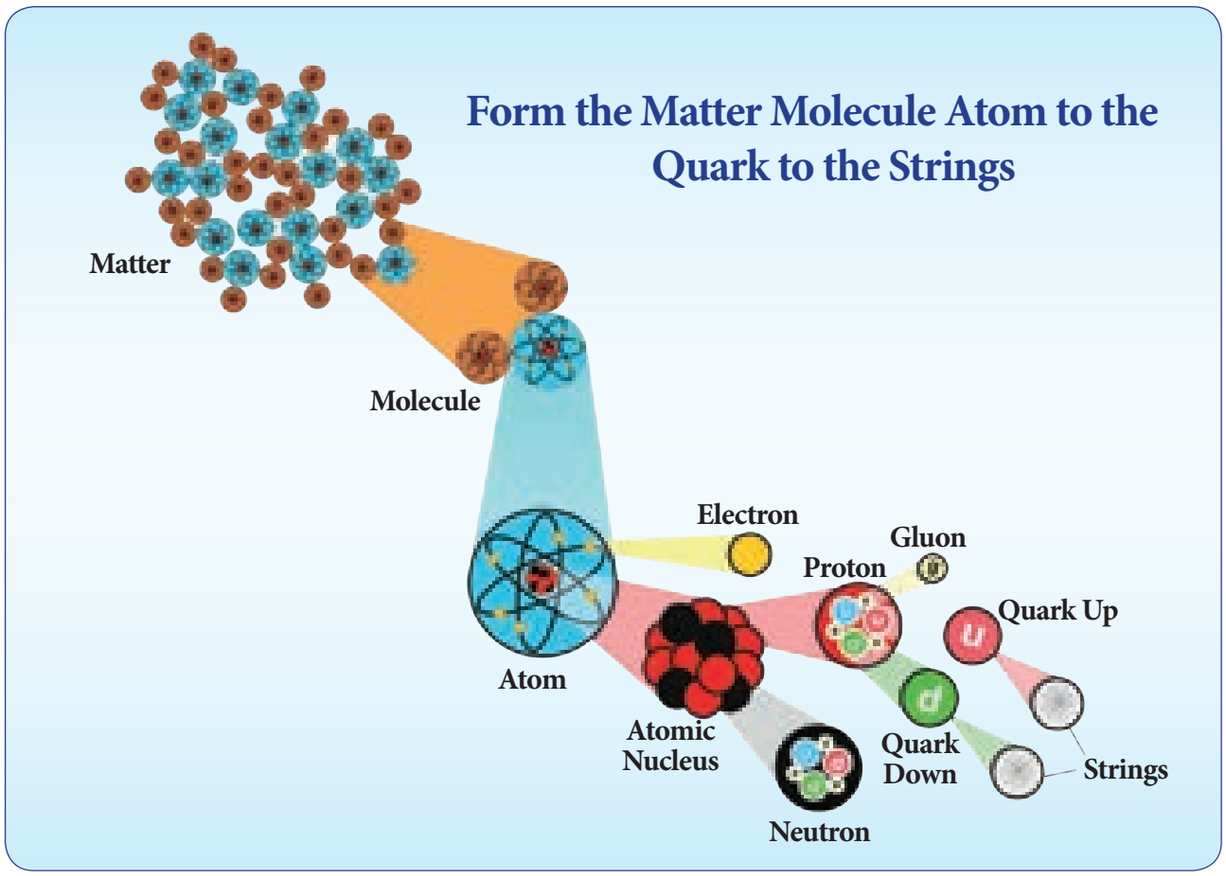
Unit 4

Atomic Structure



Learning Objectives

After studying this unit, students will be able to:

- ❖ know the structure of an atom.
- ❖ know the position of the sub-atomic particles.
- ❖ understand and compare the properties of sub-atomic particles.
- ❖ understand the terms atomic number and mass number.
- ❖ calculate the number of protons, electrons and neutrons in an atom from the symbols given in the periodic table.
- ❖ understand the term valency.

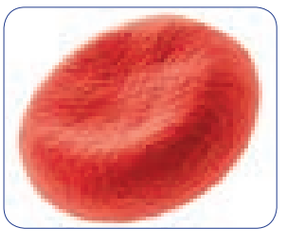
Introduction

In the last chapter we studied that anything around us is matter and it is made up of molecules. The molecules are combination of atoms of different elements or the same element. Table, chair, bag, book, chalk and blackboard, in short everything you see around are made up of atoms. Atoms are the smallest particles. They cannot be seen even through a microscope. In this lesson, we are going to study about atomic theories, sub-atomic particles, atomic number and mass number and valency.

4.1 Atomic Theories

An atom is thousand times smaller than the thickest human hair. It has an average diameter of 0.000000001 m or 1×10^{-9} m. To understand the size of an atom, now let us find what is the size of known things like pencil, red blood cell, virus and dust particle.

Pencil (1×10^{-2} m)



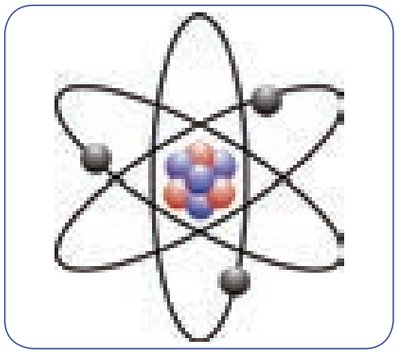
Red Blood Cell (1×10^{-4} m)

Virus (1×10^{-6} m)

Dust Particle (1×10^{-7} m)

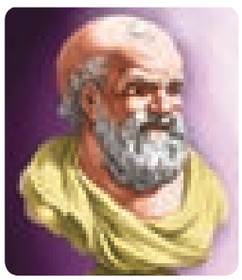
Now you could imagine how small an atom would be.

Many scientists have studied the structure of the atom and advanced their theories about it. The theories proposed by Dalton, Thomson and Rutherford are given below.



Atom (1×10^{-10} m)

4.1.1 Dalton's atomic theory



John Dalton

John Dalton proposed an atomic theory in the year 1808. He proposed that matter consists of very small particles which he named atoms. An atom is the smallest indivisible particle. It is spherical in shape. His theory does not propose anything about the positive and negative charges of an atom. Hence, it was not able to explain many of the properties of substances.

Nanometer is the smallest unit used to measure small lengths. One nanometer is equal to 1×10^{-9} m.

4.1.2 Thomson's theory

J.J. Thomson

In 1897 J.J Thomoson proposed a different theory. He compared an atom to a watermelon. His theory proposed that an atom has positively charged part like the red part of the watermelon and in it are embedded, like the seeds, negatively charged particles

ACTIVITY 1

Some known objects and its broken particles are shown.

1. Name the objects you see here. Also try to write the particles by which each of them are made of?

1. ----------
2. ----------
3. ----------
4. ----------

which he called electrons. According to this theory as the positive and negative charges are equal, the atom as a whole does not have any resultant charge.

Thomson's greatest contribution was to prove the existence of the negatively charged particles or electrons in an atom by experimentation. For this discovery, he was awarded the Nobel Prize in 1906. Although this theory explained why an atom is neutral, it was an incomplete theory in other ways.

4.1.3 Rutherford's theory

Rutherford

There were shortcoming in Thomson's theory. Earnest Rutherford gave a better understanding. Earnest Rutherford conducted an experiment. He bombarded a very thin layer of gold with positively charged alpha rays. He found that most of these rays which travel at a great velocity passed through thin gold sheet without encountering any obstacles. A few are, however, turned back from the sheet. Rutherford considered this remarkable and miraculous as if a bullet had turned back after colliding with tissue paper. Based on this experiment, Rutherford proposed his famous theory. They are:

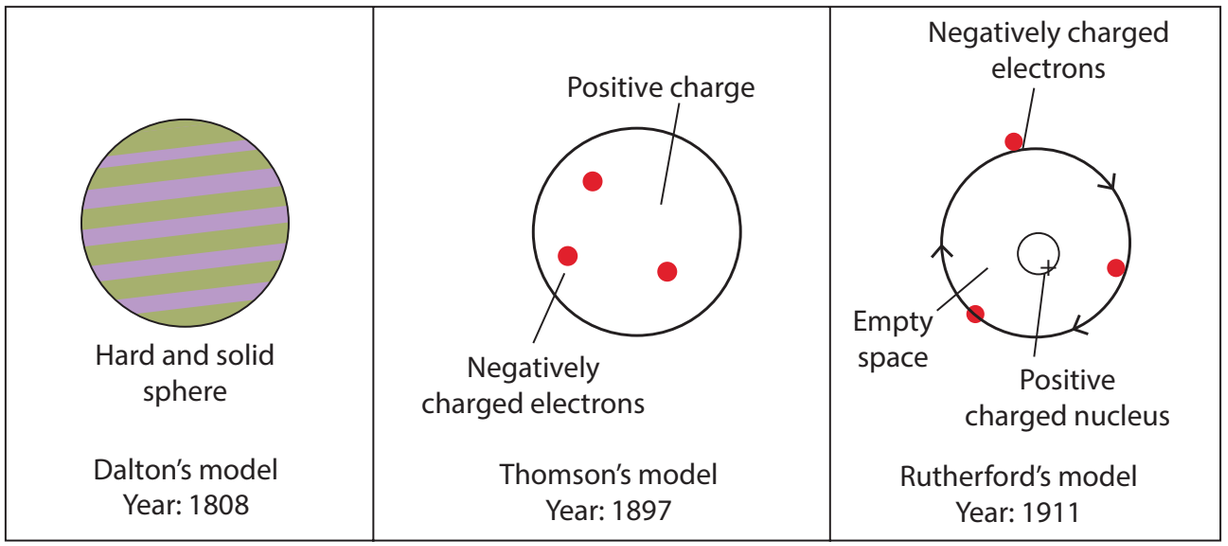
1. The fact that most alpha particles pass through the gold sheet means that the atom consists mainly of empty space.
2. The part from which the positively charged particles turned back is positively charged but it is very small in size as compared to the empty space.

From these inferences, Rutherford presented his theory of the structure of atoms. For this theory, he was awarded the Nobel prize for chemistry.

Rutherford's theory proposes the following.

1. The nucleus at the centre of the atom has positive charge. Most of the mass of the atom is concentrated in the nucleus.
2. The negatively charged electrons revolve around the nucleus in specific orbits.
3. In comparison with the size of the atom, the nucleus is very very small.

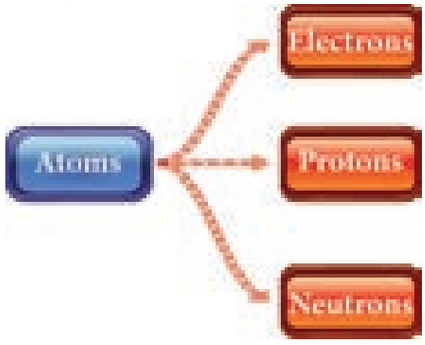
Stages of discovery of the consitituents of an atom



You have around 7 billion atoms in your body, yet you replace about 98% of them every year!

4.2 The sub-atomic particles

The discoveries made during the twentieth century proved that atoms of all elements are made up of smaller components - electron, proton and neutron. An electron from hydrogen atom is no different from the electron of a carbon atom. In the same manner, protons and neutrons of all elements also have same characteristics. These particles that make up the atom are called 'subatomic particles'.



Proton (p)

The proton is the positively charged particle and it is located at the nucleus. Its positive charge is of the same magnitude as that of the electron's negative charge.

Neutron (n)

Neutron is inside the nucleus. The neutron does not have any charge. Except hydrogen (protium), the nucleus of all atoms contain neutrons. Protons and neutrons are the two types of particles in the nucleus of an atom. They are called nucleons.

Electron (e)

This is a negatively charged particle. Electrons revolve around the nucleus of the atom in specific orbits. The mass of an electron is negligible as compared to that of a proton or neutron. Hence, the mass of an atom depends on the number of protons and neutrons in the nucleus.

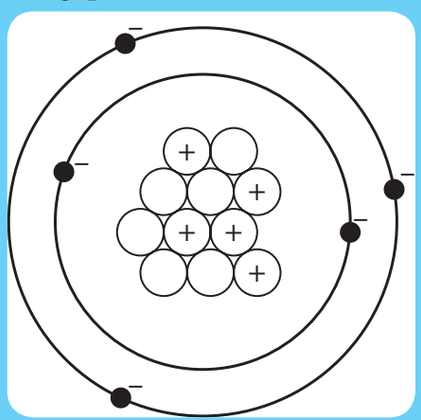
The total negative charge of all the electrons outside the nucleus is equal to the total positive charge in the nucleus. That makes the atom electrically neutral.

Table 4.1 Charge and mass of sub-atomic particles

Particle	Discoverer	Symbol	Charge	Mass (kg)
Proton	Goldstein	p	+1	1.6726×10^{-27}
Electron	Sir John Joseph Thomson	e	-1	9.1093×10^{-31}
Neutron	James Chadwick	n	0	1.6749×10^{-27}

ACTIVITY 2

Look at the given diagram and answer the following questions.



1. The positively charged particle is _____ .
2. The negatively charged particle is _____ .
3. _____ is the neutral particle.

4.3 Atomic number and Mass number

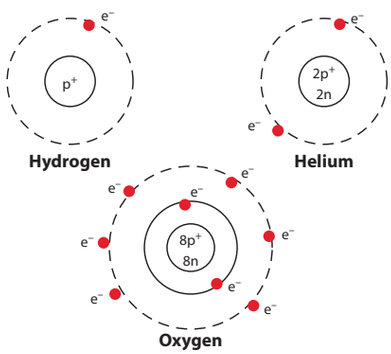
If all the elements are made up of same sub-atomic particles, how will a carbon atom differ from an iron atom? Further investigations led to the discovery that the number of protons inside the nucleus of an atom determines what element it is. For example, if the nucleus has only one proton, then all such atoms are hydrogen atoms. If there are eight protons then that atom is oxygen.

Is the structure of an atom same as the structure of the solar system? Yes ! It is similar to the solar system. It has a core (center) called nucleus and it has paths called orbits around the nucleus.

4.3.1 Atomic number (z)

The number of electrons or protons in an atom is called the atomic number of that atom. It is represented by the letter Z. If we know the atomic number of an atom, we can find the number of electrons or protons in it.

Look at the figures. The nucleus of hydrogen atom has one proton around which revolves one electron. It means that its atomic number (z) is 1.



In a helium atom, there are two protons in the nucleus and two electrons revolving in the orbit around the nucleus. So, the atomic number(z) of helium is 2.

Look at the atomic structure of oxygen shown in the figure. What is its atomic number?

Try yourself

If the atomic number of carbon is 6, what is the number of electrons revolving in its orbit?

4.3.2 Mass number (A) or Atomic mass

We have seen that the mass of an atom is concentrated in its nucleus. From this, we can get the mass number (A). It is equal to the sum of the number of protons (p) and number of neutrons (n) in the nucleus.

Atomic mass or Mass number

= Number of Protons + Number of Neutrons

$A = p + n$

Lithium atom contains 3 protons and 4 neutrons. Its mass number (A) = 3+4 = 7. In a sodium atom, there are 11 Protons and 12 neutrons. Hence, its mass number (A) is 23 (11 + 12).

Try yourself

1. Why the atomic numbers and mass numbers are always whole numbers?
2. A sulphur atom contains 16 protons and 16 neutrons. Calculate its atomic number and mass number.

While writing the symbol of an element, its atomic number and mass number are also written. For example, the symbols of hydrogen, carbon and oxygen are written as $_1H^1$, $_6C^{12}$, $_8O^{16}$ respectively. All the elements in the periodic table have the following combination of protons, electrons and neutrons.

Table 4.2 Symbols of elements

Element	Symbol	Number of proton, electron, neutron,
Carbon	$_6C^{12}$	**6p,6e,6n**
Beryllium	$_4Be^9$	4p,4e,5n
Nitrogen	$_7N^{14}$	7p,7e,7n
Boron	$_5B^{11}$	5p,5e,6n

Isotopes

Atoms of element can have different number of neutrons. Such atoms will have same atomic number but different mass numbers. These atoms are called isotopes. For example, hydrogen has three isotopes. They are: Proteum ($_1H^1$), Deuterium ($_1H^2$), Tritium ($_1H^3$).

Isobars

Atoms that have the same mass number but different atomic numbers are called isobars. Example: Calcium ($_{20}Ca^{40}$), Argon ($_{18}Ar^{40}$).

Table 4.3 Elements and their symbols with their atomic number and mass number

Element	Symbol	Atomic number	Protons (p)	Neutrons(n)	Mass number(p+n)
Hydrogen	H	1	1	0	1
Helium	He	2	2	2	4
Aluminium	Al	13	13	14	27
Oxygen	O	8	8	8	16
Sodium	Na	11	11	12	23

ACTIVITY 3

H Hydrogen Atomic Number: 1 Atomic Mass: 1 Protons: 1 Neutrons: 0 Electrons: 1	**He** Helium Atomic Number: 2 Atomic Mass: 4 Protons: 2 Neutrons: 2 Electrons: 2	**Li** Lithium Atomic Number: 3 Atomic Mass: 7 Protons: 3 Neutrons: 4 Electrons: 3	**Be** Beryllium Atomic Number: 4 Atomic Mass: 9 Protons: 4 Neutrons: 5 Electrons: 4	**B** Boron Atomic Number: 5 Atomic Mass: 11 Protons: 5 Neutrons: 6 Electrons: 5
C Carbon Atomic Number: 6 Atomic Mass: 12 Protons: 6 Neutrons: 6 Electrons: 6	**N** Nitrogen Atomic Number: 7 Atomic Mass: 14 Protons: 7 Neutrons: 7 Electrons: 7	**O** Oxygen Atomic Number: 8 Atomic Mass: 16 Protons: 8 Neutrons: 8 Electrons: 8	**F** Fluorine Atomic Number: 9 Atomic Mass: 19 Protons: 9 Neutrons: 10 Electrons: 9	**Ne** Neon Atomic Number: 10 Atomic Mass: 20 Protons: 10 Neutrons: 10 Electrons: 10
Na Sodium Atomic Number: 11 Atomic Mass: 23 Protons: 11 Neutrons: 12 Electrons: 11	**Mg** Magnesium Atomic Number: 12 Atomic Mass: 24 Protons: 12 Neutrons: 12 Electrons: 12	**Al** Aluminium Atomic Number: 13 Atomic Mass: 27 Protons: 13 Neutrons: 14 Electrons: 13	**Si** Silicon Atomic Number: 14 Atomic Mass: 28 Protons: 14 Neutrons: 14 Electrons: 14	**P** Phosphorus Atomic Number: 15 Atomic Mass: 31 Protons: 15 Neutrons: 16 Electrons: 15
S Sulfur Atomic Number: 16 Atomic Mass: 32 Protons: 16 Neutrons: 16 Electrons: 16	**Cl** Chlorine Atomic Number: 17 Atomic Mass: 35 Protons: 17 Neutrons: 18 Electrons: 17	**Ar** Argon Atomic Number: 18 Atomic Mass: 39 Protons: 19 Neutrons: 20 Electrons: 19	**K** Potassium Atomic Number: 19 Atomic Mass: 39 Protons: 19 Neutrons: 20 Electrons: 19	**Ca** Calcium Atomic Mass: 20 Atomic Number: 40 Protons: 20 Neutrons: 20 Electrons: 20

Observe the table given above and answer the following questions.

1. I am used for breathing, without me you cannot live. Write my name and symbol.

   _____.

2. It is used in filling the balloons. It is a gas, identify it. What is its mass number?

   _____.

3. Name the element present in banana. What is its atomic number?

   _____.

4. I am found in crackers. How many protons do I have?

   _____.

5. I am the most valuable element. Find who am I. Can you say my mass number?

   _____.

4.4 Valency

When we shake hands with others, we can either shake hand with one persons using one hand or shake hand with two persons using both our hands. If we have more hands, we can shake hands with more persons. In the same manner atoms can share either one electron or two or three or four electrons and some cannot share any electron. This property is called valency.

Table 4.4 Elements and their symbols with their atomic number and mass number and valency.

Element	Symbol	Atomic Number	Mass Number	Valency
Hydrogen	H	1	1	1
Carbon	C	6	12	4
Oxygen	O	8	16	2
Sodium	Na	11	23	1
Calcium	Ca	20	40	2

What makes atoms stick together?

Electrons carry a negative electric charge, and protons carry a positive charge. The attraction between them holds electrons in orbits.

Valency is the combining property of an atom. It is a measure of how many hydrogen atoms it can combine with. For example, oxygen can combine with two hydrogen atoms and create water molecule. So, the valency of oxygen atom is two. In the case of chlorine, it can combine with only one hydrogen to create HCl (hydrochloric acid). Here, the valency of chlorine is one. Methane (CH_4) has one carbon atom combining with four hydrogen atoms. Can you guess the valency of carbon in methane? In ammonia molecule, nitrogen combines with three hydrogen atoms. What is the valency of nitrogen in ammonia?

Atoms of different elements combine with each other to form molecules. Valency determines the number of atoms of an element that combines with atom or atoms of another type.

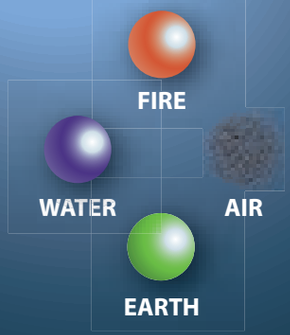
The element having valency one is called monovalent. Example: Hydrogen and Sodium. The elements having valency two are called divalent. Example: Oxygen and Beryllium. The elements having valency three are called trivalent. Example: Nitrogen and Aluminium. Some elements exhibit more than one valency. For example, iron combines with oxygen to form two types of oxides namely, ferrous oxide (exhibits valency 2) and ferric oxide (exhibits valency 3). We will study about them in detail later.

When atoms of different elements combine with each other, molecules of compounds are formed. In these instances, it is necessary to know the valancies of those elements. Valencies of some elements are given in Table 4.4.

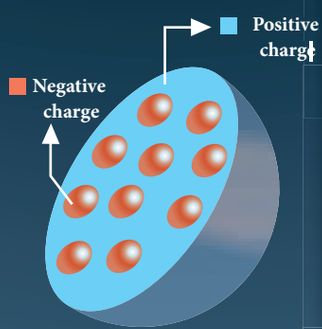
Points to Remember

- An atom is the smallest particle of an element that retains its chemical properties. They are very tiny compared to other particles.
- Atoms are too small to be seen by the naked eye or even through microscope.
- An atom consists mostly of empty space.
- Atoms of same element are identical, and atoms of different elements differ.
- An atom consists of a dense nucleus which has positively-charged protons and electrically-neutral neutrons.
- The protons and neutrons are called nucleons.
- An atom is electrically neutral. They contain equal number of protons and electrons.
- Atomic number is the number of protons in an atom.
- The total number of protons and neutrons present in the nucleus of an atom is called its mass number.
- Valency is defined as the combining capacity of an element.

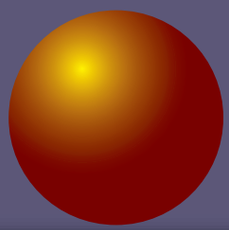
Evolution of the atomic structure



Hindu philophers discuss atoms as ultimate pieces of the elements earth, air, fire and water. Atoms are round and differ in properties such as color, flavor and odor.



J.J. Thomson proposes the "plum pudding" model of the atom, picturing negatively charged electrons rotating in concentric rings within a sphere of positive electricity

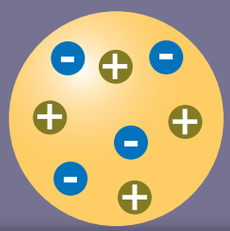


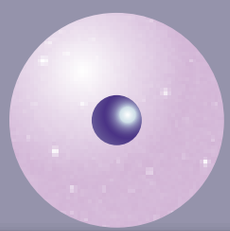
1803

DALTON THEORY

1904

J.J. THOMSON THEORY



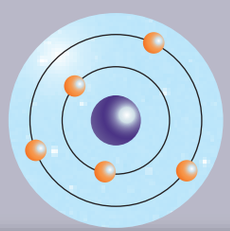


1911

RUTHERFORD THEORY
(the nucleus)

1913

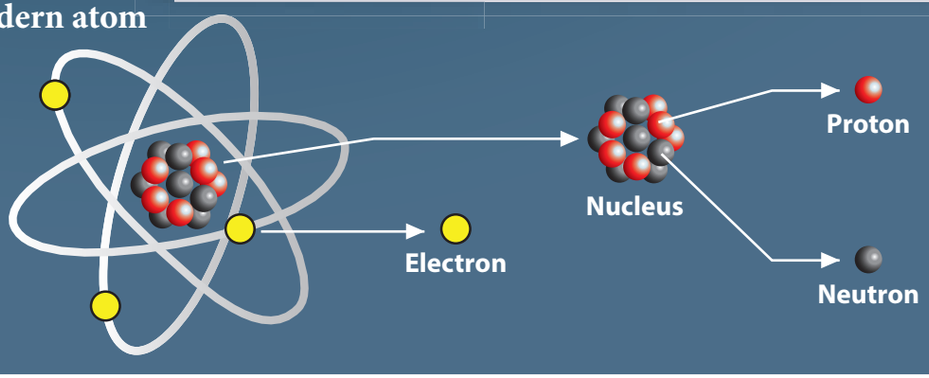
BOHR THEORY
(the energy levels)



1926

SCHRODINGER THEORY
(electron cloud model)

Modern atom



Evaluation

I. Choose the appropriate answer.

1. The basic unit of matter is _____
   a. element b. atom
   c. molecule d. electron
2. The sub-atomic particle which revolves around the nucleus is _____
   a. atom b. neutron
   c. electron d. proton
3. _____ is positively charged.
   a. Proton b. Electron
   c. Molecule d. Neutron
4. The atomic number of an atom is the _____
   a. number of neutrons
   b. number of protons
   c. total number of protons and neutrons
   d. number of atoms
5. Nucleons comprises of _____
   a. protons and electrons
   b. neutrons and electrons
   c. protons and neutrons
   d. neutrons and positron

II. Fill in the blanks.

1. The smaller particles found in the atom are called _____.
2. The nucleus has _____ and _____ .
3. The _____ revolve around the nucleus.
4. If the valency of carbon is 4 and that of hydrogen is 1, then the molecular formula of methane is_____ .
5. There are two electrons in the outermost orbit of the magnesium atom. Hence, the valency of magnesium is_____ .

III. Match the following.

Valency	Fe
Neutral particle	Proton
Iron	Electrons in the outermost orbit
Hydrogen	Neutron
Positively charged particle	Monovalent

IV. State true or false. If false, correct the statement.

1. The basic unit of an element is molecule.
2. The electrons are positively charged.
3. An atom is electrically neutral.
4. The nucleus is surrounded by protons.

V. Complete the analogy.

1. Sun : Nucleus :: Planets : _____.
2. Atomic number : _____ :: Mass number : Number of protons and neutrons.
3. K: Potassium :: C : _____.

VI. Consider the following statements and choose the correct option.

1. **Assertion**: An atom is electrically neutral.
   Reason: Atoms have equal number of protons and electrons.
2. **Assertion:** The mass of an atom is the mass of its nucleus.
   Reason: The nucleus is at the centre.

3. **Assertion:** The number of protons or the number of neutrons is known as atomic number.
   Reason: The mass number is the sum of protons and neutrons.

VII. Answer very briefly.

1. Define – Atom.
2. Name the sub-atomic particles.
3. What is atomic number?
4. What are the characteristics of proton?
5. Why neutrons are called neutral particles?

VIII. Answer briefly.

1. Distinguish isotopes from isobar.
2. What are isotones? Give one example.
3. Differentiate mass number from atomic number.
4. The atomic number of an element is 9. It has 10 neutrons. Find the element from the periodic table. What will be its mass number?

IX. Answer in detail.

1. Draw the structure of an atom and explain the position of the sub-atomic particles.
2. The atomic number and the mass number of an element is 26 and 56 respectively. Calculate the number of electrons, protons and neutrons in its atom. Draw the structure.
3. What are nucleons? Why are they called so? Write the properties of the nucleons.
4. Define valency. What is the valency of the element with atomic number 8? What is the compound format by this element with hydrogen?

X. Higher Order Thinking Skills.

1. An atom of an element has no electron. Will that atom have any mass or not? Can an atom exist without electron? If so then give example.
2. What is common salt? Name the elements present in it. Write the formula of common salt. What are the atomic number and the mass number of the elements? Write the ions in the compound.

XI. Project.

To have an idea of what atoms are, students can be asked to construct atoms using pipe cleaners (thin metal wires-electron shells), pom-poms (balls-different colours for protons and neutrons) and beads (electrons). Students will love and enjoy putting them together and they look great hanging from the ceiling in the classroom.

ICT CORNER

Atomic Structure

Let's build an atom.

PROCEDURE :

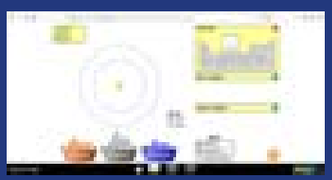
Step 1: Use the URL to reach stimulation page. Click play button to launch the simulation.

Step 2: Click on the"ATOM" , a new window will be open. Drag the particles (Protons, Neutrons and Electrons) from the baskets which is at the bottom of the display.

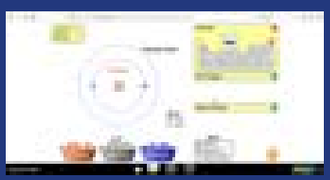
Step 3: You can observe the changes in 'Elements, Net charge and Mass number' at the right side windows.

Step 4: Click on the 'Symbol" at the bottom. Drag the particles and get the Symbol of the element.

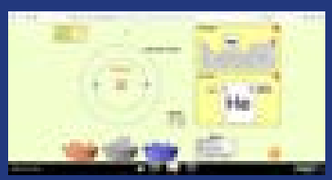
Step 5: Click on the"GAME" and play the games.



Step 1



Step 2



Step 3

Step 4

Atomic Structure URL:

https://phet.colorado.edu/en/simulation/build-an-atom

*Pictures are indicative only

*If browser requires, allow Flash Player or Java Script to load the page.