UNIT 13

POLYMERS

Student Learning Outcomes (SLOs)

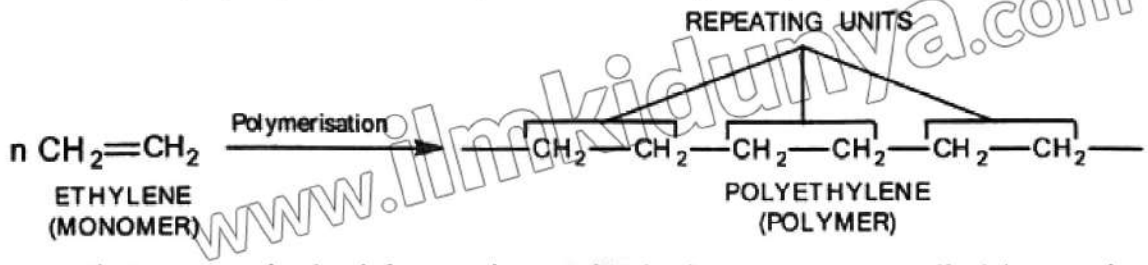
- Explain the chemical processes and properties of PVC and nylon, and the applications of these polymers in the industry.
- Describe the condensation reaction of ammonia or an amine with an acyl chloride at room temperature to give an amide.
- Discuss the importance of chemical industries in the economy of Pakistan, and describe the raw materials that are available in the country for various chemical industries.
- Describe the chemical processes of addition and condensation polymerization and the differences between them. Examples include:
  a) addition polymers such as polyethene and polychloroethene, PVC,
  b) polyesters (from reactions of diols and dicarboxylic or dioyl acid, and from hydroxycarboxylic acid),
  c) polyamides (from reactions of a diamine and a dicarboxylic acid, or between amino acids.
- Identify the polymer formed, the monomer present in a section of polymer, and classify them as one of the two polymers.
- Deduce the repeating unit of a polymer obtained from a given monomer or pair of monomers and identify the monomes present in a given section of a polymer molecule.
- Predict the type of polymerization reaction for a given monomer or pairs of monomers.

- Explain the challenges associated with the disposal of non-biodegradable polymers.
- Recognise that poly(alkenes) are chemically inert and can therefore be difficult to *biodegrade*.
- Recognise that some polymers can be degraded by the action of light.
- Recognise that polyesters and polyamides are biodegradable by acid and alkaline hydrolysis.
- Outline the use of polymers to create artificial organs in biomedical science.

13.1 Synthetic Polymers

Polymers are high molecular weight compounds whose structures are made up of a large number of simple repeating units. The repeating units are usually obtained from low molecular weight simple compounds referred to as monomers. The reaction by which monomers are converted into polymers is known as polymerization.

The formation of polyethylene from ethylene is an example of polymerisation reaction.



Polymers that are synthesized from only one kind of monomer are called homopolymers. Polymers that are prepared from more than two different monomers are called copolymers. Polymers made up of three different monomers are called terpolymers.

13.2 Classification of Polymers

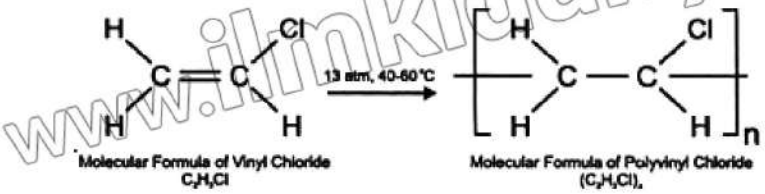
There are two main types of polymers: Addition polymers and Condensation polymers.

1. Addition Polymers

Addition polymers are formed by combining alkene monomers, resulting in just one huge molecule. These reactions are catalysed by peroxides or acids. The reactions require a pressure of 1000 atmospheres at 2000 °C. With the so-called Ziegler catalysts, which consist of trialkylaluminum $Al(R)_3$ and titanium tetrachloride $TiCl_4$ in an inert solvent, much lower temperatures and pressures can be used.

The polymer backbone consists of carbon atoms that originally formed a double bond. Nothing is lost. Monomers add to each other.

For example, polyvinyl chloride (PVC) is obtained by polymerization of vinyl chloride. PVC is used to manufacture artificial leather, floor coverings, corrugated roofing materials and gramophone records.



Vinyl chloride is obtained from acetylene by treatment with HCl in the presence of $HgCl_2$.

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

Acetylene — Vinyl chloride

2. Condensation Polymers

Condensation polymers are formed by the combination of monomers with the elimination of simple molecules such as H_2O, NH_3 or ROH. There are two main types of condensation polymers: Polyesters and Polyamides.

(a) Polyamides

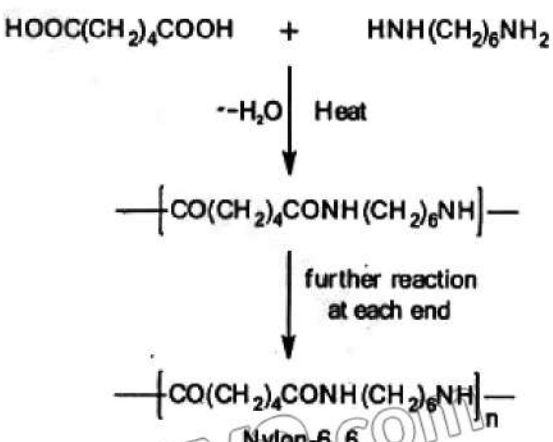
Polyamides can be made from a variety of different reactants.

(i) Nylon-6,6

Here's an example of making a polyamide from a diamine and a dicarboxylic acid. A hydroxyl (-OH) group from the dicarboxylic acid reacts with a hydrogen atom from one of the diamine's amine groups, forming water. This results in an amide linkage between the diamine and the dicarboxylic acid. Because both molecules have two functional groups, one at each end, the process happens again. This creates a long polyamide polymer chain. This polyamide is called Nylon-6,6.

It is obtained by heating adipic acid with hexamethylene diamine under nitrogen at 2000C. Nylon-6,6 derives its name from its starting materials, adipic acid and hexamethylene diamine, which have six carbons.

Nylon-6,6 was developed as a synthetic fiber for the production of stocking and other apparel. It was introduced to the public at the New York World's Fair in 1939. It is also used to make fibers for clothing and carpeting, filaments for fishing lines and ropes, bristles for brushes, and moulded objects such as gears and bearings.



CONCEPT ASSESSMENT EXERCISE 13.1

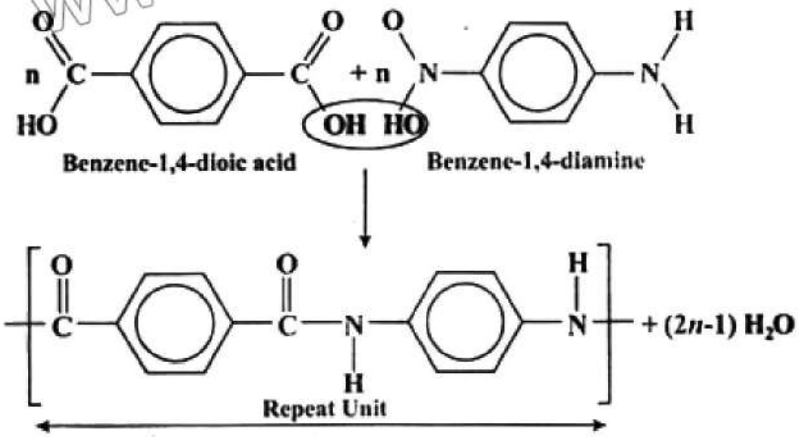
Predict the type of polymerisation reaction for the following monomers.

(i) Propylene CH_3-CH=CH_2

(ii) HO-A-OH + HOOC-B-COOH

(ii) Kevlar

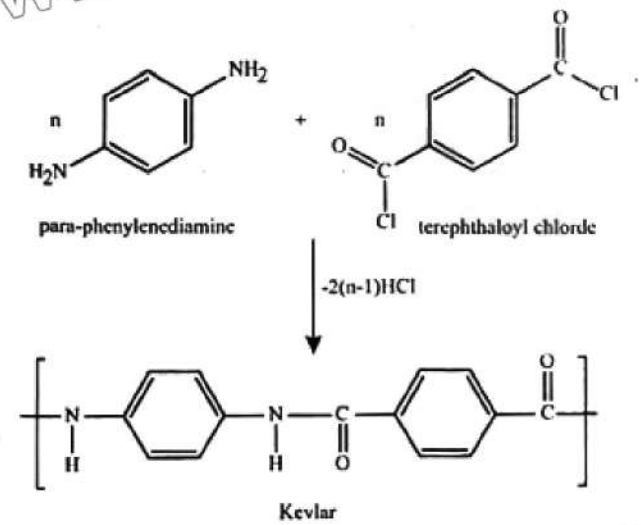
Kevlar is another polyamide. Its monomers are, benzene-1,4-dicarboxylic acid and benzene-1,4-diamine.



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.

CONCEPT ASSESSMENT EXERCISE 13.2

A polymer can be made from monomers benzene-1,4- dioyl chloride and benzene-1,4-diamine. Draw its repeat unit.



(iii) Poly peptide

Poly peptide is produced by the polymerisation of amino acid molecules. The bond between two amino acid molecules is produced with the elimination of water molecules.

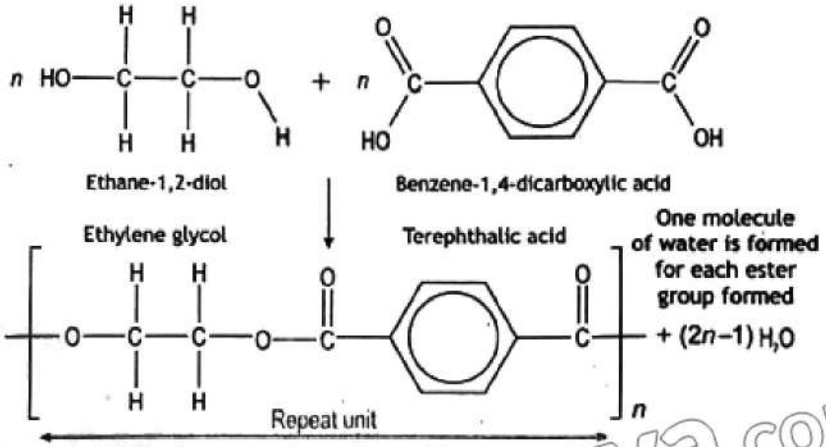
$$n\ NH_2\text{-}CH_2\text{-}COOH + n\ NH_2\text{-}CH_2\text{-}COOH \rightarrow [\text{-}NH\text{-}CH_2\text{-}COO\text{-}NH\text{-}\ COO\text{-}]_n + 2(n\text{-}1)\ H_2O$$

aminoetanoic acid — polypeptide

(b) Polyesters

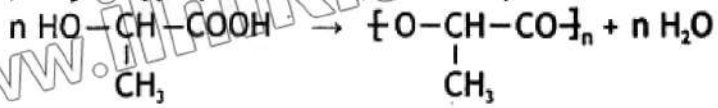
Polyesters are produced by the condensation of diols and dicarboxylic acids. For example,

(i) **Terylene:** The most common polyester is called terylene. It is also known as polyethylenetere phthalate (PET). It is made from monomers, ethane-1,2-diol and benzene-1,4-dicarboxylic acid.



(iv) Polymerisation of hydroxycarboxylic acid.

Hydroxy carboxylic acids also form polyesters. For example, polylactic acid. It is made from a monomer, 2-hydroxypropanoic acid (lactic acid).



lactic acid repeat unit

CONCEPT ASSESSMENT EXERCISE 13.3

Draw the monomer that makes the following condensation polymer.

$[\text{-O-CH}_2\text{-CH}_2\text{-CO-}]_n$

Polyester readily react with alkalis but slowly with acids. Terylene is used for making plastic bottles, clothing and carpets.

13.4 Biodegradable and Non-biodegradable Polymers

The polymers which can be decomposed by the action of microorganisms are called biodegradable polymers. For example, polyamides and polyesters. These polymers have hydrolysable amino or ester groups which can easily be broken by enzymes, acids, and alkalis.

The polymers which cannot be decomposed by the action of microorganisms are called non-biodegradable polymers. Polymers formed from addition polymerisation are unreactive or inert as they are non-polar and saturated. This makes it difficult to break down and biodegrade. Some can be recycled to form new polymers for a different purpose.

For instance, polyethylene, polypropylene, polyvinyl chloride, and polyethylene terephthalate (PET). These polymers contain long chains of carbon atoms which are chemically inert. They

have non-polar bonds. These polymers are causing harm to the environment as they can remain intact over the years. They can also enter our food chain.

Some polymers can be degraded by ultraviolet light. For example, polyethylene, polypropylene, and polystyrene. Ultraviolet light breaks down the polymer chains and leads to the weakening of materials.

13.4.1 Long term effects of non-biodegradable polymers.

Non-biodegradable polymers accumulate in the environment. They do not decompose naturally. These materials in the presence of sunlight, water, and air produce highly toxic pollutants. These pollutants can enter the water and cause water pollution.

13.5 Polymer Hydrolysis

Condensed polymers can be broken down by hydrolysis reactions. This can be done under acidic or basic conditions.

For polyesters, the hydrolysis products are

(a) Acid hydrolysis (with hydrochloric acid catalyst) - diol and dicarboxylic acid
(b) Alkaline hydrolysis (heated with sodium hydroxide) - diol and carboxylic acid salt

For polyamides, the hydrolysis products are

(a) Acid hydrolysis - dicarboxylic acid and ammonium ions
(b) Alkaline hydrolysis - sodium salts of its monomers (dicarboxylic acid salt and diamine).

When proteins are hydrolyzed by acid, amino acids are formed, but the amine group accepts a proton to become $-NH_3^+$.

13.6 Artificial Organs

Artificial organ is a biological device or tissue created by scientists to replace, replicate, or augment a functional naturally occurring organ. Artificial organs can be used as a substitute for organ donors and as a medical education tool. Types of Artificial Organs There are three main types of artificial organs, depending on the material scientists use to create them.

1. **Mechanical Artificial Organs:** Mechanical artificial organs are entirely made of non-living polymers like plastics and metals.
2. **Biomechanical Organs:** Biomassical organs contain both Living Cells and Non-Living Materials. Biological organs or Biosynthetic organs can be transformed from living cells to Biomass.
3. **Biological Organs:** Biological organs are specialized structures within living organisms that perform specific functions in our body. They are composed of different tissues that work together to carry out particular tasks. For example, heart, lungs, liver, brain, kidneys etc. They are part of larger organ systems, such as the digestive, respiratory, circulatory, and nervous systems, which coordinate to support life processes. Each organ contributes to the overall function of the organism in a precise and interdependent way.

13.7 Importance of Chemical Industries

The chemical industry is a major contributor to Pakistan's economy. It is accounting for around 4.5 % of the country's total exports and 12% of its total imports. It is also a key factor in the growth of forward-oriented industries such as Pakistan's automobile industry, textiles and leather goods, shoes, furniture, food and beverages, etc. On the other hand, chemicals are also used in backward-oriented industries like surfactants which are essential for oil refiners and extractors. Pakistan's chemical industry has experienced rapid growth in recent years due to various factors such as rising domestic demand, improved raw material availability, improved government policies, increased foreign investment, advances in technology, and increased regional integration. Therefore, the chemical industry is influencing international trade and increasing economic competitiveness.

13.7.1 The list of raw materials used in chemical industry in Pakistan

The main raw materials are fossil fuels (coal, natural gas, and oil), air, water, salt, limestone, sulphur, and specialized raw materials such as phosphates and fluorides.

Pakistan also has mineral deposits such as coal, copper, gold, chromite, mineral salt, bauxite, and many other minerals. Various precious and semi-precious minerals are also mined.

Some of the main raw materials used in the chemical industry in Pakistan are:

Soapstone

It is one of the main raw materials in the chemical industry of Pakistan. 85% of it is also used in other industries like textiles, paper, soap, detergents, leather, food, etc.

Polyvinyl chloride (PVC)

In Pakistan, PVC is mainly used for the production of pipes, fittings, cables, profiles and footwear. It is also used in medical devices, packaging materials, and consumer products. PVC demand is driven by the construction industry, which accounts for approximately 70% of total consumption.

Resin

Resin is a synthetic organic polymer used to make plastics, adhesives, paints, coatings, and other products. Resin production is mainly based on petrochemical raw materials such as petroleum, ethylene, and propylene.

Soda Ash

Soda ash is the common name for sodium carbonate, which is used to make glass, detergents, paper, textiles, and other products. Pakistan is mainly based on natural resources such as rock salt and limestone.

Hydrogen Peroxide

This chemical compound is used for bleaching, disinfecting, oxygenating and other applications. In Pakistan, the production of hydrogen peroxide is largely based on imported raw materials such as anthraquinone and hydrogen gas.

KEY POINTS

- Polymers are high molecular weight compounds whose structures are made up of. a large number of simple repeating units.
- The reaction by which monomers are converted into polymers is known as polymerization.
- Polymers that are synthesized from only one kind of monomer are called homopolymers.
- Polymers that are prepared from two different monomers are called copolymers.
- Addition polymers are formed by combining alkene monomers, resulting in just one huge molecule.
- Condensation polymers are formed by the combination of monomers with the elimination of simple molecules such as H_2O.
- Polyesters and Polyamides are condensation polymers
- Poly peptide is produced by the polymerisation of amino acid molecules.
- Polyesters are produced by the condensation of diols and dicarboxylic acids.
- Polyamide are produced by the condensation of diamines and dicarboxylic acids.
- The polymers which can be decomposed by the action of microorganisms are called biodegradable polymers.
- The polymers which cannot be decomposed by the action of microorganisms are called non-biodegradable polymers.
- Ultra violet light breaks down the polymer chains and leads to weakening of materials.
- Artificial organ is a biological device or tissue created by scientists to replace, replicate, or augment a functional naturally occurring organ.

EXERCISE

1. Multiple Choice Questions (MCQs)

i. Which polymer is produced by polymerizing vinyl chloride?

a) Nylon b) Polyethylene c) PVC d) PET

ii. What small molecule is typically released during the formation of an amide from an amine and an acyl chloride?

a) Water b) Methane c) Hydrogen chloride d) Oxygen

iii. Which raw material is abundantly available in Pakistan for the fertilizer industry?

a) Limestone b) Natural gas c) Coal d) Iron ore

iv. What type of polymerization involves monomers with double bonds?

a) Addition polymerization b) Condensation polymerization

c) Radical polymerization d) Ionic polymerization

v. Which of the following is an example of a polyamide?
   a) PET b) Nylon c) PVC d) Polyethylene

vi. Which polymer can be degraded by hydrolysis?
   a) Polyethylene b) PVC c) Nylon d) Polypropylene

vii. In what form is PVC often used in medical applications?
   a) Rigid form b) Flexible form c) Foam form d) Powder form

viii. Which reaction forms a polyester?
   a) Ethylene + chlorine b) Ethylene glycol + terephthalic acid
   c) Hexamethylenediamine + adipic acid d) Propylene + ammonia

ix. Which polymerization method produces polyethylene?
   a) Addition polymerization b) Condensation polymerization
   c) Anionic polymerization d) Cationic polymerization

x. What is a common use of nylon in the textile industry?
   a) Insulation b) Gears c) Clothing d) Packaging

2. Short Answer Questions

i. Explain the process of producing PVC from vinyl chloride.
ii. Describe the chemical reaction between an amine and an acyl chloride to form an amide.
iii. How do chemical industries contribute to the economy of Pakistan?
iv. Identify the raw materials available in Pakistan for the chemical industry.
v. Differentiate between addition and condensation polymerization.
vi. What are the environmental challenges associated with non-biodegradable polymers?
vii. How can polyesters and polyamides be degraded?
viii. What are the properties of nylon that make it suitable for use in textiles?
ix. Describe an application of polymers in biomedical science.
x. How is the disposal of poly(alkenes) challenging due to their chemical properties?
xi. Why is the hydrolysis of polyesters in an acidic environment faster than in a neutral environment?
xii. Compare the environmental benefits of using biodegradable polymers over traditional synthetic polymers
xiii. Predict the environmental impact of the widespread use of non-biodegradable polymers on marine ecosystems.

3. Long Answer Questions

i. Discuss the synthesis, properties, and applications of PVC.
ii. Discuss the process of producing nylon-6,6 and its applications in various industries.
iii. Describe the importance of chemical industries in Pakistan and the raw materials available for these industries.
iv. Compare and contrast addition and condensation polymerization with suitable examples.
v. Explain the environmental impact of non-biodegradable polymers and suggest ways to mitigate these challenges.
vi. Compare and contrast the chemical properties, production processes, and industrial applications of PVC and nylon, highlighting how these factors influence their respective environmental impacts and recycling potentials.
vii. Differentiate between addition and condensation polymerization processes, using specific examples such as polyethylene, PVC, polyesters, and polyamides.
viii. Give a variety of polymer structures, identify the monomers and classify each polymer as either an addition or condensation polymer.
ix. Analyse the role of polymers in biomedical science, particularly in the creation of artificial organs. Discuss the properties required for polymers used in biomedical applications and the challenges associated with their development and use.
x. Compare the environmental impact of the production and disposal of PVC and nylon, considering factors such as energy consumption, emissions, and waste management practices.

THINK TANK

1. Predict the type of polymerization reaction for a given set of two different monomers and justify your reasoning.
2. Evaluate the potential benefits and drawbacks of using polymers to create artificial organs.

Project

Propose a strategy for managing the disposal of non-biodegradable polymers in an environmentally friendly manner.