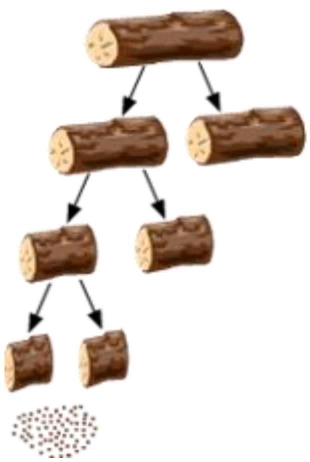
Atoms, Molecules & Radicals

Dividing Matter

Matter cannot be divided infinite number of times.



For example, if we keep chopping a log of wood into smaller and smaller pieces, then we will reach a point when the wood will not be divisible any further. Minute particles of wood will remain and these will not be visible to the naked eye. This is true for all forms of matter.The same was believed by the early Indian and Greek philosophers.

In India, around 500 BC, an Indian philosopher named Maharishi Kanad called matter as padarth and these smallest particles (atoms) as ‘parmanu’. The word ‘atom’ is derived from the Greek word ‘atomos’ which means ‘indivisible’. It was the Greek philosopher Democritus who coined the term. However, for these ancient thinkers, the idea of the minute indivisible particle was a purely philosophical consideration.

By the end of the eighteenth century, scientists had begun to distinguish between elements and compounds. Two French chemists named Antoine Lavoisier and Joseph Proust observed that elements combine in definite proportions to form compounds. On the basis of this observation, each of them proposed an important law of chemical combination. The laws proposed by them helped Dalton formulate his atomic theory.

Dalton’s Atomic Theory

In the early nineteenth century, an English chemist named John Dalton proposed a theory about **atoms**. Known as ‘Dalton’s atomic theory’, it proved to be one of the most important theories of science. The various laws of chemical combination also supported Dalton’s theory. Dalton asserted that ‘atoms are the smallest particles of matter, which cannot be divided further’. He published his atomic theory in 1808 in his book *A New System of Chemical Philosophy*. The postulates of Dalton’s atomic theory are as follows:

- All matter is made up of very tiny particles. These particles are called atoms.
- An atom cannot be divided further, i.e., atoms are indivisible.
- Atoms can be neither created nor destroyed in a chemical reaction.
- All atoms of an **element** are identical in all respects, e.g. in terms of mass, chemical properties, etc.
- Atoms of different elements have different masses and chemical properties.
- Atoms of different elements combine in small whole-number ratios to form **compounds**.
- In a given compound, the relative numbers and types of atoms are constant.

Know Your Scientist

John Dalton (1766−1844) was born into the poor family of a weaver in Eaglesfield, England. He was colour-blind from childhood. He became a teacher when he was barely twelve years old. By the time he was nineteen, he had become the principal of a school.

In 1793, Dalton left for Manchester to teach physics, chemistry and mathematics at a college. Elected a member of the Manchester Literary and Philosophy Society in 1794, he became its president in 1817 and remained in that position until his death. During his early career, he identified the hereditary nature of red−green colour blindness.

In 1803, he postulated the law of partial pressures (known as Dalton's law of partial pressures). He was the first scientist to explain the behaviour of atoms in terms of relative atomic weight. He also proposed symbolic notations for various elements.

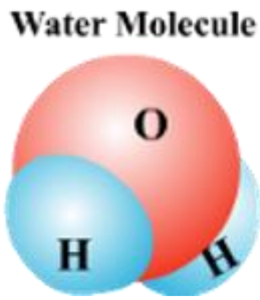
Molecules and Ions

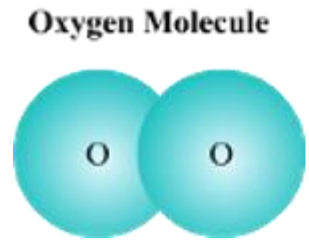
A Brief Introduction to Molecules and Ions

Most atoms are not stable in free state. So, they combine with other atoms to form molecules.

For example:

A water molecule is formed when two hydrogen atoms combine with one oxygen atom.
An oxygen molecule is formed when two oxygen atoms combine with each other.





Some atoms are charged. Such charged atoms and molecules are called ions.

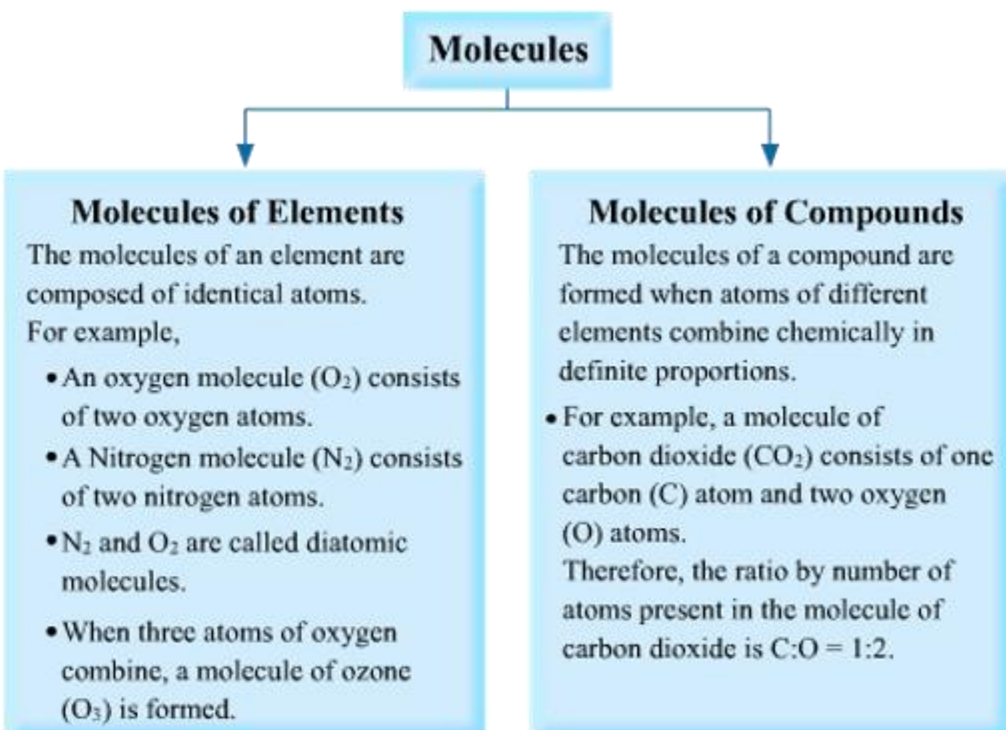
A positively charged ion is called **cation**.

A negatively charged ion is called **anion**.

In this lesson, we are going to study about:

- Molecules and molecular compounds
- Ions and ionic compounds

Molecules



Did You Know?

The term ‘**molecule’** originates from the French word ‘*molécule’,* which means ‘extremely minute particle’. It was coined by the French philosopher and mathematician Rene Descartes in the early seventeenth century.

In view of John Dalton’s laws of definite and multiple proportions, the existence of molecules was accepted by many chemists since the early nineteenth century. However, it is the work of Jean Baptiste Perrin on the Brownian motion (1911) of particles of liquids and gases which is considered to be the final proof of the existence of molecules.

Atomicity of Molecules

The number of atoms constituting a molecule is known as its atomicity. The given table lists the atomicity of some common elements.

Elements	Atomicity
Helium (He), Neon (Ne), Argon (Ar)	Monoatomic (1 atom per molecule)
Oxygen (O_2), Hydrogen (H_2), Nitrogen (N_2) Chlorine (Cl_2), Fluorine (F_2)	Diatomic (2 atoms per molecule)
Phosphorus (P_4)	Tetratomic (4 atoms per molecule)
Sulphur (S_8)	Polyatomic (8 atoms per molecule)

Did You Know?

Buckminsterfullerene is an allotrope of carbon in which sixty carbon atoms are bonded together.

Ions

An ion is a charged atom or molecule. This charge arises because the number of electrons do not equal the number of protons in the atom or molecule. An ion is also known as **radical**. A positively charged ion is called **cation**; they are also called basic radicals. While a negatively charged ion is called **anion**. Such ions are called acid radicals.

There are many ions which are **polyatomic ions**.

The given table lists the symbols and atomicity of some common ions.

Cations	Symbols	Atomicity	Anions	Symbols	Atomicity
Aluminium	Al^{3+}	Monoatomic	Bromide	Br^{-}	Monoatomic

Ammonium	NH_4^+	Polyatomic	Carbonate	CO_3^{2-}	Tetra-atomic
Calcium	Ca^{2+}	Monoatomic	Chloride	Cl^-	Monoatomic
Cuprous ion	Cu^+	Monoatomic	Fluoride	F^-	Monoatomic
Cupric ion	Cu^{2+}	Monoatomic	Hydride	H^-	Monoatomic
Hydrogen	H^+	Monoatomic	Hydroxide	OH^-	Diatomic

Ions

The given table lists the symbols and atomicity of some other common ions.

Cations	**Symbols**	**Atomicity**	**Anions**	**Symbols**	**Atomicity**
Ferric ion	Fe^{3+}	Monoatomic	Iodide	I^-	Monoatomic
Magnesium	Mg^{2+}	Monoatomic	Nitrate	NO_3^-	Tetra-atomic
Nickel	Ni^{2+}	Monoatomic	Nitride	N^{3-}	Monoatomic
Potassium	K^+	Monoatomic	Nitrite	NO_2^-	Tetra-atomic
Silver	Ag^+	Monoatomic	Oxide	O^{2-}	Monoatomic
Sodium	Na^+	Monoatomic	Phosphate	PO_4^{3-}	Polyatomic
Zinc	Zn^{2+}	Monoatomic	Sulphate	SO_4^{2-}	Polyatomic
Hydrogen carbonate	HCO_3^-	Polyatomic	Sulphite	SO_3^{2-}	Tetra-atomic

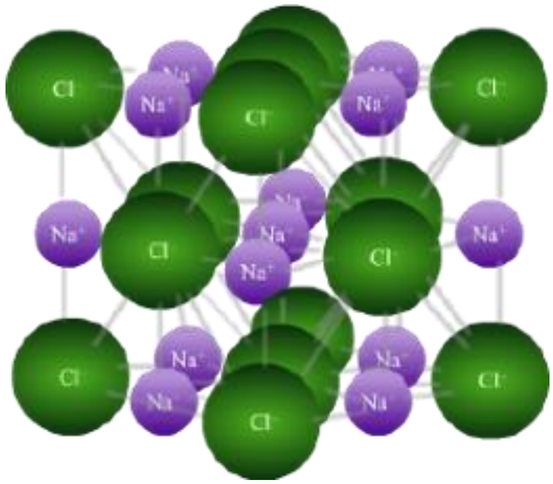
Ionic Compounds

The compounds which are formed by the combination of cations and anions are known as **ionic compounds**.

For example:

- **Zinc oxide (ZnO)**: It is formed when a zinc ion (Zn^{2+}) combines with an oxide ion (O^{2-}).
- **Magnesium chloride ($MgCl_2$)**: It is formed when a magnesium ion (Mg^{2+}) combines with two chloride ions (Cl^-).

- **Potassium bromide (KBr)**: It is formed when a potassium ion (K^+) combines with a bromide ion (Br^-).
- **Sodium chloride (NaCl)**: It is formed when a sodium ion (Na^+) combines with a chloride ion (Cl^-). The structure of NaCl crystals is shown in the given figure. You can see that there is a group of Na^+ and Cl^- ions combined with each other.



Solved Examples

Easy

Example 1:

Find the atomicity of each of the following ions.

i) $\mathbf{S^{2-}}$

ii) $\mathbf{SO_4^{2-}}$

iii) $\mathbf{NH_4^+}$

iv) $\mathbf{OH^-}$

Solution:

Ions	Atomicity
S^{2-}	1

SO_4^{2-}	5
NH_4^+	5
OH^-	2

Medium

Example 2:

Identify the anions and cations present in the following compounds.

Compounds	**Anions**	**Cations**
NaCl		
$KMnO_4$		
NaOH		
KBr		
NH_4OH		

Solution:

Compounds	**Anions**	**Cations**
NaCl	Cl^-	Na^+
$KMnO_4$	MnO_4^-	K^+
NaOH	OH^-	Na^+
KBr	Br^-	K^+
NH_4OH	OH^-	NH_4^+

Hard

Example 3:

Give the symbols and valence numbers for the following ions.

Ions	Symbols	Valence numbers
Ammonium		
Carbonate		
Sulphate		
Chloride		
Phosphate		

Solution:

Ions	Symbols	Valence numbers
Ammonium	NH_4^+	+1
Carbonate	CO_3^{2-}	−2
Sulphate	SO_4^{2-}	−2
Chloride	Cl^-	−1
Phosphate	PO_4^{3-}	−3

Valency:

We know that the outermost shell of an atom can hold a maximum of eight electrons. The elements, whose atoms have a completely filled outermost shell, have very little chemical activity. Such elements are said to have **zero combining capacity** or **valency**. For e.g., helium, neon, argon.

(The elements of the 18th group in the periodic table). These elements have either completely filled outermost shells or have 8 electrons in their outermost shell. Hence, their valency is zero. They are called **inert** or **noble gases**.

The combining capacity of atoms of the elements is their tendency to react with other atoms of the same or different molecules to attain a filled outermost shell. The outermost shell, which has eight electrons, is said to possess an **octet** and every atom tends to achieve an octet in its outermost shell. This is done by gaining, losing, or sharing its electrons. **The number of electrons gained, lost, or shared by an atom to complete its octet is called the combining capacity or valency of that atom.**

Both hydrogen and sodium contain one electron each in their outermost shells. Thus, both can lose one electron. Hence, their valency is one.

It is not always true that the number of electrons present in the outermost shell of an atom represents its valency. For example, in fluorine, there are seven electrons in the outermost shell, but the valency of fluorine is one. This is because it is energetically suitable for fluorine atom to accept one electron, rather than donating seven electrons. Hence, its valency is obtained by subtracting seven electrons from the octet.

Concept of valency

We know that the combining power or the combining capacity of an atom or an element is called its **valency**. The number of atoms of other elements with which one atom of an element combines is decided by the valency of that element.

For example, both hydrogen and chlorine have a valency of 1. Therefore, one atom of hydrogen reacts with one atom of chlorine to form one molecule of hydrogen chloride.

The valency of an ion is equal to the charge on it. The valencies of some common ions are given in the following table.

Name of ion	**Symbol**	**Valency**	**Name of ion**	**Symbol**	**Valency**
Aluminium	Al^{3+}	3	Sulphite	SO_3^{2-}	2
Ammonium	NH_4^+	1	Bromide	Br^-	1
Calcium	Ca^{2+}	2	Carbonate	CO_3^{2-}	2
Copper(II)	Cu^{2+}	2	Chloride	Cl^-	1
Hydrogen	H^+	1	Hydride	H^-	1

Iron(II)	Fe^{2+}	2	Hydrogen carbonate	HCO_3^-	1
Iron(III)	Fe^{3+}	3	Hydroxide	OH^-	1
Magnesium	Mg^{2+}	2	Nitrate	NO_3^-	1
Nickel	Ni^{2+}	2	Nitrite	NO_2^-	1
Potassium	K^+	1	Oxide	O^{2-}	2
Silver	Ag^+	1	Phosphate	PO_4^{3-}	3
Sodium	Na^+	1	Sulphate	SO_4^{2-}	2
Zinc	Zn^{2+}	2	Sulphide	S^{2-}	2

Relationship Between Valency of Elements and Periodic Table

It is observed that valency of elements increases from 1 to 4 and then decreases to 1. For noble gases, the combining capacity or the valency is zero because of their inert nature.
Since we know, there are 118 elements which are classified with the help of a periodic table, which is divided into horizontal rows and vertical columns. These horizontal rows are called periods, whereas the vertical columns are called groups.

These groups are called IA, II, IIIA, IVA, VA, VIA, VIIA, and zero group.

The periods are numbered as 1, 2, 3, 4, 5, 6 and 7.

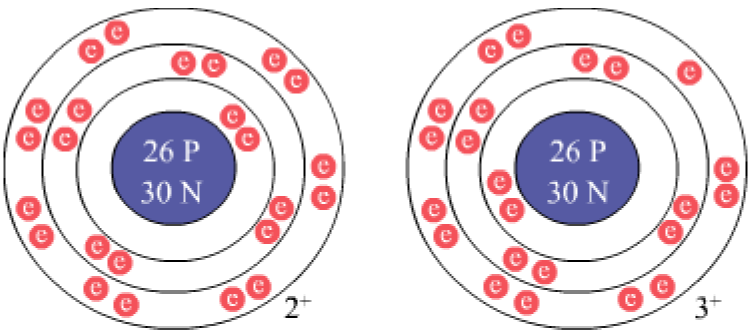
Elements present in the same group have same valency and it also corresponds to the group number up to IV.

Valencies of elements present in group V, VI and VII are 3, 2, and 1, respectively. Hence, it is clear that metals or non-metals with same valency show similar properties.

Variable valency: - It has been found that certain elements exhibit more than one valency. In such a situation, the element is said to exhibit variable valency.

The **reason for variable valency** is that an atom of some element depending upon the conditions loses more electrons than are present in its outermost shell (valence shell) i.e., it loses some electrons from the shell next to the outermost shell.

Example: - An atom of iron has two electrons in its valence shell. On losing these electrons, it attains a valency of +2. However, sometimes it loses one more electron from its inner shell and hence attains a valency of +3.



Writing Chemical Formulae of Compounds

Molecular Formula: A Brief Overview

Just like each atom has a unique symbol, each compound has a unique molecular formula.

The molecular formula of a compound provides information about the names and numbers of atoms of the different elements present in a molecule of that compound.

Molecular formula is a **chemical formula** that indicates the kinds of atoms and the numbers of each kind of atom in a molecule of a compound.

Examples

- The molecular formula of glucose is $C_6H_{12}O_6$. One molecule of glucose contains 6 atoms of carbon, 12 atoms of hydrogen and 6 atoms of oxygen.
- The molecular formula of water is H_2O. One molecule of water contains 2 atoms of hydrogen and 1 atom of oxygen.

Salient features of chemical formula:

- Compounds are formed when two or more elements combine chemically. Hence, compounds can also be represented using symbols.
- The notation used for representing any compound is called chemical formula of that compound.
- Each compound has a unique chemical formula.
- The chemical formula of any compound tells us about : The different elements which combine to form the compound and the number of atoms of each element present in a molecule of the compound
- For example, H_2O is the chemical formula of water. This denotes that there are two atoms of hydrogen and one atom of oxygen present in one molecule of water.

Chemical Formulae

Let us understand the information derived from chemical formulae by taking the example of carbon dioxide. The chemical formula of carbon dioxide is CO_2. Using this formula, we can derive the following information about carbon dioxide.

- Two elements are present in carbon dioxide: carbon(C) and oxygen (O).
- CO_2 represents one molecule of carbon dioxide.
- Since one atom of carbon combines with two atoms of oxygen, the **valency** of carbon is twice that of oxygen.
- CO_2 is a neutral molecule. It has no charge.
- The relative atomic masses of carbon and oxygen are 12 u and 16 u respectively. So, the ratio by mass between carbon and oxygen is 12 : 32, i.e., 3 : 8.

Writing Chemical Formulae

To write the chemical formula of a compound, one should have prior knowledge of two things.

- **The symbols of the constituent elements.**
- **The combining capacity of the atom of each element constituting the compound.**

The number of atoms of other elements with which one atom of an element combines is decided by the valency of that element.

For example, both hydrogen (H) and chlorine (Cl) have a valency of 1. Therefore, one atom of hydrogen reacts with one atom of chlorine to form one molecule of hydrogen chloride (HCl).

The valency of an ion is equal to the charge on it.

Chemical Formulae

The valencies of some common ions are given in the following table.

Names of ions	Symbols	Valencies	Names of ions	Symbols	Valencies
Aluminium	Al^{3+}	3	Sulphite	SO_3^{2-}	2
Ammonium	NH_4^+	1	Bromide	Br^-	1
Calcium	Ca^{2+}	2	Carbonate	CO_3^{2-}	2
Copper(II)	Cu^{2+}	2	Chloride	Cl^-	1
Hydrogen	H^+	1	Hydride	H^-	1

Chemical Formulae

The valencies of some common ions are given in the following table.

Names of ions	Symbols	Valencies	Names of ions	Symbols	Valencies
Iron(II)	Fe^{2+}	2	Hydrogen carbonate	HCO_3^-	1
Iron(III)	Fe^{3+}	3	Hydroxide	OH^-	1
Magnesium	Mg^{2+}	2	Nitrate	NO_3^-	1
Nickel	Ni^{2+}	2	Nitrite	NO_2^-	1
Potassium	K^+	1	Oxide	O^{2-}	2

Silver	Ag^{+}	1	Phosphate	PO_4^{3-}	3
Sodium	Na^{+}	1	Sulphate	SO_4^{2-}	2
Zinc	Zn^{2+}	2	Sulphide	S^{2-}	2

Chemical Formulae

The following rules need to be kept in mind while writing the chemical formulae of compounds.

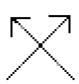
•The valencies or charges on the ions must be balanced. The charge on a cation must be equal in magnitude to the charge on an anion so that the opposite charges cancel each other out and the net charge of the molecule becomes zero.

Examples

- In case of CaO, the valency of Ca is +2 and that of O is −2. These are then crossed over and the compound formed is CaO.

Formula of calcium oxide

Symbols Ca O



Charges 2+ 2−

- The charge on Mg^{2+} is +2 and that on Cl^{-} is −1. Thus, one Mg^{2+} ion combines with two Cl^{-} ions to form a molecule with the formula $MgCl_2$.
- In case of a compound consisting of a metal and a non-metal, the symbol of the metal is written first.

Chemical Formulae

Example

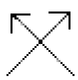
- In calcium chloride ($CaCl_2$) and zinc sulphide (ZnS), calcium and zinc are metals, so they are written first; chlorine and sulphur are non-metals, so they are written after the metals.
- In case of compounds consisting of polyatomic ions, the polyatomic ions are enclosed in brackets before writing the number to indicate the ratio.

Example

- In case of aluminium sulphate, to balance the charges, two SO_4^{2-} ions combine with one Al^{3+} ion. Thus the formula for aluminium sulphate is $Al_2(SO_4)_3$. Here, the brackets with the subscript 3 indicate that three sulphate ions are joined to two aluminium ions.

Formula of aluminium sulphate

Symbols Al SO_4



Charges 3+ 2−

Chemical Formulae

Naming Certain Compounds

Compound	Rule	Example
A metal and a non-metal	Metal is written first Non-metal is written last with suffix −*ide*	Calcium nitride (Ca_3N_2)
Two non-metals	Less electronegative non-metal is written first In case, more than one atom of a non-metal is present then prefix like −*di*, −*tri*, −*tetra* etc. is added	Phosphorous pentachloride (PCl_5)
Two elements and oxygen	Oxygen is placed at end of the formula Following prefixes or suffixes are used depending on the number of oxygen atoms present: Less than two oxygen atom: *hypo* (prefix) Two oxygen atoms: −*ite* (suffix) Three oxygen atoms: −*ate* (suffix) More than three oxygen atoms: −*per* (prefix)	Sodium hypochlorite (NaClO) Sodium chlorite ($NaClO_2$) Sodium chlorate ($NaClO_3$)

Compound	Rule	Example
		Sodium perchlorate ($NaClO_4$)
Acids	Binary acids Prefix: *hydro* Suffix: −*ic* with the name of second element Polyatomic radicals Suffix: −*ic* on the basis of second element Prefix not used	Hydrochloric acid (HCl) Sulphuric acid (H_2SO_4)
Trivial names	Used for specific compounds No systemic rule followed	Ammonia (NH_3) Water (H_2O)

Solved Examples

Easy

Example 1:

Give two examples each of molecules having one atom, two atoms and three atoms.

Solution:

Molecules having one atom (/monatomic molecules): Argon (Ar) and Neon (Ne)

Molecules having two atoms (/diatomic molecules): Nitrogen (N_2) and Oxygen (O_2)

Molecules having three atoms (/triatomic molecules): Nitrogen dioxide (NO_2) and carbon dioxide (CO_2)

Medium

Example 2:

The valencies of a few ions are provided below.

H^+ = 1, SO_4^{2-} = 2, Br^- = 1, Mg^{2+} = 2 and K^+ = 1

Write the formulae for magnesium bromide, magnesium sulphate, hydrogen bromide and potassium sulphate.

Solution:

•Magnesium bromide: $MgBr_2$

•Magnesium sulphate: $MgSO_4$

•Hydrogen bromide: HBr

•Potassium sulphate: K_2SO_4

Hard

Example 3:

Write the names of the following compounds.

i) H_2CO_3

ii) KNO_3

iii) $(NH_4)_3PO_4$

iv) Na_2CO_3

v) $Al(NO_3)_3$

vi) $NaHCO_3$

Solution:

i) H_2CO_3: Hydrogen carbonate

ii) KNO_3: Potassium nitrate

iii) $(NH_4)_3PO_4$: Ammonium phosphate

iv) Na_2CO_3: Sodium carbonate

v) $Al(NO_3)_3$: Aluminium nitrate

vi) $NaHCO_3$: Sodium hydrogen carbonate