Chapter 4

Structure of an Atom

Chapter Objectives

In this chapter, you will learn about:

- Atoms, molecules and radicals
- Valency and atomicity of different elements
- Periodic table and its organisation

All elements are made up of small fundamental units called atoms. Recall what you have learned in the previous class and tell the differences between an atom and a molecule. Let us understand how atoms and molecules of different elements combine to form compounds.

INTRODUCTION

As discussed in chapter 1, all the things that we see around us are matter. All matter is composed of atoms. Atoms are the building blocks of matter. Do all the atoms have the same size and shape? No, different atoms differ in size and shape. The characteristic properties of matter are due to the arrangement of various atoms of same or different sizes. It is found that atoms are composed of smaller sub-particles. Understanding these sub-atomic particles is important to understand the properties of matter.

The purest form of matter which consists of a single type of atom is called an ***element****.* All chemical elements consist of these small particles (atoms). The atoms of the same chemical element have equal size, mass and nature, but they differ from the atoms of other elements. This means that the properties of a chemical element are determined by its atoms. An element can exist as a molecule when it combines with another element.

Let us understand what atoms and molecules are and how they are different.

ATOMS

The word 'atom' comes from the Greek word *'atomos.'* A Greek philosopher, Democritus (about 460–370 BCE), was the first to coin the word *atomos.* He put forward the idea of his teacher, Leucippus, that matter is made up of tiny indivisible particles called *atomos.* An Indian philosopher, Kanada, defined atoms as indestructible units that cannot exist in the free state.

In 1803, John Dalton put forward his atomic theory, known as **Dalton's Atomic Theory**. According to the Dalton's atomic theory, *all the elements are made up of atoms. An atom of an element is the smallest particle that shows the properties of that element.*

Dalton also explained that the atoms cannot be broken by chemical means and hence, are

Coin: Invent a new term or phrase

indivisible. Later, experiments performed by other scientists like J. J. Thomson, Max Planck, and Rutherford showed that atoms contain particles that are known as fundamental particles or sub-atomic particles.

The atom consists of three sub-atomic particles namely, electrons, protons and neutrons. Nucleus is present at the centre of the atom which consists of protons and neutrons. *The electrons move around the nucleus in a defined path called orbits.*

Electrons are negatively charged particles. They carry one unit negative charge (–1) and have negligible mass. An electron has a mass almost 1/1840 times that of a hydrogen atom.

Protons are positively charged particles. They carry one unit positive charge (+1). It has mass almost same as that of a hydrogen atom. So, proton is 1840 times heavier than an electron.

Neutrons are electrically neutral. They do not carry any charge. The mass of a neutron is equal to the mass of a proton.

Mass of sub-atomic particles is denoted by atomic mass unit (amu or u).

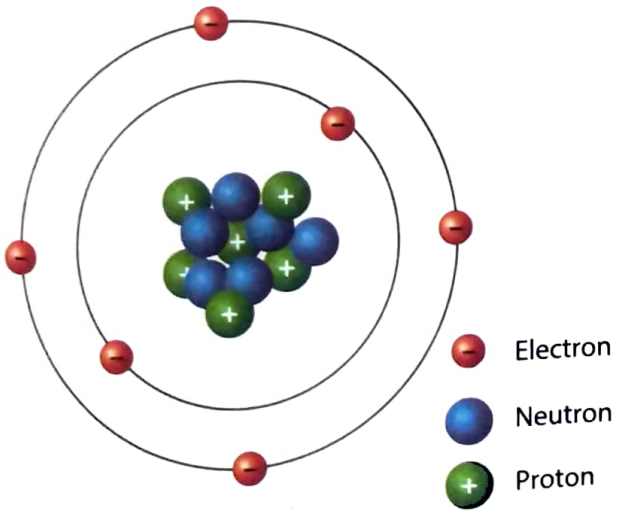


Fig. 4.1 Sub-atomic particles in an atom

Table 4.1 Sub-atomic particles and their charges

Name	Charge	Common charge notation	Mass (in gram, g)
Electron	-1.6×10^{-19} C	–1	9.109×10^{-28}
Proton	1.6×10^{-19} C	+1	1.6×10^{-24}
Neutron	0	0	1.6×10^{-24}

STRUCTURE OF AN ATOM

Now, let us understand how these sub-atomic particles are arranged inside an atom. On the basis of experiments, different models of an atom were presented by different people. Thomson's model explained the electrical neutrality of an atom by assuming atom to be a positively-charged sphere in which electrons are embedded. Another model given by Rutherford, was based on his alpha particles, scattering experiment.

The features of Rutherford's atomic model are listed here.

- An atom is composed of a positively charged nucleus orbited by one or more negatively charged particles called electrons.
- The nucleus is the core of an atom. It has a positive charge because it usually consists of two types of particles, the neutrons and the protons (a normal hydrogen atom is the exception with only a proton and no neutron in the nucleus). Any nucleus with one proton has a charge of +1 (or simply 1), and a nucleus with two protons has a +2 charge.
- Together the neutrons and protons give the nucleus its mass. But it is the proton alone, which gives the nucleus its positive charge.
- Neutrons and protons are relatively massive and are essentially equal in mass.
- The negatively charged particles that move around the nucleus are called electrons.

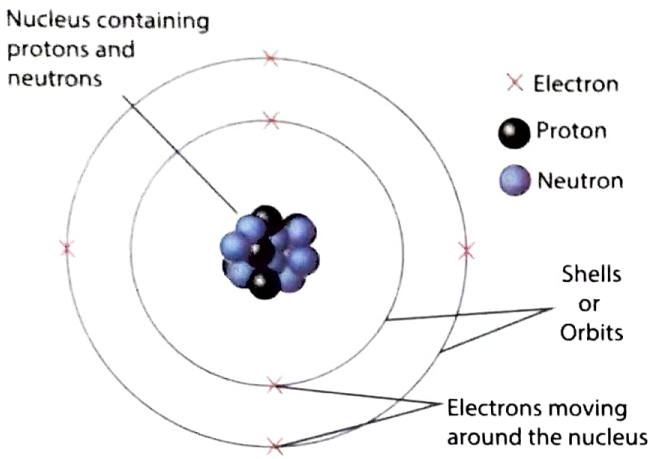


Fig. 4.2 Structure of an atom

Based on the given description, the structure of an atom may be described as:

- Atoms have a nucleus present at the centre or core.
- Atoms consist of electrons moving around the nucleus.
- Electrons revolve around the nucleus in circular paths. The circular paths of the electrons are called **shells** or **orbits**.
- The nucleus consists of two kinds of particles, protons (which possess a relative charge of +1) and neutrons (with a mass approximately equal to that of the proton but with no electrical charge). *Protons and neutrons are collectively known as nucleons*.

MOLECULES

The atoms of many elements cannot exist independently. If they combine with other atoms of the same element or other elements, they exist as **molecules.**

A molecule is the smallest unit, consisting of a group of atoms, or they are particles of a pure substance (element or compound) having independent existence.

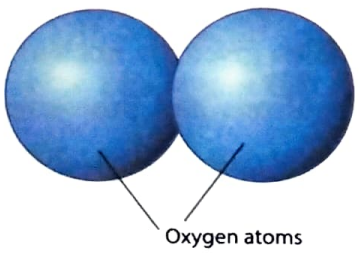
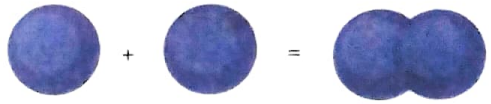


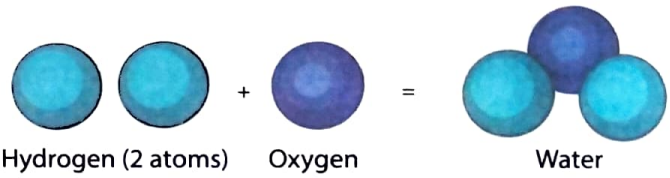
Fig. 4.3 Oxygen molecule

For example, two oxygen atoms combine to form a molecule of oxygen (element).



One atom of hydrogen combines with one atom of chlorine to form a molecule of hydrogen chloride (compound).

Similarly, two atoms of hydrogen combine with one atom of oxygen to form a water (H_2O) molecule (water is a compound).



This shows that a molecule is a group of two or more atoms that are chemically joined together.

The atoms of some elements, such as helium (He) and other noble gases can exist independently.

But atoms of other elements cannot exist independently. They combine to form the molecules that exist independently. *Atoms of the same element combine to form a molecule of that element*. For example, one atom of nitrogen combines with another atom of nitrogen to form N_2 molecule.

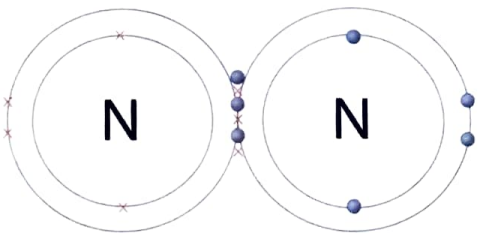


Fig. 4.4 Atoms of nitrogen forming a molecule

***Note:** N = 2, 5 means inner shell will have 2 electrons while outer shell will have 5 electrons.

ACTION TIME 1

Find details of Thomson's atomic model. This model can be compared with a watermelon. Draw a labelled diagram representing Thomson's Atomic Model.

RADICALS

Radical is a group of atoms that carries a charge and functions as a single unit. They are also known as **polyatomic ions**. A radical may be a single atom or a group of atoms. Hydroxide ion is a radical that consists of one oxygen atom and one hydrogen atom and carries –1 charge. It is represented as OH^-. Chloride ion is a radical that contains single chlorine atom and carries a –1 charge. It is represented as Cl^-.

Table 4.2 Formulae of some radicals

Radical	Formula of the radical
Bromide	Br^-
Fluoride	F^-
Iodide	I^-
Sulphate	SO_4^{2-}
Oxide	O^{2-}
Carbonate	CO_3^{2-}

Table 4.3 Differences between atoms, molecules and radicals

Atoms	Molecules	Radicals
They are the smallest units of which matter is made up of.	They are formed by a combination of two or more atoms of the same or different elements.	They are single atoms or a group of atoms that act as a single entity.
They cannot exist independently (except He and some noble gases).	They can exist independently.	They cannot exist independently.
They do not carry any charge.	They do not carry charge.	They carry a unit charge.
Example: Atom of hydrogen is represented as H.	Example: Molecule of hydrogen is represented as H_2.	Example: Hydroxide ion is represented as OH^-.

Quick Check 1

State whether the following statements are True (T) or False (F).

1. Electrons are the positively charged sub-atomic particles. .....
2. There are three types of sub-atomic particles. .....
3. Neutrons are the negatively charged sub-atomic particles. .....
4. Electrons are present in the shells of an atom. .....
5. Radicals do not carry any charge. .....

ATOMICITY

The number of atoms present in a molecule of an element or compound is called its atomicity. Depending on the atomicity, the molecules are classified as monoatomic, diatomic, triatomic or polyatomic.

- *The molecules that contain only one atom are called* ***monoatomic molecules*** *and their atomicity is 1.* Noble gases such as helium (He), neon (Ne), argon (Ar), krypton (Kr) are monoatomic molecules.
- *The molecules that contain two atoms of the same element are called* ***diatomic molecules***. Hence, their atomicity is 2. For example, hydrogen (H_2), nitrogen (N_2), oxygen (O_2), etc., have two atoms in their respective molecules.
- *The molecules that contain three atoms of the same element are called* ***triatomic molecules***. Its atomicity is 3. Ozone (O_3) has three atoms of oxygen in its molecule, and is an example of a triatomic molecule.

Ozone: A layer of gas present in atmosphere

- *The molecules that contain more than three atoms of the same element are called* ***polyatomic molecules***. For example, phosphorous (P_4) contains four atoms of phosphorous in its molecule. So, its atomicity is 4. Sulphur (S_8) contains eight atoms of sulphur in its molecule. So, its atomicity is 8.

VALENCY

Long before, through the discovery of electrons, chemists had noticed that different elements had different chemical characteristics. Some elements were very active, whereas some were practically inactive.

Niels Bohr devised a rule to find how many electrons and electron-orbits should be there in atoms. While doing this, he related the number of electrons in each atom's outermost shell to each atom's valency level. In this way, he came up with the scheme that the largest number of outer electrons that an atom could possess would be eight and the fewest would be one. For example, an atom with the valency 4, is said to have four electrons in its outer shell. The properties of the chemical elements are linked with the number and behaviour of the electrons in the outer shell. *These outer electrons are also called* ***valence electrons***.

Valency is the combining capacity of an element and it is always a positive whole number. It can be expressed in terms of number of electrons in the **outermost shell** or **valence shell**.

Valencies of elements and radicals can be derived from the chemical formula of the compound formed. For example, in case of hydrogen bromide, one atom of hydrogen combines with one atom of bromine, hence valency of bromine is 1.

Similarly, in case of the compound nitric acid (HNO_3), the number of hydrogen atoms which combined is 1, so the valency of the radical nitrate (NO_3^-) is 1. The valency of hydrogen is conventionally taken as 1. Based on this, ***valency*** *of an element or a radical can be defined as the number of hydrogen atoms with which an atom of the element is capable of combining.*

Elements that have more than two valencies are said to have ***variable valencies***. For example, carbon and nitrogen.

Table 4.4 Commonly used valencies of some elements

Atomic Number	Element	Valency
1	Hydrogen	+1
2	Helium	0
3	Lithium	+1
4	Beryllium	+2
5	Boron	+3
6	Carbon	–4, +4
7	Nitrogen	–3, +5
8	Oxygen	–2
9	Fluorine	–1
10	Neon	0
11	Sodium	+1
12	Magnesium	+2
13	Aluminium	+3
14	Silicon	+4
15	Phosphorus	–3, +3, +5
16	Sulphur	–2, +6
17	Chlorine	–1
18	Argon	0
19	Potassium	+1
20	Calcium	+2
21	Scandium	+3
22	Titanium	+4
23	Vanadium	+3, +4, +5
24	Chromium	+2, +3, +6
25	Manganese	+2, +4, +7
26	Iron	+2, +3
27	Cobalt	+2, +3
28	Nickel	+2
29	Copper	+1, +2
30	Zinc	+2

Teaching Tip: The variable valencies mentioned in table 4.4 are not core part of the syllabus, and therefore may be elaborated only if time permits.

INFO HUB

Some metals like iron and copper show more than one valency during a compound formation.
Whereas, some non-metals like sulphur, chlorine, etc., show variable valency.
These elements actually have electronic configurations in which electrons from their inner shells also participate as valence electrons and thus have different oxidation states. In other words, an atom of an element can sometimes lose more electrons than those are present in its valence shell, and hence exhibit more than one or variable valency.

Quick Check 2

Match the elements with their correct valencies.

1. Calcium	a. 0
2. Zinc	b. +3
3. Aluminium	c. +2
4. Potassium	d. +1
5. Argon	e. –4, +4

PERIODIC TABLE

The periodic table is a tabular arrangement of all the 118 elements known so far. It has 18 vertical columns called **groups** and seven horizontal rows called **periods**. The elements in this table are arranged in order of their atomic number such that the elements with similar atomic numbers are present in vertical columns. The elements are arranged in their increasing atomic numbers. The periodic table is also organised on the basis of physical and chemical properties of the elements.

The groups in the periodic table are arranged in such a manner that the elements present in each group have the same number of valence electrons. The elements present in a group exhibit similar properties. For example, Lithium and Hydrogen belong to the same group, that is, group 2. Both of them have 2 valence electrons and show similar properties.

Significance of the Periodic Table

The periodic table helps in determining:

- The symbol of an element.
- The valency of an element.
- The mass number, that is, the total number of protons and neutrons present in an atom of the element. The mass number of an element is represented as A.
- The atomic number, that is, the number of protons present in an atom of the element. The atomic number of an element is represented as Z.

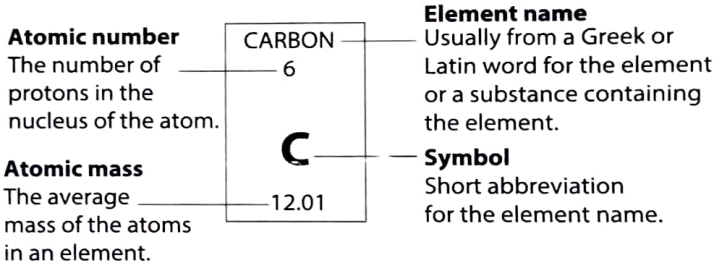


Fig. 4.5 Representation of an element in the periodic table

Quick Check 3

State whether the following statements are True (T) or False (F).

1. Total number of protons and neutrons in atoms of elements is called periodic table. .....
2. There are total 113 elements known so far in the periodic table. .....
3. Periodic table has 15 vertical columns. .....
4. Elements arranged in each group of periodic table have the same number of valence electrons. .....

Note: For lower valency of metal ions, suffix 'ous' is used and for higher valency, suffix 'ic' is used. For example, Fe^{2+} (Ferrous) and Fe^{3+} (Ferric), Cu^{+} (Cuprous) and Cu^{2+} (Cupric).

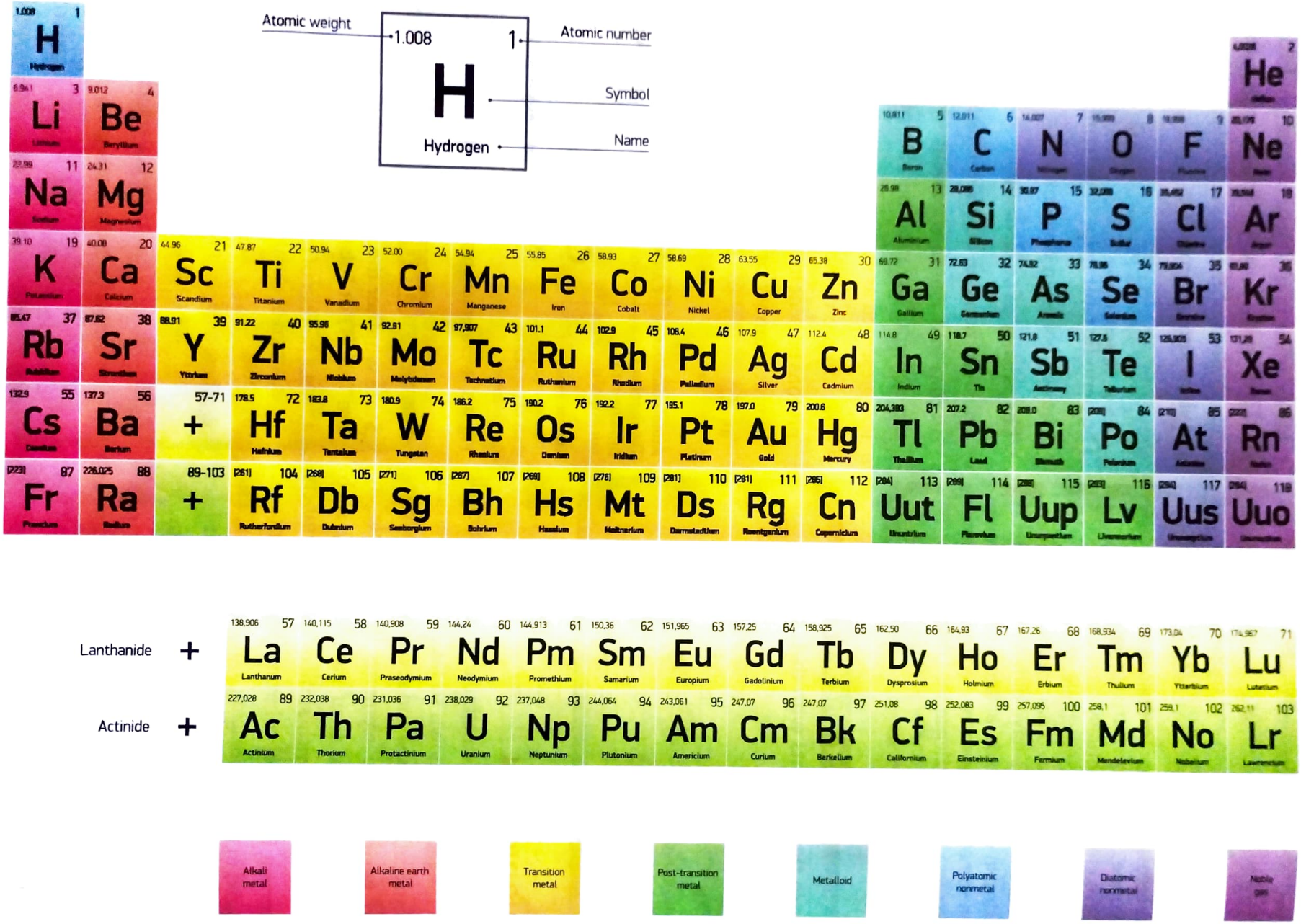


Fig. 4.6 The periodic table and representation of elements

Teaching Tip: The significance of different colours in the periodic table can be discussed in class.

KEY TERMS

Sub-atomic particles: The particles of which an atom is made up of

Orbits: The fixed paths in which electrons move around the nucleus

Nucleons: Protons and neutrons present in the nucleus of an atom are collectively known as nucleons

Radical: A single or a group of atoms that act as single entity and carry a charge

Atomicity: The number of atoms present in a molecule of an element or compound

Valency: The combining capacity of one element with another

Periodic table: A tabular arrangement of all the elements in order of atomic number

QUICK NOTES

- An atom consists of three sub-atomic particles namely, electrons, protons and neutrons.
- Nucleus is present at the centre of the atom which consists of protons and neutrons.
- Electrons are negatively charged particles.
- Protons are positively charged particles.
- Neutrons are electrically neutral. It does not carry any charge.
- Mass of sub-atomic particles is denoted by atomic mass unit (amu or u).
- Radical is a group of atoms that carries a charge and functions as a single unit. They are also known as polyatomic ions.
- The number of atoms present in a molecule of an element or compound is called its atomicity. Depending on the atomicity, the molecules are classified as monoatomic, diatomic, triatomic or polyatomic.
- Valency is the combining capacity of an element and it is always a positive whole number. It can be expressed in terms of number of electrons in the outermost shell or valence shell.
- The periodic table is a tabular arrangement of all the 118 elements known so far. It has 18 vertical columns called groups and horizontal rows called periods.

RUN-THROUGH

I. Very Short Answer Questions.

A. Tick (✓) the correct answer.

1. What are the negatively charged particles in an atom called?
   a. Atoms ☐ b. Neutrons ☐ c. Electrons ☐ d. None of these ☐
2. Protons and neutrons are collectively called as:
   a. molecules ☐ b. electrons ☐ c. nucleons ☐ d. all of these ☐
3. Which of the following has variable valency?
   a. Hydrogen ☐ b. Oxygen ☐ c. Iron ☐ d. Carbon ☐
4. Which of the following are neutral?
   a. Radicals ☐ b. Electrons ☐ c. Protons ☐ d. Neutrons ☐
5. It is also known as the core of an atom:
   a. orbit ☐ b. electron ☐ c. radical ☐ d. nucleus ☐

B. Fill in the blanks.

1. Electrons have ..... (positive/negative) charge present in them.
2. The magnitude of charge present on a proton is ..... (+1/0).
3. The number of protons in an atom is equal to its ..... (atomic number/atomic mass).
4. The combining capacity of an element is known as ..... (mass/valency).
5. A proton is ..... (1480/1840) times heavier than an electron.

C. State whether the following statements are True or False.

1. Mass of a neutron is the same as that of an electron.
2. Electrons are heavier than protons.
3. Mass of a sub-atomic particle is denoted by atomic mass unit or amu.
4. The combining capacity of an element is called its atomicity.
5. The electrons present in the outermost shell of an atom are called valence electrons.
6. The vertical columns in the periodic table are called periods and horizontal rows are called groups.
7. The elements in a periodic table are arranged in order of their atomic numbers.

II. Short Answer Questions.

A. Question and Answers.

1. Write the names of sub-atomic particles.
2. What is the charge and mass of an electron?
3. What do you mean by valence electrons?
4. What is the difference between electrons and protons?
5. What is a periodic table?
6. What are groups and periods in a periodic table?

B. Define the following terms.

1. Atoms 2. Radicals 3. Electrons 4. Valency 5. Atomicity 6. Orbits

C. Give reasons.

1. An atom is electrically neutral.
2. All molecules are not monoatomic.
3. Some elements have variable valencies.
4. Every element has an individual atomic number.
5. Isotopes of an element have the same atomic numbers.

III. Long Answer Questions.

1. Describe the structure of an atom with a well-labelled diagram.
2. Differentiate between atoms, molecules and radicals with examples.
3. Write a short note on atomicity.
4. What do you understand by the term 'valency'? Explain with examples.
5. What is a periodic table? Explain.
6. What is the significance of a periodic table?
7. What do you mean by variable valency? Write two examples of elements showing variable valency. How can an atom show variable valency?

IV. Challenge

1. How can you justify that protons are constituents of all atoms?
2. What is the maximum number of shells for electrons that an atom of any element can have?

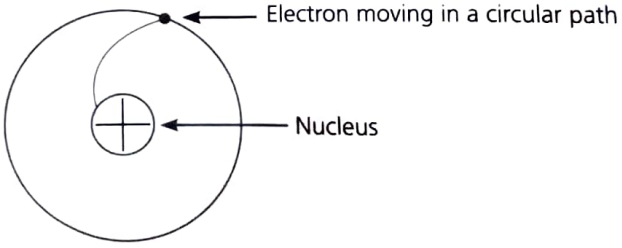
V. Enrichment

A. Isotopes of an Element Have the Same Atomic Number: Atomic number, which is the number of protons, is required to be the same for all atoms of an element. However, mass number can vary among atoms of a single element. That is, all atoms of an element have the same number of protons, but they can have different numbers of neutrons. Atoms of the same element having same atomic number, but different mass number are called **isotopes** of that element. Let us consider hydrogen and its isotopes. The atomic number of every hydrogen atom is 1, but isotopic hydrogen atoms can have mass numbers of 1, 2 or 3. These isotopes differ from one another in having 0, 1, and 2 neutrons, respectively. Oxygen is another example. The atomic number in every isotope of oxygen is 8, but their mass numbers are 16, 17, or 18, respectively. These different values of mass number correspond to having 8, 9, and 10 neutrons, respectively. Isotopes of an element have the same chemical properties but different physical properties.

B. Stability of an Atom.

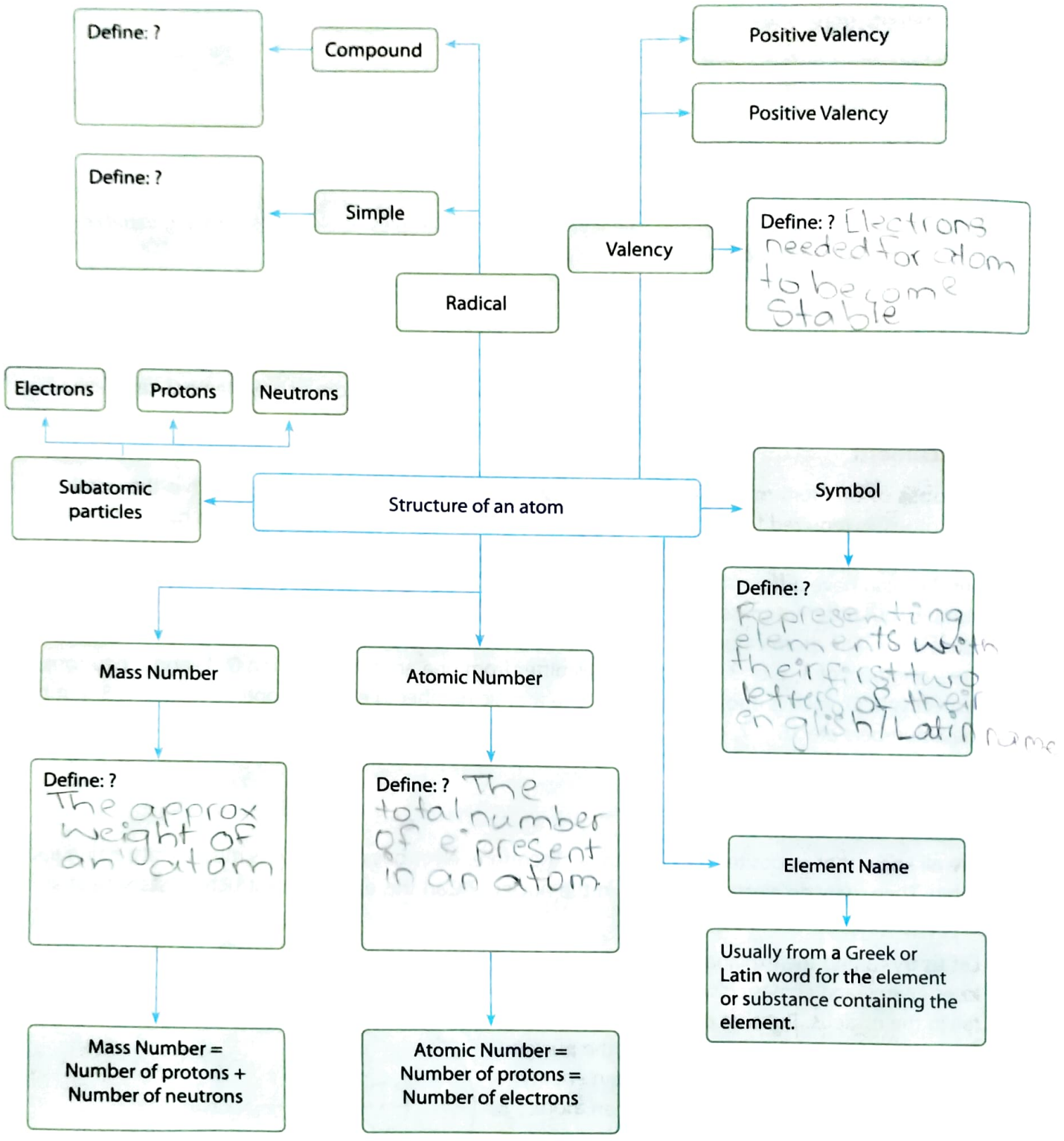
We all know that opposite charges attract. Therefore, electrons and protons must be attracting each other. Then, why do electrons not fall in the nucleus? Can this explain the structural stability of an atom?

Let us try to find the explanation. When a charged particle is allowed to move in a circular path, it loses energy and comes closer to the nucleus due to the force of attraction. After some time, it should fall in the nucleus. But that does not happen because the electrons moving around the nucleus in a given orbit can neither lose nor gain energy. This explains the structural stability of an atom. This loss or gain is possible only if an electron changes the orbit.

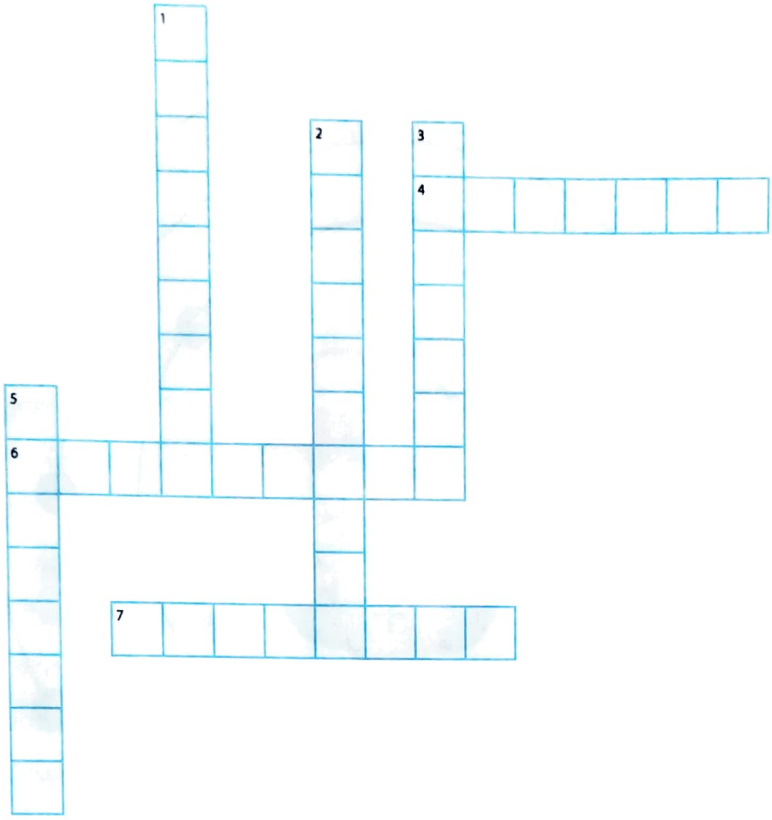


Structural stability of an atom

B. Let's learn more. Discuss, research and complete the concept map.



Solve this crossword.



Across

4. A group of atoms carrying a charge and functioning as a single unit.

6. Negatively charged particles in an atom.

7. Atoms from same or different elements combine together to form this.

Down

1. Molecules that contain three atoms of the same element.

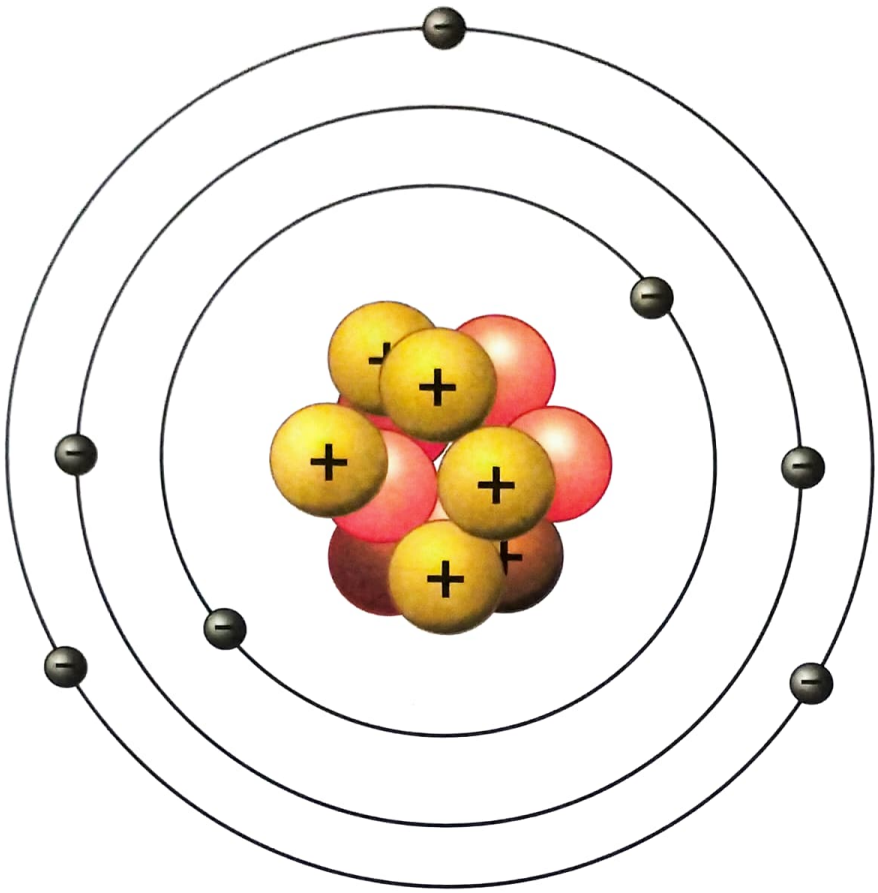
2. Molecules that contain only one atom.

3. Positively charged particles in an atom.

5. Neutral particles in an atom.

PICTURE SURVEY

Identify and label the diagram given below.



RAPID FIRE 2

Give one or two word(s) for the following:

1. The circular paths of the electrons around the nucleus.
2. An ion that consists of only one atom with a charge.
3. $Al(NO_3)_3$
4. Positively charged particles.
5. Radical with formula SO_4^{2-}.
6. A mixture in which the solute has not dissolved completely in a solvent.
7. Combining capacity of an element.
8. A pure substance made up of only one kind of particles.
9. A group of atoms that carries a charge and functions as a single unit.
10. A tabular arrangement of all the 118 elements known.
11. A substance that can be broken down into its constituent elements by chemical method.
12. Number of atoms present in a molecule of an element or compound.
13. Common name for Pb.
14. A mixture of two or more metals or non-metals in a fixed ratio.
15. Smallest unit consisting of a group of atoms.
16. An element having *Argentum* as its Latin name.
17. The symbol that we use to denote element manganese.
18. It is the symbolic representation of molecular composition.
19. A heterogeneous mixture, in which two immiscible liquids mix together.
20. Used to separate immiscible liquids from their mixture.

Help Box:

atomicity, lead, Mn, valency, shells, radical, sulphate, protons, silver, periodic table, molecule, separating funnel, element, monoatomic, compound, molecular formula, aluminium nitrate, suspension, alloy, emulsion, solution.

Practice Test Paper 1

I. State whether the following statements are True or False.

1. The process to obtain pure substance from a mixture in a solution is called distillation.
2. The more the intermolecular forces, the lesser the intermolecular spaces.
3. Digestion is a reversible process.
4. Ozone molecule is an example of triatomic molecule.
5. Burning is rapid combination of a fuel with oxygen.
6. Gases have the maximum intermolecular forces.
7. Mass of protons is more than mass of neutrons.
8. All material things in the universe are made of matter.
9. Evaporation is non-reversible in case of water.
10. Chromatography is used to separate mixture of chemicals in their liquid or gaseous form.

II. Unscramble the words to get the answer.

1. Molecules that contain only one atom. (MAOITONOMC) .....
2. Process in which matter changes from one state into another, and back to original state. (RRIINNNTVEECOOS) .....
3. Cation with symbol Li^+. (IHLTIMU) .....
4. The process by which most green plants make their food. (OSYHPHTTOSESIN) .....
5. Changes in which heat is absorbed. (DECMEINOHTR) .....

III. Give one/two word(s) for the following:

1. A reversible physical change, in which the solid can be changed back to its liquid form. .....
2. They can be compressed very easily. .....
3. An atom or molecule with a positive or negative charge. .....
4. They can flow from a higher level to a lower level. .....
5. The number of protons in the nucleus of an atom. .....

IV. Answer the following questions.

1. Briefly explain paper chromatography with an example.
2. Give five examples of monoatomic molecules.
3. Describe rusting with an example from your surroundings.
4. Why do liquids take up the shape of the container?
5. Differentiate between sublimation and melting.