$$

The fission of uranium–235 yields smaller nuclei, neutron and energy. The nuclear energy released by the fission of one kilogram of uranium–235 is equivalent to chemical energy produced by burning more than 17000 kg of coal.

Chemical properties of an element depend upon the number of protons and electrons. Neutrons do not take part in ordinary chemical reactions. Therefore, isotopes of an element have similar chemical properties.

2.2.2 Uses of Isotopes

Stable and radioactive isotopes have many applications in science and medicines. Some of these are as follows:

(i) Radioactive iodine -131 is used as a tracer in diagnosing thyroid problem.

(ii) Na-24 is used to trace the flow of blood and detect possible constrictions or obstructions in the circulatory system.

(iii) Iodine-123 is used to image the brain.

(iv) Cobalt-60 is commonly used to irradiate cancer cells in the hope of killing or shrinking the tumors.

(v) Carbon-14 is used to trace the path of carbon in photosynthesis.

(vi) Radioactive isotopes are used to determine the molecular structure e.g. sulphur-35 has been used in the structure determination of thiosulphate, $S_2O_3^{-2}$ ion.

(vii) Radioactive isotopes are also used to study the mechanism of chemical reactions.

(viii) Radioactive isotopes are used to date rocks, soils, archaeological objects, and mummies.

Important information

Carbon-14 is used to estimate the age of carbon-containing substances. Carbon atoms circulate between the oceans, and living organism at a rate very much faster than they decay. As a result the concentration of C-14 in all living things keep on increasing. After death organisms no longer pick up C-14. By comparing the activity of a sample of skull or jaw bones, with the activity of living tissues, we can estimate how long it has been since the organism died. This process is called dating.

2.3 ELECTRONIC CONFIGURATION

To understand electronic configuration, you should know about shells and sub-shells.

2.3.1 Shells

According to Bohr's atomic theory, the electron in an atom revolves around the nucleus in one of the circular paths called shells or orbits. Each shell has a fixed energy. So each shell is also called energy level. Each shell is described by an n value. n can have values 1,2,3…..

When,

n = 1, it is K shell

n = 2, it is L shell

n = 3, it is M shell etc.

As the value of n increases the distance of electron from the nucleus and energy of the shell increases.

2.3.2 Sub-Shells

A shell or energy level is sub divided into sub-shells or sub-energy levels. n value of a shell is placed before the symbol for a sub-shell. For instance

n = 1, for K shell. It has only one sub-shell which as represented by 1s.

For L shell n =2, L shell has two sub-shells, these are designated as 2s and 2p.

For M shell n =3 So M shell has 3 sub-shells called 3s , 3p and 3d. While N shell has 4s, 4p, 4d and 4f sub-shells.

s sub-shell can accommodate maximum 2 electrons.

p sub-shell can accommodate maximum 6 electrons.

d sub-shell can accommodate maximum 10 electrons.

f sub-shell can accommodate maximum 14 electrons.

The increasing order of energy of the sub-shells belonging to different shells is given below.

1s < 2s < 2p < 3s < 3p< 4s< 3d …..

The arrangement of electrons in sub-shells is called as the electronic configuration. We can fill the electrons present in various elements by using Auf Bau Principle. **According to this principle, electrons fill the lowest energy sub-shell that is available first**. This means electron will fill first 1s, then 2s, then 2p and so on.

2.3.3 Electronic Configuration of First 18 Elements.

Electronic configuration is the distribution of electrons among the different sub-shells of an atom. We can do this by listing the symbol for the occupied subs-shells one after another. Show the number of electrons in the sub-shell as a superscript to each symbol. Because the energies of sub-shells increase in the order, 1s, 2s, 2p, 3s, 3p (as indicated in section 2.2.1), the first five sub-shells fill in that order. Hydrogen has atomic number 1. So it has only one electron that will occupy lowest energy sub-shell 1s. The electronic configuration of H is $1s^1$.

Helium has atomic number 2, so it has two electrons. Since s sub-shell can accommodate two electrons, so electronic configuration of He is $1s^2$.

Lithium has atomic number 3, so it has three electrons, two will fill 1s sub-shell and one 2s sub-shell. So electronic configuration of Li is $1s^2 2s^1$.

Beryllium has atomic number 4, so it has four electrons. Two of these electrons go into1s sub-shell and two will go to 2s sub-shell. Thus electronic configuration of Be is $1s^2 2s^2$.

Once 2s sub-shell is filled, the 2p sub-shell begins to fill. 2p sub-shell can hold maximum 6 electrons. So next six elements will have configuration in which 2p sub-shell will be progressively filled. Therefore, these elements will have following electronic configuration.

$${}_{5}B = 1s^2\ 2s^2 sp^1$$

$${}_{6}C = 1s^2\ 2s^2 2p^2$$

$${}_{7}N = 1s^2\ 2s^2 2p^3$$

$${}_{8}O = 1s^2\ 2s^2 2p^4$$

$${}_{9}F = 1s^2\ 2s^2 2p^5$$

$${}_{10}Ne = 1s^2\ 2s^2 2p^6$$

After 2p has completely filled, the additional electrons will fill 3s sub-shell, so electronic configuration of Na & Mg would be

$${}_{11}Na = 1s^2 2s^2 2p^6 3s^1$$

$${}_{12}Mg = 1s^2 2s^2 2p^6 3s^2$$

After 3s has completely filled 3p sub-shell begins to fill. So next six elements have electronic configuration by filling 3p sub-shell.

Self-Assessment Exercise 2.3

Write the complete electronic configuration for the following elements;

Al (atomic number 13)

Si (atomic number 14)

P (atomic number 15)

S (atomic number 16)

Cl (atomic number 17)

Ar (atomic number 18)

Figure 2.10 shows the electronic configuration in the sub-shell last occupied for the first eighteen elements.

H $1s^1$							**He** $1s^2$
Li $2s^1$	**Be** $2s^2$	**B** $2s^2 2p^1$	**C** $2s^2 2p^2$	**N** $2s^2 2p^3$	**O** $2s^2 2p^4$	**F** $2s^2 2p^5$	**Ne** $2s^2 2p^6$
Na $3s^1$	**Mg** $3s^2$	**Al** $3s^2 3p^1$	**Si** $3s^2 3p^2$	**P** $3s^2 3p^3$	**S** $3s^2 3p^4$	**Cl** $3s^2 3p^5$	**Ar** $3s^2 3p^6$

Figure 2.10 Valence shell configuration of first 18 elements

Self-Assessment Exercise 2.4

Write the electronic configuration for the following isotopes

(a) $^{14}_{6}C$, (b) $^{35}_{17}Cl$, (c) $^{37}_{17}Cl$

Key Points

- Rutherford proposed a planetary model for an atom. The nucleus of an atom is composed of protons. The electrons surround the nucleus and occupy most of the volume of the atom.
- According to Bohr's atomic model, the electron in an atom revolves around the nucleus in fixed circular orbits called shells. Energy is absorbed when an electron jumps to a higher energy orbit and emitted when an electron falls into a lower energy orbit.

- Isotopes are atoms of an element that differ in the number of neutrons.
- $^{235}_{92}U$ isotope is used in nuclear reactors and atomic bombs.
- Radioactive isotopes have many applications in science and medicines such as killing cancer cells, diagnosing thyroid problem, to image the brain, to detect obstruction in the circulatory system, to date rocks, soils, mummies etc.
- A shell or energy level is divided into sub-shells.
- The arrangement of electrons in sub-shells is called as the electronic configuration.
- According to the Auf Bau Principle, electrons fill the lowest energy levels first.

REFERENCES FOR ADDITIONAL INFORMATION

- B.Earl and LDR Wilford, Introducion to Advanced Chemistry.
- Iain Brand and Richard Grime, Chemistry (11-14).

Review Questions

1. Encircle the correct answer:

(i) According to Bohr atomic model:
(a) Each orbit has fixed energy, so each orbit is called sub-energy level.
(b) The energy of the electron is inversely proportional to its distance from the nucleus.
(c) Light is absorbed when an electron jumps a lower energy orbit.
(d) The further the electron is from the nucleus, the more energy it has.

(ii) Chlorine has two isotopes, both of which have
(a) same mass number. (b) same number of neutrons.
(c) different number of protons. (d) same number of electrons.

(iii) Number of neutrons in $^{27}_{13}M$ are
(a) 13 (b) 14 (c) 27 (d) 15

(iv) Which isotope is commonly used to irradiate cancer cells?
(a) Iodine-123 (b) Carbon-14 (c) Cobalt-60 (d) Iodine-131

(v) M shell has sub-shells:
(a) 1s, 2s (b) 2s, 2p (c) 3s, 3p, 3d (d) 1s, 2s, 3s

(vi) A sub-shell that can accommodate 6 electrons is
(a) s (b) d (c) p (d) f

(vii) $_{11}Na$ has electronic configuration:
(a) $1s^2 2s^2 3s^1$ (b) $1s^2 2s^2 2p^7$ (c) $1s^2 2s^2 2p^5 3s^2$ (d) $1s^2 2s^2 2p^6 3s^1$

(viii) Rutherford used_______particles in his experiments.
(a) He atoms (b) He^+ (c) He^{+2} (d) He^{-2}

(ix) Which of the following statement is not correct about isotopes?
(a) they have same atomic number (b) they have same number of protons
(c) they have same chemical properties (d) they have same physical properties

(x) Which isotope is used in nuclear reactors?
(a) U-234 (b) U-238 (c) U-235 (d) All of these

2. Give short answers

i) Distinguish between shell and sub-shell
ii) Why an atom is electrically neutral?
iii) How many sub-shells are there in N shell.
iv) Give notation for sub-shells of M shell.
v) List the sub-shells of M Shell in order of increasing energy
vi) Can you identify an atom without knowing number of neutrons in it?

3. The electronic configurations listed are incorrect. Explain what mistake have been made in each and write correct electronic configurations.

$x = 1s^2 2s^2 2p^4 3p^2$, $y = 1s^2 2s^1 2p^1$, $z = 1s^2 2s^2 2p^5 3s^1$

4. Which orbital in each of the following pairs is lower in energy?

(a) 2s, 2p (b) 3p, 2p (c) 3s, 4s

5. Draw Bohr's Model for the following atoms indicating the location for electron, protons and neutrons:

(a) Potassium (Atomic No 19, Mass No. 39) (b) Silicon (Atomic No. 14 Mass No. 28)
(c) Argon (Atomic No. 18 Mass No. 39)

6. Write electronic configuration for the following elements:

(a) $^{28}_{14}Si$ (b) $^{24}_{12}Mg$ (c) $^{27}_{13}Al$ (d) $^{40}_{18}Ar$

7. Describe the contribution that Rutherford made to the development of the atomic theory.

8. Explain how Bohr's atomic theory differed from Rutherford's atomic theory.

9. Describe the presence of sub shells in a shell.

10. State the importance and uses of isotopes in various fields of life.

11. The atomic number of an element is 23 and its mass number is 56.

a. How many protons and electrons does an atom of this element have?
b. How many neutrons does this atom have?

12. The atomic symbol of aluminum is written as $^{27}_{13}Al$. What information do you get from it?

13. How the prevailing theories about testing bring changes in atomic theories?

14. How experimental results of some scientists help chemist to formulate new theories and new explanation.

Think-Tank

15. M-24 is a radioactive isotope used to diagnose restricted blood circulation, for example in legs. How many electrons, protons and neutrons are there in this isotope. Valence shell electronic configuration of M is $3s^1$.

16: Two isotopes of chlorine are $^{35}_{17}Cl$ and $^{37}_{17}Cl$. How do these isotopes differ? How are they alike?

17: How many electrons can be placed in all of the sub-Shells in the n=2 shell?

18: Mass number of an atom indicates total number of protons and neutrons in the nucleus. Can you identify an atom without any neutron?

19: The table shows the nuclei of five different atoms.

Name of atom	Number of Protons	Number of neutrons
A	5	6
B	6	6
C	6	7
D	7	7
E	8	8

a. Which atom has the highest mass number?

b. Which two atoms are isotopes?

c. Which atom has the least number of electrons?

d. Which atom will have electronic configuration $1s^2 2s^2 2p^3$.

e. Which of the atom contains the most number of electrons?

20: Naturally occurring nitrogen has two isotopes N-14 and N-15 select isotope that has greater number of electrons.