POLYMERS

Synthetic Polymers

Polymers are high molecular weight compounds whose structures consist of a large number of simple repeating units joined together in long chains. These repeating units are derived from low molecular weight simple compounds known as monomers.

The chemical reaction in which monomers combine to form polymers is called polymerization.

1.Addition Polymers

Addition polymers are formed when a large number of alkene monomers combine together to form one very large molecule (polymer). This process is called addition polymerization.

Key Features of Addition Polymerization

- Only alkene monomers (containing C=C double bonds) take part.
- The double bond breaks, and monomers link together.
- No small molecule is eliminated (nothing is lost).
- The polymer backbone consists entirely of carbon atoms.

Reaction Conditions

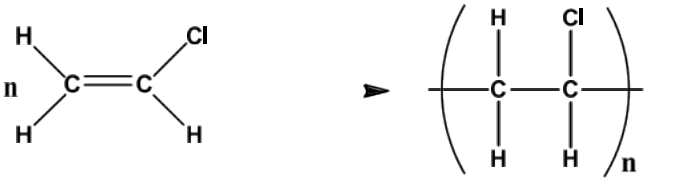
- The reaction is usually initiated by free-radical catalysts such as peroxides or sometimes acids.
- Traditional conditions require:
  - High pressure (around 1000 atmospheres)
  - High temperature (about 200 °C, not 2000 °C)
- When Ziegler–Natta catalysts are used:
  - Catalysts consist of trialkyl aluminium $Al(R)_3$ and titanium tetrachloride ($TiCl_4$).
  - The reaction occurs at much lower temperature and pressure.
  - An inert solvent is used.

Nature of the Polymer

- The carbon atoms forming the polymer chain were originally part of the **C=C** double bond in the monomer.
- Monomers simply add to one another in a chain reaction.

Example: Polyvinyl Chloride (PVC)

- **Monomer:** Vinyl chloride ($CH_2=CHCl$)
- **Polymer:** Polyvinyl chloride (PVC)



Vinylchloride Polyvinylchloride

Uses of PVC

PVC is widely used in the manufacture of:

- Artificial leather
- Floor coverings
- Corrugated roofing sheets
- Gramophone records

Vinyl chloride is obtained from acetylene by treatment with HCl in the presence of HgCl2.

$$HC{\equiv}CH + HCl \xrightarrow{HgCl_2} CH_2 = CHCl$$

2. Condensation Polymers

Condensation polymers are formed when monomer molecules combine with the elimination of small molecules such as H_2O, NH_3, or ROH (alcohol). These polymers are produced through condensation reactions involving functional groups.

There are two main types of condensation polymers:

1. Polyesters
2. Polyamides

(a) Polyamides

Polyamides are condensation polymers that contain amide (–CONH–) linkages in their polymer chains. They are commonly formed by the reaction between:

- a diamine and
- a dicarboxylic acid

(i) Nylon-6,6

Nylon-6,6 is an important example of a polyamide formed from a diamine and a dicarboxylic acid.

Formation:

- One –OH group from the dicarboxylic acid reacts with one –H atom from the amine ($–NH_2$) group of the diamine.
- A molecule of water (H_2O) is eliminated.
- An amide linkage (–CONH–) is formed.
- Since both reactants have two functional groups, the reaction continues repeatedly, producing a long polymer chain.

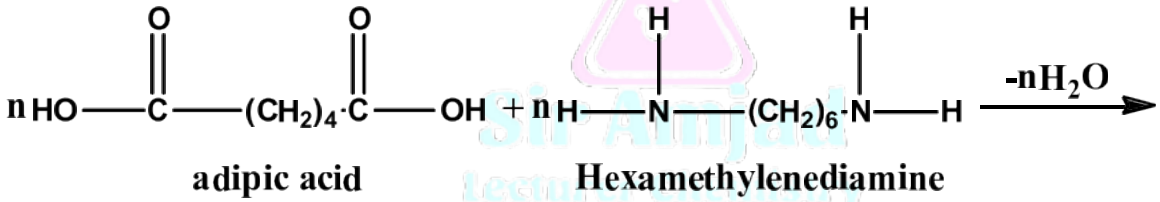
Reactants:

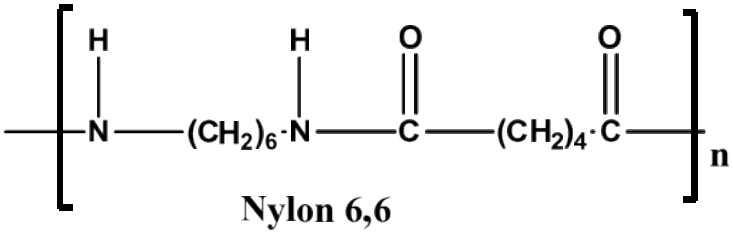
- Adipic acid: $HOOC–(CH_2)_4–COOH$
- Hexamethylene diamine: $H_2N–(CH_2)_6–NH_2$

Reaction conditions:

Nylon-6,6 is prepared by heating adipic acid with hexamethylene diamine at about 200 °C in the presence of nitrogen gas.

General reaction:





Reason for the name Nylon-6,6:

The name Nylon-6,6 is derived from the number of carbon atoms in its monomers:

- 6 carbons in adipic acid
- 6 carbons in hexamethylene diamine

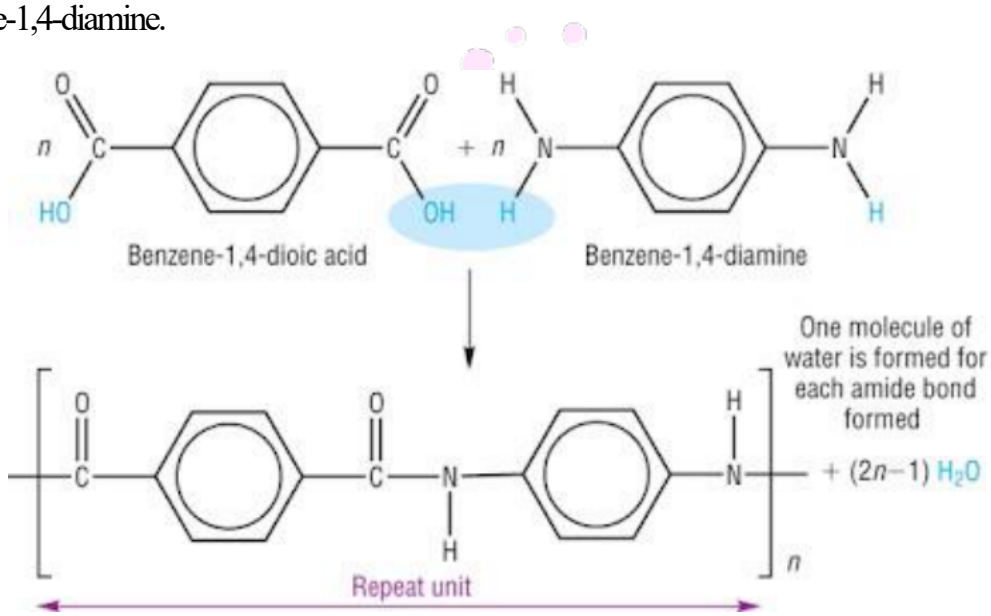
Uses of Nylon-6,6

Nylon-6,6 was developed as a synthetic fibre and was introduced to the public at the New York World's Fair in 1939. Its uses include:

- Fibres for clothing and carpets
- Stockings and other apparel
- Fishing lines and ropes
- Bristles for brushes
- Moulded objects such as gears and bearings

(ii) Kevlar

Kevlar is another polyamide. Its monomers are, benzene-1,4-dicarboxylic acid and benzene-1,4-diamine.



Kevlar is a strong and light weight polymer. It is woven into textile materials which is light weight, strong, corrosion and heat resistant.

It is used for making bullet and fireproof vests, crash helmets, body of aircraft, boats etc.

(iii) Polypeptides

Polypeptides are formed by the polymerisation of amino acid molecules. Amino acids join together through a condensation reaction, in which a peptide bond (–CO–NH–) is formed between adjacent amino acids with the elimination of water molecules.

Each peptide bond is produced when the carboxyl group (–COOH) of one amino acid reacts with the amino group ($–NH_2$) of another amino acid.

General reaction:

$n\,NH_2–CH_2–COOH \longrightarrow [–NH–CH_2–COO–]_n + (n-1)\,H_2O$

(Aminoethanoic acid → Polypeptide)

Thus, a long chain of amino acids linked by peptide bonds forms a polypeptide, which is the basic structural unit of proteins.

(b) Polyesters

Polyesters are polymers produced by the condensation polymerisation of diols (alcohols with two –OH groups) and dicarboxylic acids (acids with two –COOH groups). During polymer formation, ester linkages (–COO–) are formed with the elimination of water molecules.

(i) Terylene (Polyethylene Terephthalate, PET)

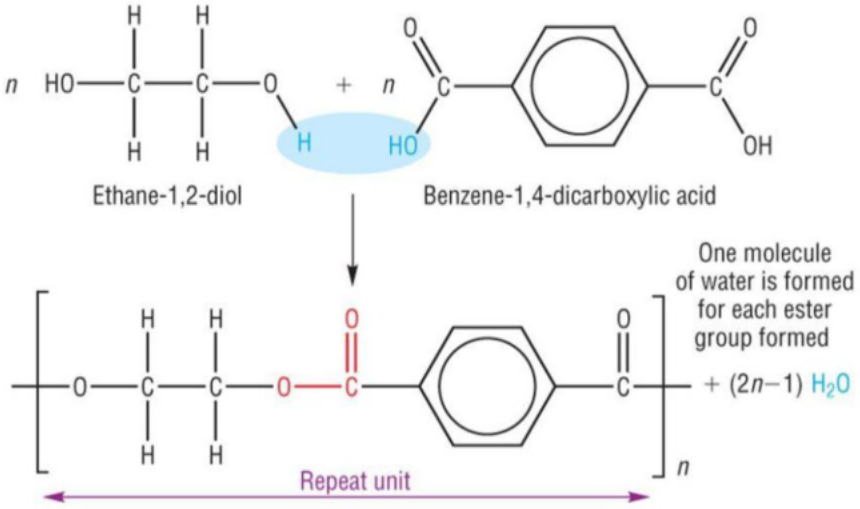
The most common polyester is terylene, also known as polyethylene terephthalate (PET).

Monomers Used:

- Ethane-1,2-diol

Benzene-1,4-dicarboxylic acid (terephthalic acid)

Formation of Terylene, a polyester



These monomers react through condensation polymerisation to form long chains containing ester linkages, producing terylene.

Terylene is widely used in the manufacture of textile fibers, plastic bottles, and packaging materials due to its strength, durability, and resistance to chemicals.

(ii) Polymerisation of Hydroxycarboxylic Acids

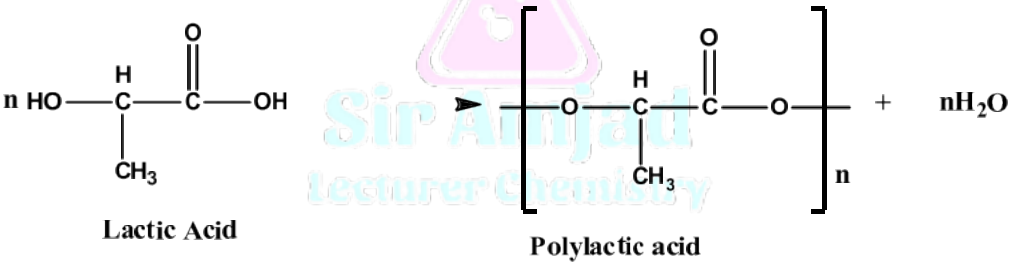
Hydroxycarboxylic acids can also undergo condensation polymerisation to form polyesters. These compounds contain both a hydroxyl group (–OH) and a carboxylic acid group (–COOH) in the same molecule, which enables them to polymerise without the need for a second monomer.

Example: Polylactic Acid (PLA)

Polylactic acid is a polyester formed by the polymerisation of 2-hydroxypropanoic acid (lactic acid).

During polymerisation, the –OH group of one lactic acid molecule reacts with the –COOH group of another molecule, forming an ester linkage (–COO–) with the elimination of water molecules.

General Reaction:



Lactic Acid Polylactic acid

Biodegradable and Non-Biodegradable Polymers

Concept:

Polymers are classified into two main types based on their ability to decompose naturally — biodegradable and non-biodegradable polymers.

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1. Biodegradable Polymers

Definition:

These are polymers that can be decomposed by the action of microorganisms such as bacteria and fungi.

Explanation:
Biodegradable polymers contain functional groups like ester (-COO-) or amide (-CONH-) linkages that can undergo hydrolysis.
These linkages are easily broken down by enzymes, acids, or alkalis, converting the polymer into simpler, harmless products.

Examples:

- Polyamides (e.g., Nylon-2-Nylon-6)
- Polyesters (e.g., PHBV – Polyhydroxybutyrate-co-valerate)

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2. Non-Biodegradable Polymers

Definition:
Polymers that cannot be decomposed by microorganisms are called non-biodegradable polymers.

Explanation:
These polymers are generally formed by addition polymerization and consist of long chains of saturated, non-polar carbon atoms.
Their chemical inertness makes them resistant to environmental degradation.
Although they are durable, they pose serious environmental problems due to their persistence in nature.

Examples:

- Polyethylene (PE)
- Polypropylene (PP)
- Polyvinyl chloride (PVC)
- Polyethylene terephthalate (PET)

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3. Photodegradable Polymers

Some polymers can degrade under ultraviolet (UV) light exposure.
UV light breaks the polymer chains, causing weakening and fragmentation of the material.

Examples:

- Polyethylene
- Polypropylene
- Polystyrene

For More Information:

Online and physical tuition is available

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