

CHAPTER – 3



Atoms and molecules

Ancient Indian and Greek philosophers suggested that if we go on dividing matter, a stage will come when particles obtained cannot be divided further. The Indian philosopher Maharishi Kanad called these indivisible particles *parmanu*. The Greek philosopher Democritus called them *atoms* (meaning indivisible). Let us suppose that we have an element iron. If we have a small piece of iron and we start grinding it, it will break into very fine particles which cannot be further subdivided. In a way we will reach a stage when iron particles cannot be further subdivided. This ultimate particle of iron will still possess the properties of iron. Moreover, if iron undergoes chemical change, then this change must start from the ultimate particle. This smallest and ultimate particle of an element is called *atom* (Fig.3.1).

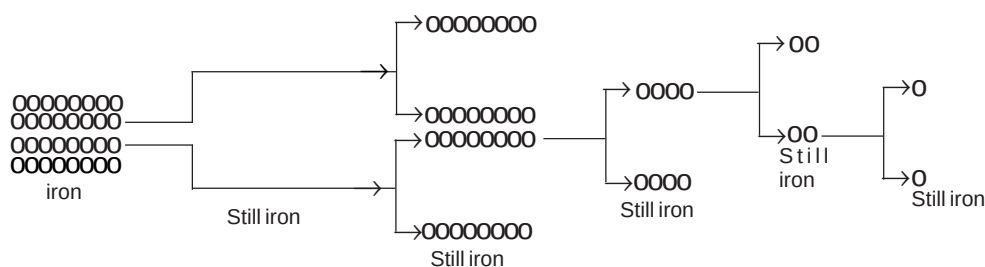


Fig.3.1. Iron divided into very fine particles

All these ideas were based on theoretical considerations and these ideas were validated by experimental works in the eighteenth century.

By the end of the eighteenth century, scientists recognised elements and compounds. They became interested in finding out *how and why elements combine and what happens when they combine*.

3.1. Laws of Chemical Combination:

Is there a change in mass when a chemical change (chemical reaction) takes place?

Activity 3.1.

- (1) Take any one of the following pairs of chemicals A and B.

A	B
(i) Barium chloride solution	Dilute sulphuric acid
(ii) Lead nitrate solution	Sodium chloride solution
(iii) Magnesium sulphate solution	Sodium carbonate solution

- (2) Take solution of A in a conical flask and some solution of B in a small test tube.

- (3) Lower the test tube along with its contents into the conical flask by holding from the free end of a thread tied to its neck.
- (4) Fix a rubber cork in the mouth of the flask so that it holds the thread firmly [Fig.3.2(a)].

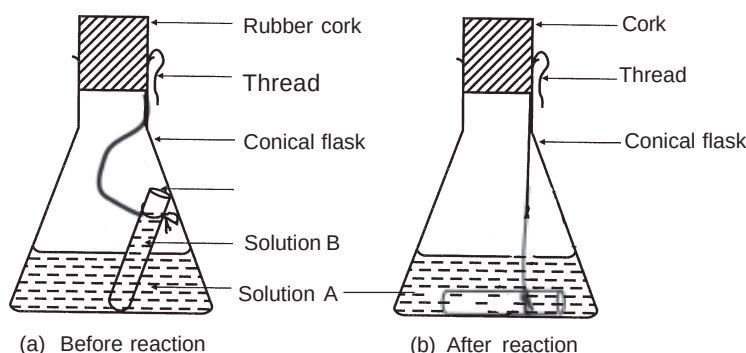


Fig. 3.2. Verification of Law of Conservation of mass.

- (5) Find the mass of flask along with its contents by weighing carefully on the balance.
- (6) Now tilt and swirl the flask so that the solutions A and B got mixed.
- (7) Observe the change in the reaction flask.
- (8) Weigh again.
- (9) Does the mass of the flask and its contents change?
- (10) Does a chemical reaction take place in the flask?

We find that there is no change in mass as a result of a chemical reaction, that is, *mass can neither be created nor destroyed*. This is known as the *Law of conservation of mass*. It was first established by Antoine L. Lavoisier in 1774 after much experimentations.

In 1799, Proust analysed the chemical composition of a large number of compounds and came to the conclusion that the proportion of each element in a compound is fixed. For example, water is a compound which always consists of the same elements, hydrogen and oxygen combined together in the same proportion of 1:8 by mass. If we decompose 9 g of water by passing electric current through it, 1 g of hydrogen and 8 g of oxygen are always obtained. Similarly in pure sodium chloride, sodium and chlorine are always present in the ratio of 23:35.5 by mass, whatever be the method or the source from which it is obtained.

This led to the *law of constant or definite proportions* which says that "*a pure compound always contains the same elements combined in the same proportions by mass*", irrespective of how it is made. Thus vitamin C (ascorbic acid) that has been prepared in the laboratory has the same composition as the vitamin C in fresh fruits and vegetables, and is equally beneficial to us.

Based on the laws of chemical combination, John Dalton put forward his atomic theory of matter in 1808. Dalton's atomic theory could provide an explanation for the law of conservation of mass and the law of definite proportion. The main postulates of the theory may be stated as follows:

- (i) Matter consists of very small particles (atoms) which are indivisible.
- (ii) Atoms cannot be created or destroyed.
- (iii) Atoms of one element are all identical: they have the same mass and the same properties.
- (iv) Atoms of different elements have different masses and different properties.
- (v) When elements combine to form compounds, the atoms of these elements unite in simple whole number ratios to form compound atoms (now called molecules).

Now think about what happens when powdered iron and powdered sulphur are heated at high temperature. They react vigorously to form the compound iron sulphide (activity 2.7). Dalton pictured such compounds as being composed of two types of atoms. Iron sulphide, for instance, consists of iron atoms and sulphur atoms. Also, because it is impossible to recognise iron and sulphur in iron sulphide, he had to imagine that the iron and sulphur atoms must be compounded or joined together in such a way that their original properties are altered.

Which postulate of Dalton's atomic theory explains the law of conservation of mass?

Since atoms can neither be created nor destroyed (postulate ii), the number and types of atoms taking part in the reaction (reactants) will necessarily be the same as the number and types of atoms in the products. So, the total mass of products is equal to the total mass of reactants.

Which postulate of Dalton's atomic theory explains the law of definite proportions?

Postulates (iii) and (iv) states that atoms of the same element are identical in mass and properties whereas atoms of different elements are different in mass and properties. And, postulates (v) says that different elements combine to form compound atoms in fixed number of ratios. Since the number of atoms, the kind of atoms and the mass of atoms of each element in a compound is fixed, therefore, a compound will always have the same elements combined together in the same proportion by mass.

Now, an atom is regarded as the smallest particle of an element which can take part in a chemical change.

You may probably like to think how much of the Dalton's atomic theory, we still accept today in the light of our considerably greater knowledge. For this you have to wait till a later stage.

Let us answer these:

1. Name any two laws of chemical combination.
2. What law of chemical combination was given by
 - (a) Lavoisier
 - (b) Proust?

3. 10.6 g of sodium carbonate reacted with 7.3 g of hydrochloric acid producing 11.7 g of sodium chloride, 1.8 g of water and 4.4 g of carbon dioxide gas. Show that this data verifies the law of conservation of mass.
4. A pure sample of calcium oxide contains calcium and oxygen in the ratio 5:2 by mass. How many grams of calcium will be required to combine with 32 g of oxygen to form calcium oxide.
5. Which postulates of Dalton's atomic theory can explain:
 - (a) Law of conservation of mass and
 - (b) Law of constant proportions?

3.2. Molecules:

How do atoms exist?

Dalton believed that all matter is composed of one or more different types of atoms. Each element must therefore consist of one type only, like a wall built of one type of bricks; and each compound must consist of several different types, like a wall built of more than one type of bricks.

Is an atom able to exist independently? It may or may not. According to Amadeo Avogadro, the *molecules*, and not the *atoms* were the smallest material particles that are capable of independent or free existence. A molecule is in general composed of two or more atoms of the same element or of different elements chemically bonded together, which are, of course, indivisible in chemical reactions. Thus, a clear distinction was made between the ultimate particles of matter, viz. the atoms, and the smallest one, capable of free existence with all the relevant properties of the matter, viz. the molecules.

Thus, *a molecule is defined as the smallest particle of an element or compound that is capable of an independent existence and shows all the properties of that substance.*

3.2.1. Molecules of elements:

Molecules of an element is composed of atoms of the same kind. For example, a molecule of oxygen consists of two atoms of oxygen and hence it is known as a *diatomic molecule*. If three atoms of oxygen unite into a molecule, instead of usual 2, we get ozone. Hydrogen, nitrogen, chlorine molecules also consist of two atom each. The number of atoms constituting a molecule is known as its *atomicity*.

Molecules of some elements, such as helium, neon, argon etc. consist of only one atom of that element. Their molecules are *monoatomic*.

Molecules of metals and some other elements, such as carbon, do not have a simple structure but consists of a very large and indefinite number of atoms bonded together.

Atomicity of some common elements are given in Table 3.1.

Table 3.1. Atomicity of some common elements.

Types of elements	Name	Atomicity
Non-metal	Helium	1 (monoatomic)
	Neon	1 "
	Argon	1 "
	Hydrogen	2 (diatomic)
	Oxygen	2 "
	Nitrogen	2 "
	Chlorine	2 "
	Ozone	3 (triatomic)
	Phosphorous	4 (tetra-atomic)
Metal	Iron	1 (monoatomic)
	Copper	1 "
	Silver	1 "

3.2.2. Molecules of compounds:

Atoms of different elements combine together in definite proportions to form molecules of compounds. For example, water is a compound whose molecules are made up of two atoms of hydrogen and one atom of oxygen. Similarly, a molecule of hydrogen chloride contains one atom of hydrogen and one atom of chlorine combined together. An ammonia molecule is formed when an atom of nitrogen combines with three atoms of hydrogen.

3.3. How big are the atoms and molecules?

If matter is made up of atoms and molecules, how large are the particles? Think of some grains of a solid that can just be seen by our naked eye. We may think of a grain of very finely sieved flour. This has a diameter of about 10^{-1} mm (or 0.0001m) . Using an ordinary microscope it is possible to see pieces of material as small as about 10^{-3} mm (0.001 mm). A modern instrument called the electron microscope is capable of much greater magnification, and this remarkable instrument has detected objects with diameters as small as 10^{-5} mm (0.00001 mm). Clearly, if matter is composed of molecules, the diameter of the constituent particles which make up cannot be larger than about 10^{-5} mm.

In activity 1.3 (chapter 1), it is shown that 0.10g of potassium permanganate can be split into at least 10^5 parts, so that each part has a mass of about 10^{-6} g. Thus the mass of the particles (molecules) which make up this substance cannot be greater than about 10^{-6} g.

From this evidence and that of electron microscope, it is clear that the particles (atoms or molecules) which appear to exist in all types of matter must be very small indeed. Is it possible to say more precisely how small these particles are?

3.3.1. Finding the approximate size of a molecule:

Activity 3.2.

- * Take water in a tray or container (more than 30 cm square so as not to restrict an oil film on the surface)
- * Sprinkle the surface of the water with a very thin light powder such as talc powder.
- * Put a drop of kerosene on water at the middle of the tray.
- * Find out the area of the oil spread out on the water surface pushing the powder away. (Fig. 3.3).
- * To find the volume of oil, pour the oil into a burette. Find the volume of fifty drops by running oil from the burette drop by drop and counting the drops.
- * Calculate the volume of oil put on the water.
- * Finally estimates can be made of the thickness of the oil layer by dividing the volume of the oil by the area it spread out.

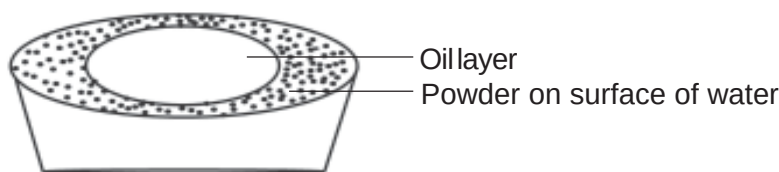


Fig. 3.3

When a drop of oil spreads over the surface of water, it forms a very thin 'skin'. Estimates can be made of thickness of this 'skin'. The smallest values obtained are about 2×10^{-6} mm (0.000002 mm). In this thickness of oil there must be at least one layer of molecules. So oil molecules must be at least as small as 10^{-6} mm in diameter, and they could be even smaller.

3.3.2. Atomic Radii

Since molecules are made up of atoms, they could be even smaller. It is very difficult to imagine anything as small as the atoms. There are about 6×10^9 people on this planet. There are about 1×10^{11} stars in the milky way. The diameter of our galaxy is about 2.3×10^{17} kilometers. But there are about 6×10^{21} atoms in 1g of silver.

The size of an atom is indicated by its radius which is called atomic radius. Atomic radius is measured in nanometers (nm)

$$1 \text{ nm} = \frac{1}{10^9} \text{ metre} \\ = 10^{-9} \text{ m}$$

Nowadays, atomic radii can be deduced from X-ray diffraction camera and spectroscopic studies. Atomic radii of some common elements are given below.

Table 3.2 Atomic radii of some common elements

Element	Atomic radius	Element	Atomic radius
1. Hydrogen	0.037 nm	Copper	0.128 nm
2. Carbon	0.077 nm	Iron	0.126 nm
3. Oxygen	0.073 nm	Gold	0.144 nm
4. Sulphur	0.104 nm	Sodium	0.191 nm
5. Nitrogen	0.074 nm	Calcium	0.197 nm

3.2.3. Atomic mass:

In his atomic theory, Dalton has proposed that a given element is made up of atoms which have identical masses. The theory could explain the law of constant proportions. This has prompted scientists to measure the mass of an atom directly. However relative atomic masses could be determined using the laws of chemical combinations and the compounds formed.

For example, a compound carbon monoxide is formed by combination of carbon with oxygen. It was found experimentally that 3g of carbon combine with 4g of oxygen to form 7g of carbon monoxide. In other words, carbon combines with $\frac{4}{3}$ times the mass of oxygen. Suppose that we have a unit which takes the mass of an atom of

carbon as 1, then we would assign the mass of oxygen as $\frac{4}{3}$. It will be more convenient to have these numbers as whole numbers or as near to whole numbers as possible.

Since, 1961, by international agreement, a universally accepted atomic mass unit (amu) has been introduced. In this unit, the mass of one atom of carbon (strictly an atom of carbon-12) is taken as 12 atomic mass units (amu). Earlier atomic mass unit was abbreviated, as "amu", but now, according to IUPAC (International Union of Pure and Applied Chemistry) recommendations, is written as "u"-unified mass). Since a carbon-12 atom has been assigned an atomic mass of exactly 12 u, therefore, the *atomic mass unit has been defined as 1/12 (one-twelfth) the mass of the carbon-12 atom.*

Thus, $1\text{ u} = \frac{1}{12}$ the mass of a carbon -12 atom.

The relative atomic masses of all elements have been found with respect to an atom of carbon-12. The atomic mass is defined as the average relative mass of *an atom of an element as compared to the mass of an atom of carbon taken as 12.*

Relative mass of atoms can be obtained from the masses of elements taking part in a chemical reaction or by an instrument called the mass spectrometre.

The atomic masses of some common elements are given in Table 3.3

Table 3.3 Atomic masses of some common elements

Element	Atomic mass (u)
Hydrogen	1
Carbon	12
Oxygen	16
Nitrogen	14
Chlorine	35.5
Sulphur	32
Sodium	23
Calcium	40
Magnesium	24
Phosphorus	31

Gram atomic mass:

The atomic mass of an element expressed in grams is called the gram-atomic mass of the element.

For example, the atomic mass of oxygen (O) = 16 u

Therefore, gram atomic mass of oxygen (O) = 16 g.

The gram-atomic mass of an element is also called *gram-atom*.

Example:

What is the gram-atomic mass of sodium (Na)?

Solution:

Atomic mass of sodium (Na) = 23 u

Gram atomic-mass of sodium (Na) = 23 g.

Let us answer these:

1. Define an atom.
2. In what unit the radius of an atom is usually expressed?
3. What is a molecule? Explain with an example.
4. What is the difference between the molecule of an element and the molecule of a compound? Illustrate with one example each.
5. What is meant by atomicity? Give example.
6. Define atomic mass. What is meant by saying that atomic mass of Calcium is 40.

SUMMARY

1. Law of conservation of mass states that, the sum of the masses of reactants and products remain unchanged in a chemical reaction.
2. Law of definite proportions states that a pure compound always contains the same elements combined in the same proportions by mass.
3. An atom is the smallest particle of an element which can take part in a chemical reaction.
4. Dalton's atomic theory explains the law of conservation of mass and the law of definite proportions.
5. A molecule is the smallest particle of an element or compound that is capable of independent existence and shows all the properties of that substance.
6. The mass of an atom of carbon -12 is assigned atomic mass of 12 atomic mass units and the atomic mass of other elements are obtained by comparison with the mass of a carbon -12 atom.

EXERCISES

1. *What are the postulates of Dalton's atomic theory?*
2. *3 g of magnesium combines with 2 g of oxygen to produce 5 g of magnesium oxide compound. If 6 g of magnesium is allowed to react with 20 g of oxygen, what mass of magnesium oxide will be produced in the reaction? Name the law which governs your answer.*
3. *Distinguish between atom and molecule of an element.*
4. *Define atomic mass unit.*
5. *Why are atoms regarded as building blocks of all matter?*