

2. Semi-synthetic polymers

Cellulose derivatives as cellulose acetate (rayon) and cellulose nitrate, etc. are the usual examples of this sub category.

3. Synthetic polymers

A variety of synthetic polymers as plastic (polythene), synthetic fibres (nylon 6,6) and synthetic rubbers (Buna - S) are examples of man-made polymers extensively used in daily life as well as in industry.

Polymers can also be classified on the basis of their structure, molecular forces or modes of polymerisation.

Intext Questions

15.1 What are polymers ?

15.2 Types of Polymerisation Reactions

15.2.1 Addition Polymerisation or Chain Growth Polymerisation

15.2.1.1 Mechanism of Addition Polymerisation

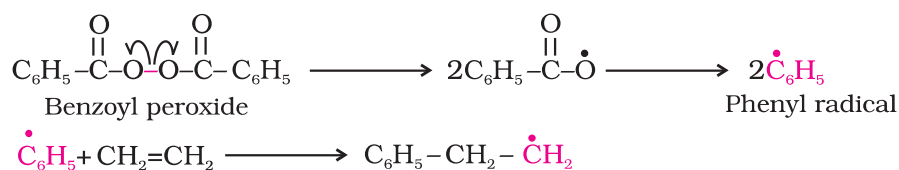
There are two broad types of polymerisation reactions, *i.e.*, the addition or chain growth polymerisation and condensation or step growth polymerisation.

In this type of polymerisation, the molecules of the same monomer or different monomers add together on a large scale to form a polymer. The monomers used are unsaturated compounds, *e.g.*, alkenes, alkadienes and their derivatives. This mode of polymerisation leads to an increase in chain length and chain growth can take place through the formation of either free radicals or ionic species. However, the free radical governed addition or chain growth polymerisation is the most common mode.

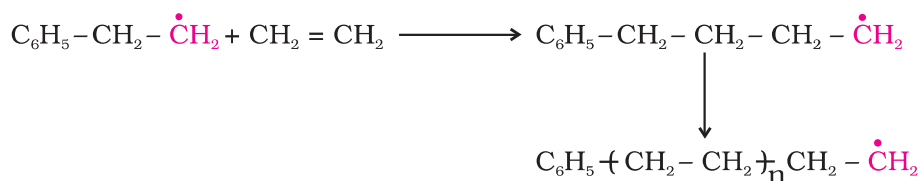
1. Free radical mechanism

A variety of alkenes or dienes and their derivatives are polymerised in the presence of a free radical generating initiator (catalyst) like benzoyl peroxide, acetyl peroxide, tert-butyl peroxide, etc. For example, the polymerisation of ethene to polythene consists of heating or exposing to light a mixture of ethene with a small amount of benzoyl peroxide initiator. The process starts with the addition of phenyl free radical formed by the peroxide to the ethene double bond thus generating a new and larger free radical. This step is called **chain initiating step**. As this radical reacts with another molecule of ethene, another bigger sized radical is formed. The repetition of this sequence with new and bigger radicals carries the reaction forward and the step is termed as **chain propagating step**. Ultimately, at some stage the product radical thus formed reacts with another radical to form the polymerised product. This step is called the **chain terminating step**. The sequence of steps involved in the formation of polythene are depicted as follows:

Chain initiation steps

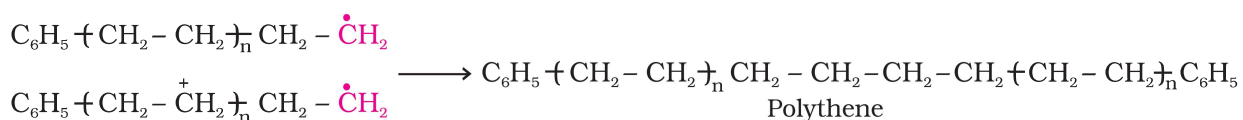


Chain propagating step



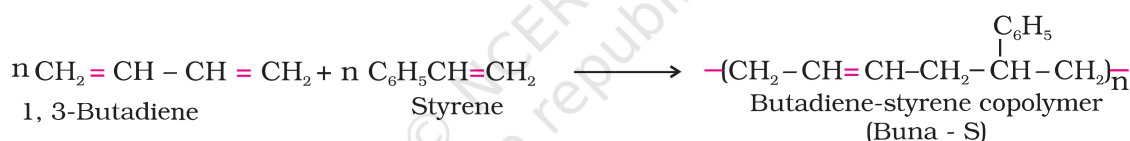
Chain terminating step

For termination of the long chain, these free radicals can combine in different ways to form polythene. One mode of termination of chain is shown as under:



The addition polymers formed by the polymerisation of a single monomeric species are known as **homopolymers**, for example polythene discussed above is a homopolymer.

The polymers made by addition polymerisation from two different monomers are termed as **copolymers**. Buna-S, which is formed by polymerisation of buta-1, 3-diene and styrene is an example of copolymer formed by addition polymerisation.



15.2.1.2

Some Important Addition Polymers

(a) Polythene

Polythenes are linear or slightly branched long chain molecules. These are capable of repeatedly softening on heating and hardening on cooling and are thus thermoplastic polymers.

There are two types of polythene as given below:

- (i) **Low density polythene:** It is obtained by the polymerisation of ethene under high pressure of 1000 to 2000 atmospheres at a temperature of 350 K to 570 K in the presence of traces of dioxygen or a peroxide initiator (catalyst). The low density polythene (LDP) is obtained through the free radical addition and H-atom abstraction. It has highly branched structure. These polymers have straight chain structure with some branches as shown below.



Low density polythene is chemically inert and tough but flexible and a poor conductor of electricity. Hence, it is used

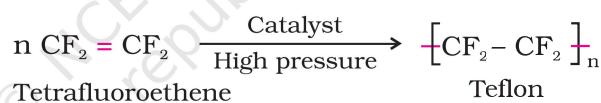
in the insulation of electricity carrying wires and manufacture of squeeze bottles, toys and flexible pipes.

(ii) **High density polythene:** It is formed when addition polymerisation of ethene takes place in a hydrocarbon solvent in the presence of a catalyst such as triethylaluminium and titanium tetrachloride (Ziegler-Natta catalyst) at a temperature of 333 K to 343 K and under a pressure of 6-7 atmospheres. High density polythene (HDP) thus produced, consists of linear molecules as shown below and has a high density due to close packing. Such polymers are also called linear polymers. High density polymers are also chemically inert and more tough and hard. It is used for manufacturing buckets, dustbins, bottles, pipes, etc.



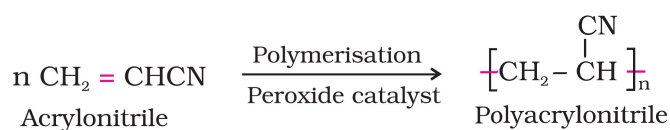
(b) Polytetrafluoroethene (Teflon)

Teflon is manufactured by heating tetrafluoroethene with a free radical or persulphate catalyst at high pressures. It is chemically inert and resistant to attack by corrosive reagents. It is used in making oil seals and gaskets and also used for non-stick surface coated utensils.



(c) Polyacrylonitrile

The addition polymerisation of acrylonitrile in presence of a peroxide catalyst leads to the formation of polyacrylonitrile.



Polyacrylonitrile is used as a substitute for wool in making commercial fibres as orlon or acrilan.

Example 15.1

Is $\left[\text{CH}_2 - \text{CH}(\text{C}_6\text{H}_5) \right]_n$ a homopolymer or a copolymer?

Solution

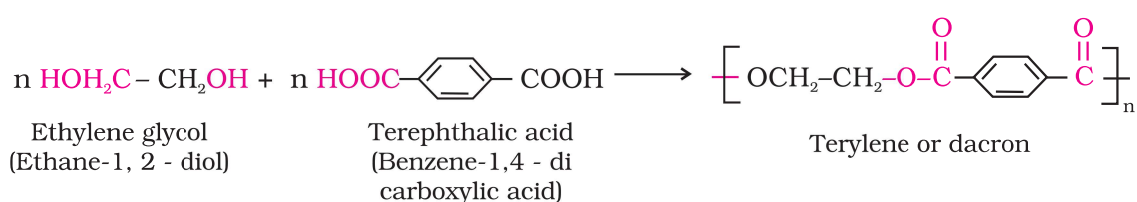
It is a homopolymer and the monomer from which it is obtained is styrene $\text{C}_6\text{H}_5\text{CH} = \text{CH}_2$.

15.2.2 Condensation Polymerisation or Step Growth Polymerisation

This type of polymerisation generally involves a repetitive condensation reaction between two bi-functional or trifunctional mono-meric units. These polycondensation reactions may result in the loss of some simple molecules as water, alcohol, hydrogen chloride, etc., and lead to the formation of high molecular mass condensation polymers.

In these reactions, the product of each step is again a bi-functional species and the sequence of condensation goes on. Since, each step produces a distinct functionalised species and is independent of each other, this process is also called as step growth polymerisation.

The formation of terylene or dacron by the interaction of ethylene glycol and terephthalic acid is an example of this type of polymerisation.



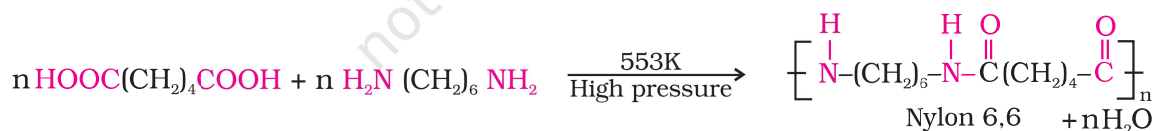
15.2.2.1 Some Important Condensation Polymers

(a) Polyamides

These polymers possessing amide linkages are important examples of synthetic fibres and are termed as nylons. The general method of preparation consists of the condensation polymerisation of diamines with dicarboxylic acids or condensation of amino acids or their lactams.

Nylons

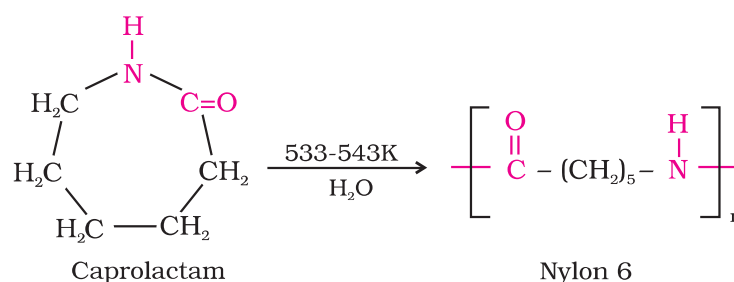
(i) **Nylon 6,6:** It is prepared by the condensation polymerisation of hexamethylenediamine with adipic acid under high pressure and at high temperature.



Nylon 6, 6 is fibre forming solid. It possess high tensile strength. This characteristic can be attributed to the strong intermolecular forces like hydrogen bonding. These strong forces also lead to close packing of chains and thus impart crystalline nature.

Nylon 6, 6 is used in making sheets, bristles for brushes and in textile industry.

(ii) **Nylon 6:** It is obtained by heating caprolactum with water at a high temperature.



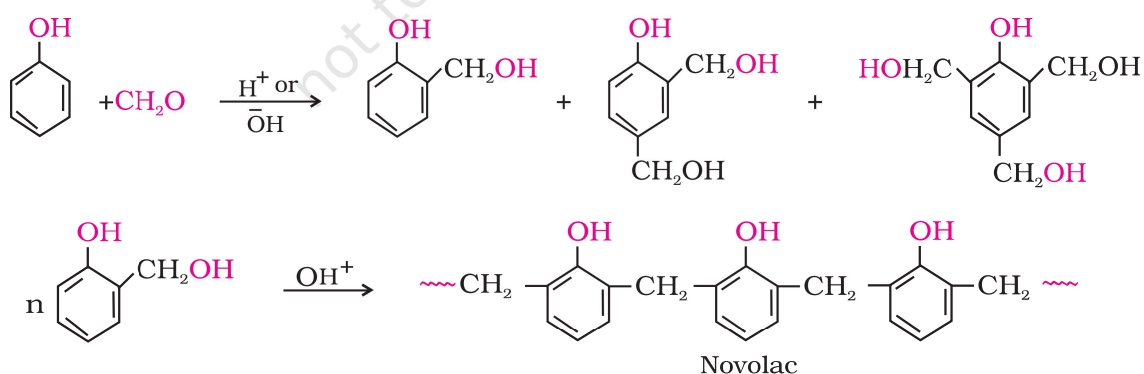
Nylon 6 is used for the manufacture of tyre cords, fabrics and ropes.

(b) Polyesters

These are the polycondensation products of dicarboxylic acids and diols. Dacron or terylene is the best known example of polyesters. It is manufactured by heating a mixture of ethylene glycol and terephthalic acid at 420 to 460 K in the presence of zinc acetate-antimony trioxide catalyst as per the reaction given earlier. Dacron fibre (terylene) is crease resistant and is used in blending with cotton and wool fibres and also as glass reinforcing materials in safety helmets, etc.

(c) Phenol - formaldehyde polymer (Bakelite and related polymers)

Phenol - formaldehyde polymers are the oldest synthetic polymers. These are obtained by the condensation reaction of phenol with formaldehyde in the presence of either an acid or a base catalyst. The reaction starts with the initial formation of *o*-and/or *p*-hydroxymethylphenol derivatives, which further react with phenol to form compounds having rings joined to each other through $-\text{CH}_2-$ groups. The initial product could be a linear product - **Novolac** used in paints.



Novolac on heating with formaldehyde undergoes cross linking to form an infusible solid mass called **bakelite**. It is thermosetting polymer which cannot be reused or remoulded. Thus, bakelite is formed by cross linking of linear chains of the polymer novolac. Bakelite is used for making combs, phonograph records, electrical switches and handles of various utensils.

Intext Questions

15.4 Explain the difference between Buna-N and Buna-S.

15.5 Arrange the following polymers in increasing order of their intermolecular forces. Nylon 6,6, Buna-S, Polythene.

15.3 Molecular Mass of Polymers

Polymer properties are closely related to their molecular mass, size and structure. The growth of the polymer chain during their synthesis is dependent upon the availability of the monomers in the reaction mixture. Thus, the polymer sample contains chains of varying lengths and hence its molecular mass is always expressed as an average. The molecular mass of polymers can be determined by chemical and physical methods.

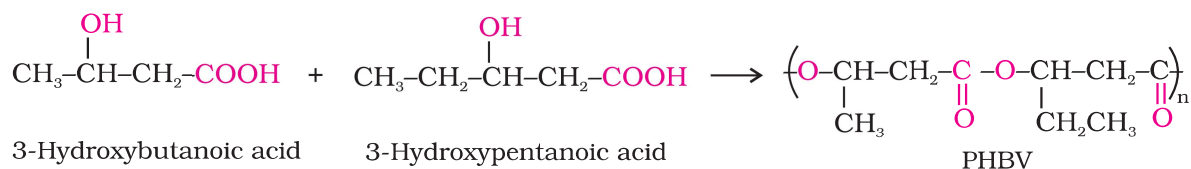
15.4 Biodegradable Polymers

A large number of polymers are quite resistant to the environmental degradation processes and are thus responsible for the accumulation of polymeric solid waste materials. These solid wastes cause acute environmental problems and remain undegraded for quite a long time. In view of the general awareness and concern for the problems created by the polymeric solid wastes, certain new biodegradable synthetic polymers have been designed and developed. These polymers contain functional groups similar to the functional groups present in biopolymers.

Aliphatic polyesters are one of the important classes of biodegradable polymers. Some important examples are given below:

1. Poly β -hydroxybutyrate - co- β -hydroxy valerate (PHBV)

It is obtained by the copolymerisation of 3-hydroxybutanoic acid and 3-hydroxypentanoic acid. PHBV is used in speciality packaging, orthopaedic devices and in controlled release of drugs. PHBV undergoes bacterial degradation in the environment.



2. Nylon 2-nylon 6

It is an alternating polyamide copolymer of glycine ($\text{H}_2\text{N-CH}_2\text{-COOH}$) and amino caproic acid [$\text{H}_2\text{N}(\text{CH}_2)_5\text{COOH}$] and is biodegradable. Can you write the structure of this copolymer?