Applied Chemistry

Polymers — Plastics and Rubber

1. Basic Concepts of Polymers

1.1 Monomer and Polymer

A monomer is a small, simple molecule capable of chemically joining (reacting) with other similar or different monomer molecules, through repeated chemical bonding, to form a very large molecule called a polymer. The process by which monomers join together to form a polymer is called polymerisation.

A polymer is thus a large molecule (a macromolecule) built up of a very large number of repeating structural units, each derived from a monomer, joined together by covalent chemical bonds. Polymers may occur naturally (such as natural rubber, cellulose, and proteins) or may be synthesised artificially (such as plastics and synthetic fibres).

1.2 Homopolymers and Copolymers

Depending on the number of different types of monomer units used in its formation, a polymer is classified as follows:

- Homopolymer: A polymer formed from only one type of monomer unit, repeated throughout the polymer chain. For example, polyvinyl chloride (PVC) is a homopolymer formed entirely from vinyl chloride monomer units.
- Copolymer: A polymer formed from two or more different types of monomer units, arranged along the polymer chain. For example, nylon-66 is essentially a copolymer, since it is formed from two different monomers, hexamethylenediamine and adipic acid, joined alternately along the chain.

1.3 Degree of Polymerization

The degree of polymerization (denoted by n) is defined as the number of repeating monomer units present in a single polymer chain. It is an important characteristic of a polymer, since the physical properties of a polymer, such as its strength, melting behaviour, and viscosity, generally depend significantly on its degree of polymerization — polymers with a higher degree of polymerization (longer chains) generally exhibit greater strength and higher melting points, compared to polymers with a lower degree of polymerization (shorter chains) formed from the same monomer.

2. Thermoplastics and Thermosetting Plastics

Based on their behaviour on heating, plastics (synthetic polymers moulded into shape) are broadly classified into two categories: thermoplastics and thermosetting plastics. The key differences between the two are summarised below:

Aspect	Thermoplastics	Thermosetting Plastics
Structure	Linear or branched polymer chains, held together by weak intermolecular forces	Highly cross-linked, three-dimensional network structure
Effect of Heat	Soften on heating and harden again on cooling; this process can generally be repeated	Once moulded and cured (set) by heating, they cannot be softened or reshaped again on reheating
Recyclability	Can generally be remoulded and recycled	Cannot be remoulded or recycled easily, since heating causes them to char or decompose rather than melt
Examples	PVC, polystyrene (PS), PTFE, nylon-6, nylon-66	Bakelite

3. Preparation and Applications of Thermoplastics

The monomer, a simple representative reaction involved in the preparation, and typical applications of four important thermoplastics — PVC, polystyrene (PS), PTFE, and the two types of nylon — are summarised below (simple reactions only; detailed reaction mechanisms and conditions are omitted):

Plastic	Monomer(s)	Simple Reaction (Preparation)	Applications
Polyvinyl Chloride (PVC)	Vinyl chloride ($CH_2=CHCl$)	Addition polymerisation of vinyl chloride monomer units, under suitable catalytic conditions, to form long PVC chains: $n\ CH_2=CHCl \rightarrow [–CH_2–CHCl–]_n$	Pipes and fittings, electrical cable insulation, flooring, raincoats, and packaging sheets
Polystyrene (PS)	Styrene ($C_6H_5–CH=CH_2$)	Addition polymerisation of styrene monomer units: $n\ C_6H_5CH=CH_2 \rightarrow [–CH_2–CH(C_6H_5)–]_n$	Disposable cups and packaging (as expanded polystyrene/thermocol), toys, insulation panels, appliance housings
Polytetrafluoroethylene (PTFE, Teflon)	Tetrafluoroethylene ($CF_2=CF_2$)	Addition polymerisation of tetrafluoroethylene monomer units: n	Non-stick cookware coatings, chemically resistant gaskets and seals, insulation for

		CF2=CF2 → [–CF2–CF2–]n	high-performance electrical wires
Nylon-6	Caprolactam (a cyclic monomer)	Ring-opening polymerisation of caprolactam, in which the cyclic monomer opens up and joins with other units to form a long polyamide chain	Synthetic fibres for textiles, ropes, brushes, and moulded engineering components such as gears
Nylon-66	Hexamethylenediamine and adipic acid	Condensation polymerisation between hexamethylenediamine and adipic acid, with the elimination of water molecules, forming a polyamide chain: n H2N(CH2)6NH2 + n HOOC(CH2)4COOH → Nylon-66 + 2n H2O	Synthetic fibres for textiles and carpets, tyre cords, ropes, and moulded mechanical parts such as gears and bearings

Of these, PVC, PS, and PTFE are formed by addition polymerisation, in which monomer units containing a reactive double bond join together directly, without the loss of any small molecule, while nylon-6 and nylon-66 are formed respectively by ring-opening and condensation polymerisation; in condensation polymerisation, monomer units join together with the elimination of a small molecule, such as water, at each linking step.

4. Preparation and Applications of Thermosetting Plastics — Bakelite

Bakelite, one of the earliest synthetic thermosetting plastics, is prepared by the condensation polymerisation of phenol and formaldehyde. On heating (curing) in the presence of a suitable catalyst, the initially formed linear or lightly branched resin undergoes extensive cross-linking, forming a rigid, infusible, three-dimensional network structure that cannot be softened or remoulded again by reheating.

Plastic	Monomer(s)	Simple Reaction (Preparation)	Applications
Bakelite (Phenol-Formaldehyde Resin)	Phenol and formaldehyde	Condensation polymerisation between phenol and formaldehyde, with the elimination of water molecules, forming a cross-linked, three-dimensional	Electrical switches, sockets, and insulating parts, handles of cooking utensils, adhesives, and moulded electrical fittings

		thermosetting resin on curing (heating)	

Because of its excellent electrical insulating properties, heat resistance, and rigidity once cured, Bakelite has traditionally been widely used for electrical fittings, switches, and handles of cooking utensils, and remains an important historical and practical example of a thermosetting plastic.

5. Rubber and Vulcanization of Rubber

Natural rubber is a naturally occurring polymer obtained mainly from the latex (milky sap) of the rubber tree, and is chemically composed of long chains of the polyisoprene molecule (specifically, the cis-form of polyisoprene). In its raw, natural state, rubber is soft, sticky, and becomes excessively soft and tacky in hot weather while becoming hard and brittle in cold weather, making it unsuitable for most practical applications without further chemical treatment.

Vulcanization is the chemical process by which raw natural rubber is heated together with sulphur (and often small amounts of accelerators and other additives), causing sulphur atoms to form cross-links between the individual long polymer chains of the rubber. These sulphur cross-links bind the previously independent, freely sliding polymer chains together into a connected three-dimensional network.

As a result of this cross-linking, vulcanized rubber acquires several improved properties compared to raw rubber:

- Increased mechanical strength, hardness, and resistance to abrasion (wear).
- Improved elasticity, allowing the rubber to stretch considerably and return effectively to its original shape.
- Greater resistance to changes in temperature, remaining more stable over a wider temperature range, without becoming excessively soft in heat or brittle in cold.
- Improved resistance to chemical attack and general durability, extending the useful working life of the rubber.

Because of these significantly improved properties, vulcanized rubber, rather than raw natural rubber, is used in the overwhelming majority of practical rubber products, including vehicle tyres, conveyor belts, rubber hoses, footwear, and a wide range of industrial rubber components.

6. Multiple Choice Questions (MCQs)

Answer the following questions by selecting the most appropriate option.

1. A monomer is best described as:

A) A very large, complex molecule

B) A small, simple molecule that can join with other similar molecules to form a polymer

C) A type of catalyst used in polymerisation

D) A cross-linking agent

2. A polymer formed from only one type of monomer unit is called:

A) A copolymer

B) A homopolymer

C) An elastomer

D) A thermosetting polymer

3. A polymer formed from two or more different types of monomer units is called:

A) A homopolymer

B) A copolymer

C) A monomer

D) A cross-linked polymer

4. The degree of polymerization refers to:

A) The temperature at which polymerisation occurs

B) The number of repeating monomer units present in a single polymer chain

C) The colour of the polymer formed

D) The rate of the polymerisation reaction

5. Thermoplastics, when heated, generally:

A) Char and decompose without melting

B) Soften and can be remoulded, then harden again on cooling

C) Become permanently cross-linked

D) Explode

6. Thermosetting plastics, once cured (set) by heating, generally:

A) Can be remelted and remoulded any number of times

B) Cannot be softened or reshaped again on reheating

C) Turn back into their original monomers

D) Remain in liquid form

7. PVC (polyvinyl chloride) is prepared from the monomer:

A) Styrene

B) Vinyl chloride

C) Tetrafluoroethylene

D) Caprolactam

8. Polystyrene (PS) is prepared by the polymerisation of:

A) Vinyl chloride
B) Styrene
C) Ethylene
D) Phenol

9. PTFE (Teflon), known for its non-stick and chemically resistant properties, is prepared from the monomer:

A) Vinyl chloride
B) Styrene
C) Tetrafluoroethylene
D) Caprolactam

10. Nylon-6 is prepared by the ring-opening polymerisation of:

A) Caprolactam
B) Adipic acid
C) Phenol
D) Formaldehyde

11. Nylon-66 is prepared by the condensation polymerisation of:

A) Caprolactam alone
B) Hexamethylenediamine and adipic acid
C) Phenol and formaldehyde
D) Styrene and vinyl chloride

12. Bakelite is prepared by the condensation polymerisation of:

A) Phenol and formaldehyde
B) Vinyl chloride and styrene
C) Caprolactam and water
D) Ethylene and propylene

13. Natural rubber is obtained mainly from the polymer:

A) Polystyrene
B) Polyisoprene (cis form)
C) Polyvinyl chloride
D) Polytetrafluoroethylene

14. Vulcanization of rubber involves heating raw rubber with:

A) Sulphur
B) Chlorine
C) Nitrogen
D) Oxygen only

15. The main purpose of vulcanizing rubber is to:

A) Make it softer and more sticky

B) Introduce cross-links between polymer chains, improving strength, elasticity, and durability

C) Dissolve the rubber completely

D) Change its monomer unit entirely

Answer Key

1. B) A small, simple molecule that can join with other similar molecules to form a polymer | 2. B) A homopolymer | 3. B) A copolymer | 4. B) The number of repeating monomer units present in a single polymer chain | 5. B) Soften and can be remoulded, then harden again on cooling | 6. B) Cannot be softened or reshaped again on reheating | 7. B) Vinyl chloride | 8. B) Styrene | 9. C) Tetrafluoroethylene | 10. A) Caprolactam | 11. B) Hexamethylenediamine and adipic acid | 12. A) Phenol and formaldehyde | 13. B) Polyisoprene (cis form) | 14. A) Sulphur | 15. B) Introduce cross-links between polymer chains, improving strength, elasticity, and durability

7. Broad / Long Answer Questions

1. Define monomer and polymer, and explain the process of polymerisation in general terms.

2. Distinguish between a homopolymer and a copolymer, giving one example of each.

3. Define the degree of polymerization, and explain its significance in determining the properties of a polymer.

4. Distinguish between thermoplastics and thermosetting plastics, giving two examples of each.

5. Describe the monomer, simple preparation reaction, and applications of PVC (polyvinyl chloride).

6. Describe the monomer, simple preparation reaction, and applications of polystyrene (PS) and PTFE (Teflon).

7. Describe the monomer(s), simple preparation reaction, and applications of nylon-6 and nylon-66.

8. Describe the monomers, simple preparation reaction, and applications of Bakelite, and explain why it is classified as a thermosetting plastic.

9. Explain the process of vulcanization of rubber, and describe how it improves the properties of raw natural rubber.

10. Explain why vulcanized rubber is preferred over raw (unvulcanized) rubber for applications such as vehicle tyres, referring to the properties gained through vulcanization.