

## UNIT 1

## SOME BASIC CONCEPTS OF CHEMISTRY

## Objectives

After studying this unit, you will be able to

- understand and appreciate the role of chemistry in different spheres of life;
- explain the characteristics of three states of matter;
- classify different substances into elements, compounds and mixtures;
- define SI base units and list some commonly used prefixes;
- use scientific notations and perform simple mathematical operations on numbers;
- differentiate between precision and accuracy;
- determine significant figures;
- convert physical quantities from one system of units to another;
- explain various laws of chemical combination;
- appreciate significance of atomic mass, average atomic mass, molecular mass and formula mass;
- describe the terms – mole and molar mass;
- calculate the mass per cent of different elements constituting a compound;
- determine empirical formula and molecular formula for a compound from the given experimental data;
- perform the stoichiometric calculations.

*Chemistry is the science of molecules and their transformations. It is the science not so much of the one hundred elements but of the infinite variety of molecules that may be built from them...*

Roald Hoffmann

Chemistry deals with the composition, structure and properties of matter. These aspects can be best described and understood in terms of basic constituents of matter: **atoms** and **molecules**. That is why chemistry is called the science of atoms and molecules. Can we see, weigh and perceive these entities? Is it possible to count the number of atoms and molecules in a given mass of matter and have a quantitative relationship between the mass and number of these particles (atoms and molecules)? We will like to answer some of these questions in this Unit. We would further describe how physical properties of matter can be quantitatively described using numerical values with suitable units.

### 1.1 IMPORTANCE OF CHEMISTRY

Science can be viewed as a continuing human effort to systematize knowledge for describing and understanding nature. For the sake of convenience science is sub-divided into various disciplines: chemistry, physics, biology, geology etc. Chemistry is the branch of science that studies the composition, properties and interaction of matter. Chemists are interested in knowing how chemical transformations occur. Chemistry plays a central role in science and is often intertwined with other branches of science like physics, biology, geology etc. Chemistry also plays an important role in daily life.

Chemical principles are important in diverse areas, such as: weather patterns, functioning of brain and operation

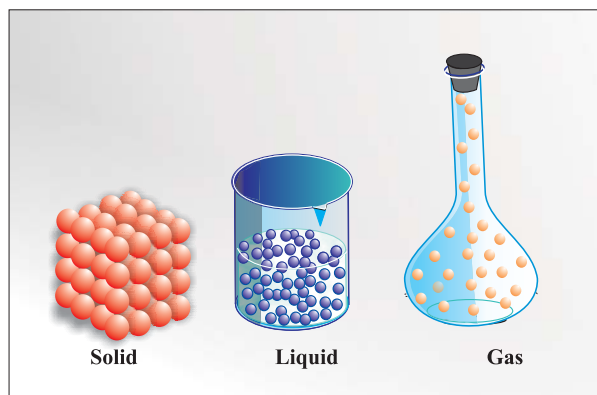
of a computer. Chemical industries manufacturing fertilizers, alkalis, acids, salts, dyes, polymers, drugs, soaps, detergents, metals, alloys and other inorganic and organic chemicals, including new materials, contribute in a big way to the national economy.

Chemistry plays an important role in meeting human needs for food, health care products and other materials aimed at improving the quality of life. This is exemplified by the large scale production of a variety of fertilizers, improved varieties of pesticides and insecticides. Similarly many life saving drugs such as **cisplatin** and **taxol**, are effective in cancer therapy and AZT (Azidothymidine) used for helping AIDS victims, have been isolated from plant and animal sources or prepared by synthetic methods.

With a better understanding of chemical principles it has now become possible to design and synthesize new materials having specific magnetic, electric and optical properties. This has led to the production of superconducting ceramics, conducting polymers, optical fibres and large scale miniaturization of solid state devices. In recent years chemistry has tackled with a fair degree of success some of the pressing aspects of environmental degradation. Safer alternatives to environmentally hazardous refrigerants like CFCs (chlorofluorocarbons), responsible for ozone depletion in the stratosphere, have been successfully synthesised. However, many big environmental problems continue to be matters of grave concern to the chemists. One such problem is the management of the Green House gases like methane, carbon dioxide etc. Understanding of bio-chemical processes, use of enzymes for large-scale production of chemicals and synthesis of new exotic materials are some of the intellectual challenges for the future generation of chemists. A developing country like India needs talented and creative chemists for accepting such challenges.

## 1.2 NATURE OF MATTER

You are already familiar with the term **matter** from your earlier classes. Anything which has mass and occupies space is called **matter**.



**Fig. 1.1** Arrangement of particles in solid, liquid and gaseous state

Everything around us, for example, book, pen, pencil, water, air, all living beings etc. are composed of matter. You know that they have mass and they occupy space.

You are also aware that matter can exist in three physical states *viz.* **solid**, **liquid** and **gas**. The constituent particles of matter in these three states can be represented as shown in Fig. 1.1. In **solids**, these particles are held very close to each other in an orderly fashion and there is not much freedom of movement. In **liquids**, the particles are close to each other but they can move around. However, in **gases**, the particles are far apart as compared to those present in solid or liquid states and their movement is easy and fast. Because of such arrangement of particles, different states of matter exhibit the following characteristics:

- (i) Solids have *definite volume* and *definite shape*.
- (ii) Liquids have *definite volume* but *not the definite shape*. They take the shape of the container in which they are placed.
- (iii) Gases have *neither definite volume nor definite shape*. They completely occupy the container in which they are placed.

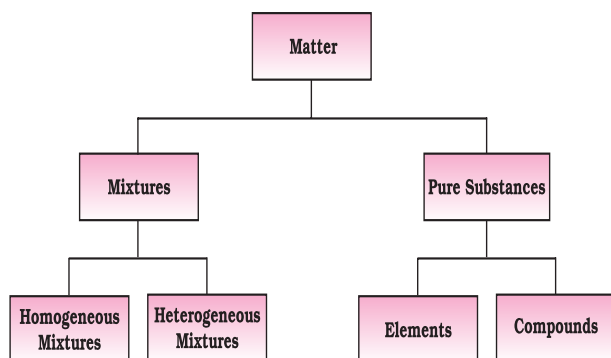
These three states of matter are interconvertible by changing the conditions of temperature and pressure.



On heating a solid usually changes to a liquid and the liquid on further heating

changes to the gaseous ( or vapour) state. In the reverse process, a gas on cooling liquifies to the liquid and the liquid on further cooling freezes to the solid.

At the macroscopic or bulk level, matter can be classified as **mixtures** or **pure substances**. These can be further sub-divided as shown in Fig. 1.2.



**Fig. 1.2** Classification of matter

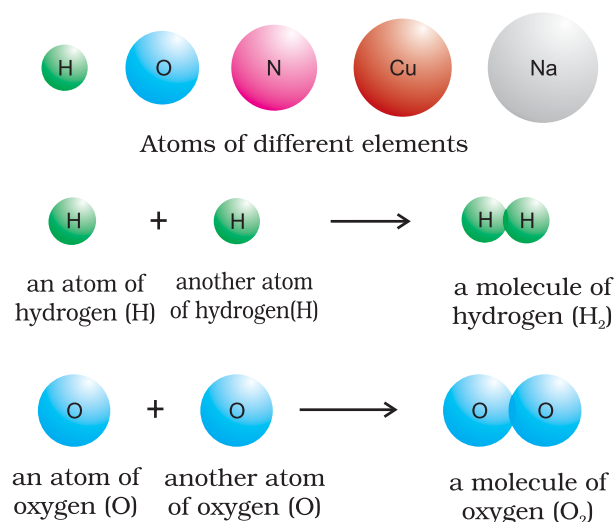
Many of the substances present around you are **mixtures**. For example, sugar solution in water, air, tea etc., are all mixtures. A mixture contains two or more substances present in it (in any ratio) which are called its components. A mixture may be **homogeneous** or **heterogeneous**. In a **homogeneous mixture**, the components completely mix with each other and its composition is uniform throughout. Sugar solution, and air are thus, the examples of homogeneous mixtures. In contrast to this, in **heterogeneous mixtures**, the composition is not uniform throughout and sometimes the different components can be observed. For example, the mixtures of salt and sugar, grains and pulses along with some dirt (often stone) pieces, are heterogeneous mixtures. You can think of many more examples of mixtures which you come across in the daily life. It is worthwhile to mention here that the components of a mixture can be separated using physical methods such as simple hand picking, filtration, crystallisation, distillation etc.

**Pure substances** have characteristics different from the mixtures. They have fixed composition, whereas mixtures may contain the components in any ratio and their

composition is variable. Copper, silver, gold, water, glucose are some examples of pure substances. Glucose contains carbon, hydrogen and oxygen in a fixed ratio and thus, like all other pure substances has a fixed composition. Also, the constituents of pure substances cannot be separated by simple physical methods.

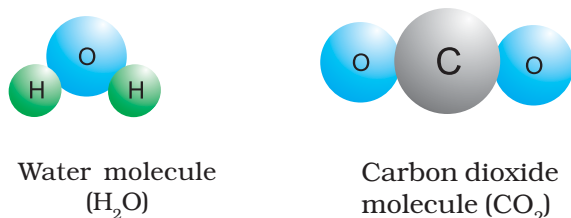
*Pure substances* can be further classified into **elements** and **compounds**. An **element** consists of only one type of particles. These particles may be **atoms** or **molecules**. You may be familiar with atoms and molecules from the previous classes; however, you will be studying about them in detail in Unit 2. Sodium, copper, silver, hydrogen, oxygen etc. are some examples of elements. They all contain atoms of one type. However, the atoms of different elements are different in nature. Some elements such as sodium or copper, contain single atoms held together as their constituent particles whereas in some others, two or more atoms combine to give **molecules** of the element. Thus, hydrogen, nitrogen and oxygen gases consist of molecules in which two atoms combine to give their respective molecules. This is illustrated in Fig. 1.3.

When two or more atoms of different elements combine, the molecule of a **compound** is obtained. The examples of some compounds are water, ammonia, carbon



**Fig. 1.3** A representation of atoms and molecules

dioxide, sugar etc. The molecules of water and carbon dioxide are represented in Fig 1.4.



**Fig. 1.4** A depiction of molecules of water and carbon dioxide

You have seen above that a water molecule comprises two hydrogen atoms and one oxygen atom. Similarly, a molecule of carbon dioxide contains two oxygen atoms combined with one carbon atom. Thus, the atoms of different elements are present in a compound in a fixed and definite ratio and this ratio is characteristic of a particular compound. Also, the properties of a compound are different from those of its constituent elements. For example, hydrogen and oxygen are gases whereas the compound formed by their combination *i.e.*, water is a liquid. It is interesting to note that hydrogen burns with a pop sound and oxygen is a supporter of combustion, but water is used as a fire extinguisher.

Moreover, the constituents of a compound cannot be separated into simpler substances by physical methods. They can be separated by chemical methods.

### 1.3 PROPERTIES OF MATTER AND THEIR MEASUREMENT

Every substance has unique or characteristic properties. These properties can be classified into two categories – **physical properties** and **chemical properties**.

**Physical properties** are those properties which can be measured or observed without changing the identity or the composition of the substance. Some examples of physical properties are colour, odour, melting point, boiling point, density etc. The measurement or observation of **chemical properties** require a chemical change to occur. The examples of

chemical properties are characteristic reactions of different substances; these include acidity or basicity, combustibility etc.

Many properties of matter such as length, area, volume, etc., are quantitative in nature. Any quantitative observation or measurement is represented by a number followed by units in which it is measured. For example length of a room can be represented as 6 m; here 6 is the number and m denotes *metre* – the unit in which the length is measured.

Two different systems of measurement, *i.e.* the **English System** and the **Metric System** were being used in different parts of the world. The metric system which originated in France in late eighteenth century, was more convenient as it was based on the decimal system. The need of a common standard system was being felt by the scientific community. Such a system was established in 1960 and is discussed below in detail.

#### 1.3.1 The International System of Units (SI)

The International System of Units (in French *Le Systeme International d'Unités* – abbreviated as SI) was established by the 11th General Conference on Weights and Measures (CGPM from *Conference Generale des Poids at Measures*). The CGPM is an inter governmental treaty organization created by a diplomatic treaty known as Meter Convention which was signed in Paris in 1875.

The SI system has seven *base units* and they are listed in Table 1.1. These units pertain to the seven fundamental scientific quantities. The other physical quantities such as speed, volume, density etc. can be derived from these quantities.

The definitions of the SI base units are given in Table 1.2.

The SI system allows the use of prefixes to indicate the multiples or submultiples of a unit. These prefixes are listed in Table 1.3.

Let us now quickly go through some of the quantities which you will be often using in this book.

**Table 1.1 Base Physical Quantities and their Units**

| Base Physical Quantity    | Symbol for Quantity  | Name of SI Unit | Symbol for SI Unit |
|---------------------------|----------------------|-----------------|--------------------|
| Length                    | <i>l</i>             | metre           | m                  |
| Mass                      | <i>m</i>             | kilogram        | kg                 |
| Time                      | <i>t</i>             | second          | s                  |
| Electric current          | <i>I</i>             | ampere          | A                  |
| Thermodynamic temperature | <i>T</i>             | kelvin          | K                  |
| Amount of substance       | <i>n</i>             | mole            | mol                |
| Luminous intensity        | <i>I<sub>v</sub></i> | candela         | cd                 |

**Table 1.2 Definitions of SI Base Units**

|  |                 |   |
|--|-----------------|---|
| <b>Unit of length</b>                    | <b>metre</b>    | The <i>metre</i> is the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second.  |
| <b>Unit of mass</b>                      | <b>kilogram</b> | The <i>kilogram</i> is the unit of mass; it is equal to the mass of the international prototype of the kilogram.  |
| <b>Unit of time</b>                      | <b>second</b>   | The <i>second</i> is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium-133 atom.   |
| <b>Unit of electric current</b>          | <b>ampere</b>   | The <i>ampere</i> is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 metre apart in vacuum, would produce between these conductors a force equal to $2 \times 10^{-7}$ newton per metre of length.  |
| <b>Unit of thermodynamic temperature</b> | <b>kelvin</b>   | The <i>kelvin</i> , unit of thermodynamic temperature, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.  |
| <b>Unit of amount of substance</b>       | <b>mole</b>     | 1. The <i>mole</i> is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon-12; its symbol is "mol."<br>2. When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles. |
| <b>Unit of luminous intensity</b>        | <b>candela</b>  | The <i>candela</i> is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency $540 \times 10^{12}$ hertz and that has a radiant intensity in that direction of 1/683 watt per steradian.  |

**Table 1.3 Prefixes used in the SI System**

| Multiple   | Prefix | Symbol |
|------------|--------|--------|
| $10^{-24}$ | yocto  | y      |
| $10^{-21}$ | zepto  | z      |
| $10^{-18}$ | atto   | a      |
| $10^{-15}$ | femto  | f      |
| $10^{-12}$ | pico   | p      |
| $10^{-9}$  | nano   | n      |
| $10^{-6}$  | micro  | $\mu$  |
| $10^{-3}$  | milli  | m      |
| $10^{-2}$  | centi  | c      |
| $10^{-1}$  | deci   | d      |
| 10         | deca   | da     |
| $10^2$     | hecto  | h      |
| $10^3$     | kilo   | k      |
| $10^6$     | mega   | M      |
| $10^9$     | giga   | G      |
| $10^{12}$  | tera   | T      |
| $10^{15}$  | peta   | P      |
| $10^{18}$  | exa    | E      |
| $10^{21}$  | zeta   | Z      |
| $10^{24}$  | yotta  | Y      |

### 1.3.2 Mass and Weight

**Mass** of a substance is the amount of matter present in it while **weight** is the force exerted by gravity on an object. The mass of a substance is constant whereas its weight may vary from one place to another due to change in gravity. You should be careful in using these terms.

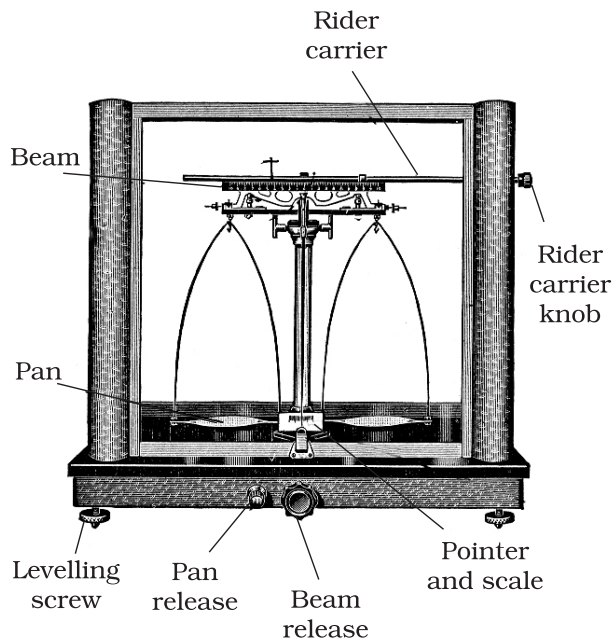
The mass of a substance can be determined very accurately in the laboratory by using an analytical balance (Fig. 1.5).

The SI unit of mass as given in Table 1.1 is kilogram. However, its fraction gram (1 kg = 1000 g), is used in laboratories due to the smaller amounts of chemicals used in chemical reactions.

### Volume

Volume has the units of (length)<sup>3</sup>. So in SI system, volume has units of m<sup>3</sup>. But again, in

chemistry laboratories, smaller volumes are used. Hence, volume is often denoted in cm<sup>3</sup> or dm<sup>3</sup> units.

**Fig. 1.5** Analytical balance

### Maintaining the National Standards of Measurement

The system of units including unit definitions keeps on changing with time. Whenever the accuracy of measurement of a particular unit was enhanced substantially by adopting new principles, member nations of *metre treaty* (signed in 1875), agreed to change the formal definition of that unit. Each modern industrialized country including India has a National Metrology Institute (NMI) which maintains standards of measurements. This responsibility has been given to the National Physical Laboratory (NPL), New Delhi. This laboratory establishes experiments to realize the *base units* and *derived units* of measurement and maintains National Standards of Measurement. These standards are periodically inter-compared with standards maintained at other National Metrology Institutes in the world as well as those established at the International Bureau of Standards in Paris.

A common unit, litre (L) which is not an SI unit, is used for measurement of volume of liquids.

$$1 \text{ L} = 1000 \text{ mL}, 1000 \text{ cm}^3 = 1 \text{ dm}^3$$

Fig. 1.6 helps to visualise these relations.

In the laboratory, volume of liquids or solutions can be measured by graduated cylinder, burette, pipette etc. A volumetric flask is used to prepare a known volume of a solution. These measuring devices are shown in Fig. 1.7.

### Density

Density of a substance is its amount of mass per unit volume. So SI units of density can be obtained as follows:

$$\begin{aligned} \text{SI unit of density} &= \frac{\text{SI unit of } m}{\text{SI unit of } v} \\ &= \frac{\text{kg}}{\text{m}^3} \text{ or } \text{kg m}^{-3} \end{aligned}$$

This unit is quite large and a chemist often expresses density in  $\text{g cm}^{-3}$ , where mass is expressed in gram and volume is expressed in  $\text{cm}^3$ .

### Temperature

There are three common scales to measure temperature — C (degree celsius), F (degree fahrenheit) and K (kelvin). Here, K is the SI unit. The thermometers based on these scales are shown in Fig. 1.8. Generally, the thermometer with celsius scale are calibrated from 0 to 100 where these two temperatures are the freezing point and the boiling point of water respectively. The fahrenheit scale is represented between 32 to 212.

The temperatures on two scales are related to each other by the following relationship:

$$^{\circ}\text{F} = \frac{9}{5}(^{\circ}\text{C}) + 32$$

The kelvin scale is related to celsius scale as follows :

$$\text{K} = ^{\circ}\text{C} + 273.15$$

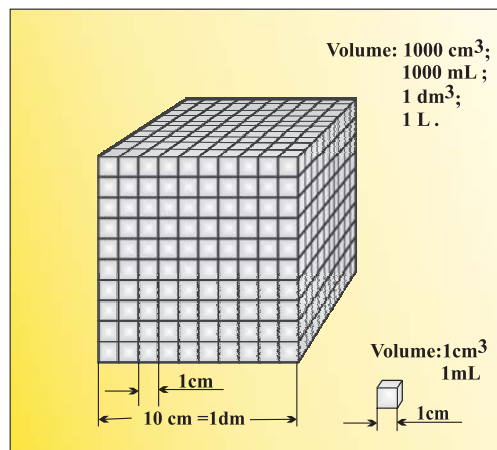


Fig. 1.6 Different units used to express volume

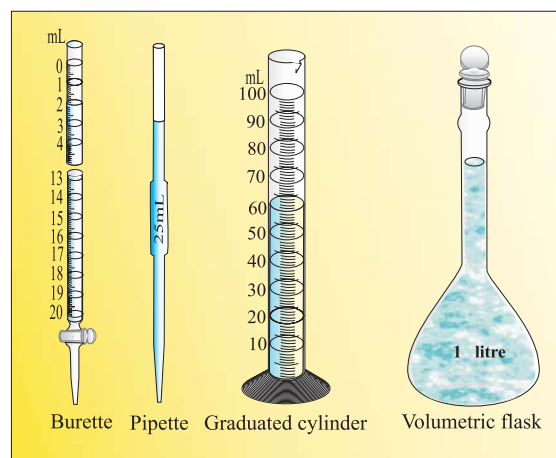


Fig 1.7 Some volume measuring devices

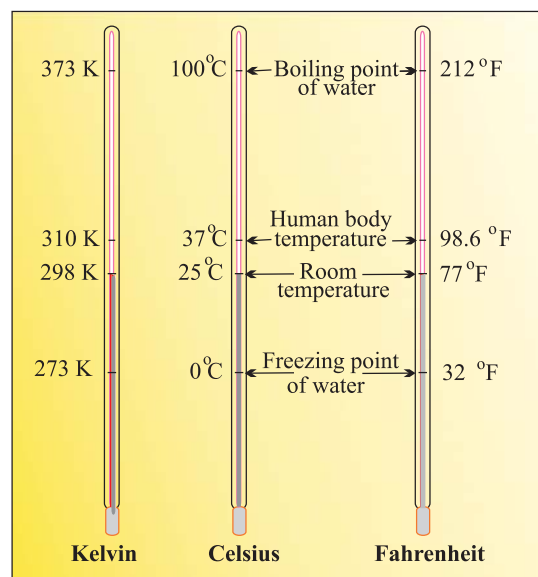


Fig. 1.8 Thermometers using different temperature scales

It is interesting to note that temperature below 0 °C (i.e. negative values) are possible in Celsius scale but in Kelvin scale, negative temperature is not possible.

### Reference Standard

After defining a unit of measurement such as the kilogram or the metre, scientists agreed on reference standards that make it possible to calibrate all measuring devices. For getting reliable measurements, all devices such as *metre sticks* and *analytical balances* have been calibrated by their manufacturers to give correct readings. However, each of these devices is standardised or calibrated against some reference. The mass standard is the kilogram since 1889. It has been defined as the mass of platinum-iridium (Pt-Ir) cylinder that is stored in an airtight jar at International Bureau of Weights and Measures in Sevres, France. Pt-Ir was chosen for this standard because it is highly resistant to chemical attack and its mass will not change for an extremely long time.

Scientists are in search of a new standard for mass. This is being attempted through accurate determination of Avogadro constant. Work on this new standard focuses on ways to measure accurately the number of atoms in a well-defined mass of sample. One such method, which uses X-rays to determine the atomic density of a crystal of ultrapure silicon, has an accuracy of about 1 part in  $10^6$  but has not yet been adopted to serve as a standard. There are other methods but none of them are presently adequate to replace the Pt-Ir cylinder. No doubt, changes are expected within this decade.

The metre was originally defined as the length between two marks on a Pt-Ir bar kept at a temperature of 0 °C (273.15 K). In 1960 the length of the metre was defined as  $1.65076373 \times 10^6$  times the wavelength of light emitted by a krypton laser. Although this was a cumbersome number, it preserved the length of the metre at its agreed value. The metre was redefined in 1983 by CGPM as the length of path travelled by light in vacuum during a time interval of  $1/299\,792\,458$  of a second. Similar to the length and the mass, there are reference standards for other physical quantities.

## 1.4 UNCERTAINTY IN MEASUREMENT

Many a times in the study of chemistry, one has to deal with experimental data as well as theoretical calculations. There are meaningful ways to handle the numbers conveniently and present the data realistically with certainty to the extent possible. These ideas are discussed below in detail.

### 1.4.1 Scientific Notation

As chemistry is the study of atoms and molecules which have extremely low masses and are present in extremely large numbers, a chemist has to deal with numbers as large as 602, 200,000,000,000,000,000 for the molecules of 2 g of hydrogen gas or as small as 0.00000000000000000000000166 g mass of a H atom. Similarly other constants such as Planck's constant, speed of light, charges on particles etc., involve numbers of the above magnitude.

It may look funny for a moment to write or count numbers involving so many zeros but it offers a real challenge to do simple mathematical operations of addition, subtraction, multiplication or division with such numbers. You can write any two numbers of the above type and try any one of the operations you like to accept the challenge and then you will really appreciate the difficulty in handling such numbers.

This problem is solved by using scientific notation for such numbers, i.e., exponential notation in which any number can be represented in the form  $N \times 10^n$  where n is an exponent having positive or negative values and N can vary between 1 to 10.

Thus, we can write 232.508 as  $2.32508 \times 10^2$  in scientific notation. Note that while writing it, the decimal had to be moved to the *left* by two places and same is the exponent (2) of 10 in the scientific notation.

Similarly, 0.00016 can be written as  $1.6 \times 10^{-4}$ . Here the decimal has to be moved four places to the *right* and (-4) is the exponent in the scientific notation.

Now, for performing mathematical operations on numbers expressed in scientific



notations, the following points are to be kept in mind.

### Multiplication and Division

These two operations follow the same rules which are there for exponential numbers, i.e.

$$(5.6 \times 10^5) \times ($$

$$(9.8 \times 10^{-2}) \times ($$

$$= (9.8 \times 2.5) (1$$

$$= 24.50 \times 10^{-}$$

$$\frac{2.7 \times 10^{-3}}{5.5 \times 10^4} = (2.$$

### Addition and Subtraction

For these two operations, first the numbers are written in such a way that they have same exponent. After that, the coefficient are added or subtracted as the case may be.

Thus, for adding  $6.65 \times 10^4$  and  $8.95 \times 10^3$ ,  $6.65 \times 10^4 + 0.895 \times 10^4$  exponent is made same for both the numbers.

Then, these numbers can be added as follows  $(6.65 + 0.895) \times 10^4 = 7.545 \times 10^4$

Similarly, the subtraction of two numbers can be done as shown below :

$$2.5 \times 10^{-2} - 4.8 \times 10^{-3}$$

$$= (2.5 \times 10^{-2}) - (0.48 \times 10^{-2})$$

$$= (2.5 - 0.48) \times 10^{-2} = 2.02 \times 10^{-2}$$

### 1.4.2 Significant Figures

Every experimental measurement has some amount of uncertainty associated with it. However, one would always like the results to be precise and accurate. Precision and accuracy are often referred to while we talk about the measurement.

**Precision** refers to the closeness of various measurements for the same quantity. However, **accuracy** is the agreement of a particular value to the true value of the result. For example, if

the true value for a result is 2.00 g and a student 'A' takes two measurements and reports the results as 1.95 g and 1.93 g. These values are precise as they are close to each other but are not accurate. Another student repeats the experiment and obtains 1.94 g and 2.05 g as the results for two measurements. These observations are neither precise nor accurate. When a third student repeats these measurements and reports 2.01 g and 1.99 g as the result. These values are both precise and accurate. This can be more clearly understood from the data given in Table 1.4

**Table 1.4 Data to Illustrate Precision and Accuracy**

| Measurements/g |      |      |             |
|----------------|------|------|-------------|
|                | 1    | 2    | Average (g) |
| Student A      | 1.95 | 1.93 | 1.940       |
| Student B      | 1.94 | 2.05 | 1.995       |
| Student C      | 2.01 | 1.99 | 2.000       |

The uncertainty in the experimental or the calculated values is indicated by mentioning the number of significant figures. **Significant figures** are meaningful digits which are known with certainty. The uncertainty is indicated by writing the certain digits and the last uncertain digit. Thus, if we write a result as 11.2 mL, we say the 11 is certain and 2 is uncertain and the uncertainty would be  $\pm 1$  in the last digit. Unless otherwise stated, an uncertainty of  $\pm 1$  in the last digit is always understood.

There are certain rules for determining the number of significant figures. These are stated below:

- (1) All non-zero digits are significant. For example in 285 cm, there are three significant figures and in 0.25 mL, there are two significant figures.
- (2) Zeros preceding to first non-zero digit are not significant. Such zero indicates the position of decimal point.  
Thus, 0.03 has one significant figure and 0.0052 has two significant figures.
- (3) Zeros between two non-zero digits are

significant. Thus, 2.005 has four significant figures.

- (4) Zeros at the end or right of a number are significant provided they are on the right side of the decimal point. For example, 0.200 g has three significant figures.

But, if otherwise, the zeros are not significant. For example, 100 has only one significant figure.

- (5) Exact numbers have an infinite number of significant figures. For example, in 2 balls or 20 eggs, there are infinite significant figures as these are exact numbers and can be represented by writing infinite number of zeros after placing a decimal i.e.,  $2 = 2.000000$  or  $20 = 20.000000$

When numbers are written in scientific notation, the number of digits between 1 and 10 gives the number of significant figures. Thus,

$4.01 \times 10^2$  has three significant figures, and  $8.256 \times 10^{-3}$  has four significant figures.

### Addition and Subtraction of Significant Figures

The result cannot have more digits to the right of the decimal point than either of the original numbers.

$$\begin{array}{r} 12.11 \\ 18.0 \\ 1.012 \\ \hline 31.122 \end{array}$$

Here, 18.0 has only one digit after the decimal point and the result should be reported only up to one digit after the decimal point which is 31.1.

### Multiplication and Division of Significant Figures

In these operations, the result must be reported with no more significant figures as are there in the measurement with the few significant figures.

$$2.5 \times 1.25 = 3.125$$

Since 2.5 has two significant figures, the result should not have more than two significant figures, thus, it is 3.1.

While limiting the result to the required number of significant figures as done in the above mathematical operation, one has to keep in mind the following points for rounding off the numbers

1. If the rightmost digit to be removed is more than 5, the preceding number is increased by one. for example  
1.386  
If we have to remove 6, we have to round it to 1.39
2. If the rightmost digit to be removed is less than 5, the preceding number is not changed. For example, 4.334 if 4 is to be removed, then the result is rounded upto 4.33.
3. If the rightmost digit to be removed is 5, then the preceding number is not changed if it is an even number but it is increased by one if it is an odd number. For example, if 6.35 is to be rounded by removing 5, we have to increase 3 to 4 giving 6.4 as the result. However, if 6.25 is to be rounded off it is rounded off to 6.2.

### 1.4.3 Dimensional Analysis

Often while calculating, there is a need to convert units from one system to other. The method used to accomplish this is called **factor label method** or **unit factor method** or **dimensional analysis**. This is illustrated below.

#### Example

A piece of metal is 3 inch (represented by in) long. What is its length in cm?

We know that 1 in = 2.54 cm

From this equivalence, we can write

$$\frac{1 \text{ in}}{2.54 \text{ cm}} = 1 =$$

$$\text{thus } \frac{1 \text{ in}}{2.54 \text{ cm}} \text{ equals } 1 \text{ and } \frac{2.54 \text{ cm}}{1 \text{ in}} \text{ also}$$

equals 1. Both of these are called **unit factors**. If some number is multiplied by these unit factors (i.e. 1), it will not be affected otherwise.

Say, the 3 in given above is multiplied by the unit factor. So,

$$3 \text{ in} = 3 \text{ in} \frac{2.54 \text{ cm}}{1 \text{ in}} = 3 \times 2.54 \text{ cm} = 7.62 \text{ cm}$$

Now the unit factor by which multiplication is to be done is that unit factor ( $\frac{2.54 \text{ cm}}{1 \text{ in}}$  in the above case) which gives the desired units i.e., the numerator should have that part which is required in the desired result.

It should also be noted in the above example that units can be handled just like other numerical part. It can be cancelled, divided, multiplied, squared etc. Let us study one more example for it.

#### Example

A jug contains 2L of milk. Calculate the volume of the milk in  $\text{m}^3$ .

Since  $1 \text{ L} = 1000 \text{ cm}^3$   
and  $1 \text{ m} = 100 \text{ cm}$  which gives

$$\frac{1 \text{ m}}{100 \text{ cm}} = 1 =$$

To get  $\text{m}^3$  from the above unit factors, the first unit factor is taken and it is cubed.

$$\left(\frac{1 \text{ m}}{100 \text{ m}}\right)^3 \Rightarrow \frac{1}{1}$$

Now  $2 \text{ L} = 2 \times 1000 \text{ cm}^3$   
The above is multiplied by the unit factor

$$2 \times 1000 \text{ cm}^3 :$$

#### Example

How many seconds are there in 2 days?

Here, we know  $1 \text{ day} = 24 \text{ hours (h)}$

$$\text{or } \frac{1 \text{ day}}{24 \text{ h}} = 1 = \frac{24}{24}$$

then  $1 \text{ h} = 60 \text{ min}$

$$\text{or } \frac{1 \text{ h}}{60 \text{ min}} = 1 = \frac{60}{60}$$

so, for converting 2 days to seconds,

i.e.,  $2 \text{ days} \text{-----} \text{ seconds}$

The unit factors can be multiplied in series in one step only as follows:

$$\begin{aligned} & 2 \text{ day} \times \frac{24 \text{ h}}{1 \text{ day}} \times \\ & = 2 \times 24 \times 60 \times 60 \text{ s} \\ & = 172800 \text{ s} \end{aligned}$$

## 1.5 LAWS OF CHEMICAL COMBINATIONS

The combination of elements to form compounds is governed by the following five basic laws.



### 1.5.1 Law of Conservation of Mass

It states that *matter can neither be created nor destroyed*. Antoine Lavoisier (1743—1794)

This law was put forth by Antoine Lavoisier in 1789. He performed careful experimental studies for combustion reactions for reaching to the above conclusion. This law formed the basis for several later developments in chemistry. Infact, this was the result of exact measurement of masses of reactants and products, and carefully planned experiments performed by Lavoisier.

### 1.5.2 Law of Definite Proportions

This law was given by, a French chemist, Joseph Proust. He stated that *a given compound always contains exactly the same proportion of elements by weight*.



Proust worked with two samples of cupric carbonate — one of which was of natural origin and the other was synthetic one. He found that the composition of elements present in it was same for both the samples as shown below :

|                  | % of copper | % of oxygen | % of carbon |
|------------------|-------------|-------------|-------------|
| Natural Sample   | 51.35       | 9.74        | 38.91       |
| Synthetic Sample | 51.35       | 9.74        | 38.91       |

Thus, irrespective of the source, a given compound always contains same elements in the same proportion. The validity of this law has been confirmed by various experiments. It is sometimes also referred to as **Law of definite composition**.

### 1.5.3 Law of Multiple Proportions

This law was proposed by Dalton in 1803. According to this law, *if two elements can combine to form more than one compound, the masses of one element that combine with a fixed mass of the other element, are in the ratio of small whole numbers.*

For example, hydrogen combines with oxygen to form two compounds, namely, water and hydrogen peroxide.

Hydrogen + Oxygen → Water

2g      16g      18g

Hydrogen + Oxygen → Hydrogen Peroxide

2g      32g      34g

Here, the masses of oxygen (i.e. 16 g and 32 g) which combine with a fixed mass of hydrogen (2g) bear a simple ratio, i.e. 16:32 or 1 : 2.

### 1.5.4 Gay Lussac's Law of Gaseous Volumes

This law was given by Gay Lussac in 1808. He observed that *when gases combine or are produced in a chemical reaction they do so in a simple ratio by volume provided all gases are at same temperature and pressure.*



Joseph Louis  
Gay Lussac

Thus, 100 mL of hydrogen combine with 50 mL of oxygen to give 100 mL of water vapour.

Hydrogen + Oxygen → Water

100 mL      50 mL      100 mL

Thus, the volumes of hydrogen and oxygen which combine together (i.e. 100 mL and 50 mL) bear a simple ratio of 2:1.

Gay-Lussac's discovery of integer ratio in volume relationship is actually the law of definite proportions by volume. The law of definite proportions, stated earlier, was with respect to mass. The Gay-Lussac's law was explained properly by the work of Avogadro in 1811.

### 1.5.5 Avogadro Law

In 1811, Avogadro proposed that *equal volumes of gases at the same temperature and pressure should contain equal number of molecules.*

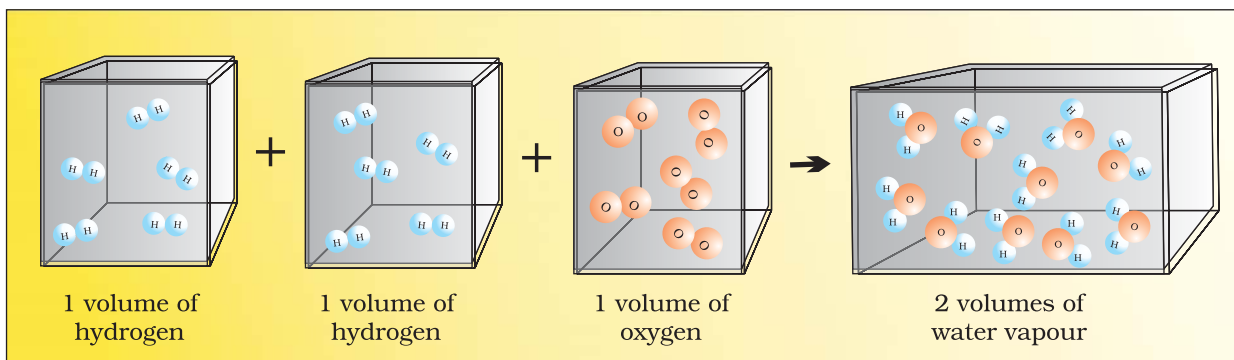
Avogadro made a distinction between **atoms** and **molecules** which is quite understandable in the present times. If we consider again the reaction of hydrogen and oxygen to produce water,

we see that two volumes of hydrogen combine with one volume of oxygen to give two volumes of water without leaving any unreacted oxygen.

Note that in the Fig. 1.9, each box contains equal number of molecules. In fact, Avogadro could explain the above result by considering the molecules to be **polyatomic**. If hydrogen



Lorenzo Romano  
Amedeo Carlo  
Avogadro di  
Quareqa edì  
Carreto  
(1776-1856)



**Fig. 1.9** Two volumes of hydrogen react with One volume of oxygen to give Two volumes of water vapour

and oxygen were considered as **diatomic** as recognised now, then the above results are easily understandable. However, Dalton and others believed at that time that atoms of the same kind cannot combine and molecules of oxygen or hydrogen containing two atoms did not exist. Avogadro's proposal was published in the French **Journal de Physique**. In spite of being correct, it did not gain much support.

After about 50 years, in 1860, first international conference on chemistry was held in Karlsruhe, Germany to resolve various ideas. At the meeting, Stanislao Cannizzaro presented a sketch of a course of chemical philosophy which emphasised the importance of Avogadro's work.

## 1.6 DALTON'S ATOMIC THEORY

Although the origin of idea that matter is composed of small indivisible particles called '*a-tomio*' (meaning — *indivisible*), dates back to the time of Democritus, a Greek Philosopher (460 — 370 BC), it again started emerging as a result of several experimental studies which led to the Laws mentioned above.



John Dalton  
(1776—1884)

In 1808, Dalton published 'A New System of Chemical Philosophy' in which he proposed the following :

1. Matter consists of indivisible atoms.
2. All the atoms of a given element have identical properties including identical mass. Atoms of different elements differ in mass.
3. Compounds are formed when atoms of different elements combine in a fixed ratio.
4. Chemical reactions involve reorganisation of atoms. These are neither created nor destroyed in a chemical reaction.

Dalton's theory could explain the laws of chemical combination.

## 1.7 ATOMIC AND MOLECULAR MASSES

After having some idea about the terms atoms and molecules, it is appropriate here to

understand what we mean by atomic and molecular masses.

### 1.7.1 Atomic Mass

The atomic mass or the mass of an atom is actually very-very small because atoms are extremely small. Today, we have sophisticated techniques e.g., mass spectrometry for determining the atomic masses fairly accurately. But, in the nineteenth century, scientists could determine mass of one atom **relative** to another by experimental means, as has been mentioned earlier. Hydrogen, being lightest atom was arbitrarily assigned a mass of 1 (without any units) and other elements were assigned masses relative to it. However, the present system of atomic masses is based on carbon - 12 as the standard and has been agreed upon in 1961. Here, Carbon - 12 is one of the *isotopes* of carbon and can be represented as  $^{12}\text{C}$ . In this system,  $^{12}\text{C}$  is assigned a mass of exactly 12 atomic mass unit (**amu**) and masses of all other atoms are given relative to this standard. One **atomic mass unit** is defined as a mass exactly equal to one-twelfth the mass of one carbon - 12 atom.

$$\text{And 1 amu} = 1.66056 \times 10^{-24} \text{ g}$$

$$\begin{aligned} \text{Mass of an atom of hydrogen} \\ &= 1.6736 \times 10^{-24} \text{ g} \end{aligned}$$

Thus, in terms of amu, the mass

$$\begin{aligned} \text{of hydrogen atom} &= \frac{1.6736 \times 10^{-24}}{1.66056 \times 10^{-24}} \\ &= 1.0078 \text{ amu} \\ &= 1.0080 \text{ amu} \end{aligned}$$

Similarly, the mass of oxygen - 16 ( $^{16}\text{O}$ ) atom would be 15.995 amu.

Today, '**amu**' has been replaced by '**u**' which is known as **unified mass**.

When we use atomic masses of elements in calculations, we actually use *average atomic masses* of elements which are explained below.

### 1.7.2 Average Atomic Mass

Many naturally occurring elements exist as more than one isotope. When we take into account the existence of these isotopes and their relative abundance (per cent occurrence),

the average atomic mass of that element can be computed. For example, carbon has the following three isotopes with relative abundances and masses as shown against each of them.

| Isotope         | Relative Abundance (%) | Atomic Mass (amu) |
|-----------------|------------------------|-------------------|
| $^{12}\text{C}$ | 98.892                 | 12                |
| $^{13}\text{C}$ | 1.108                  | 13.00335          |
| $^{14}\text{C}$ | $2 \times 10^{-10}$    | 14.00317          |

From the above data, the average atomic mass of carbon will come out to be :

$$(0.98892)(12 \text{ u}) + (0.01108)(13.00335 \text{ u}) + (2 \times 10^{-10})(14.00317 \text{ u})$$

$$= 12.011 \text{ u}$$

Similarly, average atomic masses for other elements can be calculated. In the periodic table of elements, the atomic masses mentioned for different elements actually represented their average atomic masses.

### 1.7.3 Molecular Mass

Molecular mass is the sum of atomic masses of the elements present in a molecule. It is obtained by multiplying the atomic mass of each element by the number of its atoms and adding them together. For example, molecular mass of methane which contains one carbon atom and four hydrogen atoms can be obtained as follows :

$$\text{Molecular mass of methane,}$$

$$(\text{CH}_4) = (12.011 \text{ u}) + 4(1.008 \text{ u})$$

$$= 16.043 \text{ u}$$

$$\text{Similarly, molecular mass of water (H}_2\text{O)}$$

$$= 2 \text{ atomic mass of hydrogen} + 1 \text{ atomic mass of oxygen}$$

$$= 2(1.008 \text{ u}) + 16.00 \text{ u}$$

$$= 18.02 \text{ u}$$

#### Problem 1.1

Calculate molecular mass of glucose ( $\text{C}_6\text{H}_{12}\text{O}_6$ ) molecule.

#### Solution

$$\text{Molecular mass of glucose (C}_6\text{H}_{12}\text{O}_6)$$

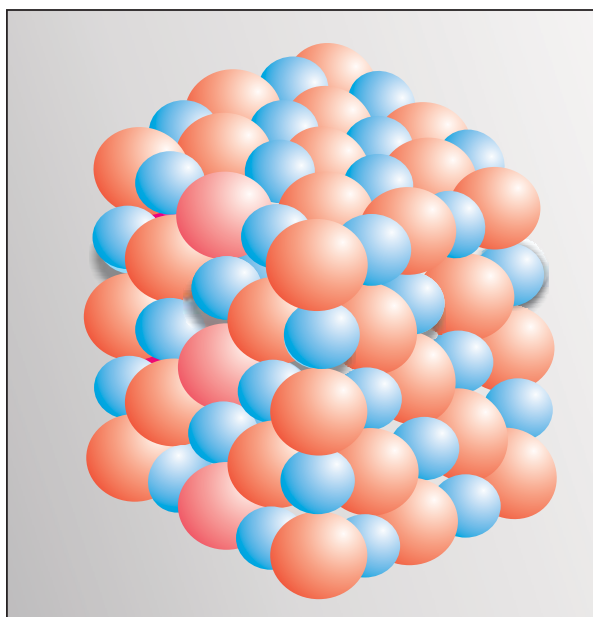
$$= 6(12.011 \text{ u}) + 12(1.008 \text{ u}) + 6(16.00 \text{ u})$$

$$= (72.066 \text{ u}) + (12.096 \text{ u}) + (96.00 \text{ u})$$

$$= 180.162 \text{ u}$$

### 1.7.4 Formula Mass

Some substances such as sodium chloride do not contain discrete molecules as their constituent units. In such compounds, positive (sodium) and negative (chloride) entities are arranged in a three-dimensional structure, as shown in Fig. 1.10.



**Fig. 1.10** Packing of  $\text{Na}^+$  and  $\text{Cl}^-$  ions in sodium chloride

It may be noted that in sodium chloride, one  $\text{Na}^+$  is surrounded by six  $\text{Cl}^-$  and *vice-versa*.

The formula such as  $\text{NaCl}$  is used to calculate the **formula mass** instead of molecular mass as in the solid state sodium chloride does not exist as a single entity.

Thus, formula mass of sodium chloride = atomic mass of sodium + atomic mass of chlorine

$$= 23.0 \text{ u} + 35.5 \text{ u} = 58.5 \text{ u}$$

## 1.8 MOLE CONCEPT AND MOLAR MASSES

Atoms and molecules are extremely small in size and their numbers in even a small amount of any substance is really very large. To handle such large numbers, a unit of similar magnitude is required.

Just as we denote one dozen for 12 items, score for 20 items, gross for 144 items, we use the idea of mole to count entities at the microscopic level (i.e. atoms/molecules/particles, electrons, ions, etc).

In SI system, **mole** (symbol, mol) was introduced as seventh base quantity for the amount of a substance.

**One mole is the amount of a substance that contains as many particles or entities as there are atoms in exactly 12 g (or 0.012 kg) of the  $^{12}\text{C}$  isotope.** It may be emphasised that the mole of a substance always contain the same number of entities, no matter what the substance may be. In order to determine this number precisely, the mass of a carbon-12 atom was determined by a mass spectrometer and found to be equal to  $1.992648 \times 10^{-23}$  g. Knowing that one mole of carbon weighs 12 g, the number of atoms in it is equal to :

$$\frac{12 \text{ g/mol}}{1.992648 \times 10^{-23} \text{ g}} \\ = 6.0221367 \times 10^{23}$$

This number of entities in 1 mol is so important that it is given a separate name and symbol, known as '**Avogadro**' constant, denoted by ( $N_A$ ) in honour of Amedeo Avogadro. To really appreciate largeness of this number, let us write it with all the zeroes without using any powers of ten.

602213670000000000000000

Hence, so many entities (atoms, molecules or any other particle) constitute one mole of a particular substance.

We can, therefore, say that 1 mol of hydrogen atoms =  $6.022 \times 10^{23}$  atoms

1 mol of water molecules =  $6.022 \times 10^{23}$  water molecules



**Fig. 1.11** One mole of various substances

1 mol of sodium chloride =  $6.022 \times 10^{23}$  formula units of sodium chloride

Having defined the mole, it is easier to know mass of one mole of the substance or the constituent entities. **The mass of one mole of a substance in grams is called its molar mass.** The molar mass in grams is numerically equal to atomic/molecular/formula mass in u.

Molar mass of water = 18.02 g

Molar mass of sodium chloride = 58.5 g

## 1.9 PERCENTAGE COMPOSITION

So far, we were dealing with the number of entities present in a given sample. But many a time, the information regarding the percentage of a particular element present in a compound is required. Suppose an unknown or new compound is given to you, the first question you would ask is: what is its formula or what are its constituents and in what ratio are they present in the given compound? For known compounds also, such information provides a check whether the given sample contains the same percentage of elements as is present in a pure sample. In other words, one can check the purity of a given sample by analysing this data.

Let us understand it by taking the example of water ( $\text{H}_2\text{O}$ ). Since water contains hydrogen and oxygen, the percentage composition of both these elements can be calculated as follows :

Mass % of an element =

$$\frac{\text{mass of that element}}{\text{molar mass}} \times 100$$

$$\begin{aligned} \text{Molar mass of water} &= 18.02 \text{ g} \\ \text{Mass \% of hydrogen} &= \frac{2 \times 1.008}{18.02} \times 100 \\ &= 11.18 \\ \text{Mass \% of oxygen} &= \frac{16.00}{18.02} \times 100 \\ &= 88.79 \end{aligned}$$

Let us take one more example. What is the percentage of carbon, hydrogen and oxygen in ethanol?

Molecular formula of ethanol is :  $\text{C}_2\text{H}_5\text{OH}$   
Molar mass of ethanol is :  $(2 \times 12.01 + 6 \times 1.008 + 16.00) \text{ g}$

$$\begin{aligned} &= 46.068 \text{ g} \\ \text{Mass per cent of carbon} &= \frac{24.02 \text{ g}}{46.068 \text{ g}} \times 100 = 52.14\% \end{aligned}$$

$$\begin{aligned} \text{Mass per cent of hydrogen} &= \frac{6.048 \text{ g}}{46.068 \text{ g}} \times 100 = 13.13\% \end{aligned}$$

$$\begin{aligned} \text{Mass per cent of oxygen} &= \frac{16.00 \text{ g}}{46.068 \text{ g}} \times 100 = 34.73\% \end{aligned}$$

After understanding the calculation of per cent of mass, let us now see what information can be obtained from the per cent composition data.

### 1.9.1 Empirical Formula for Molecular Formula

An **empirical formula** represents the simplest whole number ratio of various atoms present in a compound whereas the **molecular formula** shows the exact number of different types of atoms present in a molecule of a compound.

If the mass per cent of various elements present in a compound is known, its empirical formula can be determined. Molecular formula can further be obtained if the molar mass is known. The following example illustrates this sequence.

#### Problem 1.2

A compound contains 4.07 % hydrogen, 24.27 % carbon and 71.65 % chlorine. Its molar mass is 98.96 g. What are its empirical and molecular formulas ?

#### Solution

##### Step 1. Conversion of mass per cent to grams.

Since we are having mass per cent, it is convenient to use 100 g of the compound as the starting material. Thus, in the 100 g sample of the above compound, 4.07g hydrogen is present, 24.27g carbon is present and 71.65 g chlorine is present.

##### Step 2. Convert into number moles of each element

Divide the masses obtained above by respective atomic masses of various elements.

$$\text{Moles of hydrogen} = \frac{4.07 \text{ g}}{1.008 \text{ g}} = 4.04$$

$$\text{Moles of carbon} = \frac{24.27 \text{ g}}{12.01 \text{ g}} = 2.021$$

$$\text{Moles of chlorine} = \frac{71.65 \text{ g}}{35.453 \text{ g}} = 2.021$$

##### Step 3. Divide the mole value obtained above by the smallest number

Since 2.021 is smallest value, division by it gives a ratio of 2:1:1 for H:C:Cl .

In case the ratios are not whole numbers, then they may be converted into whole number by multiplying by the suitable coefficient.

##### Step 4. Write empirical formula by mentioning the numbers after writing the symbols of respective elements.

$\text{CH}_2\text{Cl}$  is, thus, the empirical formula of the above compound.

##### Step 5. Writing molecular formula

(a) Determine empirical formula mass  
Add the atomic masses of various atoms present in the empirical formula.



For  $\text{CH}_2\text{Cl}$ , empirical formula mass is

$$12.01 + 2 \times 1.008 + 35.453$$

$$= 49.48 \text{ g}$$

(b) Divide Molar mass by empirical formula mass

$$\frac{\text{Molar mass}}{\text{Empirical formula mass}}$$

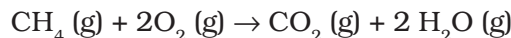
$$= 2 = (n)$$

(c) Multiply empirical formula by  $n$  obtained above to get the molecular formula

Empirical formula =  $\text{CH}_2\text{Cl}$ ,  $n = 2$ . Hence molecular formula is  $\text{C}_2\text{H}_4\text{Cl}_2$ .

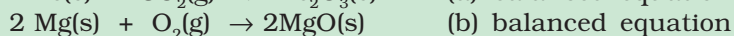
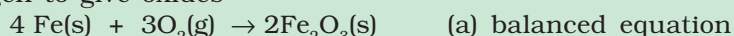
## 1.10 STOICHIOMETRY AND STOICHIOMETRIC CALCULATIONS

The word 'stoichiometry' is derived from two Greek words - *stoicheion* (meaning *element*) and *metron* (meaning *measure*). Stoichiometry, thus, deals with the calculation of masses (sometimes volumes also) of the reactants and the products involved in a chemical reaction. Before understanding how to calculate the amounts of reactants required or those produced in a chemical reaction, let us study what information is available from the *balanced* chemical equation of a given reaction. Let us consider the combustion of methane. A balanced equation for this reaction is as given below :



### Balancing a chemical equation

According to the law of conservation of mass, a balanced chemical equation has the *same number of atoms of each element on both sides* of the equation. Many chemical equations can be balanced by *trial and error*. Let us take the reactions of a few metals and non-metals with oxygen to give oxides

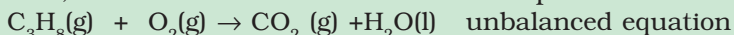


Equations (a) and (b) are balanced since there are same number of metal and oxygen atoms on each side of equations. However equation (c) is not balanced. In this equation, phosphorus atoms are balanced but not the oxygen atoms. To balance it, we must place the coefficient 5 on the left of oxygen on the left side of the equation to balance the oxygen atoms appearing on the right side of the equation.

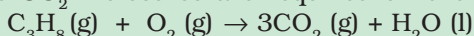


Now let us take combustion of propane,  $\text{C}_3\text{H}_8$ . This equation can be balanced in steps.

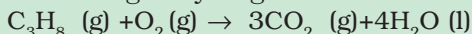
**Step 1** Write down the correct formulas of reactants and products. Here propane and oxygen are reactants, and carbon dioxide and water are products.



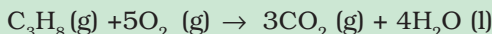
**Step 2** Balance the number of C atoms: Since 3 carbon atoms are in the reactant, therefore, three  $\text{CO}_2$  molecules are required on the right side.



**Step 3** Balance the number of H atoms : on the left there are 8 hydrogen atoms in the reactants however, each molecule of water has two hydrogen atoms, so four molecules of water will be required for eight hydrogen atoms on the right side.



**Step 4** Balance the number of O atoms: There are ten oxygen atoms on the right side ( $3 \times 2 = 6$  in  $\text{CO}_2$  and  $4 \times 1 = 4$  in water). Therefore, five  $\text{O}_2$  molecules are needed to supply the required ten oxygen atoms.



**Step 5** Verify that the number of atoms of each element is balanced in the final equation. The equation shows three carbon atoms, eight hydrogen atoms, and ten oxygen atoms on each side.

All equations that have correct formulas for all reactants and products can be balanced. Always remember that subscripts in formulas of reactants and products cannot be changed to balance an equation.

Here, methane and dioxygen are called *reactants* and carbon dioxide and water are called *products*. Note that all the reactants and the products are gases in the above reaction and this has been indicated by letter (g) in the brackets next to its formula. Similarly, in the case of solids and liquids, (s) and (l) are written respectively.

The coefficients 2 for O<sub>2</sub> and H<sub>2</sub>O are called stoichiometric coefficients. Similarly the coefficient for CH<sub>4</sub> and CO<sub>2</sub> is one in each case. They represent the number of molecules (and moles as well) taking part in the reaction or formed in the reaction.

Thus, according to the above chemical reaction,

- One **mole** of CH<sub>4</sub>(g) reacts with two **moles** of O<sub>2</sub>(g) to give one **mole** of CO<sub>2</sub>(g) and two **moles** of H<sub>2</sub>O(g)
- One **molecule** of CH<sub>4</sub>(g) reacts with 2 **molecules** of O<sub>2</sub>(g) to give one **molecule** of CO<sub>2</sub>(g) and 2 molecules of H<sub>2</sub>O(g)
- 22.4 L of CH<sub>4</sub>(g) reacts with 44.8 L of O<sub>2</sub> (g) to give 22.4 L of CO<sub>2</sub> (g) and 44.8 L of H<sub>2</sub>O(g)
- 16 g of CH<sub>4</sub> (g) reacts with 2 32 g of O<sub>2</sub> (g) to give 44 g of CO<sub>2</sub> (g) and 2 18 g of H<sub>2</sub>O (g).

From these relationships, the given data can be interconverted as follows :

mass *f* mole

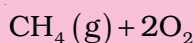
$$\frac{\text{Mass}}{\text{Volume}} = \text{Den}$$

### Problem 1.3

Calculate the amount of water (g) produced by the combustion of 16 g of methane.

#### Solution

The balanced equation for combustion of methane is :



- 16 g of CH<sub>4</sub> corresponds to one mole.
- From the above equation, 1 mol of

CH<sub>4</sub> (g) gives 2 mol of H<sub>2</sub>O (g).

$$2 \text{ mol of water (H}_2\text{O)} = 2 (2+16) \\ = 2 \quad 18 = 36 \text{ g}$$

$$1 \text{ mol H}_2\text{O} = 18 \text{ g H}_2\text{O} \Rightarrow \frac{18 \text{ g H}_2\text{O}}{1 \text{ mol H}_2\text{O}} = 1$$

$$\text{Hence } 2 \text{ mol H}_2\text{O} \quad \frac{18 \text{ g H}_2\text{O}}{1 \text{ mol H}_2\text{O}} \\ = 2 \quad 18 \text{ g H}_2\text{O} = 36 \text{ g H}_2\text{O}$$

### Problem 1.4

How many moles of methane are required to produce 22 g CO<sub>2</sub> (g) after combustion?

#### Solution

According to the chemical equation,



44g CO<sub>2</sub> (g) is obtained from 16 g CH<sub>4</sub> (g).

[ Q 1 mol CO<sub>2</sub>(g) is obtained from 1 mol of CH<sub>4</sub>(g)]

mole of CO<sub>2</sub> (g)

$$= 22 \text{ g CO}_2 (\text{g}) \quad \frac{1 \text{ mol CO}_2 (\text{g})}{44 \text{ g CO}_2 (\text{g})}$$

$$= 0.5 \text{ mol CO}_2 (\text{g})$$

Hence, 0.5 mol CO<sub>2</sub> (g) would be obtained from 0.5 mol CH<sub>4</sub> (g) or 0.5 mol of CH<sub>4</sub> (g) would be required to produce 22 g CO<sub>2</sub> (g).

### 1.10.1 Limiting Reagent

Many a time, the reactions are carried out when the reactants are not present in the amounts as required by a balanced chemical reaction. In such situations, one reactant is in excess over the other. The reactant which is present in the lesser amount gets consumed after sometime and after that no further reaction takes place whatever be the amount of the other reactant present. Hence, the reactant which gets consumed, limits the amount of product formed and is, therefore, called the **limiting reagent**.

In performing stoichiometric calculations, this aspect is also to be kept in mind.

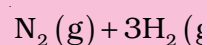
**Problem 1.5**

50.0 kg of  $N_2$  (g) and 10.0 kg of  $H_2$  (g) are mixed to produce  $NH_3$  (g). Calculate the  $NH_3$  (g) formed. Identify the limiting reagent in the production of  $NH_3$  in this situation.

**Solution**

A balanced equation for the above reaction is written as follows :

Calculation of moles :



moles of  $N_2$

$$= 50.0 \text{ kg } N_2 \times \frac{1000 \text{ g } N_2}{1 \text{ kg } N_2}$$

$$= 17.86 \times 10^2 \text{ mol}$$

moles of  $H_2$

$$= 10.00 \text{ kg } H_2 \times \frac{1000 \text{ g } H_2}{1 \text{ kg } H_2} \times \frac{1}{2}$$

$$= 4.96 \times 10^3 \text{ mol}$$

According to the above equation, 1 mol  $N_2$  (g) requires 3 mol  $H_2$  (g), for the reaction. Hence, for  $17.86 \times 10^2$  mol of  $N_2$ , the moles of  $H_2$  (g) required would be

$$17.86 \times 10^2 \text{ mol } N_2 \times \frac{3 \text{ mol } H_2(g)}{1 \text{ mol } N_2(g)}$$

$$= 5.36 \times 10^3 \text{ mol } H_2$$

But we have only  $4.96 \times 10^3$  mol  $H_2$ . Hence, dihydrogen is the limiting reagent in this case. So  $NH_3$ (g) would be formed only from that amount of available dihydrogen *i.e.*,  $4.96 \times 10^3$  mol

Since 3 mol  $H_2$ (g) gives 2 mol  $NH_3$ (g)

$$4.96 \times 10^3 \text{ mol } H_2(g) \times \frac{2 \text{ mol } NH_3(g)}{3 \text{ mol } H_2(g)}$$

$$= 3.30 \times 10^3 \text{ mol } NH_3(g)$$

$3.30 \times 10^3$  mol  $NH_3$  (g) is obtained.

If they are to be converted to grams, it is done as follows :

$$1 \text{ mol } NH_3(g) = 17.0 \text{ g } NH_3(g)$$

$$3.30 \times 10^3 \text{ mol } NH_3(g) \times \frac{17.0 \text{ g } NH_3(g)}{1 \text{ mol } NH_3(g)}$$

$$= 3.30 \times 10^3 \times 17 \text{ g } NH_3(g)$$

$$= 56.1 \times 10^3 \text{ g } NH_3$$

$$= 56.1 \text{ kg } NH_3$$

**1.10.2 Reactions in Solutions**

A majority of reactions in the laboratories are carried out in solutions. Therefore, it is important to understand as how the amount of substance is expressed when it is present in the form of a solution. The concentration of a solution or the amount of substance present in its given volume can be expressed in any of the following ways.

1. Mass per cent or weight per cent (w/w %)
2. Mole fraction
3. Molarity
4. Molality

Let us now study each one of them in detail.

**1. Mass per cent**

It is obtained by using the following relation:

Mass per cent

**Problem 1.6**

A solution is prepared by adding 2 g of a substance A to 18 g of water. Calculate the mass per cent of the solute.

**Solution**

Mass per cent

$$= \frac{2}{2 \text{ g of A} + 18}$$

$$= \frac{2 \text{ g}}{20 \text{ g}} \times 100$$

$$= 10 \%$$

## 2. Mole Fraction

It is the ratio of number of moles of a particular component to the total number of moles of the solution. If a substance 'A' dissolves in substance 'B' and their number of moles are  $n_A$  and  $n_B$  respectively; then the mole fractions of A and B are given as

$$\begin{aligned} \text{Mole fraction} &= \frac{\text{No. of moles}}{\text{No. of moles}} \\ &= \frac{n_A}{n_A + n_B} \end{aligned}$$

$$\begin{aligned} \text{Mole fraction} &= \frac{\text{No. of moles}}{\text{No. of moles}} \\ &= \frac{n_B}{n_A + n_B} \end{aligned}$$

## 3. Molarity

It is the most widely used unit and is denoted by M. It is defined as the number of moles of the solute in 1 litre of the solution. Thus,

$$\text{Molarity (M)} = \frac{\text{No. of moles}}{\text{Volume of solution}}$$

Suppose we have 1 M solution of a substance, say NaOH and we want to prepare a 0.2 M solution from it.

1 M NaOH means 1 mol of NaOH present in 1 litre of the solution. For 0.2 M solution we require 0.2 moles of NaOH in 1 litre solution.

Hence, we have to take 0.2 moles of NaOH and make the solution to 1 litre.

Now how much volume of concentrated (1M) NaOH solution be taken which contains 0.2 moles of NaOH can be calculated as follows:

If 1 mol is present in 1 L or 1000 mL  
then 0.2 mol is present in

$$\begin{aligned} &\frac{1000 \text{ mL}}{1 \text{ mol}} \times 0.2 \\ &= 200 \text{ mL} \end{aligned}$$

Thus, 200 mL of 1M NaOH are taken and enough water is added to dilute it to make it 1 litre.

In fact for such calculations, a general formula,  $M_1 V_1 = M_2 V_2$  where M and V are molarity and volume respectively can be used. In this case,  $M_1$  is equal to 0.2;  $V_1 = 1000$  mL and,  $M_2 = 1.0$ ;  $V_2$  is to be calculated. Substituting the values in the formula:

$$\begin{aligned} 0.2 \text{ M} \times 1000 \text{ mL} &= 1.0 \text{ M} \times V_2 \\ \therefore V_2 &= \frac{0.2 \text{ M} \times 1000 \text{ mL}}{1.0 \text{ M}} = 200 \text{ mL} \end{aligned}$$

Note that the **number of moles of solute** (NaOH) was 0.2 in 200 mL and *it has remained the same*, i.e., 0.2 even after dilution (in 1000 mL) as we have changed just the amount of solvent (i.e. water) and have not done anything with respect to NaOH. But keep in mind the concentration.

### Problem 1.7

Calculate the molarity of NaOH in the solution prepared by dissolving its 4 g in enough water to form 250 mL of the solution.

### Solution

Since molarity (M)

$$\begin{aligned} &= \frac{\text{No. of moles}}{\text{Volume of solution}} \\ &= \frac{\text{Mass of NaOH}}{\text{Molar mass of NaOH} \times \text{Volume of solution}} \\ &= \frac{4 \text{ g} / 40 \text{ g}}{0.250 \text{ L}} \\ &= 0.4 \text{ mol L}^{-1} \\ &= 0.4 \text{ M} \end{aligned}$$

Note that molarity of a solution depends upon temperature because volume of a solution is temperature dependent.

## 4. Molality

It is defined as the number of moles of solute present in 1 kg of solvent. It is denoted by m.

$$\text{Thus, Molality (m)} = \frac{\text{No. of moles}}{\text{Mass of solvent}}$$

**Problem 1.8**

The density of 3 M solution of NaCl is  $1.25 \text{ g mL}^{-1}$ . Calculate molality of the solution.

**Solution**

$$M = 3 \text{ mol L}^{-1}$$

Mass of NaCl  
in 1 L solution =  $3 \times 58.5 = 175.5 \text{ g}$

Mass of  
1L solution =  $1000 \times 1.25 = 1250 \text{ g}$   
(since density =  $1.25 \text{ g mL}^{-1}$ )

Mass of  
water in solution =  $1250 - 175.5$   
=  $1074.5 \text{ g}$

$$\begin{aligned} \text{Molality} &= \frac{\text{No. of mole}}{\text{Mass of so}} \\ &= \frac{3 \text{ mol}}{1.0745 \text{ kg}} \\ &= 2.79 \text{ m} \end{aligned}$$

Often in a chemistry laboratory, a solution of a desired concentration is prepared by diluting a solution of known higher concentration. The solution of higher concentration is also known as stock solution. Note that molality of a solution does not change with temperature since mass remains unaffected with temperature.

**SUMMARY**

The study of chemistry is very important as its domain encompasses every sphere of life. Chemists study the properties and structure of substances and the changes undergone by them. All substances contain matter which can exist in three states – solid, liquid or gas. The constituent particles are held in different ways in these states of matter and they exhibit their characteristic properties. Matter can also be classified into elements, compounds or mixtures. An **element** contains particles of only one type which may be **atoms** or **molecules**. The compounds are formed where atoms of two or more elements combine in a fixed ratio to each other. Mixtures occur widely and many of the substances present around us are mixtures.

When the properties of a substance are studied, measurement is inherent. The quantification of properties requires a system of measurement and units in which the quantities are to be expressed. Many systems of measurement exist out of which the English and the Metric Systems are widely used. The scientific community, however, has agreed to have a uniform and common system throughout the world which is abbreviated as SI units (International System of Units).

Since measurements involve recording of data which are always associated with a certain amount of uncertainty, the proper handling of data obtained by measuring the quantities is very important. The measurements of quantities in chemistry are spread over a wide range of  $10^{-31}$  to  $10^{+23}$ . Hence, a convenient system of expressing the numbers in **scientific notation** is used. The uncertainty is taken care of by specifying the number of **significant figures** in which the observations are reported. The **dimensional analysis** helps to express the measured quantities in different systems of units. Hence, it is possible to interconvert the results from one system of units to another.

The combination of different atoms is governed by basic laws of chemical combination – these being the **Law of Conservation of Mass**, **Law of Definite Properties**, **Law of Multiple Proportions**, **Gay Lussac's Law of Gaseous Volumes** and **Avogadro Law**. All these laws led to the **Dalton's atomic theory** which states that atoms are building blocks of matter. The **atomic mass** of an element is expressed relative to  $^{12}\text{C}$  isotope of carbon which has an exact value of 12. Usually, the atomic mass used for an element is

the **average atomic mass** obtained by taking into account the natural abundance of different isotopes of that element. The **molecular mass** of a molecule is obtained by taking sum of the atomic masses of different atoms present in a molecule. The **molecular formula** can be calculated by determining the mass per cent of different elements present in a compound and its molecular mass.

The number of atoms, molecules or any other particles present in a given system are expressed in the terms of **Avogadro constant** ( $6.022 \times 10^{23}$ ). This is known as **1 mol** of the respective particles or entities.

Chemical reactions represent the chemical changes undergone by different elements and compounds. A **balanced** chemical equation provides a lot of information. The coefficients indicate the molar ratios and the respective number of particles taking part in a particular reaction. The quantitative study of the reactants required or the products formed is called **stoichiometry**. Using stoichiometric calculations, the amounts of one or more reactant(s) required to produce a particular amount of product can be determined and vice-versa. The amount of substance present in a given volume of a solution is expressed in number of ways, e.g., mass per cent, mole fraction, molarity and molality.

### EXERCISES

- 1.1 Calculate the molecular mass of the following :  
(i)  $\text{H}_2\text{O}$  (ii)  $\text{CO}_2$  (iii)  $\text{CH}_4$
- 1.2 Calculate the mass per cent of different elements present in sodium sulphate ( $\text{Na}_2\text{SO}_4$ ).
- 1.3 Determine the empirical formula of an oxide of iron which has 69.9% iron and 30.1% dioxygen by mass.
- 1.4 Calculate the amount of carbon dioxide that could be produced when
  - (i) 1 mole of carbon is burnt in air.
  - (ii) 1 mole of carbon is burnt in 16 g of dioxygen.
  - (iii) 2 moles of carbon are burnt in 16 g of dioxygen.
- 1.5 Calculate the mass of sodium acetate ( $\text{CH}_3\text{COONa}$ ) required to make 500 mL of 0.375 molar aqueous solution. Molar mass of sodium acetate is  $82.0245 \text{ g mol}^{-1}$ .
- 1.6 Calculate the concentration of nitric acid in moles per litre in a sample which has a density,  $1.41 \text{ g mL}^{-1}$  and the mass per cent of nitric acid in it being 69%.
- 1.7 How much copper can be obtained from 100 g of copper sulphate ( $\text{CuSO}_4$ ) ?
- 1.8 Determine the molecular formula of an oxide of iron in which the mass per cent of iron and oxygen are 69.9 and 30.1 respectively.
- 1.9 Calculate the atomic mass (average) of chlorine using the following data :

|                  | % Natural Abundance | Molar Mass |
|------------------|---------------------|------------|
| $^{35}\text{Cl}$ | 75.77               | 34.9689    |
| $^{37}\text{Cl}$ | 24.23               | 36.9659    |
- 1.10 In three moles of ethane ( $\text{C}_2\text{H}_6$ ), calculate the following :
  - (i) Number of moles of carbon atoms.
  - (ii) Number of moles of hydrogen atoms.
  - (iii) Number of molecules of ethane.

- 1.11 What is the concentration of sugar ( $C_{12}H_{22}O_{11}$ ) in mol  $L^{-1}$  if its 20 g are dissolved in enough water to make a final volume up to 2L?
- 1.12 If the density of methanol is  $0.793 \text{ kg L}^{-1}$ , what is its volume needed for making 2.5 L of its 0.25 M solution?
- 1.13 Pressure is determined as force per unit area of the surface. The SI unit of pressure, pascal is as shown below :  
 $1\text{Pa} = 1\text{N m}^{-2}$   
 If mass of air at sea level is  $1034 \text{ g cm}^{-2}$ , calculate the pressure in pascal.
- 1.14 What is the SI unit of mass? How is it defined?
- 1.15 Match the following prefixes with their multiples:

| <b>Prefixes</b> | <b>Multiples</b> |
|-----------------|------------------|
|-----------------|------------------|

- |            |            |
|------------|------------|
| (i) micro  | $10^6$     |
| (ii) deca  | $10^9$     |
| (iii) mega | $10^{-6}$  |
| (iv) giga  | $10^{-15}$ |
| (v) femto  | 10         |

- 1.16 What do you mean by significant figures ?
- 1.17 A sample of drinking water was found to be severely contaminated with chloroform,  $\text{CHCl}_3$ , supposed to be carcinogenic in nature. The level of contamination was 15 ppm (by mass).  
 (i) Express this in percent by mass.  
 (ii) Determine the molality of chloroform in the water sample.
- 1.18 Express the following in the scientific notation:  
 (i) 0.0048  
 (ii) 234,000  
 (iii) 8008  
 (iv) 500.0  
 (v) 6.0012
- 1.19 How many significant figures are present in the following?  
 (i) 0.0025  
 (ii) 208  
 (iii) 5005  
 (iv) 126,000  
 (v) 500.0  
 (vi) 2.0034
- 1.20 Round up the following upto three significant figures:  
 (i) 34.216  
 (ii) 10.4107  
 (iii) 0.04597  
 (iv) 2808
- 1.21 The following data are obtained when dinitrogen and dioxygen react together to form different compounds :

|  | <b>Mass of dinitrogen</b> | <b>Mass of dioxygen</b> |
|--|---------------------------|-------------------------|
|--|---------------------------|-------------------------|

- |      |      |      |
|------|------|------|
| (i)  | 14 g | 16 g |
| (ii) | 14 g | 32 g |

- (iii)            28 g                            32 g  
(iv)            28 g                            80 g
- (a) Which law of chemical combination is obeyed by the above experimental data? Give its statement.
- (b) Fill in the blanks in the following conversions:  
(i) 1 km = ..... mm = ..... pm  
(ii) 1 mg = ..... kg = ..... ng  
(iii) 1 mL = ..... L = ..... dm<sup>3</sup>
- 1.22 If the speed of light is  $3.0 \times 10^8 \text{ m s}^{-1}$ , calculate the distance covered by light in 2.00 ns.
- 1.23 In a reaction  
 $A + B_2 \rightarrow AB_2$   
Identify the limiting reagent, if any, in the following reaction mixtures.  
(i) 300 atoms of A + 200 molecules of B  
(ii) 2 mol A + 3 mol B  
(iii) 100 atoms of A + 100 molecules of B  
(iv) 5 mol A + 2.5 mol B  
(v) 2.5 mol A + 5 mol B
- 1.24 Dinitrogen and dihydrogen react with each other to produce ammonia according to the following chemical equation:  
 $N_2(g) + H_2(g) \rightarrow 2NH_3(g)$   
(i) Calculate the mass of ammonia produced if  $2.00 \times 10^3 \text{ g}$  dinitrogen reacts with  $1.00 \times 10^3 \text{ g}$  of dihydrogen.  
(ii) Will any of the two reactants remain unreacted?  
(iii) If yes, which one and what would be its mass?
- 1.25 How are 0.50 mol Na<sub>2</sub>CO<sub>3</sub> and 0.50 M Na<sub>2</sub>CO<sub>3</sub> different?
- 1.26 If ten volumes of dihydrogen gas reacts with five volumes of dioxygen gas, how many volumes of water vapour would be produced?
- 1.27 Convert the following into basic units:  
(i) 28.7 pm  
(ii) 15.15 pm  
(iii) 25365 mg
- 1.28 Which one of the following will have largest number of atoms?  
(i) 1 g Au (s)  
(ii) 1 g Na (s)  
(iii) 1 g Li (s)  
(iv) 1 g of Cl<sub>2</sub>(g)
- 1.29 Calculate the molarity of a solution of ethanol in water in which the mole fraction of ethanol is 0.040.
- 1.30 What will be the mass of one <sup>12</sup>C atom in g ?
- 1.31 How many significant figures should be present in the answer of the following calculations?  
(i)  $\frac{0.02856 \times 29}{0.5}$                             (ii)  $5 \times 5.364$   
(iii)  $0.0125 + 0.7864 + 0.0215$



- 1.32 Use the data given in the following table to calculate the molar mass of naturally occurring *argon* isotopes:

| Isotope          | Isotopic molar mass           | Abundance |
|------------------|-------------------------------|-----------|
| $^{36}\text{Ar}$ | $35.96755 \text{ g mol}^{-1}$ | 0.337%    |
| $^{38}\text{Ar}$ | $37.96272 \text{ g mol}^{-1}$ | 0.063%    |
| $^{40}\text{Ar}$ | $39.9624 \text{ g mol}^{-1}$  | 99.600%   |

- 1.33 Calculate the number of atoms in each of the following (i) 52 moles of Ar (ii) 52 u of He (iii) 52 g of He.
- 1.34 A welding fuel gas contains carbon and hydrogen only. Burning a small sample of it in oxygen gives 3.38 g carbon dioxide, 0.690 g of water and no other products. A volume of 10.0 L (measured at STP) of this welding gas is found to weigh 11.6 g. Calculate (i) empirical formula, (ii) molar mass of the gas, and (iii) molecular formula.
- 1.35 Calcium carbonate reacts with aqueous HCl to give  $\text{CaCl}_2$  and  $\text{CO}_2$  according to the reaction,  $\text{CaCO}_3(\text{s}) + 2 \text{HCl}(\text{aq}) \rightarrow \text{CaCl}_2(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$   
What mass of  $\text{CaCO}_3$  is required to react completely with 25 mL of 0.75 M HCl?
- 1.36 Chlorine is prepared in the laboratory by treating manganese dioxide ( $\text{MnO}_2$ ) with aqueous hydrochloric acid according to the reaction  
 $4 \text{HCl}(\text{aq}) + \text{MnO}_2(\text{s}) \rightarrow 2\text{H}_2\text{O}(\text{l}) + \text{MnCl}_2(\text{aq}) + \text{Cl}_2(\text{g})$   
How many grams of HCl react with 5.0 g of manganese dioxide?

# ENVIRONMENTAL CHEMISTRY

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## Objectives

After studying this unit, you will be able to

- understand the meaning of environmental chemistry;
- define atmospheric pollution, list reasons for global warming, green house effect and acid rain;
- identify causes for ozone layer depletion and its effects;
- give reasons for water pollution and know about international standards for drinking water;
- describe causes of soil pollution;
- suggest and adopt strategies for control of environmental pollution;
- appreciate the importance of green chemistry in day to day life.

*“The world has achieved brilliance without wisdom, power without conscience. Ours is a world of nuclear giants and ethical infants.”*

You have already studied about environment in your earlier classes. Environmental studies deal with the sum of all social, economical, biological, physical and chemical interrelations with our surroundings. In this unit the focus will be on environmental chemistry. Environmental chemistry deals with the study of the origin, transport, reactions, effects and fates of chemical species in the environment. Let us discuss some important aspects of environmental chemistry.

### 14.1 ENVIRONMENTAL POLLUTION

Environmental pollution is the effect of undesirable changes in our surroundings that have harmful effects on plants, animals and human beings. A substance, which causes pollution, is known as pollutant. Pollutants can be solid, liquid or gaseous substances present in greater concentration than in natural abundance and are produced due to human activities or due to natural happenings. Do you know, an average human being requires nearly 12-15 times more air than the food. So, even small amounts of pollutants in the air become significant compared to similar levels present in the food. Pollutants can be degradable, like discarded vegetables which rapidly break down by natural processes. On the other hand, pollutants which are slowly degradable, remain in the environment in an unchanged form for many decades. For example, substances such as dichlorodiphenyltrichloroethane (DDT), plastic materials, heavy metals, many chemicals, nuclear wastes etc., once released into the environment are difficult to remove. These

pollutants cannot be degraded by natural processes and are harmful to living organisms. In the process of environmental pollution, pollutants originate from a source and get transported by air or water or are dumped into the soil by human beings.

## 14.2 ATMOSPHERIC POLLUTION

The atmosphere that surrounds the earth is not of the same thickness at all heights. There are concentric layers of air or regions and each layer has different density. The lowest region of atmosphere in which the human beings along with other organisms live is called **troposphere**. It extends up to the height of ~ 10 km from sea level. Above the troposphere, between 10 and 50 km above sea level lies **stratosphere**. Troposphere is a turbulent, dusty zone containing air, much water vapour and clouds. This is the region of strong air movement and cloud formation. The stratosphere, on the other hand, contains dinitrogen, dioxygen, ozone and little water vapour.

Atmospheric pollution is generally studied as tropospheric and stratospheric pollution. The presence of ozone in the stratosphere prevents about 99.5 per cent of the sun's harmful ultraviolet (UV) radiations from reaching the earth's surface and thereby protecting humans and other animals from its effect.

### 14.2.1 Tropospheric Pollution

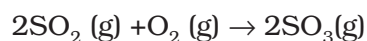
Tropospheric pollution occurs due to the presence of undesirable solid or gaseous particles in the air. The following are the major gaseous and particulate pollutants present in the troposphere:

1. Gaseous air pollutants: These are oxides of sulphur, nitrogen and carbon, hydrogen sulphide, hydrocarbons, ozone and other oxidants.
2. Particulate pollutants: These are dust, mist, fumes, smoke, smog etc.

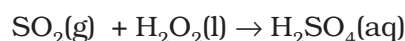
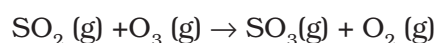
#### 1. Gaseous air pollutants

**(a) Oxides of Sulphur:** Oxides of sulphur are produced when sulphur containing fossil fuel is burnt. The most common species,

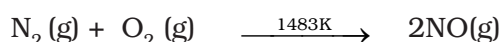
sulphur dioxide, is a gas that is poisonous to both animals and plants. It has been reported that even a low concentration of sulphur dioxide causes respiratory diseases e.g., asthma, bronchitis, emphysema in human beings. Sulphur dioxide causes irritation to the eyes, resulting in tears and redness. High concentration of  $\text{SO}_2$  leads to stiffness of flower buds which eventually fall off from plants. Uncatalysed oxidation of sulphur dioxide is slow. However, the presence of particulate matter in polluted air catalyses the oxidation of sulphur dioxide to sulphur trioxide.



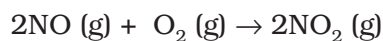
The reaction can also be promoted by ozone and hydrogen peroxide.



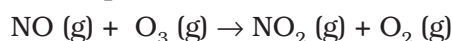
**(b) Oxides of Nitrogen:** Dinitrogen and dioxygen are the main constituents of air. These gases do not react with each other at a normal temperature. At high altitudes when lightning strikes, they combine to form oxides of nitrogen.  $\text{NO}_2$  is oxidised to nitrate ion,  $\text{NO}_3^-$  which is washed into soil, where it serves as a fertilizer. In an automobile engine, (at high temperature) when fossil fuel is burnt, dinitrogen and dioxygen combine to yield significant quantities of nitric oxide (NO) and nitrogen dioxide ( $\text{NO}_2$ ) as given below:



NO reacts instantly with oxygen to give  $\text{NO}_2$



Rate of production of  $\text{NO}_2$  is faster when nitric oxide reacts with ozone in the stratosphere.



The irritant red haze in the traffic and congested places is due to oxides of nitrogen. Higher concentrations of  $\text{NO}_2$  damage the leaves of plants and retard the rate of photosynthesis. Nitrogen dioxide is a lung irritant that can lead to an acute respiratory disease in children. It is toxic to living tissues also. Nitrogen dioxide is also harmful to various textile fibres and metals.

**(c) Hydrocarbons:** Hydrocarbons are composed of hydrogen and carbon only and are formed by incomplete combustion of fuel used in automobiles. Hydrocarbons are carcinogenic, *i.e.*, they cause cancer. They harm plants by causing ageing, breakdown of tissues and shedding of leaves, flowers and twigs.

**(d) Oxides of Carbon**

**(i) Carbon monoxide:** Carbon monoxide (CO) is one of the most serious air pollutants. It is a colourless and odourless gas, highly poisonous to living beings because of its ability to block the delivery of oxygen to the organs and tissues. It is produced as a result of incomplete combustion of carbon. Carbon monoxide is mainly released into the air by automobile exhaust. Other sources, which produce CO, involve incomplete combustion of coal, firewood, petrol, etc. The number of vehicles has been increasing over the years all over the world. Many vehicles are poorly maintained and several have inadequate pollution control equipments resulting in the release of greater amount of carbon monoxide and other polluting gases. Do you know why carbon monoxide is poisonous? It binds to haemoglobin to form carboxyhaemoglobin, which is about 300 times more stable than the oxygen-haemoglobin complex. In blood, when the concentration of carboxyhaemoglobin reaches about 3–4 per cent, the oxygen carrying capacity of blood is greatly reduced. This oxygen deficiency, results into headache, weak eyesight, nervousness and cardiovascular disorder. This is the reason why people are advised not to smoke. In pregnant women who have the habit of smoking the increased CO level in blood may induce premature birth, spontaneous abortions and deformed babies.

**(ii) Carbon dioxide:** Carbon dioxide (CO<sub>2</sub>) is released into the atmosphere by respiration, burning of fossil fuels for energy, and by decomposition of limestone during the manufacture of cement. It is also emitted during volcanic eruptions. Carbon dioxide gas is confined to troposphere only. Normally it forms about 0.03 per cent by volume of the

atmosphere. With the increased use of fossil fuels, a large amount of carbon dioxide gets released into the atmosphere. Excess of CO<sub>2</sub> in the air is removed by green plants and this maintains an appropriate level of CO<sub>2</sub> in the atmosphere. Green plants require CO<sub>2</sub> for photosynthesis and they, in turn, emit oxygen, thus maintaining the delicate balance. As you know, deforestation and burning of fossil fuel increases the CO<sub>2</sub> level and disturb the balance in the atmosphere. The increased amount of CO<sub>2</sub> in the air is mainly responsible for global warming.

**Global Warming and Greenhouse Effect**

About 75 % of the solar energy reaching the earth is absorbed by the earth's surface, which increases its temperature. The rest of the heat radiates back to the atmosphere. Some of the heat is trapped by gases such as carbon dioxide, methane, ozone, chlorofluorocarbon compounds (CFCs) and water vapour in the atmosphere. Thus, they add to the heating of the atmosphere. This causes global warming.

We all know that in cold places flowers, vegetables and fruits are grown in glass covered areas called greenhouse. Do you know that we humans also live in a greenhouse? Of course, we are not surrounded by glass but a blanket of air called the atmosphere, which has kept the temperature on earth constant for centuries. But it is now undergoing change, though slowly. Just as the glass in a greenhouse holds the sun's warmth inside, atmosphere traps the sun's heat near the earth's surface and keeps it warm. This is called *natural greenhouse effect* because it maintains the temperature and makes the earth perfect for life. In a greenhouse, visible light passes through the transparent glass and heats up the soil and the plants. The warm soil and plants emit infrared radiations. Since glass is opaque to infrared (heat) radiations, it partly reflects and partly absorbs these radiations. This mechanism keeps the energy of the sun trapped in the greenhouse. Similarly, carbon dioxide molecules also trap heat as they are transparent to sunlight but not to the heat radiation. If the amount of

carbon dioxide crosses the delicate proportion of 0.03 per cent, the natural greenhouse balance may get disturbed. Carbon dioxide is the major contributor to global warming.

Besides carbon dioxide, other greenhouse gases are methane, water vapour, nitrous oxide, CFCs and ozone. Methane is produced naturally when vegetation is burnt, digested or rotted in the absence of oxygen. Large amounts of methane are released in paddy fields, coal mines, from rotting garbage dumps and by fossil fuels. Chlorofluorocarbons (CFCs) are man-made industrial chemicals used in air conditioning etc. CFCs are also damaging the ozone layer (Section 14.2.2). Nitrous oxide occurs naturally in the environment. In recent years, their quantities have increased significantly due to the use of chemical fertilizers and the burning of fossil fuels. If these trends continue, the average global temperature will increase to a level which may lead to melting of polar ice caps and flooding of low lying areas all over the earth. Increase in the global temperature increases the incidence of infectious diseases like dengue, malaria, yellow fever, sleeping sickness etc.

### Think it Over

What can we do to reduce the rate of global warming?

If burning of fossil fuels, cutting down forests and trees add to greenhouse gases in the atmosphere, we must find ways to use these just efficiently and judiciously. One of the simple things which we can do to reduce global warming is to minimise the use of automobiles. Depending upon the situation, one can use bicycle, public transport system, or go for carpool. We should plant more trees to increase the green cover. Avoid burning of dry leaves, wood etc. It is illegal to smoke in public places and work places, because it is harmful not only for the one who is smoking but also for others, and therefore, we should avoid it. Many people do not understand the greenhouse effect and the global warming. We can help them by sharing the information that we have.

### Acid rain

We are aware that normally rain water has a pH of 5.6 due to the presence of  $H^+$  ions formed by the reaction of rain water with carbon

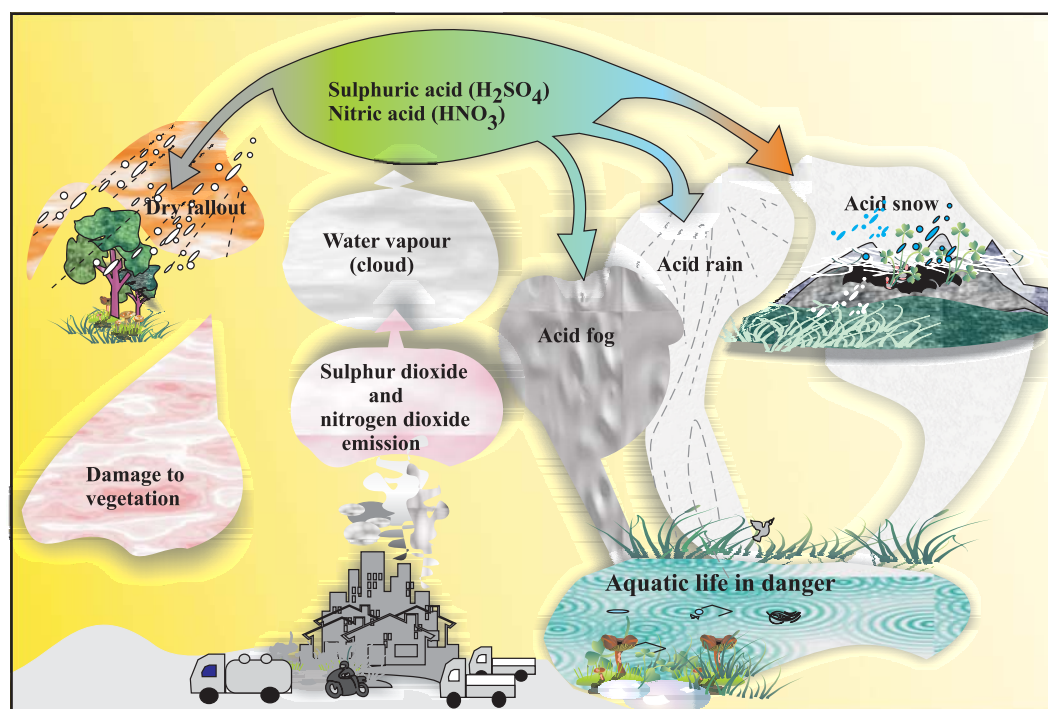
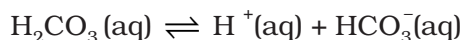
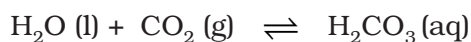


Fig. 14.1 Acid deposition

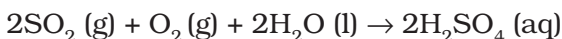
dioxide present in the atmosphere.



When the pH of the rain water drops below 5.6, it is called acid rain.

Acid rain refers to the ways in which acid from the atmosphere is deposited on the earth's surface. Oxides of nitrogen and sulphur which are acidic in nature can be blown by wind along with solid particles in the atmosphere and finally settle down either on the ground as dry deposition or in water, fog and snow as wet deposition. (Fig. 14.1)

Acid rain is a byproduct of a variety of human activities that emit the oxides of sulphur and nitrogen in the atmosphere. As mentioned earlier, burning of fossil fuels (which contain sulphur and nitrogenous matter) such as coal and oil in power stations and furnaces or petrol and diesel in motor engines produce sulphur dioxide and nitrogen oxides.  $\text{SO}_2$  and  $\text{NO}_2$  after oxidation and reaction with water are major contributors to acid rain, because polluted air usually contains particulate matter that catalyse the oxidation.



Ammonium salts are also formed and can be seen as an atmospheric haze (aerosol of fine particles). Aerosol particles of oxides or ammonium salts in rain drops result in wet-deposition.  $\text{SO}_2$  is also absorbed directly on both solid and liquid ground surfaces and is thus deposited as dry-deposition.

Acid rain is harmful for agriculture, trees and plants as it dissolves and washes away nutrients needed for their growth. It causes respiratory ailments in human beings and animals. When acid rain falls and flows as ground water to reach rivers, lakes etc. it affects plants and animal life in aquatic ecosystem. It corrodes water pipes resulting in the leaching of heavy metals such as iron, lead and copper into the drinking water. Acid rain damages buildings and other structures made of stone or metal. The Taj Mahal in India has been affected by acid rain.

### Activity 1

You can collect samples of water from nearby places and record their pH values. Discuss your results in the class. Let us discuss how we can help to reduce the formation of acid rain.

This can be done by reducing the emission of sulphur dioxide and nitrogen dioxide in the atmosphere. We should use less vehicles driven by fossil fuels; use less sulphur content fossil fuels for power plants and industries. We should use natural gas which is a better fuel than coal or use coal with less sulphur content. Catalytic converters must be used in cars to reduce the effect of exhaust fumes on the atmosphere. The main component of the converter is a ceramic honeycomb coated with precious metals — Pd, Pt and Rh. The exhaust gases containing unburnt fuel, CO and  $\text{NO}_x$ , when pass through the converter at 573 K, are converted into  $\text{CO}_2$  and  $\text{N}_2$ . We can also reduce the acidity of the soil by adding powdered limestone to neutralise the acidity of the soil. Many people do not know of acid rain and its harmful effects. We can make them aware by passing on this information and save the Nature.

### Taj Mahal and Acid Rain

The air around the city of Agra, where the Taj Mahal is located, contains fairly high levels of sulphur and nitrogen oxides. It is mainly due to a large number of industries and power plants around the area. Use of poor quality of coal, kerosene and firewood as fuel for domestic purposes add up to this problem. The resulting acid rain reacts with marble,  $\text{CaCO}_3$  of Taj Mahal ( $\text{CaCO}_3 + \text{H}_2\text{SO}_4 \rightarrow \text{CaSO}_4 + \text{H}_2\text{O} + \text{CO}_2$ ) causing damage to this wonderful monument that has attracted people from around the world. As a result, the monument is being slowly disfigured and the marble is getting discoloured and lustreless. The Government of India announced an action plan in early 1995 to prevent the disfiguring of this historical monument. Mathura refinery has already taken suitable measures to check the emission of toxic gases.

This plan aims at clearing the air in the '**Taj Trapezium**'- an area that includes the towns of Agra, Firozabad, Mathura and Bharatpur. Under this plan more than 2000 polluting industries lying inside the trapezium would switch over to the use of natural gas or liquefied petroleum gas instead of coal or oil. A new natural gas pipeline would bring more than half a million cubic metres of natural gas a day to this area. People living in the city will also be encouraged to use liquefied petroleum gas in place of coal, kerosene or firewood. Vehicles plying on highways in the vicinity of Taj would be encouraged to use low sulphur content diesel.

## 2. Particulate Pollutants

Particulates pollutants are the minute solid particles or liquid droplets in air. These are present in vehicle emissions, smoke particles from fires, dust particles and ash from industries. Particulates in the atmosphere may be viable or non-viable. The viable particulates *e.g.*, bacteria, fungi, moulds, algae etc., are minute living organisms that are dispersed in the atmosphere. Human beings are allergic to some of the fungi found in air. They can also cause plant diseases.

Non-viable particulates may be classified according to their nature and size as follows:

- (a) Smoke particulates consist of solid or mixture of solid and liquid particles formed during combustion of organic matter. Examples are cigarette smoke, smoke from burning of fossil fuel, garbage and dry leaves, oil smoke etc.
- (b) Dust is composed of fine solid particles (over  $1\mu\text{m}$  in diameter), produced during crushing, grinding and attrition of solid materials. Sand from sand blasting, saw dust from wood works, pulverized coal, cement and fly ash from factories, dust storms etc., are some typical examples of this type of particulate emission.
- (c) Mists are produced by particles of spray liquids and by condensation of vapours in air. Examples are sulphuric acid mist and

herbicides and insecticides that miss their targets and travel through air and form mists.

- (d) Fumes are generally obtained by the condensation of vapours during sublimation, distillation, boiling and several other chemical reactions. Generally, organic solvents, metals and metallic oxides form fume particles.

The effect of particulate pollutants are largely dependent on the particle size. Air-borne particles such as dust, fumes, mist etc., are dangerous for human health. Particulate pollutants bigger than 5 microns are likely to lodge in the nasal passage, whereas particles of about 1.0 micron enter into lungs easily.

Lead used to be a major air pollutant emitted by vehicles. Leaded petrol used to be the primary source of air-borne lead emission in Indian cities. This problem has now been overcome by using unleaded petrol in most of the cities in India. Lead interferes with the development and maturation of red blood cells.

### Smog

The word smog is derived from smoke and fog. This is the most common example of air pollution that occurs in many cities throughout the world. There are two types of smog:

- (a) Classical smog occurs in cool humid climate. It is a mixture of smoke, fog and sulphur dioxide. Chemically it is a reducing mixture and so it is also called as reducing smog.
- (b) Photochemical smog occurs in warm, dry and sunny climate. The main components of the photochemical smog result from the action of sunlight on unsaturated hydrocarbons and nitrogen oxides produced by automobiles and factories. Photochemical smog has high concentration of oxidising agents and is, therefore, called as oxidising smog.

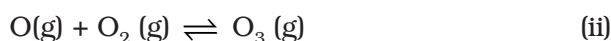
### Formation of photochemical smog

When fossil fuels are burnt, a variety of pollutants are emitted into the earth's

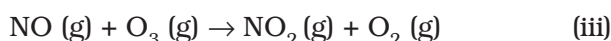
troposphere. Two of the pollutants that are emitted are hydrocarbons (unburnt fuels) and nitric oxide (NO). When these pollutants build up to sufficiently high levels, a chain reaction occurs from their interaction with sunlight in which NO is converted into nitrogen dioxide (NO<sub>2</sub>). This NO<sub>2</sub> in turn absorbs energy from sunlight and breaks up into nitric oxide and free oxygen atom (Fig. 14.2).



Oxygen atoms are very reactive and combine with the O<sub>2</sub> in air to produce ozone.

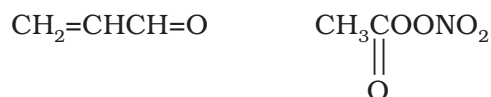
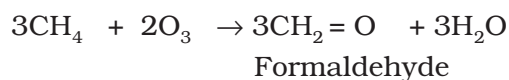


The ozone formed in the above reaction (ii) reacts rapidly with the NO(g) formed in the reaction (i) to regenerate NO<sub>2</sub>. NO<sub>2</sub> is a brown gas and at sufficiently high levels can contribute to haze.



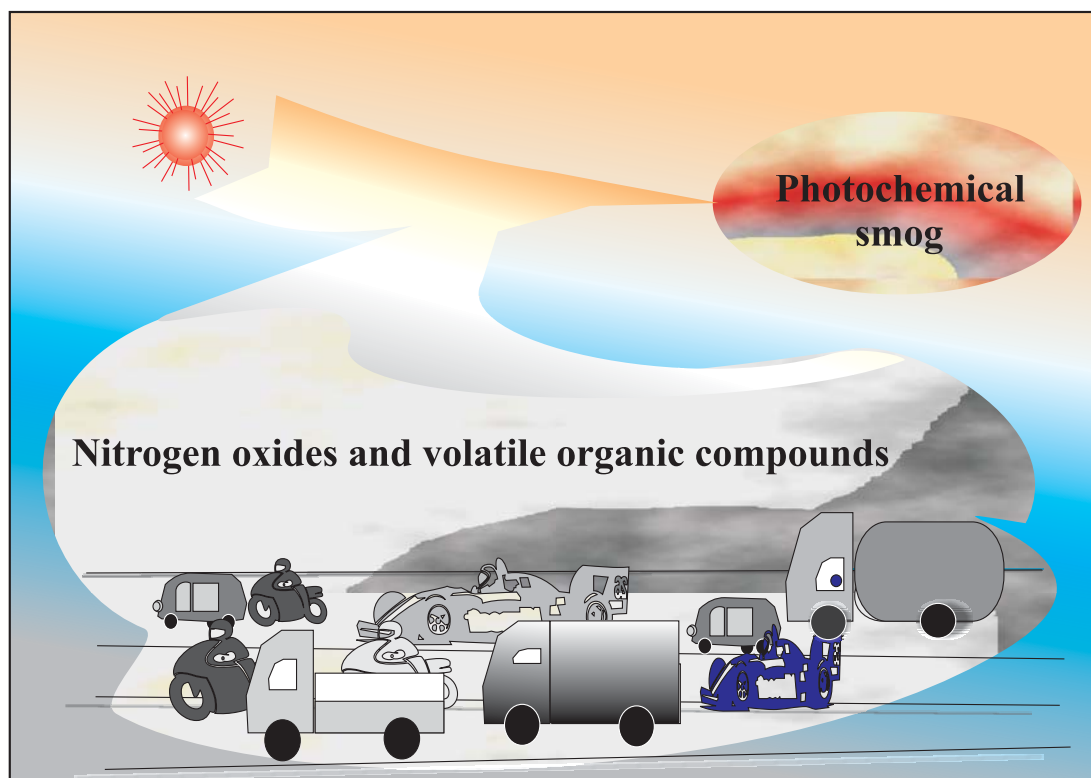
Ozone is a toxic gas and both NO<sub>2</sub> and O<sub>3</sub> are strong oxidising agents and can react with the unburnt hydrocarbons in the polluted air

to produce chemicals such as formaldehyde, acrolein and peroxyacetyl nitrate (PAN).



### Effects of photochemical smog

The common components of photochemical smog are ozone, nitric oxide, acrolein, formaldehyde and peroxyacetyl nitrate (PAN). Photochemical smog causes serious health problems. Both ozone and PAN act as powerful eye irritants. Ozone and nitric oxide irritate the nose and throat and their high concentration causes headache, chest pain, dryness of the throat, cough and difficulty in breathing. Photochemical smog leads to cracking of rubber and extensive damage to plant life. It also causes corrosion of metals, stones, building materials, rubber and painted surfaces.



**Fig. 14.2** Photochemical smog occurs where sunlight acts on vehicle pollutants.



### How can photochemical smog be controlled ?

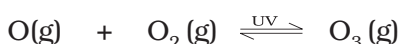
Many techniques are used to control or reduce the formation of photochemical smog. If we control the primary precursors of photochemical smog, such as  $\text{NO}_2$  and hydrocarbons, the secondary precursors such as ozone and PAN, the photochemical smog will automatically be reduced. Usually catalytic converters are used in the automobiles, which prevent the release of nitrogen oxide and hydrocarbons to the atmosphere. Certain plants e.g., Pinus, Juniparus, Quercus, Pyrus and Vitis can metabolise nitrogen oxide and therefore, their plantation could help in this matter.

#### 14.2.2 Stratospheric Pollution

##### Formation and Breakdown of Ozone

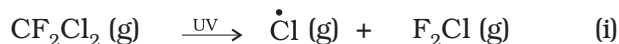
The upper stratosphere consists of considerable amount of ozone ( $\text{O}_3$ ), which protects us from the harmful ultraviolet (UV) radiations ( $\lambda$  255 nm) coming from the sun. These radiations cause skin cancer (melanoma) in humans. Therefore, it is important to maintain the ozone shield.

Ozone in the stratosphere is a product of UV radiations acting on dioxygen ( $\text{O}_2$ ) molecules. The UV radiations split apart molecular oxygen into free oxygen (O) atoms. These oxygen atoms combine with the molecular oxygen to form ozone.

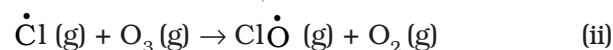


Ozone is thermodynamically unstable and decomposes to molecular oxygen. Thus, a dynamic equilibrium exists between the production and decomposition of ozone molecules. In recent years, there have been reports of the depletion of this protective ozone layer because of the presence of certain chemicals in the stratosphere. The main reason of ozone layer depletion is believed to be the release of chlorofluorocarbon compounds (CFCs), also known as freons. These compounds are nonreactive, non flammable, non toxic organic molecules and therefore used in refrigerators, air conditioners,

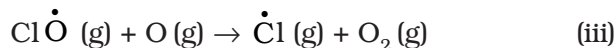
in the production of plastic foam and by the electronic industry for cleaning computer parts etc. Once CFCs are released in the atmosphere, they mix with the normal atmospheric gases and eventually reach the stratosphere. In stratosphere, they get broken down by powerful UV radiations, releasing chlorine free radical.



The chlorine radical then react with stratospheric ozone to form chlorine monoxide radicals and molecular oxygen.



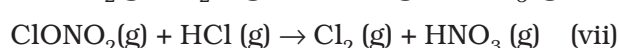
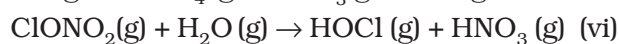
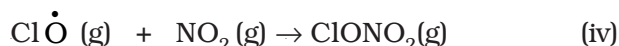
Reaction of chlorine monoxide radical with atomic oxygen produces more chlorine radicals.



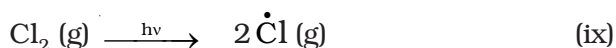
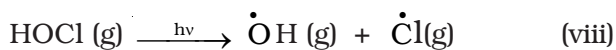
The chlorine radicals are continuously regenerated and cause the breakdown of ozone. Thus, CFCs are transporting agents for continuously generating chlorine radicals into the stratosphere and damaging the ozone layer.

##### The Ozone Hole

In 1980s atmospheric scientists working in Antarctica reported about depletion of ozone layer commonly known as ozone hole over the South Pole. It was found that a unique set of conditions was responsible for the ozone hole. In summer season, nitrogen dioxide and methane react with chlorine monoxide (reaction iv) and chlorine atoms (reaction v) forming chlorine sinks, preventing much ozone depletion, whereas in winter, special type of clouds called polar stratospheric clouds are formed over Antarctica. These polar stratospheric clouds provide surface on which chlorine nitrate formed (reaction iv) gets hydrolysed to form hypochlorous acid (reaction (vi)). It also reacts with hydrogen chloride produced as per reaction (v) to give molecular chlorine.



When sunlight returns to the Antarctica in the spring, the sun's warmth breaks up the clouds and HOCl and Cl<sub>2</sub> are photolysed by sunlight, as given in reactions (viii) and (ix).



The chlorine radicals thus formed, initiate the chain reaction for ozone depletion as described earlier.

### Effects of Depletion of the Ozone Layer

With the depletion of ozone layer, more UV radiation filters into troposphere. UV radiations lead to ageing of skin, cataract, sunburn, skin cancer, killing of many phytoplanktons, damage to fish productivity etc. It has also been reported that plant proteins get easily affected by UV radiations which leads to the harmful mutation of cells. It also increases evaporation of surface water through the stomata of the leaves and decreases the moisture content of the soil. Increase in UV radiations damage paints and fibres, causing them to fade faster.

## 14.3 WATER POLLUTION

Water is essential for life. Without water there would be no life. We usually take water as granted for its purity, but we must ensure the quality of water. Pollution of water originates from human activities. Through different paths, pollution reaches surface or ground water. Easily identified source or place of pollution is called as point source. e.g., municipal and industrial discharge pipes

where pollutants enter the water-source. Non point sources of pollution are those where a source of pollution cannot be easily identified, e.g., agricultural run off (from farm, animals and crop-lands), acid rain, storm-water drainage (from streets, parking lots and lawns), etc. Table 14.1 lists the major water pollutants and their sources.

### 14.3.1 Causes of Water Pollution

**(i) Pathogens:** The most serious water pollutants are the disease causing agents called pathogens. Pathogens include bacteria and other organisms that enter water from domestic sewage and animal excreta. Human excreta contain bacteria such as *Escherichia coli* and *Streptococcus faecalis* which cause gastrointestinal diseases.

**(ii) Organic wastes:** The other major water pollutant is organic matter such as leaves, grass, trash etc. They pollute water as a consequence of run off. Excessive phytoplankton growth within water is also a cause of water pollution. These wastes are biodegradable.

The large population of bacteria decomposes organic matter present in water. They consume oxygen dissolved in water. The amount of oxygen that water can hold in the solution is limited. In cold water, dissolved oxygen (DO) can reach a concentration up to 10 ppm (parts per million), whereas oxygen in air is about 200,000 ppm. That is why even a moderate amount of organic matter when decomposes in water can deplete the water of its dissolved oxygen. The concentration of

Table 14.1 Major Water Pollutants

| Pollutant              | Source  |
|------------------------|---|
| Micro-organisms        | Domestic sewage   |
| Organic wastes         | Domestic sewage, animal excreta and waste, decaying animals and plants, discharge from food processing factories. |
| Plant nutrients        | Chemical fertilizers  |
| Toxic heavy metals     | Industries and chemical factories   |
| Sediments              | Erosion of soil by agriculture and strip mining   |
| Pesticides             | Chemicals used for killing insects, fungi and weeds   |
| Radioactive substances | Mining of uranium containing minerals   |
| Heat                   | Water used for cooling in industries  |

dissolved oxygen in water is very important for aquatic life. If the concentration of dissolved oxygen of water is below 6 ppm, the growth of fish gets inhibited. Oxygen reaches water either through atmosphere or from the process of photosynthesis carried out by many aquatic green plants during day light. However, during night, photosynthesis stops but the plants continue to respire, resulting in reduction of dissolved oxygen. The dissolved oxygen is also used by microorganisms to oxidise organic matter.

If too much of organic matter is added to water, all the available oxygen is used up. This causes oxygen dependent aquatic life to die. Thus, anaerobic bacteria (which do not require oxygen) begin to break down the organic waste and produce chemicals that have a foul smell and are harmful to human health. Aerobic (oxygen requiring) bacteria degrade these organic wastes and keep the water depleted in dissolved oxygen.

Thus, the amount of oxygen required by bacteria to break down the organic matter present in a certain volume of a sample of water, is called **Biochemical Oxygen Demand (BOD)**. The amount of BOD in the water is a measure of the amount of organic material in the water, in terms of how much oxygen will be required to break it down biologically. Clean water would have BOD value of less than 5 ppm whereas highly polluted water could have a BOD value of 17 ppm or more.

**(iii) Chemical Pollutants:** As we know that water is an excellent solvent, water soluble inorganic chemicals that include heavy metals such as cadmium, mercury, nickel etc constitute an important class of pollutants. All these metals are dangerous to humans because our body cannot excrete them. Over the time, it crosses the tolerance limit. These metals then can damage kidneys, central nervous system, liver etc. Acids (like sulphuric acid) from mine drainage and salts from many different sources including raw salt used to melt snow and ice in the colder climates (sodium and calcium chloride) are water soluble chemical pollutants.

The organic chemicals are another group of substances that are found in polluted water. Petroleum products pollute many sources of water e.g., major oil spills in oceans. Other organic substances with serious impacts are the pesticides that drift down from sprays or runoff from lands. Various industrial chemicals like polychlorinated biphenyls, (PCBs) which are used as cleansing solvent, detergents and fertilizers add to the list of water pollutants. PCBs are suspected to be carcinogenic. Nowadays most of the detergents available are biodegradable. However, their use can create other problems. The bacteria responsible for degrading biodegradable detergent feed on it and grow rapidly. While growing, they may use up all the oxygen dissolved in water. The lack of oxygen kills all other forms of aquatic life such as fish and plants. Fertilizers contain phosphates as additives. The addition of phosphates in water enhances algae growth. Such profuse growth of algae, covers the water surface and reduces the oxygen concentration in water. This leads to anaerobic conditions, commonly with accumulation of abnoxious decay and animal death. Thus, bloom-infested water inhibits the growth of other living organisms in the water body. This process in which nutrient enriched water bodies support a dense plant population, which kills animal life by depriving it of oxygen and results in subsequent loss of biodiversity is known as **Eutrophication**.

### 14.3.2 International Standards for Drinking Water

The International Standards for drinking water are given below and they must be followed.

**Fluoride:** For drinking purposes, water should be tested for fluoride ion concentration. Its deficiency in drinking water is harmful to man and causes diseases such as tooth decay etc. Soluble fluoride is often added to drinking water to bring its concentration upto 1 ppm or  $1 \text{ mg dm}^{-3}$ . The  $\text{F}^-$  ions make the enamel on teeth much harder by converting hydroxyapatite,  $[\text{3}(\text{Ca}_3(\text{PO}_4)_2 \cdot \text{Ca}(\text{OH})_2)]$ , the enamel on the surface of the teeth, into much harder fluorapatite,  $[\text{3}(\text{Ca}_3(\text{PO}_4)_2 \cdot \text{CaF}_2)]$ .

However,  $F^-$  ion concentration above 2 ppm causes brown mottling of teeth. At the same time, excess fluoride (over 10 ppm) causes harmful effect to bones and teeth, as reported from some parts of Rajasthan.

**Lead:** Drinking water gets contaminated with lead when lead pipes are used for transportation of water. The prescribed upper limit concentration of lead in drinking water is about 50 ppb. Lead can damage kidney, liver, reproductive system etc.

**Sulphate:** Excessive sulphate (>500 ppm) in drinking water causes laxative effect, otherwise at moderate levels it is harmless.

**Nitrate:** The maximum limit of nitrate in drinking water is 50 ppm. Excess nitrate in drinking water can cause disease such as methemoglobinemia ('blue baby' syndrome).

**Other metals:** The maximum concentration of some common metals recommended in drinking water are given in Table 14.2.

**Table 14.2 Maximum Prescribed Concentration of Some Metals in Drinking Water.**

| Metal | Maximum concentration (ppm or $mg\ dm^{-3}$ ) |
|-------|---|
| Fe    | 0.2   |
| Mn    | 0.05  |
| Al    | 0.2   |
| Cu    | 3.0   |
| Zn    | 5.0   |
| Cd    | 0.005   |

### Activity 2

You can visit local water sources and observe if the river/lake/tank/pond are unpolluted/slightly polluted/moderately polluted or severely polluted by looking at water or by checking pH of water. Document the name of the river and the nearby urban or industrial site from where the pollution is generated. Inform about this to Pollution Control Board's office set up by Government to measure

pollution levels. Ensure that appropriate action is taken. You can write to the press also. Do not dump waste into a household or industrial drain which can enter directly to any water body, such as, river, pond, stream or lake. Use compost instead of chemical fertilizers in gardens. Avoid the use of pesticides like DDT, malathion etc., at home and try to use dried neem leaves to help keep insects away. Add a few crystals of potassium permanganate ( $KMnO_4$ ) or bleaching powder to the water tank of your house.

## 14.4 SOIL POLLUTION

India being an agriculture based economy gives high priority to agriculture, fisheries and livestock development. The surplus production is stored by governmental and non-governmental organisations for the lean season. The food loss during the storage also needs special attention. Have you ever seen the damages caused to the crops, food items by insects, rodents, weeds and crop diseases etc? How can we protect them? You are acquainted with some insecticides and pesticides for protection of our crops. However, these insecticides, pesticides and herbicides cause soil pollution. Hence, there is a need for their judicious use.

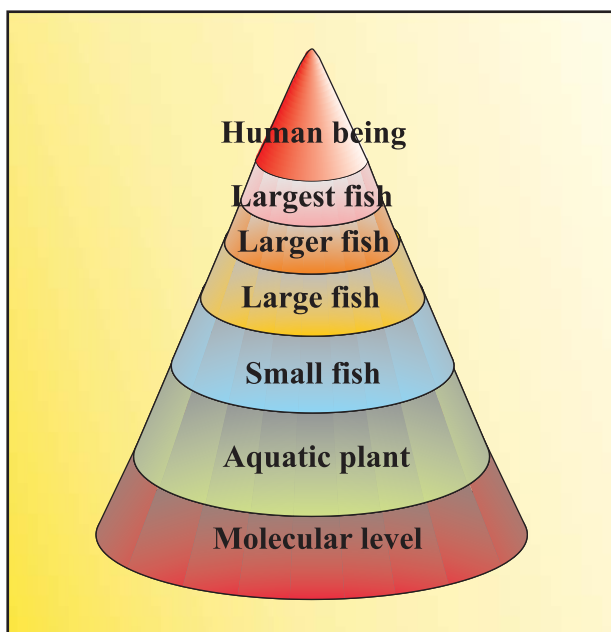
### 14.4.1 Pesticides

Prior to World War II, many naturally occurring chemicals such as nicotine (by planting tobacco plants in the crop field), were used as pest controlling substance for major crops in agricultural practices.

During World War II, DDT was found to be of great use in the control of malaria and other insect-borne diseases. Therefore, after the war, DDT was put to use in agriculture to control the damages caused by insects, rodents, weeds and various crop diseases. However, due to adverse effects, its use has been banned in India.

Pesticides are basically synthetic toxic chemicals with ecological repercussions. The repeated use of the same or similar pesticides give rise to pests that are resistant to that

group of pesticides thus making the pesticides ineffective. Therefore, as insect resistance of DDT increased, other organic toxins such as Aldrin and Dieldrin were introduced in the market by pesticide industry. Most of the organic toxins are water insoluble and non-biodegradable. These high persistent toxins are, therefore, transferred from lower trophic level to higher trophic level through food chain (Fig. 14.3). Over the time, the concentration of toxins in higher animals reach a level which causes serious metabolic and physiological disorders.



**Fig. 14.3** At each trophic level, the pollutant gets 10 times concentrated.

In response to high persistence of chlorinated organic toxins, a new series of less persistent or more bio-degradable products called organo-phosphates and carbamates have been introduced in the market. But these chemicals are severe nerve toxins and hence more harmful to humans. As a result, there are reports of some pesticides related deaths of agricultural field workers. Insects have become resistant to these insecticides also. The insecticide industry is engaged in developing new groups of insecticides. But one has to think, is this the only solution to pest menace?

These days, the pesticide industry has shifted its attention to **herbicides** such as

sodium chlorate ( $\text{NaClO}_3$ ), sodium arsenite ( $\text{Na}_3\text{AsO}_3$ ) and many others. During the first half of the last century, the shift from mechanical to chemical weed control had provided the industry with flourishing economic market. But one must remember that these are also not environment friendly.

Most herbicides are toxic to mammals but are not as persistent as organo-chlorides. These chemicals decompose in a few months. Like organo-chlorides, these too become concentrated in the food web. Some herbicides cause birth defects. Studies show that corn-fields sprayed with herbicides are more prone to insect attack and plant disease than fields that are weeded manually.

Pesticides and herbicides represent only a very small portion of widespread chemical pollution. A large number of other compounds that are used regularly in chemical and industrial processes for manufacturing activities are finally released in the atmosphere in one or other form.

#### 14.5 INDUSTRIAL WASTE

Industrial solid wastes are also sorted out as biodegradable and non-degradable wastes. Biodegradable wastes are generated by cotton mills, food processing units, paper mills, and textile factories.

Non-biodegradable wastes are generated by thermal power plants which produce fly ash; integrated iron and steel plants which produce blast furnace slag and steel melting slag. Industries manufacturing aluminium, zinc and copper produce mud and tailings. Fertilizer industries produce gypsum. Hazardous wastes such as inflammables, composite explosives or highly reactive substances are produced by industries dealing in metals, chemicals, drugs, pharmaceuticals, dyes, pesticides, rubber goods etc.

The disposal of non-degradable industrial solid wastes, if not done by a proper and suitable method, may cause serious threat to the environment. New innovations have led to different uses of waste material. Nowadays, fly ash and slag from the steel industry are utilised by the cement industry. Large

quantities of toxic wastes are usually destroyed by controlled incineration, whereas small quantities are burnt along with factory garbage in open bins. Moreover, solid wastes if not managed effectively, affect the components of the environment.

#### Do you know about waste recycling?

- Fuel obtained from plastic waste has high octane rating. It contains no lead and is known as “green fuel”.
- Due to recent developments made in chemical and textile industries, clothes will be made from recycled plastic waste. These will be available soon in the global textile market.
- In India, our cities and towns face endless hours of power cut. We can also see piles of rotting garbage here and there. There is a good news that we can get rid from both these problems simultaneously. Technology has now been developed to produce electricity from the garbage. A pilot plant has been set up, where after removing ferrous metals, plastic, glass, paper etc. from garbage, it is mixed with water. It is then cultured with bacterial species for producing methane, commonly known as biogas. The remaining product is used as manure and biogas is used to produce electricity.

### 14.6 STRATEGIES TO CONTROL ENVIRONMENTAL POLLUTION

After studying air, water, soil and industrial waste pollution in this unit, by now you must have started feeling the need of controlling environmental pollution: How can you save your immediate environment? Think of the steps/activities, which you would like to undertake for controlling air, water, soil and industrial waste pollution in your neighbourhood. Here, an idea about the strategies for the management of waste is given.

#### 14.6.1 Waste Management

Solid waste is not the only waste, which you see in your household garbage box. Besides

household discards, there are medical, agricultural, industrial and mining wastes. The improper disposal of wastes is one of the major causes of environmental degradation. Therefore, the management of wastes is of utmost importance.

#### Collection and Disposal

Domestic wastes are collected in small bins, which are then transferred to community bins by private or municipal workers. From these community bins, these are collected and carried to the disposable site. At the site, garbage is sorted out and separated into biodegradable and non-biodegradable materials. Non-biodegradable materials such as plastic, glass, metal scraps etc. are sent for recycling. Biodegradable wastes are deposited in land fills and are converted into compost.

The waste if not collected in garbage bins, finds its way into the sewers. Some of it is eaten by cattle. Non-biodegradable wastes like polythene bag, metal scraps, etc. choke the sewers and cause inconvenience. Polythene bags, if swallowed by cattle can cost their lives also.

As a normal practice, therefore, all domestic wastes should be properly collected and disposed. The poor management causes health problems leading to epidemics due to contamination of ground water. It is specially hazardous for those who are in direct contact with the waste such as rag pickers and workers involved in waste disposal, as they are the ones who handle waste materials mostly without protective device such as gloves or water proof boots and gas masks. What can you do for them?

### 14.7 GREEN CHEMISTRY

#### 14.7.1 Introduction

It is well known fact that self-sufficiency in food has been achieved in India since late 20<sup>th</sup> century by using fertilizers and pesticides and exploring improved methods of farming, good quality seeds, irrigation etc. But over-exploitation of soil and excessive use of fertilizers and pesticides have resulted in the deterioration of soil, water and air.

The solution of this problem does not lie in stopping the process of development that has been set in; but to discover methods, which would help in the reduction of deterioration of the environment. *Green chemistry is a way of thinking and is about utilising the existing knowledge and principles of chemistry and other sciences to reduce the adverse impact on environment. Green chemistry is a production process that would bring about minimum pollution or deterioration to the environment. The byproducts generated during a process, if not used gainfully, add to the environmental pollution. Such processes are not only environmental unfriendly but also cost-ineffective. The waste generation and its disposal both are economically unsound. Utilisation of existing knowledge base for reducing the chemical hazards along with the developmental activities is the foundation of green chemistry.* Have you perceived the idea of green chemistry? It is well known that organic solvents such as benzene, toluene, carbon

tetrachloride etc., are highly toxic. One should be careful while using them.

As you know, a chemical reaction involves reactants, attacking reagents and the medium in which the reaction takes place. Extent of any reaction depends upon physical parameters like temperature, pressure and use of catalyst. In a chemical reaction, if reactants are fully converted into useful environmental friendly products by using an environment friendly medium then there would be no chemical pollutants introduced in the environment.

During a synthesis, care must be taken to choose starting materials that can be converted into end products with yield approximately upto 100 per cent. This can be achieved by arriving at optimum conditions of synthesis. It may be worthwhile to carry out synthetic reactions in aqueous medium since water has high specific heat and low volatility. Water is cost effective, noninflammable and devoid of any carcinogenic effects.

### Nobel goes to Green Chemists



Yves Chauvin



Robert H. Grubbs



Richard R. Schrock

**Yves Chauvin**, Institut Français du Pétrole, Rueil-Malmaison France, **Robert H. Grubbs** California Institute of Technology (Caltech), Pasadena, CA, USA and **Richard R. Schrock** Massachusetts Institute of Technology (MIT), Cambridge, MA, USA won the 2005 Nobel Prize in chemistry for work that reduces hazardous waste in creating new chemicals. The trio won the award for their development of the metathesis method in organic synthesis –a way to rearrange groups of atoms within molecules that the Royal Swedish Academy of Sciences likened to a dance in which couples change partners. The metathesis has tremendous commercial potential in the pharmaceuticals, biotechnology and food stuffs production industries. It is also used in the development of revolutionary environmentally-friendlier polymers.

This represents a great step forward for 'green chemistry', reducing potentially hazardous waste through smarter production. Metathesis is an example of how important application of basic science is for the benefit of man, society and the environment.

### 14.7.2 Green Chemistry in day-to-day Life

#### (i) Dry Cleaning of Clothes

Tetra chloroethene ( $\text{Cl}_2\text{C}=\text{CCl}_2$ ) was earlier used as solvent for dry cleaning. The compound contaminates the ground water and is also a suspected carcinogen. The process using this compound is now being replaced by a process, where liquefied carbondioxide, with a suitable detergent is used. Replacement of halogenated solvent by liquid  $\text{CO}_2$  will result in less harm to ground water.

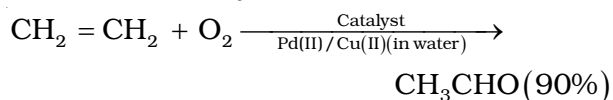
These days hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) is used for the purpose of bleaching clothes in the process of laundry, which gives better results and makes use of lesser amount of water.

#### (ii) Bleaching of Paper

Chlorine gas was used earlier for bleaching paper. These days, hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) with suitable catalyst, which promotes the bleaching action of hydrogen peroxide, is used.

#### (iii) Synthesis of Chemicals

Ethanal ( $\text{CH}_3\text{CHO}$ ) is now commercially prepared by one step oxidation of ethene in the presence of ionic catalyst in aqueous medium with an yield of 90%.



Green chemistry, in a nutshell, is a cost effective approach which involves reduction in material, energy consumption and waste generation.

#### Think it Over

What is our responsibility as a human being to protect our environment?

Some concepts, if followed by an individual, contribute towards a better quality of our environment and human life. Always set up a compost tin in your garden or any other place in your home and use it to produce manure for your plants to reduce the use of fertilizers. Use a cloth bag and avoid asking for plastic carry bags when you buy groceries, vegetables or any other item. See that all newspapers, glass, aluminum and other items in your area are recycled. We might have to take little trouble to locate such dealers. We must realize that we do not have solutions for every problem but we can concentrate on issues, which we feel strongly about and can do some thing about. We should take care to put into practice whatever we preach. Always remember environment protection begins with us.

#### SUMMARY

Environmental chemistry plays a major role in environment. Chemical species present in the environment are either naturally occurring or generated by human activities. **Environmental pollution** is the effect of undesirable changes in the surrounding that have harmful effects on plants, animals and human beings. Pollutants exist in all the three states of matter. We have discussed only those pollutants, which are due to human activities, and can be controlled. Atmospheric pollution is generally studied as **tropospheric** and **stratospheric pollution**. Troposphere is the lowest region of the atmosphere (~10 km) in which man along with other organisms including plants exist. Whereas stratosphere extends above troposphere up to 50 km above sea level. Ozone layer is one of the important constituents of stratosphere. Tropospheric pollution is basically due to various oxides of sulphur, nitrogen, carbon, halogens and also due to particulate pollutants. The gaseous pollutants come down to the earth in the form of **acid rain**. 75% of the solar energy reaching earth is absorbed by the earth surface and rest is radiated back to the atmosphere. These gases mentioned above trap the heat which result into **global warming**. It is important to realise that these very gases are also responsible for the life on the earth as they trap the requisite amount of solar



energy for the sustenance of life. The increase in the **greenhouse gases** is raising the temperature of the earth's atmosphere which, if not checked, may eventually result in melting of polar ice caps and consequently may submerge the coastal land mass. Many human activities are producing chemicals, which are responsible for the **depletion of ozone layer** in the stratosphere, leading to the formation of **ozone hole**. Through the ozone hole, ultraviolet radiations can penetrate into the earth's atmosphere causing mutation of genes. Water is the elixir of life but the same water, if polluted by pathogens, organic wastes, toxic heavy metals, pesticides etc., will turn into poison. Therefore, one should take care to follow international standards to maintain purity levels of drinking water. Industrial wastes and excessive use of pesticides, result into pollution of land mass and water bodies. Judicious use of chemicals required for agricultural practices can lead to sustainable development. **Strategies for controlling environmental pollution** can be: (i) waste management *i.e.*, reduction of the waste and proper disposal, also recycling of materials and energy, (ii) adopting methods in day-to-day life, which results in the reduction of environmental pollution. The second method is a new branch of chemistry, which is in its infancy known as **green chemistry**. It utilizes the existing knowledge and practices so as to bring about reduction in the production of pollutants.

### EXERCISES

- 14.1 Define environmental chemistry.
- 14.2 Explain tropospheric pollution in 100 words.
- 14.3 Carbon monoxide gas is more dangerous than carbon dioxide gas. Why?
- 14.4 List gases which are responsible for greenhouse effect.
- 14.5 Statues and monuments in India are affected by acid rain. How?
- 14.6 What is smog? How is classical smog different from photochemical smogs?
- 14.7 Write down the reactions involved during the formation of photochemical smog.
- 14.8 What are the harmful effects of photochemical smog and how can they be controlled?
- 14.9 What are the reactions involved for ozone layer depletion in the stratosphere?
- 14.10 What do you mean by ozone hole? What are its consequences?
- 14.11 What are the major causes of water pollution? Explain.
- 14.12 Have you ever observed any water pollution in your area? What measures would you suggest to control it?
- 14.13 What do you mean by Biochemical Oxygen Demand (BOD)?
- 14.14 Do you observe any soil pollution in your neighbourhood? What efforts will you make for controlling the soil pollution?
- 14.15 What are pesticides and herbicides? Explain giving examples.
- 14.16 What do you mean by green chemistry? How will it help decrease environmental pollution?
- 14.17 What would have happened if the greenhouse gases were totally missing in the earth's atmosphere? Discuss.
- 14.18 A large number of fish are suddenly found floating dead on a lake. There is no evidence of toxic dumping but you find an abundance of phytoplankton. Suggest a reason for the fish kill.
- 14.19 How can domestic waste be used as manure?
- 14.20 For your agricultural field or garden you have developed a compost producing pit. Discuss the process in the light of bad odour, flies and recycling of wastes for a good produce.

# Unit 14

## Biomolecules

### Objectives

After studying this Unit, you will be able to

- define the biomolecules like carbohydrates, proteins and nucleic acids;
- classify carbohydrates, proteins, nucleic acids and vitamins on the basis of their structures;
- explain the difference between DNA and RNA;
- appreciate the role of biomolecules in biosystem.

*“It is the harmonious and synchronous progress of chemical reactions in body which leads to life”.*

A living system grows, sustains and reproduces itself. The most amazing thing about a living system is that it is composed of non-living atoms and molecules. The pursuit of knowledge of what goes on chemically within a living system falls in the domain of **biochemistry**. Living systems are made up of various complex biomolecules like carbohydrates, proteins, nucleic acids, lipids, etc. Proteins and carbohydrates are essential constituents of our food. These biomolecules interact with each other and constitute the molecular logic of life processes. In addition, some simple molecules like vitamins and mineral salts also play an important role in the functions of organisms. Structures and functions of some of these biomolecules are discussed in this Unit.

### 14.1 Carbohydrates

Carbohydrates are primarily produced by plants and form a very large group of naturally occurring organic compounds. Some common examples are cane sugar, glucose, starch, etc. Most of them have a general formula,  $C_x(H_2O)_y$ , and were considered as hydrates of carbon from where the name carbohydrate was derived. For example, the molecular formula of glucose ( $C_6H_{12}O_6$ ) fits into this general formula,  $C_6(H_2O)_6$ . But all the compounds which fit into this formula may not be classified as carbohydrates. Acetic acid ( $CH_3COOH$ ) fits into this general formula,  $C_2(H_2O)_2$  but is not a carbohydrate. Similarly, rhamnose,  $C_6H_{12}O_5$  is a carbohydrate but does not fit in this definition. A large number of their reactions have shown that they contain specific functional groups. Chemically, *the carbohydrates may be defined as optically active polyhydroxy aldehydes or ketones or the compounds which produce such units on hydrolysis*. Some of the carbohydrates,

which are sweet in taste, are also called sugars. The most common sugar, used in our homes is named as sucrose whereas the sugar present in milk is known as lactose. Carbohydrates are also called saccharides (Greek: *sakcharon* means sugar).

### 14.1.1 Classification of Carbohydrates

Carbohydrates are classified on the basis of their behaviour on hydrolysis. They have been broadly divided into following three groups.

- (i) **Monosaccharides:** A carbohydrate that cannot be hydrolysed further to give simpler unit of polyhydroxy aldehyde or ketone is called a monosaccharide. About 20 monosaccharides are known to occur in nature. Some common examples are glucose, fructose, ribose, etc.
- (ii) **Oligosaccharides:** Carbohydrates that yield two to ten monosaccharide units, on hydrolysis, are called oligosaccharides. They are further classified as disaccharides, trisaccharides, tetrasaccharides, etc., depending upon the number of monosaccharides, they provide on hydrolysis. Amongst these the most common are disaccharides. The two monosaccharide units obtained on hydrolysis of a disaccharide may be same or different. For example, sucrose on hydrolysis gives one molecule each of glucose and fructose whereas maltose gives two molecules of glucose only.
- (iii) **Polysaccharides:** Carbohydrates which yield a large number of monosaccharide units on hydrolysis are called polysaccharides. Some common examples are starch, cellulose, glycogen, gums, etc. Polysaccharides are not sweet in taste, hence they are also called non-sugars.

The carbohydrates may also be classified as either reducing or non-reducing sugars. All those carbohydrates which reduce Fehling's solution and Tollens' reagent are referred to as reducing sugars. All monosaccharides whether aldose or ketose are *reducing sugars*.

In disaccharides, if the reducing groups of monosaccharides i.e., aldehydic or ketonic groups are bonded, these are non-reducing sugars e.g. sucrose. On the other hand, sugars in which these functional groups are free, are called reducing sugars, for example, maltose and lactose.

### 14.1.2 Monosaccharides

Monosaccharides are further classified on the basis of number of carbon atoms and the functional group present in them. If a monosaccharide contains an aldehyde group, it is known as an aldose and if it contains a keto group, it is known as a ketose. Number of carbon atoms constituting the monosaccharide is also introduced in the name as is evident from the examples given in Table 14.1

**Table 14.1: Different Types of Monosaccharides**

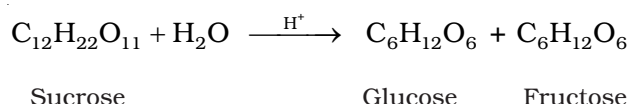
| Carbon atoms | General term | Aldehyde    | Ketone      |
|--------------|--------------|-------------|-------------|
| 3            | Triose       | Aldotriose  | Ketotriose  |
| 4            | Tetrose      | Aldotetrose | Ketotetrose |
| 5            | Pentose      | Aldopentose | Ketopentose |
| 6            | Hexose       | Aldohexose  | Ketohexose  |
| 7            | Heptose      | Aldoheptose | Ketoheptose |

## I Glucose

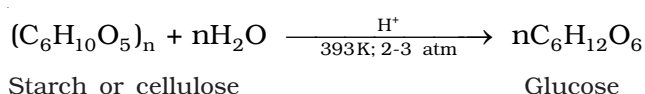
Glucose occurs freely in nature as well as in the combined form. It is present in sweet fruits and honey. Ripe grapes also contain glucose in large amounts. It is prepared as follows:

### 14.1.3 Preparation of Glucose

1. *From sucrose (Cane sugar)*: If sucrose is boiled with dilute HCl or H<sub>2</sub>SO<sub>4</sub> in alcoholic solution, glucose and fructose are obtained in equal amounts.

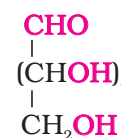


2. *From starch*: Commercially glucose is obtained by hydrolysis of starch by boiling it with dilute H<sub>2</sub>SO<sub>4</sub> at 393 K under pressure.

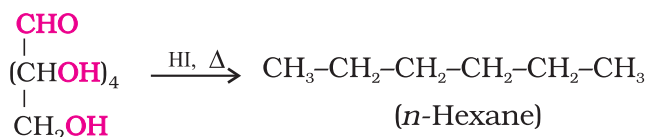


### 14.1.4 Structure of Glucose

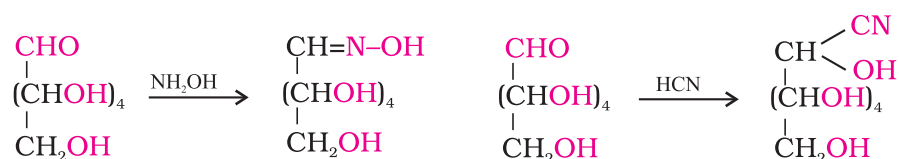
Glucose is an aldohexose and is also known as dextrose. It is the monomer of many of the larger carbohydrates, namely starch, cellulose. It is probably the most abundant organic compound on earth. It was assigned the structure given below on the basis of the following evidences:



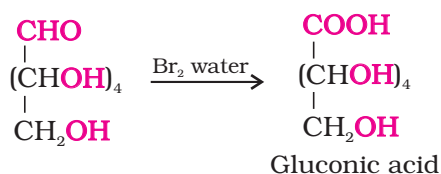
1. Its molecular formula was found to be C<sub>6</sub>H<sub>12</sub>O<sub>6</sub>.
2. On prolonged heating with HI, it forms n-hexane, suggesting that all the six carbon atoms are linked in a straight chain.



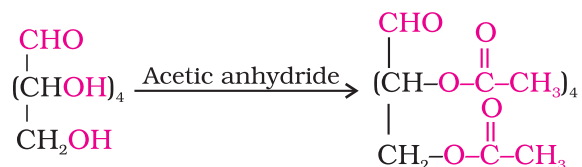
3. Glucose reacts with hydroxylamine to form an oxime and adds a molecule of hydrogen cyanide to give cyanohydrin. These reactions confirm the presence of a carbonyl group (>C = O) in glucose.



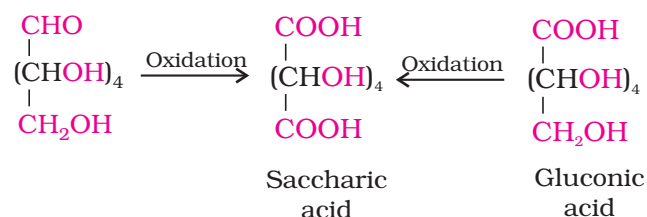
4. Glucose gets oxidised to six carbon carboxylic acid (gluconic acid) on reaction with a mild oxidising agent like bromine water. This indicates that the carbonyl group is present as an aldehydic group.



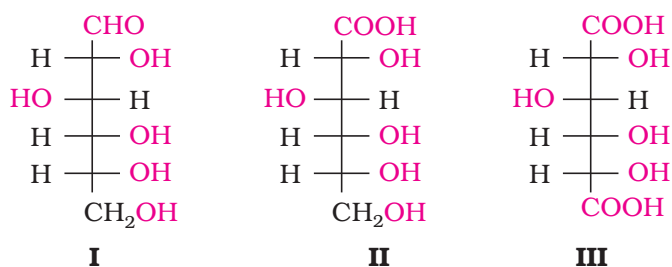
5. Acetylation of glucose with acetic anhydride gives glucose pentaacetate which confirms the presence of five –OH groups. Since it exists as a stable compound, five –OH groups should be attached to different carbon atoms.



6. On oxidation with nitric acid, glucose as well as gluconic acid both yield a dicarboxylic acid, saccharic acid. This indicates the presence of a primary alcoholic (–OH) group in glucose.

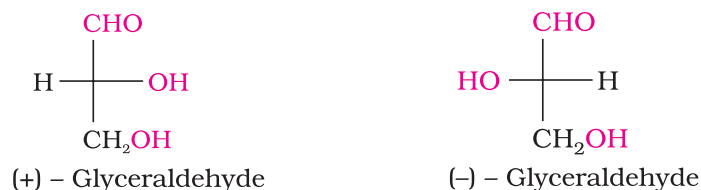


The exact spatial arrangement of different –OH groups was given by Fischer after studying many other properties. Its configuration is correctly represented as **I**. So gluconic acid is represented as **II** and saccharic acid as **III**.

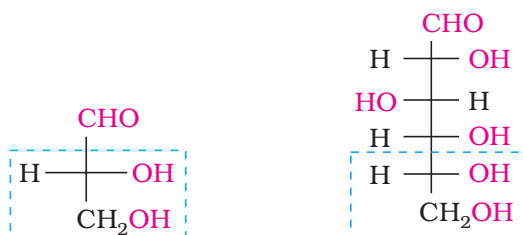


Glucose is correctly named as D(+)-glucose. 'D' before the name of glucose represents the configuration whereas '(+)' represents dextrorotatory nature of the molecule. It may be remembered that 'D' and 'L' have no relation with the optical activity of the compound. The meaning of D- and L- notations is given as follows.

The letters 'D' or 'L' before the name of any compound indicate the relative configuration of a particular stereoisomer. This refers to their relation with a particular isomer of glyceraldehyde. Glyceraldehyde contains one asymmetric carbon atom and exists in two enantiomeric forms as shown below.



All those compounds which can be chemically correlated to (+) isomer of glyceraldehyde are said to have D-configuration whereas those which can be correlated to (-) isomer of glyceraldehyde are said to have L-configuration. For assigning the configuration of monosaccharides, it is the lowest asymmetric carbon atom (as shown below) which is compared. As in (+) glucose, —OH on the lowest asymmetric carbon is on the right side which is comparable to (+) glyceraldehyde, so it is assigned D-configuration. For this comparison, the structure is written in a way that most oxidised carbon is at the top.



D- (+) - Glyceraldehyde

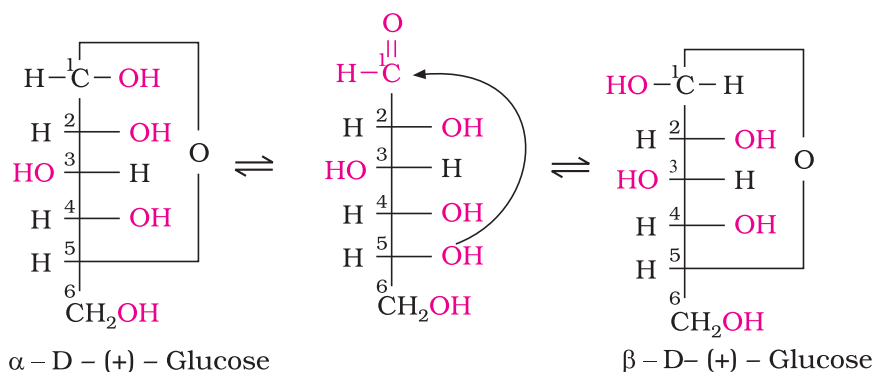
D-(+) - Glucose

#### 14.1.5 Cyclic Structure of Glucose

The structure (I) of glucose explained most of its properties but the following reactions and facts could not be explained by this structure.

1. Despite having the aldehyde group, glucose does not give 2,4-DNP test, Schiff's test and it does not form the hydrogensulphite addition product with  $\text{NaHSO}_3$ .
2. The pentaacetate of glucose does not react with hydroxylamine indicating the absence of free —CHO group.
3. Glucose is found to exist in two different crystalline forms which are named as  $\alpha$  and  $\beta$ . The  $\alpha$ -form of glucose (m.p. 419 K) is obtained by crystallisation from concentrated solution of glucose at 303 K while the  $\beta$ -form (m.p. 423 K) is obtained by crystallisation from hot and saturated aqueous solution at 371 K.

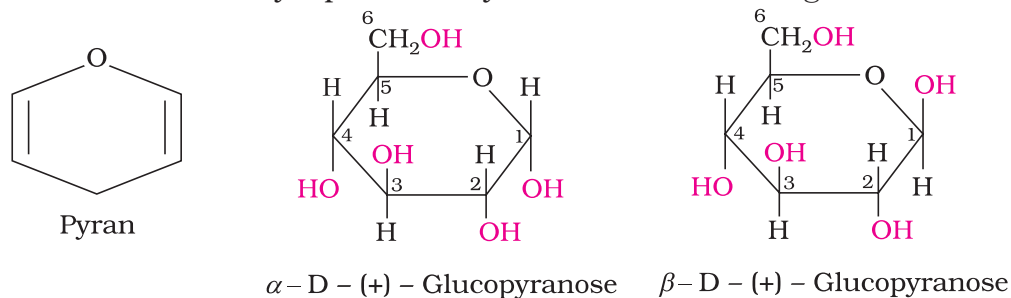
This behaviour could not be explained by the open chain structure (I) for glucose. It was proposed that one of the —OH groups may add to the —CHO group and form a cyclic hemiacetal structure. It was found that glucose forms a six-membered ring in which —OH at C-5 is involved in ring formation. This explains the absence of —CHO group and also existence of glucose in two forms as shown below. These two cyclic forms exist in equilibrium with open chain structure.



$\alpha$  - D - (+) - Glucose

$\beta$  - D - (+) - Glucose

The two cyclic hemiacetal forms of glucose differ only in the configuration of the hydroxyl group at C1, called *anomeric carbon* (the aldehyde carbon before cyclisation). Such isomers, i.e.,  $\alpha$ -form and  $\beta$ -form, are called **anomers**. The six membered cyclic structure of glucose is called **pyranose structure** ( $\alpha$ - or  $\beta$ -), in analogy with pyran. Pyran is a cyclic organic compound with one oxygen atom and five carbon atoms in the ring. The cyclic structure of glucose is more correctly represented by Haworth structure as given below.

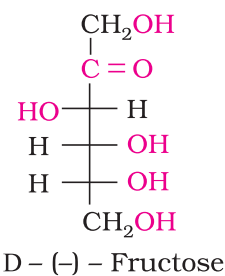


## II. Fructose

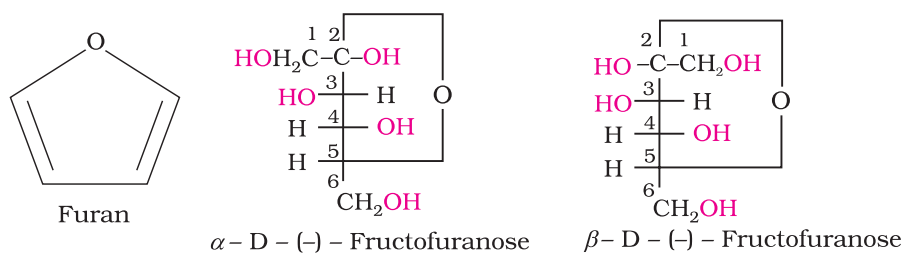
Fructose is an important ketohexose. It is obtained along with glucose by the hydrolysis of disaccharide, sucrose.

### 14.1.6 Structure of Fructose

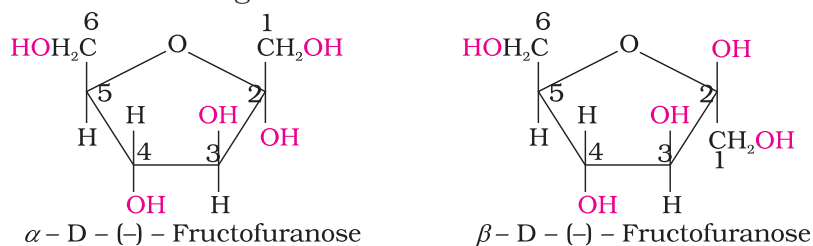
Fructose also has the molecular formula  $C_6H_{12}O_6$  and on the basis of its reactions it was found to contain a ketonic functional group at carbon number 2 and six carbons in straight chain as in the case of glucose. It belongs to D-series and is a laevorotatory compound. It is appropriately written as D-(-)-fructose. Its open chain structure is as shown.



It also exists in two cyclic forms which are obtained by the addition of  $-OH$  at C5 to the ( $>C=O$ ) group. The ring, thus formed is a five membered ring and is named as furanose with analogy to the compound furan. Furan is a five membered cyclic compound with one oxygen and four carbon atoms.



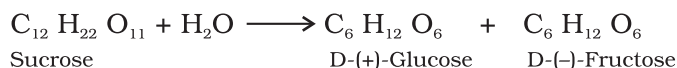
The cyclic structures of two anomers of fructose are represented by Haworth structures as given.



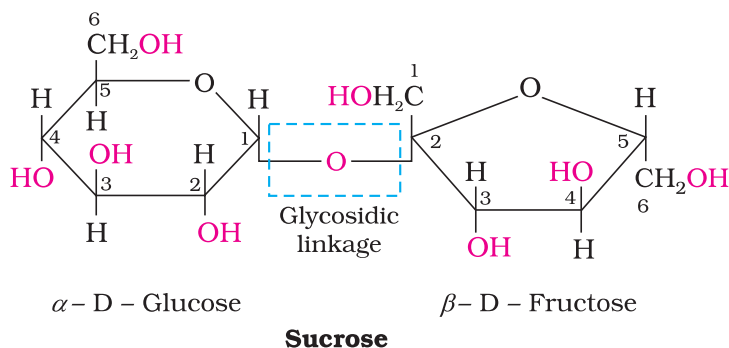
### 14.1.7 Disaccharides

You have already read that disaccharides on hydrolysis with dilute acids or enzymes yield two molecules of either the same or different monosaccharides. The two monosaccharides are joined together by an oxide linkage formed by the loss of a water molecule. Such a linkage between two monosaccharide units through oxygen atom is called *glycosidic linkage*.

- (i) **Sucrose:** One of the common disaccharides is **sucrose** which on hydrolysis gives equimolar mixture of D-(+)-glucose and D-(-) fructose.

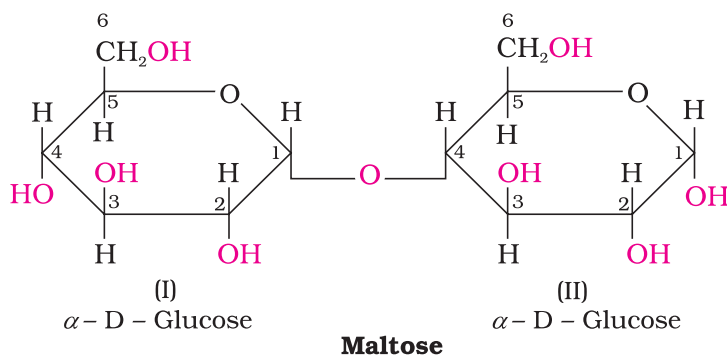


These two monosaccharides are held together by a glycosidic linkage between C1 of  $\alpha$ -glucose and C2 of  $\beta$ -fructose. Since the reducing groups of glucose and fructose are involved in glycosidic bond formation, sucrose is a non reducing sugar.



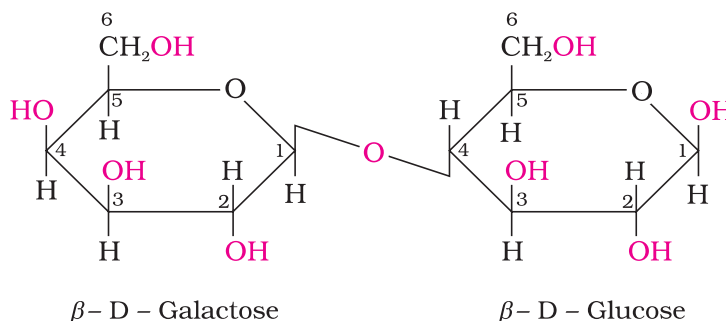
Sucrose is dextrorotatory but after hydrolysis gives dextrorotatory glucose and laevorotatory fructose. Since the laevorotation of fructose (-92.4) is more than dextrorotation of glucose (+ 52.5), the mixture is laevorotatory. Thus, hydrolysis of sucrose brings about a change in the sign of rotation, from dextro (+) to laevo (-) and the product is named as **invert sugar**.

- (ii) **Maltose:** Another disaccharide, maltose is composed of two  $\alpha$ -D-glucose units in which C1 of one glucose (I) is linked to C4 of another glucose unit (II). The free aldehyde group can be produced at C1 of second glucose in solution and it shows reducing properties so it is a reducing sugar.





(iii) *Lactose*: It is more commonly known as milk sugar since this disaccharide is found in milk. It is composed of  $\beta$ -D-galactose and  $\beta$ -D-glucose. The linkage is between C1 of galactose and C4 of glucose. Hence it is also a reducing sugar.



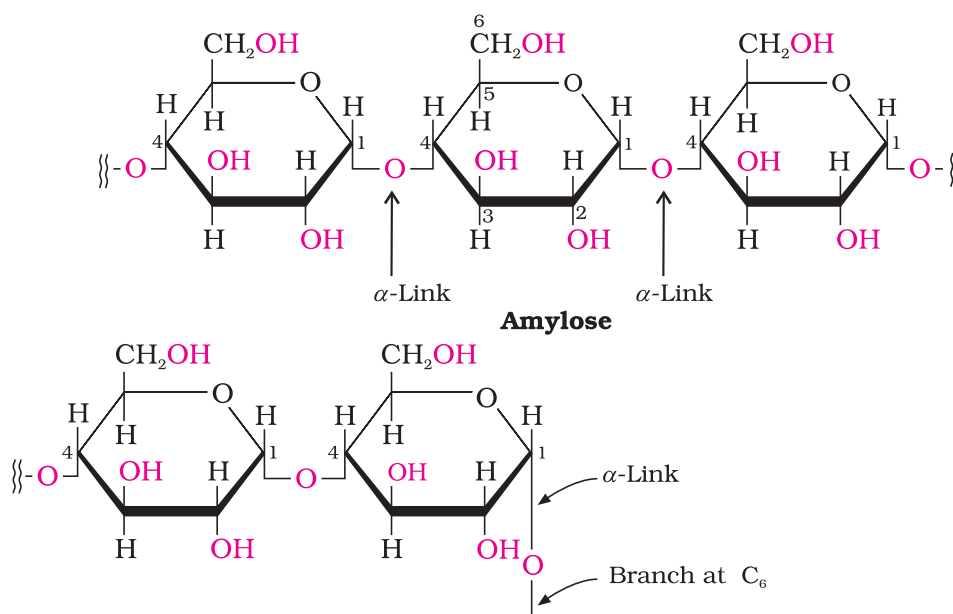
**Lactose**

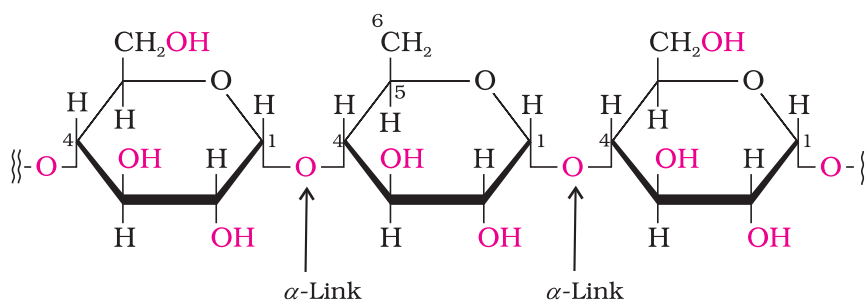
### 14.1.8 Polysaccharides

Polysaccharides contain a large number of monosaccharide units joined together by glycosidic linkages. These are the most commonly encountered carbohydrates in nature. They mainly act as the food storage or structural materials.

(i) *Starch*: Starch is the main storage polysaccharide of plants. It is the most important dietary source for human beings. High content of starch is found in cereals, roots, tubers and some vegetables. It is a polymer of  $\alpha$ -glucose and consists of two components—**Amylose** and **Amylopectin**. Amylose is water soluble component which constitutes about 15-20% of starch. Chemically amylose is a long unbranched chain with 200-1000  $\alpha$ -D-(+)-glucose units held by C1- C4 glycosidic linkage.

Amylopectin is insoluble in water and constitutes about 80-85% of starch. It is a branched chain polymer of  $\alpha$ -D-glucose

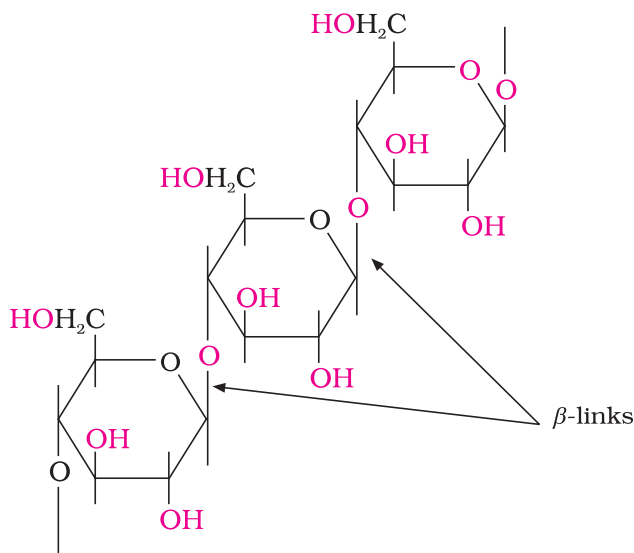




### Amylopectin

units in which chain is formed by C1–C4 glycosidic linkage whereas branching occurs by C1–C6 glycosidic linkage.

- (ii) *Cellulose*: Cellulose occurs exclusively in plants and it is the most abundant organic substance in plant kingdom. It is a predominant constituent of cell wall of plant cells. Cellulose is a straight chain



### Cellulose

polysaccharide composed only of  $\beta$ -D-glucose units which are joined by glycosidic linkage between C1 of one glucose unit and C4 of the next glucose unit.

- (iii) *Glycogen*: The carbohydrates are stored in animal body as glycogen. It is also known as *animal starch* because its structure is similar to amylopectin and is rather more highly branched. It is present in liver, muscles and brain. When the body needs glucose, enzymes break the glycogen down to glucose. Glycogen is also found in yeast and fungi.

### 14.1.9 Importance of Carbohydrates

Carbohydrates are essential for life in both plants and animals. They form a major portion of our food. Honey has been used for a long time as an instant source of energy by 'Vaidis' in ayurvedic system of medicine. Carbohydrates are used as storage molecules as starch in plants and **glycogen** in animals. Cell wall of bacteria and plants is made up of cellulose. We build furniture, etc. from cellulose in the form of wood

and clothe ourselves with cellulose in the form of cotton fibre. They provide raw materials for many important industries like textiles, paper, lacquers and breweries.

Two aldopentoses viz. D-ribose and 2-deoxy-D-ribose (Section 14.5.1, Class XII) are present in nucleic acids. Carbohydrates are found in biosystem in combination with many proteins and lipids.

### Intext Questions

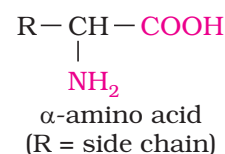
- 14.1** Glucose or sucrose are soluble in water but cyclohexane or benzene (simple six membered ring compounds) are insoluble in water. Explain.
- 14.2** What are the expected products of hydrolysis of lactose?
- 14.3** How do you explain the absence of aldehyde group in the pentaacetate of D-glucose?

## 14.2 Proteins

Proteins are the most abundant biomolecules of the living system. Chief sources of proteins are milk, cheese, pulses, peanuts, fish, meat, etc. They occur in every part of the body and form the fundamental basis of structure and functions of life. They are also required for growth and maintenance of body. The word protein is derived from Greek word, “**proteios**” which means primary or of prime importance. All proteins are polymers of  $\alpha$ -amino acids.

### 14.2.1 Amino Acids

Amino acids contain amino ( $-\text{NH}_2$ ) and carboxyl ( $-\text{COOH}$ ) functional groups. Depending upon the relative position of amino group with respect to carboxyl group, the amino acids can be classified as  $\alpha$ ,  $\beta$ ,  $\gamma$ ,  $\delta$  and so on. Only  $\alpha$ -amino acids are obtained on hydrolysis of proteins. They may contain other functional groups also.

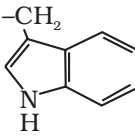
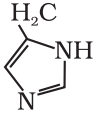
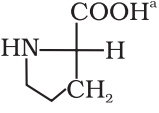


All  $\alpha$ -amino acids have trivial names, which usually reflect the property of that compound or its source. Glycine is so named since it has sweet taste (in Greek *glykos* means sweet) and tyrosine was first obtained from cheese (in Greek, *tyros* means cheese.) Amino acids are generally represented by a three letter symbol, sometimes one letter symbol is also used. Structures of some commonly occurring amino acids along with their 3-letter and 1-letter symbols are given in Table 14.2.

**Table 14.2: Natural Amino Acids**

$$\begin{array}{c} \text{COOH} \\ | \\ \text{H}_2\text{N}-\text{C}-\text{H} \\ | \\ \text{R} \end{array}$$

| Name of the amino acids | Characteristic feature of side chain, R              | Three letter symbol | One letter code |
|-------------------------|--|---------------------|-----------------|
| 1. Glycine              | H  | Gly                 | G               |
| 2. Alanine              | - CH <sub>3</sub>                                    | Ala                 | A               |
| 3. Valine*              | (H <sub>3</sub> C) <sub>2</sub> CH-                  | Val                 | V               |
| 4. Leucine*             | (H <sub>3</sub> C) <sub>2</sub> CH-CH <sub>2</sub> - | Leu                 | L               |

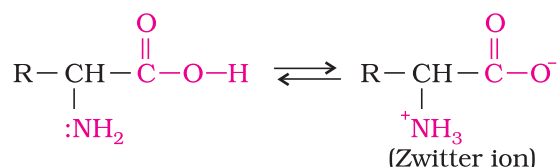
|                    |   |     |   |
|--------------------|---|-----|---|
| 5. Isoleucine*     | $\begin{array}{c} \text{H}_3\text{C}-\text{CH}_2-\text{CH}- \\   \\ \text{CH}_3 \end{array}$          | Ile | I |
| 6. Arginine*       | $\begin{array}{c} \text{HN}=\text{C}-\text{NH}-(\text{CH}_2)_3- \\   \\ \text{NH}_2 \end{array}$      | Arg | R |
| 7. Lysine*         | $\text{H}_2\text{N}-(\text{CH}_2)_4-$   | Lys | K |
| 8. Glutamic acid   | $\text{HOOC}-\text{CH}_2-\text{CH}_2-$  | Glu | E |
| 9. Aspartic acid   | $\text{HOOC}-\text{CH}_2-$  | Asp | D |
| 10. Glutamine      | $\begin{array}{c} \text{O} \\    \\ \text{H}_2\text{N}-\text{C}-\text{CH}_2-\text{CH}_2- \end{array}$ | Gln | Q |
| 11. Asparagine     | $\begin{array}{c} \text{O} \\    \\ \text{H}_2\text{N}-\text{C}-\text{CH}_2- \end{array}$             | Asn | N |
| 12. Threonine*     | $\text{H}_3\text{C}-\text{CHOH}-$   | Thr | T |
| 13. Serine         | $\text{HO}-\text{CH}_2-$  | Ser | S |
| 14. Cysteine       | $\text{HS}-\text{CH}_2-$  | Cys | C |
| 15. Methionine*    | $\text{H}_3\text{C}-\text{S}-\text{CH}_2-\text{CH}_2-$  | Met | M |
| 16. Phenylalanine* | $\text{C}_6\text{H}_5-\text{CH}_2-$   | Phe | F |
| 17. Tyrosine       | $(p)\text{HO}-\text{C}_6\text{H}_4-\text{CH}_2-$  | Tyr | Y |
| 18. Tryptophan*    |                     | Trp | W |
| 19. Histidine*     |                    | His | H |
| 20. Proline        |                    | Pro | P |

\* essential amino acid, a = entire structure

### 14.2.2 Classification of Amino Acids

Amino acids are classified as acidic, basic or neutral depending upon the relative number of amino and carboxyl groups in their molecule. Equal number of amino and carboxyl groups makes it neutral; more number of amino than carboxyl groups makes it basic and more carboxyl groups as compared to amino groups makes it acidic. The amino acids, which can be synthesised in the body, are known as **non-essential amino acids**. On the other hand, those which cannot be synthesised in the body and must be obtained through diet, are known as **essential amino acids** (marked with asterisk in Table 14.2).

Amino acids are usually colourless, crystalline solids. These are water-soluble, high melting solids and behave like salts rather than simple amines or carboxylic acids. This behaviour is due to the presence of both acidic (carboxyl group) and basic (amino group) groups in the same molecule. In aqueous solution, the carboxyl group can lose a proton and amino group can accept a proton, giving rise to a dipolar ion known as *zwitter ion*. This is neutral but contains both positive and negative charges.

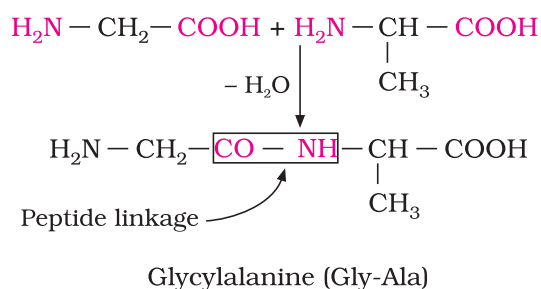


In zwitter ionic form, amino acids show amphoteric behaviour as they react both with acids and bases.

Except glycine, all other naturally occurring  $\alpha$ -amino acids are optically active, since the  $\alpha$ -carbon atom is asymmetric. These exist both in 'D' and 'L' forms. Most naturally occurring amino acids have L-configuration. L-Aminoacids are represented by writing the  $-\text{NH}_2$  group on left hand side.

### 14.2.3 Structure of Proteins

You have already read that proteins are the polymers of  $\alpha$ -amino acids and they are connected to each other by **peptide bond** or **peptide linkage**. Chemically, peptide linkage is an amide formed between  $-\text{COOH}$  group and  $-\text{NH}_2$  group. The reaction between two molecules of



similar or different amino acids, proceeds through the combination of the amino group of one molecule with the carboxyl group of the other. This results in the elimination of a water molecule and formation of a peptide bond  $-\text{CO}-\text{NH}-$ . The product of the reaction is called a dipeptide because it is made up of two amino acids. For example, when carboxyl group of glycine combines with the amino group of alanine we get a **dipeptide**, glycylalanine.

If a third amino acid combines to a dipeptide, the product is called a **tripeptide**. A tripeptide contains three amino acids linked by two peptide linkages. Similarly when four, five or six amino acids are linked, the respective products are known as **tetrapeptide**, **pentapeptide** or **hexapeptide**, respectively. When the number of such amino acids is more than ten, then the products are called **polypeptides**. A polypeptide with more than hundred amino acid residues, having molecular mass higher than 10,000u is called a protein. However, the distinction between a polypeptide and a protein is not very sharp. Polypeptides with fewer amino acids are likely to be called proteins if they ordinarily have a well defined conformation of a protein such as insulin which contains 51 amino acids.

**Proteins** can be classified into two types on the basis of their molecular shape.

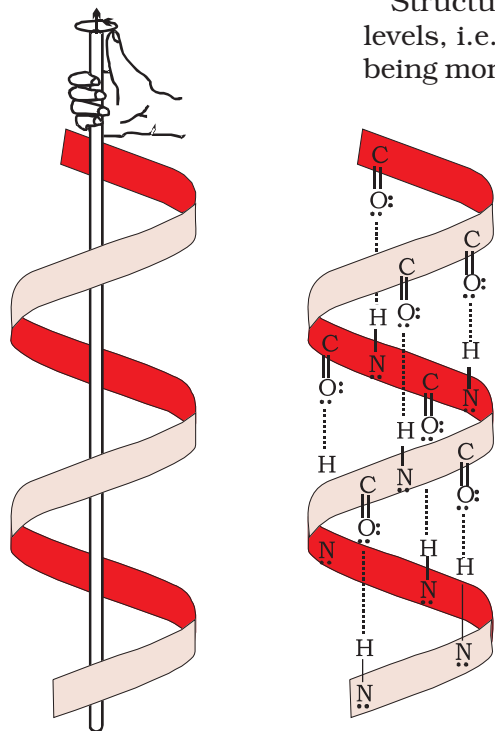
#### (a) Fibrous proteins

When the polypeptide chains run parallel and are held together by hydrogen and disulphide bonds, then fibre-like structure is formed. Such proteins are generally insoluble in water. Some common examples are keratin (present in hair, wool, silk) and myosin (present in muscles), etc.

### (b) Globular proteins

This structure results when the chains of polypeptides coil around to give a spherical shape. These are usually soluble in water. Insulin and albumins are the common examples of globular proteins.

Structure and shape of proteins can be studied at four different levels, i.e., primary, secondary, tertiary and quaternary, each level being more complex than the previous one.



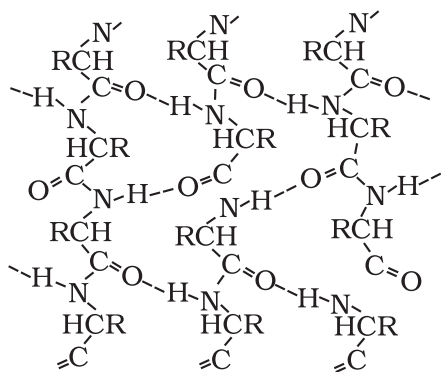
**Fig. 14.1:**  $\alpha$ -Helix structure of proteins

(i) *Primary structure of proteins:* Proteins may have one or more polypeptide chains. Each polypeptide in a protein has amino acids linked with each other in a specific sequence and it is this sequence of amino acids that is said to be the primary structure of that protein. Any change in this primary structure i.e., the sequence of amino acids creates a different protein.

(ii) *Secondary structure of proteins:* The secondary structure of protein refers to the shape in which a long polypeptide chain can exist. They are found to exist in two different types of structures viz.  $\alpha$ -helix and  $\beta$ -pleated sheet structure. These structures arise due to the regular folding of the backbone of the polypeptide chain due to hydrogen bonding between  $\text{C}=\text{O}$  and  $-\text{NH}-$  groups of the peptide bond.

$\alpha$ -Helix is one of the most common ways in which a polypeptide chain forms all possible hydrogen bonds by twisting into a right handed screw (helix) with the  $-\text{NH}$  group of each amino acid residue hydrogen bonded to the  $\text{C}=\text{O}$  of an adjacent turn of the helix as shown in Fig.14.1.

In  $\beta$ -structure all peptide chains are stretched out to nearly maximum extension and then laid side by side which are held together by intermolecular hydrogen bonds. The structure resembles the pleated folds of drapery and therefore is known as  $\beta$ -pleated sheet.

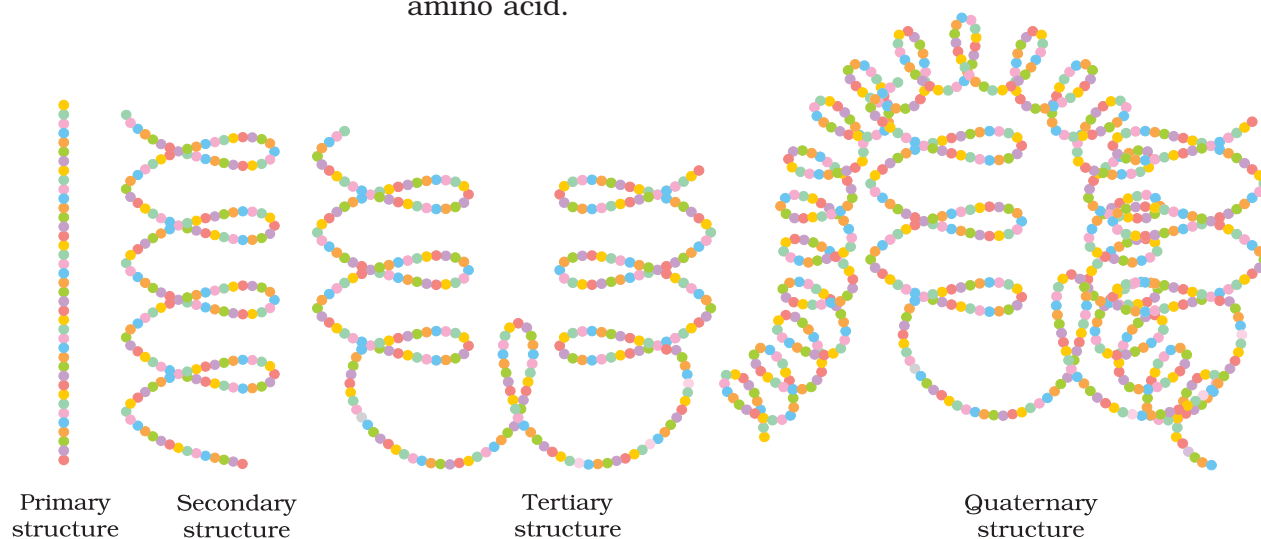


**Fig. 14.2:**  $\beta$ -Pleated sheet structure of proteins

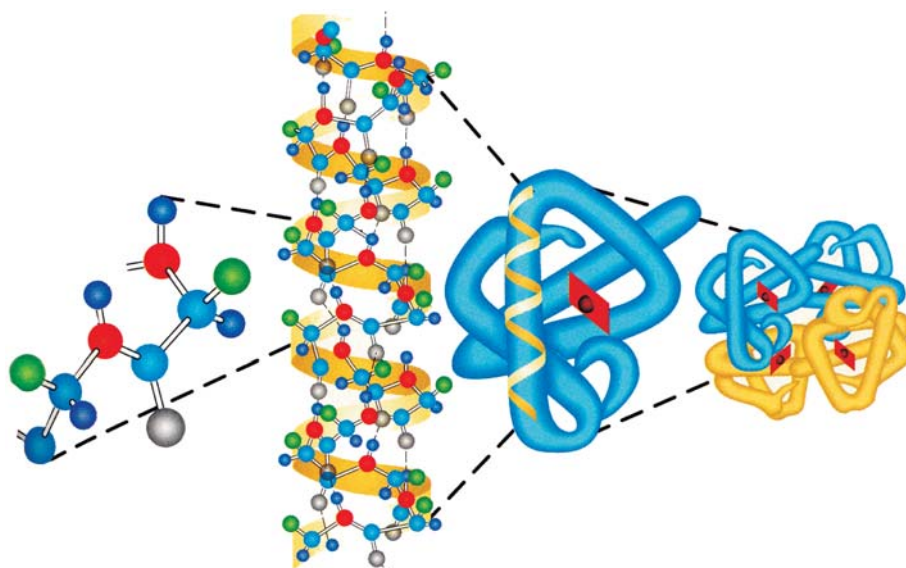
(iii) *Tertiary structure of proteins:* The tertiary structure of proteins represents overall folding of the polypeptide chains i.e., further folding of the secondary structure. It gives rise to two major molecular shapes viz. fibrous and globular. The main forces which stabilise the 2 and 3 structures of proteins are hydrogen bonds, disulphide linkages, van der Waals and electrostatic forces of attraction.

(iv) *Quaternary structure of proteins:* Some of the proteins are composed of two or more polypeptide chains referred to as sub-units. The spatial arrangement of these subunits with respect to each other is known as quaternary structure.

A diagrammatic representation of all these four structures is given in Figure 14.3 where each coloured ball represents an amino acid.



**Fig. 14.3:** Diagrammatic representation of protein structure (two sub-units of two types in quaternary structure)



**Fig. 14.4:** Primary, secondary, tertiary and quaternary structures of haemoglobin

(a) Primary structure  
● C  
● H

(b) Secondary structure  
● N  
● O

(c) Tertiary structure  
● R groups  
■ Haeme group

(d) Quaternary structure

#### 14.2.4 Denaturation of Proteins

Protein found in a biological system with a unique three-dimensional structure and biological activity is called a native protein. When a protein in its native form, is subjected to physical change like change in temperature or chemical change like change in pH, the hydrogen bonds are disturbed. Due to this, globules unfold and helix get uncoiled and protein loses its biological activity. This is called **denaturation** of

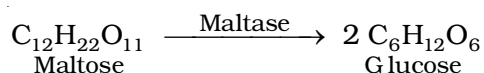
protein. During denaturation 2 and 3 structures are destroyed but 1° structure remains intact. The coagulation of egg white on boiling is a common example of denaturation. Another example is curdling of milk which is caused due to the formation of lactic acid by the bacteria present in milk.

### Intext Questions

- 14.4** The melting points and solubility in water of amino acids are generally higher than that of the corresponding halo acids. Explain.
- 14.5** Where does the water present in the egg go after boiling the egg?

## 14.3 Enzymes

Life is possible due to the coordination of various chemical reactions in living organisms. An example is the digestion of food, absorption of appropriate molecules and ultimately production of energy. This process involves a sequence of reactions and all these reactions occur in the body under very mild conditions. This occurs with the help of certain biocatalysts called **enzymes**. Almost all the enzymes are globular proteins. Enzymes are very specific for a particular reaction and for a particular substrate. They are generally named after the compound or class of compounds upon which they work. For example, the enzyme that catalyses hydrolysis of maltose into glucose is named as *maltase*.



Sometimes enzymes are also named after the reaction, where they are used. For example, the enzymes which catalyse the oxidation of one substrate with simultaneous reduction of another substrate are named as **oxidoreductase** enzymes. The ending of the name of an enzyme is **-ase**.

### **14.3.1 Mechanism of Enzyme Action**

Enzymes are needed only in small quantities for the progress of a reaction. Similar to the action of chemical catalysts, enzymes are said to reduce the magnitude of activation energy. For example, activation energy for acid hydrolysis of sucrose is  $6.22 \text{ kJ mol}^{-1}$ , while the activation energy is only  $2.15 \text{ kJ mol}^{-1}$  when hydrolysed by the enzyme, sucrase. Mechanism for the enzyme action has been discussed in Unit 5.

## 14.4 Vitamins

It has been observed that certain organic compounds are required in small amounts in our diet but their deficiency causes specific diseases. These compounds are called **vitamins**. Most of the vitamins cannot be synthesised in our body but plants can synthesise almost all of them, so they are considered as essential food factors. However, the bacteria of the gut can produce some of the vitamins required by us. All the vitamins are generally available in our diet. Different vitamins belong to various chemical classes and it is difficult to define them on the basis of structure. They are generally regarded as **organic compounds required in the diet in small amounts to perform specific biological functions for normal maintenance of optimum growth**



**and health of the organism.** Vitamins are designated by alphabets A, B, C, D, etc. Some of them are further named as sub-groups e.g. B<sub>1</sub>, B<sub>2</sub>, B<sub>6</sub>, B<sub>12</sub>, etc. Excess of vitamins is also harmful and vitamin pills should not be taken without the advice of doctor.

The term “**Vitamine**” was coined from the word vital + amine since the earlier identified compounds had amino groups. Later work showed that most of them did not contain amino groups, so the letter ‘e’ was dropped and the term **vitamin** is used these days.

#### 14.4.1 Classification of Vitamins

Vitamins are classified into two groups depending upon their solubility in water or fat.

- (i) *Fat soluble vitamins:* Vitamins which are soluble in fat and oils but insoluble in water are kept in this group. These are vitamins A, D, E and K. They are stored in liver and adipose (fat storing) tissues.
- (ii) *Water soluble vitamins:* B group vitamins and vitamin C are soluble in water so they are grouped together. Water soluble vitamins must be supplied regularly in diet because they are readily excreted in urine and cannot be stored (except vitamin B<sub>12</sub>) in our body.

Some important vitamins, their sources and diseases caused by their deficiency are listed in Table 14.3.

**Table 14.3: Some important Vitamins, their Sources and their Deficiency Diseases**

| Sl. No. | Name of Vitamins                    | Sources  | Deficiency diseases  |
|---------|-------------------------------------|--|--|
| 1.      | Vitamin A                           | Fish liver oil, carrots, butter and milk       | Xerophthalmia (hardening of cornea of eye)<br>Night blindness  |
| 2.      | Vitamin B <sub>1</sub> (Thiamine)   | Yeast, milk, green vegetables and cereals      | Beri beri (loss of appetite, retarded growth)  |
| 3.      | Vitamin B <sub>2</sub> (Riboflavin) | Milk, eggwhite, liver, kidney                  | Cheilosis (fissuring at corners of mouth and lips), digestive disorders and burning sensation of the skin. |
| 4.      | Vitamin B <sub>6</sub> (Pyridoxine) | Yeast, milk, egg yolk, cereals and grams       | Convulsions  |
| 5.      | Vitamin B <sub>12</sub>             | Meat, fish, egg and curd                       | Pernicious anaemia (RBC deficient in haemoglobin)  |
| 6.      | Vitamin C (Ascorbic acid)           | Citrus fruits, amla and green leafy vegetables | Scurvy (bleeding gums)   |
| 7.      | Vitamin D                           | Exposure to sunlight, fish and egg yolk        | Rickets (bone deformities in children) and osteomalacia (soft bones and joint pain in adults)              |

|              |   |   |
|--------------|---|---|
| 8. Vitamin E | Vegetable oils like wheat germ oil, sunflower oil, etc. | Increased fragility of RBCs and muscular weakness |
| 9. Vitamin K | Green leafy vegetables                                  | Increased blood clotting time                     |

## 14.5: Nucleic Acids

Every generation of each and every species resembles its ancestors in many ways. How are these characteristics transmitted from one generation to the next? It has been observed that nucleus of a living cell is responsible for this transmission of inherent characters, also called **heredity**. The particles in nucleus of the cell, responsible for heredity, are called chromosomes which are made up of proteins and another type of biomolecules called **nucleic acids**. These are mainly of two types, the **deoxyribonucleic acid (DNA)** and **ribonucleic acid (RNA)**. Since nucleic acids are long chain polymers of **nucleotides**, so they are also called polynucleotides.

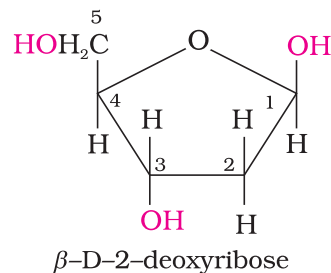
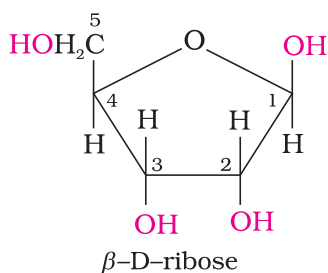
### James Dewey Watson



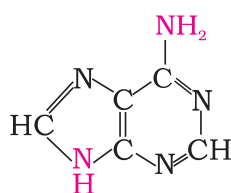
Born in Chicago, Illinois, in 1928, Dr Watson received his Ph.D. (1950) from Indiana University in Zoology. He is best known for his discovery of the structure of DNA for which he shared with Francis Crick and Maurice Wilkins the 1962 Nobel prize in Physiology and Medicine. They proposed that DNA molecule takes the shape of a double helix, an elegantly simple structure that resembles a gently twisted ladder. The rails of the ladder are made of alternating units of phosphate and the sugar deoxyribose; the rungs are each composed of a pair of purine/ pyrimidine bases. This research laid the foundation for the emerging field of **molecular biology**. The complementary pairing of nucleotide bases explains how identical copies of parental DNA pass on to two daughter cells. This research launched a revolution in biology that led to modern recombinant DNA techniques.

#### 14.5.1 Chemical Composition of Nucleic Acids

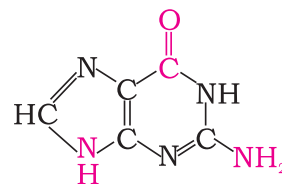
Complete hydrolysis of DNA (or RNA) yields a pentose sugar, phosphoric acid and nitrogen containing heterocyclic compounds (called bases). In DNA molecules, the sugar moiety is  $\beta$ -D-2-deoxyribose whereas in RNA molecule, it is  $\beta$ -D-ribose.



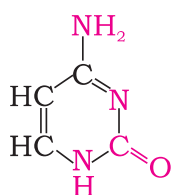
DNA contains four bases viz. adenine (A), guanine (G), cytosine (C) and thymine (T). RNA also contains four bases, the first three bases are same as in DNA but the fourth one is uracil (U).



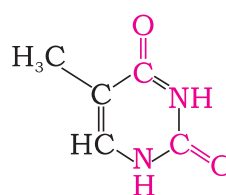
Adenine (A)



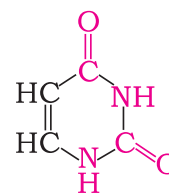
Guanine (G)



Cytosine (C)



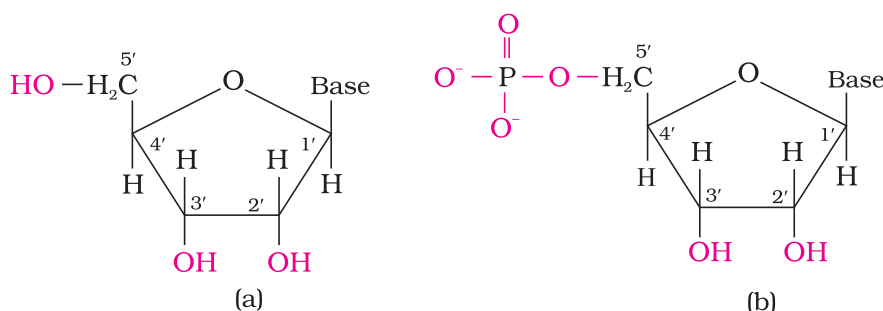
Thymine (T)



Uracil (U)

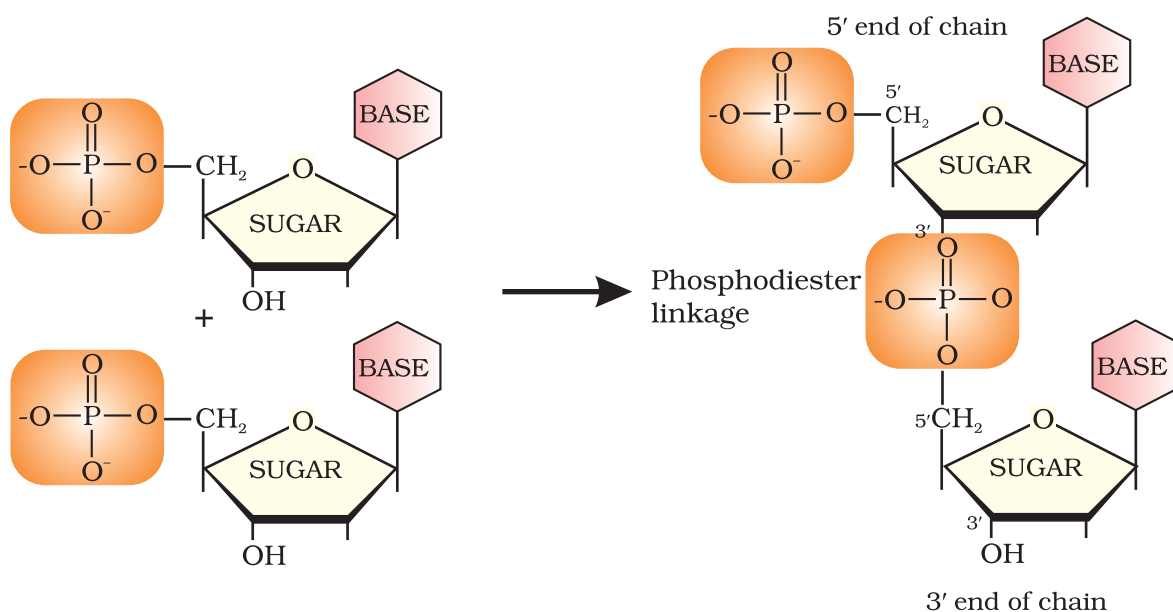
### 14.5.2 Structure of Nucleic Acids

A unit formed by the attachment of a base to 1' position of sugar is known as **nucleoside**. In nucleosides, the sugar carbons are numbered as 1', 2', 3', etc. in order to distinguish these from the bases (Fig. 14.5a). When nucleoside is linked to phosphoric acid at 5'-position of sugar moiety, we get a nucleotide (Fig. 14.5).

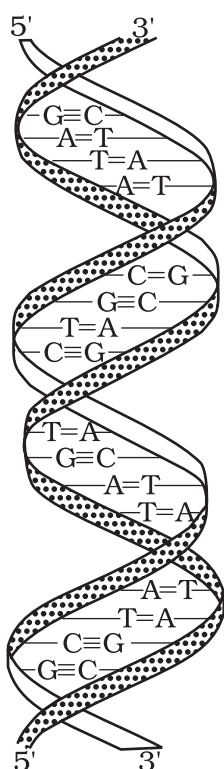


**Fig. 14.5:** Structure of (a) a nucleoside and (b) a nucleotide

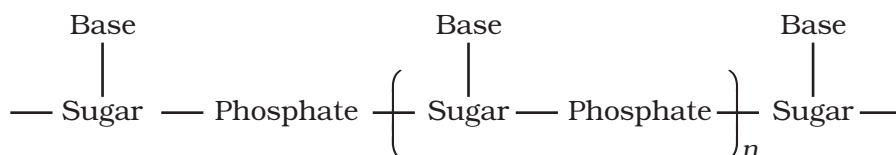
Nucleotides are joined together by phosphodiester linkage between 5' and 3' carbon atoms of the pentose sugar. The formation of a typical dinucleotide is shown in Fig. 14.6.



**Fig. 14.6:** Formation of a dinucleotide



A simplified version of nucleic acid chain is as shown below.



Information regarding the sequence of nucleotides in the chain of a nucleic acid is called its primary structure. Nucleic acids have a secondary structure also. James Watson and Francis Crick gave a double strand helix structure for DNA (Fig. 14.7). Two nucleic acid chains are wound about each other and held together by hydrogen bonds between pairs of bases. The two strands are complementary to each other because the hydrogen bonds are formed between specific pairs of bases. Adenine forms hydrogen bonds with thymine whereas cytosine forms hydrogen bonds with guanine.

In secondary structure of RNA, helices are present which are only single stranded. Sometimes they fold back on themselves to form a double helix structure. RNA molecules are of three types and they perform different functions. They are named as **messenger RNA (m-RNA)**, **ribosomal RNA (r-RNA)** and **transfer RNA (t-RNA)**.

**Fig. 14.7:** Double strand helix structure for DNA



### Har Gobind Khorana

Har Gobind Khorana, was born in 1922. He obtained his M.Sc. degree from Punjab University in Lahore. He worked with Professor Vladimir Prelog, who moulded Khorana's thought and philosophy towards science, work and effort. After a brief stay in India in 1949, Khorana went back to England and worked with Professor G.W. Kenner and Professor A.R.Todd. It was at Cambridge, U.K. that he got interested in both proteins and nucleic acids. Dr Khorana shared the Nobel Prize for Medicine and Physiology in 1968 with Marshall Nirenberg and Robert Holley for cracking the genetic code.

### DNA Fingerprinting

It is known that every individual has unique fingerprints. These occur at the tips of the fingers and have been used for identification for a long time but these can be altered by surgery. A sequence of bases on DNA is also unique for a person and information regarding this is called DNA fingerprinting. It is same for every cell and cannot be altered by any known treatment. DNA fingerprinting is now used

- (i) in forensic laboratories for identification of criminals.
- (ii) to determine paternity of an individual.
- (iii) to identify the dead bodies in any accident by comparing the DNA's of parents or children.
- (iv) to identify racial groups to rewrite biological evolution.

#### 14.5.3 Biological Functions of Nucleic Acids

DNA is the chemical basis of heredity and may be regarded as the reserve of genetic information. DNA is exclusively responsible for maintaining the identity of different species of organisms over millions of years. A DNA molecule is capable of self duplication during cell division and identical DNA strands are transferred to daughter cells. Another important function of nucleic acids is the protein synthesis in the cell. Actually, the proteins are synthesised by various RNA molecules in the cell but the message for the synthesis of a particular protein is present in DNA.

#### *Intext Questions*

- 14.6 Why cannot vitamin C be stored in our body?
- 14.7 What products would be formed when a nucleotide from DNA containing thymine is hydrolysed?
- 14.8 When RNA is hydrolysed, there is no relationship among the quantities of different bases obtained. What does this fact suggest about the structure of RNA?

## Summary

**Carbohydrates** are optically active polyhydroxy aldehydes or ketones or molecules which provide such units on hydrolysis. They are broadly classified into three groups — **monosaccharides**, **disaccharides** and **polysaccharides**. Glucose, the most important source of energy for mammals, is obtained by the digestion of starch. Monosaccharides are held together by glycosidic linkages to form disaccharides or polysaccharides.

**Proteins** are the **polymers** of about twenty different  **$\alpha$ -amino acids** which are linked by peptide bonds. Ten amino acids are called essential amino acids because they cannot be synthesised by our body, hence must be provided through diet. Proteins perform various structural and dynamic functions in the organisms. Proteins which contain only  $\alpha$ -amino acids are called simple proteins. The **secondary** or **tertiary structure of proteins** get disturbed on change of pH or temperature and they are not able to perform their functions. This is called **denaturation of proteins**. Enzymes are **biocatalysts** which speed up the reactions in biosystems. They are very specific and selective in their action and chemically all **enzymes** are proteins.

**Vitamins** are accessory food factors required in the diet. They are classified as fat soluble (A, D, E and K) and water soluble (B group and C). Deficiency of vitamins leads to many diseases.

Nucleic acids are the polymers of nucleotides which in turn consist of a base, a pentose sugar and phosphate moiety. Nucleic acids are responsible for the transfer of characters from parents to offsprings. There are two types of nucleic acids — **DNA** and **RNA**. DNA contains a five carbon sugar molecule called **2-deoxyribose** whereas RNA contains ribose. Both DNA and RNA contain adenine, guanine and cytosine. The fourth base is thymine in DNA and uracil in RNA. The structure of DNA is a double strand whereas RNA is a single strand molecule. DNA is the chemical basis of heredity and have the coded message for proteins to be synthesised in the cell. There are three types of RNA — mRNA, rRNA and tRNA which actually carry out the protein synthesis in the cell.

## Exercises

- 14.1 What are monosaccharides?
- 14.2 What are reducing sugars?
- 14.3 Write two main functions of carbohydrates in plants.
- 14.4 Classify the following into monosaccharides and disaccharides.  
Ribose, 2-deoxyribose, maltose, galactose, fructose and lactose.
- 14.5 What do you understand by the term glycosidic linkage?
- 14.6 What is glycogen? How is it different from starch?
- 14.7 What are the hydrolysis products of  
(i) sucrose and (ii) lactose?
- 14.8 What is the basic structural difference between starch and cellulose?
- 14.9 What happens when D-glucose is treated with the following reagents?  
(i) HI (ii) Bromine water (iii)  $\text{HNO}_3$

- 14.10** Enumerate the reactions of D-glucose which cannot be explained by its open chain structure.
- 14.11** What are essential and non-essential amino acids? Give two examples of each type.
- 14.12** Define the following as related to proteins  
(i) Peptide linkage      (ii) Primary structure      (iii) Denaturation.
- 14.13** What are the common types of secondary structure of proteins?
- 14.14** What type of bonding helps in stabilising the  $\alpha$ -helix structure of proteins?
- 14.15** Differentiate between globular and fibrous proteins.
- 14.16** How do you explain the amphoteric behaviour of amino acids?
- 14.17** What are enzymes?
- 14.18** What is the effect of denaturation on the structure of proteins?
- 14.19** How are vitamins classified? Name the vitamin responsible for the coagulation of blood.
- 14.20** Why are vitamin A and vitamin C essential to us? Give their important sources.
- 14.21** What are nucleic acids? Mention their two important functions.
- 14.22** What is the difference between a nucleoside and a nucleotide?
- 14.23** The two strands in DNA are not identical but are complementary. Explain.
- 14.24** Write the important structural and functional differences between DNA and RNA.
- 14.25** What are the different types of RNA found in the cell?

# Unit 16

## Chemistry in Everyday Life

### Objectives

After studying this Unit you will be able to

- visualise the importance of Chemistry in daily life;
- explain the term 'chemotherapy';
- describe the basis of classification of drugs;
- explain drug-target interaction of enzymes and receptors;
- explain how various types of drugs function in the body;
- know about artificial sweetening agents and food preservatives;
- discuss the chemistry of cleansing agents.

*From living perception to abstract thought, and from this to practice.  
V.I. Lenin.*

By now, you have learnt the basic principles of chemistry and also realised that it influences every sphere of human life. The principles of chemistry have been used for the benefit of mankind. Think of cleanliness — the materials like soaps, detergents, household bleaches, tooth pastes, etc. will come to your mind. Look towards the beautiful clothes — immediately chemicals of the synthetic fibres used for making clothes and chemicals giving colours to them will come to your mind. Food materials — again a number of chemicals about which you have learnt in the previous Unit will appear in your mind. Of course, sickness and diseases remind us of medicines — again chemicals. Explosives, fuels, rocket propellents, building and electronic materials, etc., are all chemicals. Chemistry has influenced our life so much that we do not even realise that we come across chemicals at every moment; that we ourselves are beautiful chemical creations and all our activities are controlled by chemicals. In this Unit, we shall learn the application of Chemistry in three important and interesting areas, namely – medicines, food materials and cleansing agents.

### 16.1 Drugs and their Classification

**Drugs** are chemicals of low molecular masses (~100 – 500u). These interact with macromolecular targets and produce a biological response. When the biological response is therapeutic and useful, these chemicals are called **medicines** and are used in diagnosis, prevention and treatment of diseases. If taken in doses higher than those recommended, most of the drugs used as medicines are potential poisons. Use of chemicals for therapeutic effect is called **chemotherapy**,



### 16.1.1 Classification of Drugs

Drugs can be classified mainly on criteria outlined as follows:

#### (a) *On the basis of pharmacological effect*

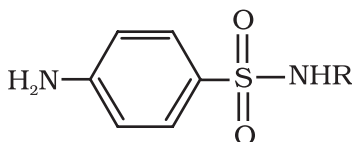
This classification is based on pharmacological effect of the drugs. It is useful for doctors because it provides them the whole range of drugs available for the treatment of a particular type of problem. For example, analgesics have pain killing effect, antiseptics kill or arrest the growth of microorganisms.

#### (b) *On the basis of drug action*

It is based on the action of a drug on a particular biochemical process. For example, all antihistamines inhibit the action of the compound, histamine which causes inflammation in the body. There are various ways in which action of histamines can be blocked. You will learn about this in Section 16.3.2.

#### (c) *On the basis of chemical structure*

It is based on the chemical structure of the drug. Drugs classified in this way share common structural features and often have similar pharmacological activity. For example, sulphonamides have common structural feature, given below.



Structural features of sulphonamides

#### (d) *On the basis of molecular targets*

Drugs usually interact with biomolecules such as carbohydrates, lipids, proteins and nucleic acids. These are called target molecules or drug targets. Drugs possessing some common structural features may have the same mechanism of action on targets. The classification based on molecular targets is the most useful classification for medicinal chemists.

## 16.2 Drug-Target Interaction

Macromolecules of biological origin perform various functions in the body. For example, proteins which perform the role of biological catalysts in the body are called **enzymes**, those which are crucial to communication system in the body are called **receptors**. Carrier proteins carry polar molecules across the cell membrane. Nucleic acids have coded genetic information for the cell. Lipids and carbohydrates are structural parts of the cell membrane. We shall explain the drug-target interaction with the examples of enzymes and receptors.

### 16.2.1 Enzymes as Drug Targets

#### (a) *Catalytic action of enzymes*

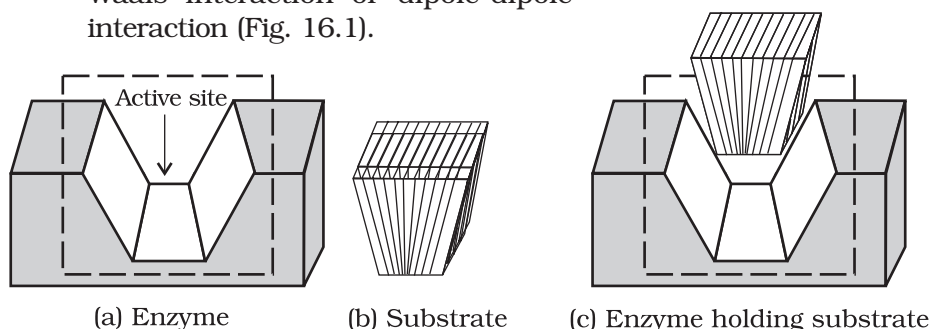
For understanding the interaction between a drug and an enzyme, it is important to know how enzymes catalyse the reaction (Section 5.2.4). In their catalytic activity, enzymes perform two major functions:

- (i) The first function of an enzyme is to hold the substrate for a chemical reaction. Active sites of enzymes hold the substrate molecule in a suitable position, so that it can be attacked by the reagent effectively.

Substrates bind to the active site of the enzyme through a variety of interactions such as ionic bonding, hydrogen bonding, van der Waals interaction or dipole-dipole interaction (Fig. 16.1).

**Fig. 16.1**

(a) Active site of an enzyme  
(b) Substrate  
(c) Substrate held in active site of the enzyme



(ii) The second function of an enzyme is to provide functional groups that will attack the substrate and carry out chemical reaction.

**(b) Drug-enzyme interaction**

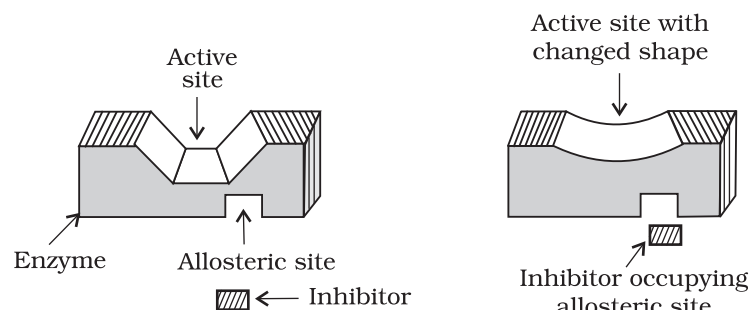
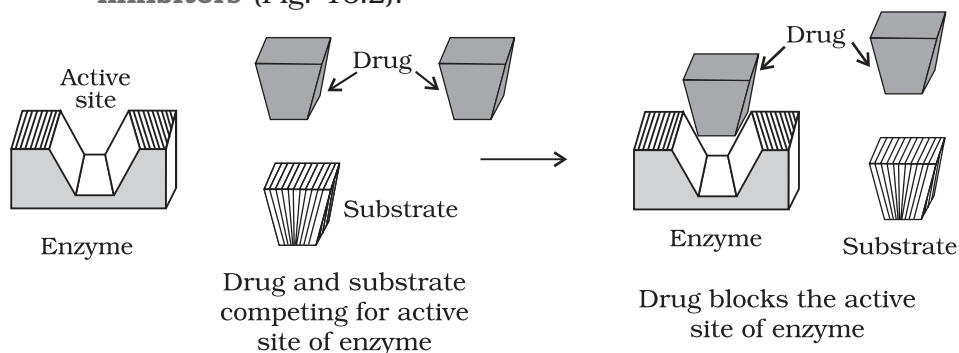
Drugs inhibit any of the above mentioned activities of enzymes. These can block the binding site of the enzyme and prevent the binding of substrate, or can inhibit the catalytic activity of the enzyme. Such drugs are called **enzyme inhibitors**.

Drugs inhibit the attachment of substrate on active site of enzymes in two different ways;

(i) Drugs compete with the natural substrate for their attachment on the active sites of enzymes. Such drugs are called **competitive inhibitors** (Fig. 16.2).

**Fig. 16.2**

Drug and substrate competing for active site



**Fig. 16.3:** Non-competitive inhibitor changes the active site of enzyme after binding at allosteric site.

(ii) Some drugs do not bind to the enzyme's active site. These bind to a different site of enzyme which is called **allosteric site**. This binding of inhibitor at allosteric site (Fig.16.3) changes the shape of the active site in such a way that substrate cannot recognise it.

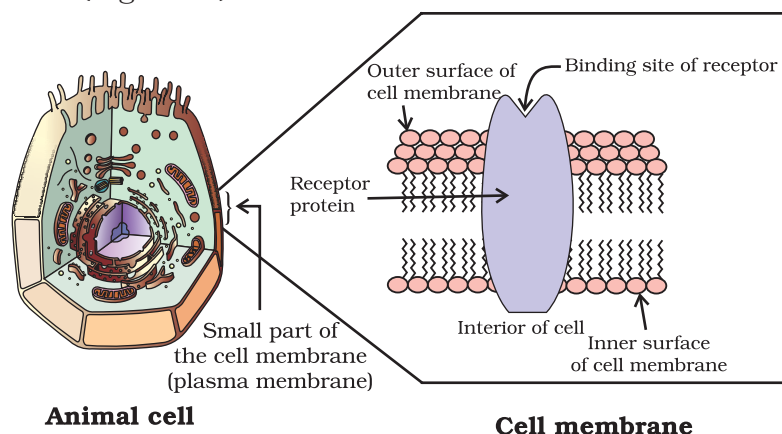
If the bond formed between an enzyme and an inhibitor is a strong covalent bond and

cannot be broken easily, then the enzyme is blocked permanently. The body then degrades the enzyme-inhibitor complex and synthesises the new enzyme.

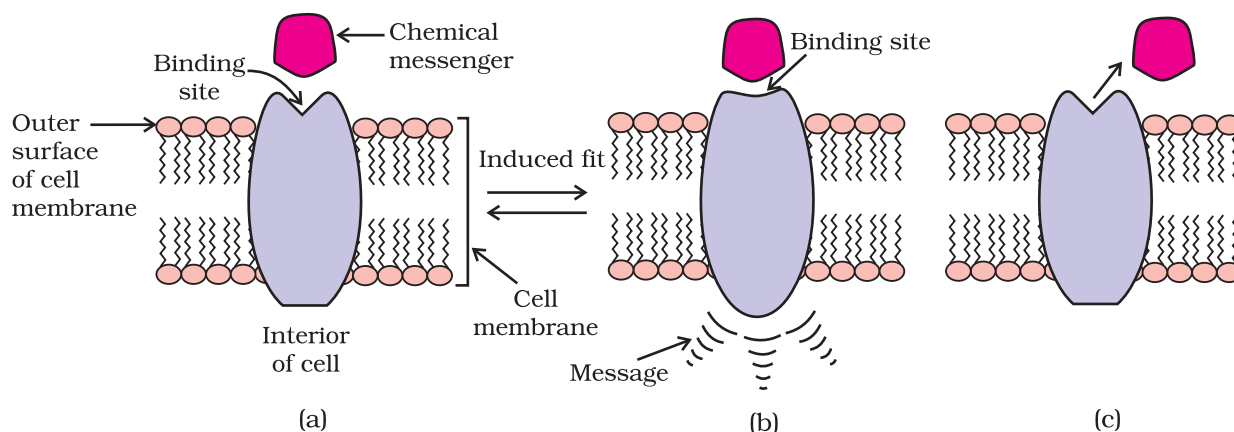
### 16.2.2 Receptors as Drug Targets

Receptors are proteins that are crucial to body's communication process. Majority of these are embedded in cell membranes (Fig. 16.4). Receptor proteins are embedded in the cell membrane in such a way that their small part possessing active site projects out of the surface of the membrane and opens on the outside region of the cell membrane (Fig. 16.4).

**Fig. 16.4**  
Receptor protein embedded in the cell membrane, the active site of the receptor opens on the outside region of the cell.



In the body, message between two neurons and that between neurons to muscles is communicated through certain chemicals. These chemicals, known as **chemical messengers** are received at the binding sites of receptor proteins. To accommodate a messenger, shape of the receptor site changes. This brings about the transfer of message into the cell. Thus, chemical messenger gives message to the cell without entering the cell (Fig. 16.5).



**Fig. 16.5:** (a) Receptor receiving chemical messenger  
(b) Shape of the receptor changed after attachment of messenger  
(c) Receptor regains structure after removal of chemical messenger.

There are a large number of different receptors in the body that interact with different chemical messengers. These receptors show selectivity for one chemical messenger over the other because their binding sites have different shape, structure and amino acid composition.

Drugs that bind to the receptor site and inhibit its natural function are called **antagonists**. These are useful when blocking of message is required. There are other types of drugs that mimic the natural messenger by switching on the receptor, these are called **agonists**. These are useful when there is lack of natural chemical messenger.

### 16.3 Therapeutic Action of Different Classes of Drugs

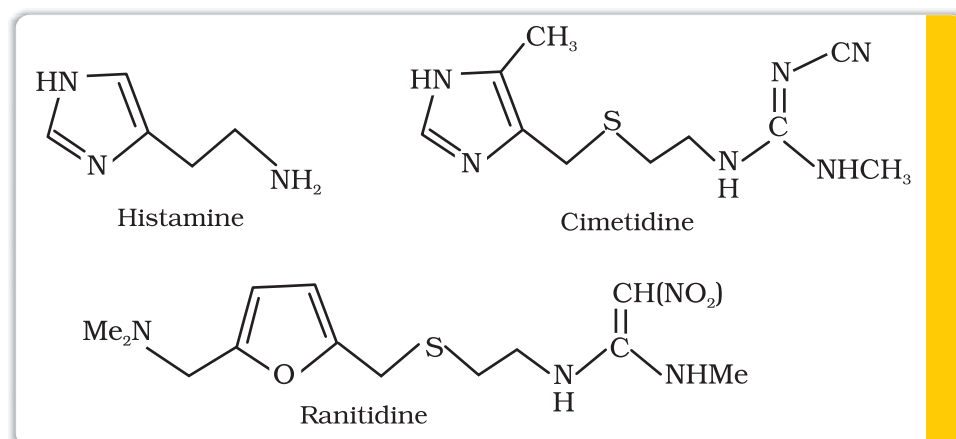
In this Section, we shall discuss the therapeutic action of a few important classes of drugs.

#### 16.3.1 Antacids

Over production of acid in the stomach causes irritation and pain. In severe cases, ulcers are developed in the stomach. Until 1970, only treatment for acidity was administration of antacids, such as sodium hydrogencarbonate or a mixture of aluminium and magnesium hydroxide. However, excessive hydrogencarbonate can make the stomach alkaline and trigger the production of even more acid. Metal hydroxides are better alternatives because of being insoluble, these do not increase the pH above neutrality. These treatments control only symptoms, and not the cause. Therefore, with these metal salts, the patients cannot be treated easily. In advanced stages, ulcers become life threatening and its only treatment is removal of the affected part of the stomach.

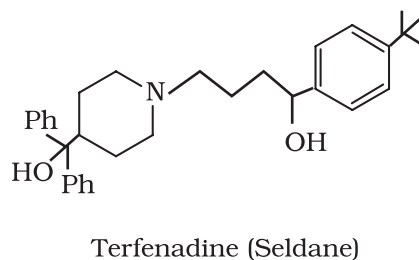
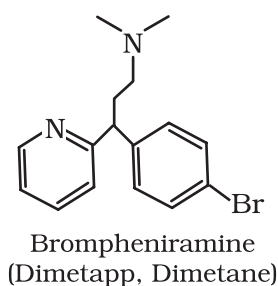
#### 16.3.2 Antihistamines

A major breakthrough in the treatment of hyperacidity came through the discovery according to which a chemical, histamine, stimulates the secretion of pepsin and hydrochloric acid in the stomach. The drug cimetidine (Tegamet), was designed to prevent the interaction of histamine with the receptors present in the stomach wall. This resulted in release of lesser amount of acid. The importance of the drug was so much that it remained the largest selling drug in the world until another drug, ranitidine (Zantac), was discovered.



Histamine is a potent vasodilator. It has various functions. It contracts the smooth muscles in the bronchi and gut and relaxes other muscles, such as those in the walls of fine blood vessels. Histamine is also responsible for the nasal congestion associated with common cold and allergic response to pollen.

Synthetic drugs, **brompheniramine (Dimetapp)** and **terfenadine (Seldane)**, act as antihistamines. They interfere with the natural action



of histamine by competing with histamine for binding sites of receptor where histamine exerts its effect.

Now the question that arises is, "Why do above mentioned antihistamines not affect the secretion of acid in stomach?" The reason is that antiallergic and antacid drugs work on different receptors.

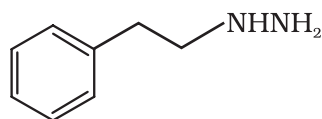
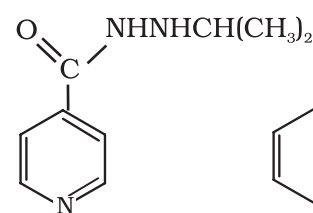
### 16.3.3 Neurologically Active Drugs

#### (a) Tranquilizers

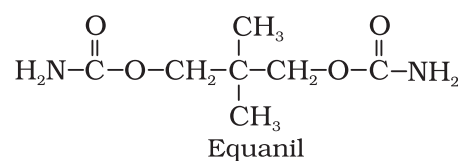
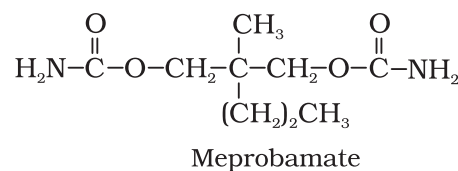
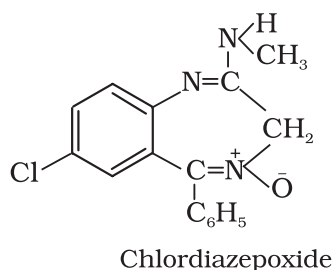
**Tranquilizers** and **analgesics** are neurologically active drugs. These affect the message transfer mechanism from nerve to receptor.

Tranquilizers are a class of chemical compounds used for the treatment of stress, and mild or even severe mental diseases. These relieve anxiety, stress, irritability or excitement by inducing a sense of well-being. They form an essential component of sleeping pills. There are various types of tranquilizers. They function by different mechanisms. For example, noradrenaline is one of the neurotransmitters that plays a role in mood changes. If the level of noradrenaline is low for some reason, then the signal-sending activity

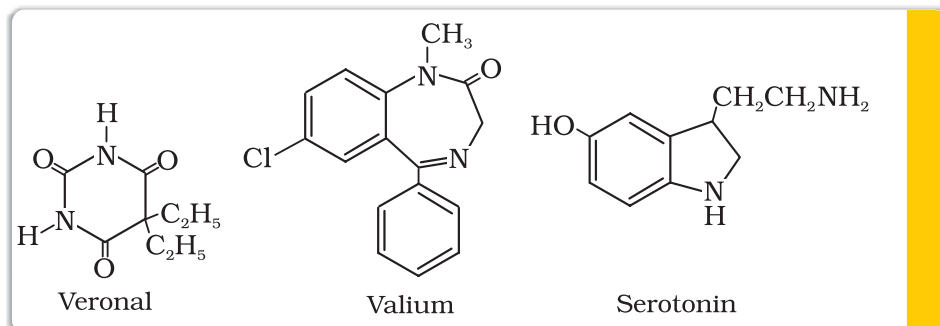
becomes low, and the person suffers from depression. In such situations, **antidepressant drugs** are required. These drugs inhibit the enzymes which catalyse the degradation of noradrenaline. If the enzyme is inhibited, this important neurotransmitter is slowly metabolised and can activate its receptor for longer periods of time, thus counteracting the effect of depression. Iproniazid and phenelzine are two such drugs.



Some tranquilizers namely, chlordiazepoxide and meprobamate, are relatively mild tranquilizers suitable for relieving tension. Equanil is used in controlling depression and hypertension.



Derivatives of barbituric acid viz., veronal, amytal, nembutal, luminal and seconal constitute an important class of tranquilizers. These derivatives are called **barbiturates**. Barbiturates are hypnotic, *i.e.*, sleep producing agents. Some other substances used as tranquilizers are valium and serotonin.



### (b) Analgesics

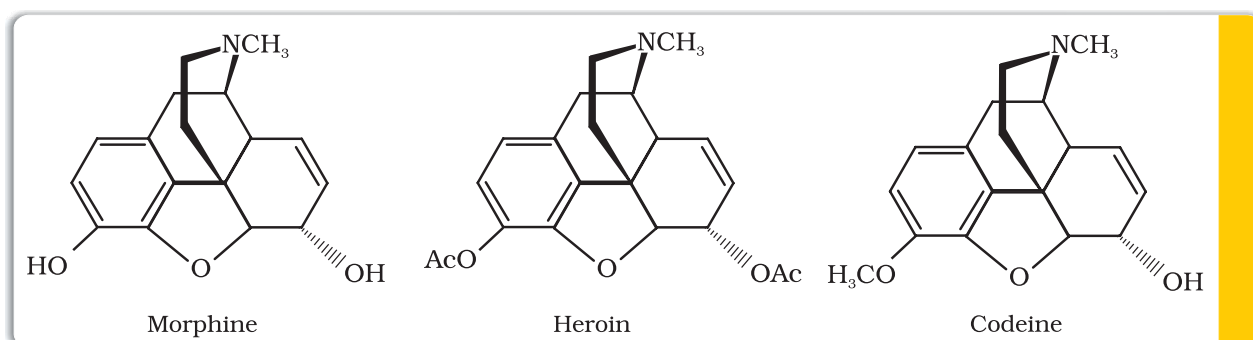
**Analgesics** reduce or abolish pain without causing impairment of consciousness, mental confusion, incoordination or paralysis or some other disturbances of nervous system. These are classified as follows:

- (i) Non-narcotic (non-addictive) analgesics
- (ii) Narcotic drugs

(i) **Non-narcotic (non-addictive) analgesics:** Aspirin and paracetamol belong to the class of **non-narcotic analgesics**. **Aspirin** is the most familiar example. Aspirin inhibits the synthesis of chemicals known as prostaglandins which stimulate inflammation in the tissue and cause pain. These drugs are effective in relieving skeletal pain such as that due to arthritis. These drugs have many other effects such as reducing fever (**antipyretic**) and preventing platelet coagulation. Because of its anti blood clotting action, aspirin finds use in prevention of heart attacks.

(ii) **Narcotic analgesics:** Morphine and many of its homologues, when administered in medicinal doses, relieve pain and produce sleep. In poisonous doses, these produce stupor, coma, convulsions and ultimately death. Morphine narcotics are sometimes referred to as opiates, since they are obtained from the opium poppy.

These analgesics are chiefly used for the relief of postoperative pain, cardiac pain and pains of terminal cancer, and in child birth.



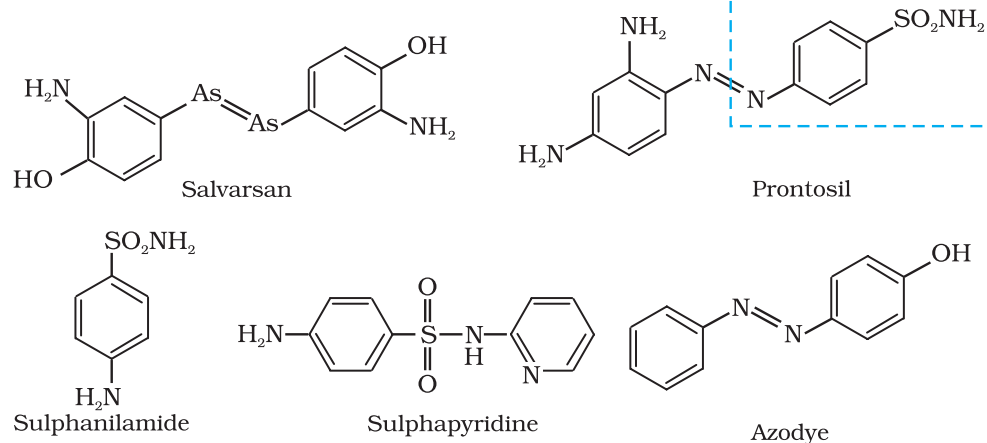
### 16.3.4 Antimicrobials

Diseases in human beings and animals may be caused by a variety of microorganisms such as bacteria, virus, fungi and other pathogens. An antimicrobial tends to destroy/prevent development or inhibit the pathogenic action of microbes such as bacteria (antibacterial drugs), fungi (antifungal agents), virus (antiviral agents), or other parasites (antiparasitic drugs) selectively. Antibiotics, antiseptics and disinfectants are antimicrobial drugs.

#### (a) Antibiotics

Antibiotics are used as drugs to treat infections because of their low toxicity for humans and animals. Initially antibiotics were classified as chemical substances produced by microorganisms (bacteria, fungi and molds) that inhibit the growth or even destroy microorganisms. The development of synthetic methods has helped in synthesising some of the compounds that were originally discovered as products of microorganisms. Also, some purely synthetic compounds have antibacterial activity, and therefore, definition of antibiotic has been modified. An antibiotic now refers to a substance produced wholly or partly by chemical synthesis, which in low concentrations inhibits the growth or destroys microorganisms by intervening in their metabolic processes.

The search for chemicals that would adversely affect invading bacteria but not the host began in the nineteenth century. Paul Ehrlich, a German bacteriologist, conceived this idea. He investigated arsenic based structures in order to produce less toxic substances for the treatment of syphilis. He developed the medicine, **arsphenamine**, known as **salvarsan**. Paul Ehrlich got Nobel prize for Medicine in 1908 for this discovery. It was the first effective treatment discovered for syphilis. Although salvarsan is toxic to human beings, its effect on the bacteria, spirochete, which causes syphilis is much greater than on human beings. At the same time, Ehrlich was working on azodyes also. He noted that there is similarity in structures of salvarsan and



*The structures of salvarsan, prontosil azodye and sulphapyridine showing structural similarity.*

H.W. Florey and Alexander Fleming shared the Nobel prize for Medicine in 1945 for their independent contributions to the development of penicillin.

azodyes. The  $-As = As-$  linkage present in arsphenamine resembles the  $-N = N-$  linkage present in azodyes in the sense that arsenic atom is present in place of nitrogen. He also noted tissues getting coloured by dyes selectively. Therefore, Ehrlich began to search for the compounds which resemble in structure to azodyes and selectively bind to bacteria. In 1932, he succeeded in preparing the first effective antibacterial agent, **prontosil**, which resembles in structure to the compound, salvarsan. Soon it was discovered that in the body prontosil is converted to a compound called **sulphanilamide**, which is the real active compound. Thus the sulpha drugs were discovered. A large range of sulphonamide analogues was synthesised. One of the most effective is sulphapyridine.

Despite the success of sulfonamides, the real revolution in antibacterial therapy began with the discovery of Alexander Fleming in 1929, of the antibacterial properties of a *Penicillium* fungus. Isolation and purification of active compound to accumulate sufficient material for clinical trials took thirteen years.

Antibiotics have either cidal (killing) effect or a static (inhibitory) effect on microbes. A few examples of the two types of antibiotics are as follows:

#### Bactericidal

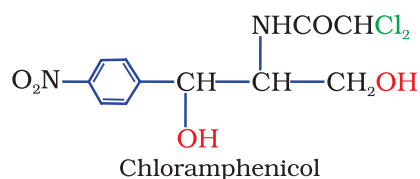
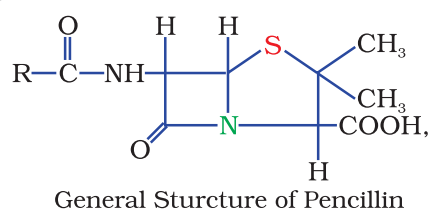
Penicillin  
Aminoglycosides  
Ofloxacin

#### Bacteriostatic

Erythromycin  
Tetracycline  
Chloramphenicol

The range of bacteria or other microorganisms that are affected by a certain antibiotic is expressed as its spectrum of action. Antibiotics which kill or inhibit a wide range of Gram-positive and Gram-negative bacteria are said to be **broad spectrum antibiotics**. Those effective mainly against Gram-positive or Gram-negative bacteria are **narrow spectrum antibiotics**. If effective against a single organism or disease, they are referred to as **limited spectrum** antibiotics. Penicillin G has a narrow spectrum. Ampicillin and Amoxycillin are synthetic modifications of penicillins. These have broad spectrum. It is absolutely essential to test the patients for sensitivity (allergy) to penicillin before it is administered. In India, penicillin is manufactured at the Hindustan Antibiotics in Pimpri and in private sector industry.

*Chloramphenicol*, isolated in 1947, is a broad spectrum antibiotic. It is rapidly absorbed from the gastrointestinal tract and hence can be given orally in case of typhoid, dysentery, acute fever, certain form of urinary infections, meningitis and pneumonia. *Vancomycin* and *ofloxacin* are the other important broad spectrum antibiotics. The antibiotic *dysidazine* is supposed to be toxic towards certain strains of cancer cells.

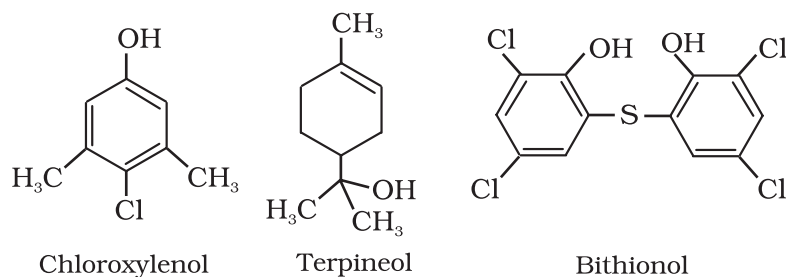




### (b) Antiseptics and disinfectants

Antiseptics and disinfectants are also the chemicals which either kill or prevent the growth of microorganisms.

**Antiseptics** are applied to the living tissues such as wounds, cuts, ulcers and diseased skin surfaces. Examples are **furacine**, **soframincine**, etc. These are not ingested like antibiotics. Commonly used antiseptic, dettol is a mixture of **chloroxylenol** and **terpineol**. Bithionol (the compound is also called bithional) is added to soaps to



impart antiseptic properties. Iodine is a powerful antiseptic. Its 2-3 per cent solution in alcohol-water mixture is known as **tincture of iodine**. It is applied on wounds. **Iodoform** is also used as an antiseptic for wounds. Boric acid in dilute aqueous solution is weak antiseptic for eyes.

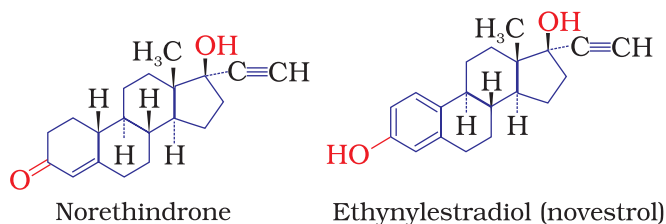
**Disinfectants** are applied to inanimate objects such as floors, drainage system, instruments, etc. Some substances can act as an antiseptic as well as disinfectant by varying the concentration. For example, 0.2 per cent solution of phenol is an antiseptic while its one percent solution is disinfectant.

Chlorine in the concentration of 0.2 to 0.4 ppm in aqueous solution and sulphur dioxide in very low concentrations, are disinfectants.

### 16.3.5 Antifertility Drugs

Antibiotic revolution has provided long and healthy life to people. The life expectancy has almost doubled. The increased population has caused many social problems in terms of food resources, environmental issues, employment, etc. To control these problems, population is required to be controlled. This has led to the concept of family planning. Antifertility drugs are of use in this direction. Birth control pills essentially contain a mixture of synthetic estrogen and progesterone derivatives. Both of these compounds are hormones. It is known that progesterone suppresses ovulation. Synthetic progesterone derivatives are more potent than

progesterone. **Norethindrone** is an example of synthetic progesterone derivative most widely used as antifertility drug. The estrogen derivative which is used in combination with progesterone derivative is **ethynylestradiol (novestrol)**.



#### Intext Questions

- 16.1** Sleeping pills are recommended by doctors to the patients suffering from sleeplessness but it is not advisable to take its doses without consultation with the doctor. Why ?
- 16.2** With reference to which classification has the statement, "ranitidine is an antacid" been given?

## 16.4 Chemicals in Food

Chemicals are added to food for (i) their preservation, (ii) enhancing their appeal, and (iii) adding nutritive value in them. Main categories of food additives are as follows:

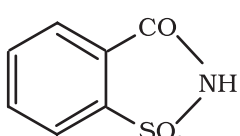
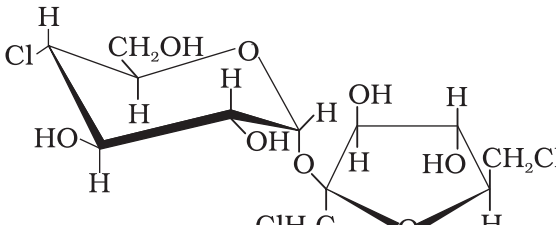
- (i) Food colours
- (ii) Flavours and sweeteners
- (iii) Fat emulsifiers and stabilising agents
- (iv) Flour improvers - antistaling agents and bleaches
- (v) Antioxidants
- (vi) Preservatives
- (vii) Nutritional supplements such as minerals, vitamins and amino acids.

Except for chemicals of category (vii), none of the above additives have nutritive value. These are added either to increase the shelf life of stored food or for cosmetic purposes. In this Section we will discuss only sweeteners and food preservatives.

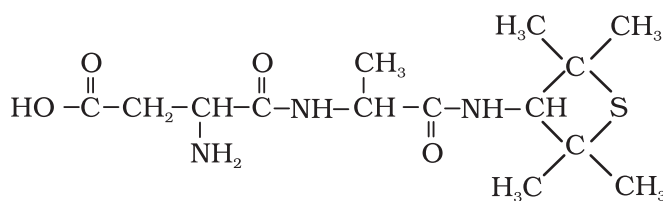
### 16.4.1 Artificial Sweetening Agents

Natural sweeteners, e.g., sucrose add to calorie intake and therefore many people prefer to use artificial sweeteners. Ortho-sulphobenzimide, also called saccharin, is the first popular artificial sweetening agent. It has been used as a sweetening agent ever since it was discovered in 1879. It is about 550 times as sweet as cane sugar. It is excreted from the body in urine unchanged. It appears to be entirely inert and harmless when taken. Its use is of great value to diabetic persons and people who need to control intake of calories. Some other commonly marketed artificial sweeteners are given in Table 16.1.

**Table 16.1: Artificial Sweeteners**

| Artificial sweetener | Structural formula  | Sweetness value in comparison to cane sugar |
|----------------------|---|---|
| Aspartame            | $\text{HO}-\overset{\text{O}}{\parallel}{\text{C}}-\text{CH}_2-\underset{\text{NH}_2}{\text{CH}}-\overset{\text{O}}{\parallel}{\text{C}}-\text{NH}-\underset{\text{CH}_2}{\text{CH}}-\overset{\text{O}}{\parallel}{\text{C}}-\text{OCH}_3$ <p style="text-align: center;"> <span style="display: inline-block; border-top: 1px solid black; width: 150px; margin-right: 50px;"></span> <span style="display: inline-block; border-top: 1px solid black; width: 150px;"></span> </p> <p style="text-align: center;"> <span style="display: inline-block; width: 150px; text-align: center;">Aspartic acid part</span> <span style="display: inline-block; width: 150px; text-align: center;">Phenylalanine methyl ester part</span> </p> | 100   |
| Saccharin            |    | 550   |
| Sucrolose            |    | 600   |

Alitame



2000

**Aspartame** is the most successful and widely used artificial sweetener. It is roughly 100 times as sweet as cane sugar. It is methyl ester of dipeptide formed from aspartic acid and phenylalanine. Use of aspartame is limited to cold foods and soft drinks because it is unstable at cooking temperature.

**Alitame** is high potency sweetener, although it is more stable than aspartame, the control of sweetness of food is difficult while using it.

**Sucrolose** is trichloro derivative of sucrose. Its appearance and taste are like sugar. It is stable at cooking temperature. It does not provide calories.

#### 16.4.2 Food Preservatives

Food preservatives prevent spoilage of food due to microbial growth. The most commonly used preservatives include table salt, sugar, vegetable oils and sodium benzoate,  $\text{C}_6\text{H}_5\text{COONa}$ . Sodium benzoate is used in limited quantities and is metabolised in the body. Salts of sorbic acid and propanoic acid are also used as preservatives.

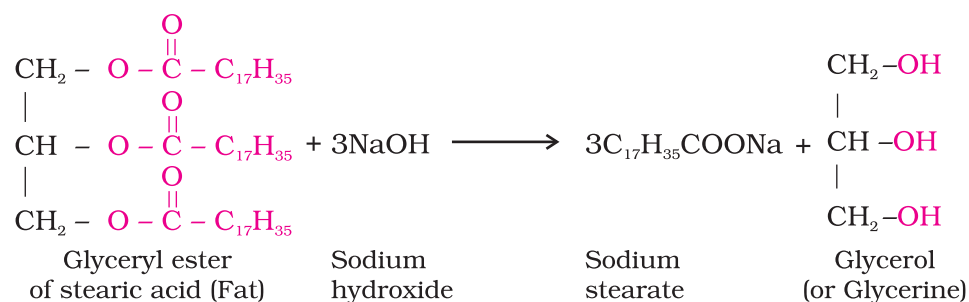
#### Intext Question

16.3 Why do we require artificial sweetening agents ?

### 16.5 Cleansing Agents

In this Section, we will learn about **detergents**. Two types of detergents are used as cleansing agents. These are soaps and synthetic detergents. These improve cleansing properties of water. These help in removal of fats which bind other materials to the fabric or skin.

#### 16.5.1 Soaps



Soaps are the detergents used since long. Soaps used for cleaning purpose are sodium or potassium salts of long chain fatty acids, e.g., stearic, oleic and palmitic acids. Soaps containing sodium salts are formed by heating fat (*i.e.*, glyceryl ester of fatty acid) with aqueous sodium hydroxide solution. This reaction is known as **saponification**.

In this reaction, esters of fatty acids are hydrolysed and the soap obtained remains in colloidal form. It is precipitated from the solution by adding sodium chloride. The solution left after removing the soap contains glycerol, which can be recovered by fractional distillation. Only sodium and potassium soaps are soluble in water and are used for cleaning purposes. Generally potassium soaps are soft to the skin than sodium soaps. These can be prepared by using potassium hydroxide solution in place of sodium hydroxide.

### **Types of soaps**

Basically all soaps are made by boiling fats or oils with suitable soluble hydroxide. Variations are made by using different raw materials.

*Toilet soaps* are prepared by using better grades of fats and oils and care is taken to remove excess alkali. Colour and perfumes are added to make these more attractive.

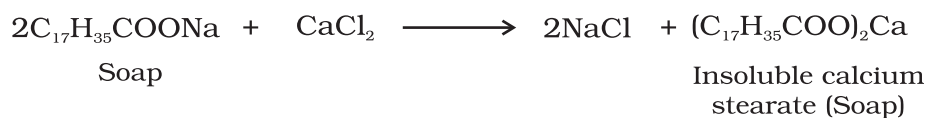
*Soaps that float* in water are made by beating tiny air bubbles before their hardening. *Transparent soaps* are made by dissolving the soap in ethanol and then evaporating the excess solvent.

In *medicated soaps*, substances of medicinal value are added. In some soaps, deodorants are added. *Shaving soaps* contain glycerol to prevent rapid drying. A gum called, rosin is added while making them. It forms sodium rosinate which lathers well. *Laundry soaps* contain fillers like sodium rosinate, sodium silicate, borax and sodium carbonate.

Soap chips are made by running a thin sheet of melted soap onto a cool cylinder and scraping off the soaps in small broken pieces. *Soap granules* are dried miniature soap bubbles. *Soap powders* and *scouring soaps* contain some soap, a scouring agent (abrasive) such as powdered pumice or finely divided sand, and builders like sodium carbonate and trisodium phosphate. Builders make the soaps act more rapidly. The cleansing action of soap has been discussed in Unit 5.

### **Why do soaps not work in hard water?**

Hard water contains calcium and magnesium ions. These ions form insoluble calcium and magnesium soaps respectively when sodium or potassium soaps are dissolved in hard water.



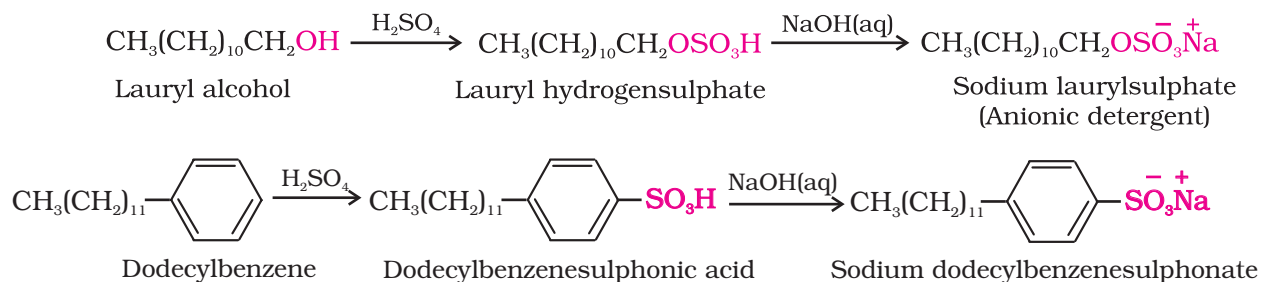
These insoluble soaps separate as scum in water and are useless as cleansing agent. In fact these are hinderance to good washing, because the precipitate adheres onto the fibre of the cloth as gummy mass. Hair washed with hard water looks dull because of this sticky precipitate. Dye does not absorb evenly on cloth washed with soap using hard water, because of this gummy mass.

### **16.5.2 Synthetic Detergents**

Synthetic detergents are cleansing agents which have all the properties of soaps, but which actually do not contain any soap. These can be used both in soft and hard water as they give foam even in hard water. Some of the detergents give foam even in ice cold water.

Synthetic detergents are mainly classified into three categories: (i) Anionic detergents (ii) Cationic detergents and (iii) Non-ionic detergents

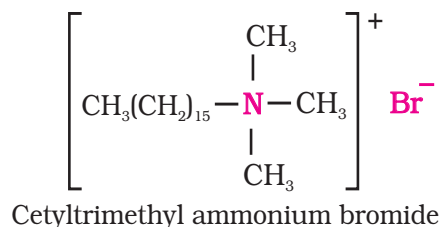
(i) *Anionic Detergents*: Anionic detergents are sodium salts of sulphonated long chain alcohols or hydrocarbons. Alkyl hydrogensulphates formed by treating long chain alcohols with concentrated sulphuric acid are neutralised with alkali to form anionic detergents. Similarly alkyl benzene sulphonates are obtained by neutralising alkyl benzene sulphonic acids with alkali.



In anionic detergents, the anionic part of the molecule is involved in the cleansing action. Sodium salts of alkylbenzenesulphonates are an important class of anionic detergents.

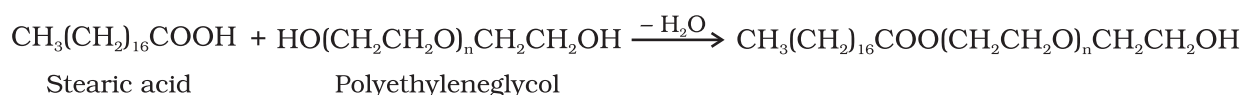
They are mostly used for household work. Anionic detergents are also used in toothpastes.

(ii) *Cationic Detergents*: Cationic detergents are quarternary ammonium salts of amines with acetates, chlorides or bromides as anions. Cationic part possess a long hydrocarbon chain and a positive charge on nitrogen atom. Hence, these are called cationic detergents. Cetyltrimethylammonium bromide is a popular cationic detergent and is used in hair conditioners.



Cationic detergents have germicidal properties and are expensive, therefore, these are of limited use.

(iii) *Non-ionic Detergents*: Non-ionic detergents do not contain any ion in their constitution. One such detergent is formed when stearic acid reacts with polyethyleneglycol.



Liquid dishwashing detergents are non-ionic type. Mechanism of cleansing action of this type of detergents is the same as that of soaps. These also remove grease and oil by micelle formation.

Main problem that appears in the use of detergents is that if their hydrocarbon chain is highly branched, then bacteria cannot degrade

this easily. Slow degradation of detergents leads to their accumulation. Effluents containing such detergents reach the rivers, ponds, etc. These persist in water even after sewage treatment and cause foaming in rivers, ponds and streams and their water gets polluted.

These days the branching of the hydrocarbon chain is controlled and kept to the minimum. Unbranched chains can be biodegraded more easily and hence pollution is prevented.

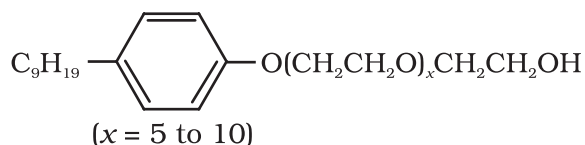
### Intext Questions

**16.4** Write the chemical equation for preparing sodium soap from glyceryl oleate and glyceryl palmitate. Structural formulae of these compounds are given below.

(i)  $(C_{15}H_{31}COO)_3C_3H_5$  - Glyceryl palmitate

(ii)  $(C_{17}H_{32}COO)_3C_3H_5$  - Glyceryl oleate

**16.5** Following type of non-ionic detergents are present in liquid detergents, emulsifying agents and wetting agents. Label the hydrophilic and hydrophobic parts in the molecule. Identify the functional group(s) present in the molecule.



### Summary

Chemistry is essentially the study of materials and the development of new materials for the betterment of humanity. A **drug** is a chemical agent, which affects human metabolism and provides cure from ailment. If taken in doses higher than recommended, these may have poisonous effect. Use of chemicals for therapeutic effect is called **chemotherapy**. Drugs usually interact with biological macromolecules such as carbohydrates, proteins, lipids and nucleic acids. These are called **target molecules**. Drugs are designed to interact with specific targets so that these have the least chance of affecting other targets. This minimises the side effects and localises the action of the drug. Drug chemistry centres around arresting microbes/destroying microbes, preventing the body from various infectious diseases, releasing mental stress, etc. Thus, drugs like analgesics, antibiotics, antiseptics, disinfectants, antacids and tranquilizers are used for specific purpose. To check the population explosion, antifertility drugs have also become prominent in our life.

Food additives such as **preservatives, sweetening agents, flavours, antioxidants, edible colours** and **nutritional supplements** are added to the food to make it attractive, palatable and add nutritive value. Preservatives are added to the food to prevent spoilage due to microbial growth. Artificial sweeteners are used by those who need to check the calorie intake or are diabetic and want to avoid taking sucrose.

These days, **detergents** are much in vogue and get preference over soaps because they work even in hard water. Synthetic detergents are classified into

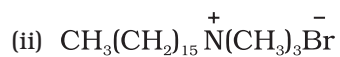
three main categories, namely: **anionic**, **cationic** and **non-ionic**, and each category has its specific uses. Detergents with straight chain of hydrocarbons are preferred over branched chain as the latter are **non-biodegradable** and consequently cause **environmental pollution**.

## Exercises

- 16.1 Why do we need to classify drugs in different ways ?
- 16.2 Explain the term, target molecules or drug targets as used in medicinal chemistry.
- 16.3 Name the macromolecules that are chosen as drug targets.
- 16.4 Why should not medicines be taken without consulting doctors ?
- 16.5 Define the term chemotherapy.
- 16.6 Which forces are involved in holding the drugs to the active site of enzymes ?
- 16.7 While antacids and antiallergic drugs interfere with the function of histamines, why do these not interfere with the function of each other ?
- 16.8 Low level of noradrenaline is the cause of depression. What type of drugs are needed to cure this problem ? Name two drugs.
- 16.9 What is meant by the term 'broad spectrum antibiotics' ? Explain.
- 16.10 How do antiseptics differ from disinfectants ? Give one example of each.
- 16.11 Why are cimetidine and ranitidine better antacids than sodium hydrogencarbonate or magnesium or aluminium hydroxide ?
- 16.12 Name a substance which can be used as an antiseptic as well as disinfectant.
- 16.13 What are the main constituents of dettol ?
- 16.14 What is tincture of iodine ? What is its use ?
- 16.15 What are food preservatives ?
- 16.16 Why is use of aspartame limited to cold foods and drinks ?
- 16.17 What are artificial sweetening agents ? Give two examples.
- 16.18 Name the sweetening agent used in the preparation of sweets for a diabetic patient.
- 16.19 What problem arises in using alitame as artificial sweetener ?
- 16.20 How are synthetic detergents better than soaps ?
- 16.21 Explain the following terms with suitable examples
  - (i) cationic detergents
  - (ii) anionic detergents and
  - (iii) non-ionic detergents.
- 16.22 What are biodegradable and non-biodegradable detergents ? Give one example of each.
- 16.23 Why do soaps not work in hard water ?
- 16.24 Can you use soaps and synthetic detergents to check the hardness of water ?
- 16.25 Explain the cleansing action of soaps.

**16.26** If water contains dissolved calcium hydrogencarbonate, out of soaps and synthetic detergents which one will you use for cleaning clothes ?

**16.27** Label the hydrophilic and hydrophobic parts in the following compounds.



### Answers to Some Intext Questions

**16.1** Most of the drugs taken in doses higher than recommended may cause harmful effect and act as poison. Therefore, a doctor should always be consulted before taking medicine.

**16.2** This statement refers to the classification according to pharmacological effect of the drug because any drug which will be used to counteract the effect of excess acid in the stomach will be called antacid.

**16.5**

