Polymers

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Polymers

A polymer is an enormous molecule built by linking thousands of small repeating units called monomers. Polymers surround us: the plastic in a water bottle, the nylon in a sports kit, the starch in a potato, and the DNA in every cell are all polymers. Their properties depend entirely on the monomer used and the way the monomers link together.

Key Definitions

A **polymer** is a macromolecule formed by joining 50 or more small monomer units together. The monomers are linked by covalent bonds to form a long chain.

A **monomer** is the small, repeating structural unit from which a polymer is built. Monomers must have at least one reactive site — either a double bond (for addition polymerisation) or two functional groups (for condensation polymerisation).

Polymerisation is the chemical process of joining monomers to form a polymer.

Addition Polymerisation

In **addition polymerisation**, alkene monomers join together by the opening of their C=C double bonds. No atoms are lost — every atom in every monomer ends up in the polymer. The monomers simply add to a growing chain.

General pattern (using ethene as an example):

$$n(\mathrm{CH_2{=}CH_2}) \rightarrow (-\mathrm{CH_2{-}CH_2}-)_n$$

The repeat unit is written inside brackets with a subscript n to show that the pattern repeats thousands of times. A short section of the chain is usually enough to represent the polymer.

Common Addition Polymers

Polymer	Monomer	Monomer formula	Uses
Poly(ethene) / polyethylene	Ethene	$CH_2=CH_2$	Plastic bags, bottles, packaging film
Poly(propene) / polypropylene	Propene	$CH_3CH=CH_2$	Food containers, ropes, carpet fibres
Poly(chloroethene) / PVC	Chloroethene (vinyl chloride)	$CH_2=CHCl$	Pipes, electrical insulation, window frames
Poly(styrene)	Styrene (phenylethene)	$CH_2=CHC_6H_5$	Foam packaging, disposable cups

To write the repeat unit: remove the double bond and show the two carbons now joined by a single bond, with brackets and subscript n. Any substituents remain attached to their respective carbons.

> 📋 **Example**
> Poly(chloroethene) (PVC) from chloroethene:
>
> Monomer: $CH_2=CHCl$
>
> Repeat unit: $(–CH_2–CHCl–)_n$
>
> Each monomer contributes two carbons: one with two H atoms, one with one H and one Cl. The double bond is gone; the chain is saturated.

Condensation Polymerisation

In **condensation polymerisation**, monomers join together with the simultaneous elimination of a small molecule — usually water (H_2O) or hydrogen chloride (HCl). Unlike addition polymerisation, monomers for condensation polymers must have **two functional groups** (one at each end of the molecule) so that each monomer can link to two neighbours, forming a long chain.

Polyamides (Nylon)

Nylon is a polyamide formed by condensation polymerisation between a diamine (two $–NH_2$ groups) and a dicarboxylic acid (two –COOH groups). Water is eliminated as the amide link –CO–NH– forms:

$$H_2N\text{–}(CH_2)_6\text{–}NH_2 + HOOC\text{–}(CH_2)_4\text{–}COOH \rightarrow \text{nylon-6,6} + nH_2O$$

The amide (–CO–NH–) linkage gives nylons their characteristic strength and toughness.

Uses of nylon: clothing fabrics, stockings, toothbrush bristles, ropes, parachutes, gears and bearings.

Polyesters (Terylene / PET)

Polyesters are formed by condensation polymerisation between a diol (two –OH groups) and a dicarboxylic acid (two –COOH groups). Water is eliminated as the ester link –COO– forms.

PET (polyethylene terephthalate, Terylene) is the most common polyester:

Uses of polyester: clothing fabrics, soft-drink bottles (PET), food trays, film for tapes and capacitors.

Natural Polymers

Many essential biological molecules are natural polymers formed by condensation polymerisation:

Natural polymer	Monomer(s)	Function
Starch	Glucose	Energy storage in plants
Cellulose	Glucose	Structural support in plant cell walls
Proteins	Amino acids	Enzymes, structural proteins, antibodies
DNA	Nucleotides	Genetic information storage
Rubber	Isoprene	Natural elastomer

Uses of Polymers

Polymer type	Examples	Key uses
Polyalkenes (addition)	Polyethene, PVC, polypropene	Packaging, pipes, containers, insulation
Polyamides (condensation)	Nylon-6,6	Clothing, ropes, engineering plastics

Polyesters (condensation)	PET (Terylene)	Bottles, fibres, film
Polysaccharides (natural condensation)	Starch, cellulose	Food, paper, cotton fabric

Environmental Issues with Plastics

Advantages of Synthetic Plastics

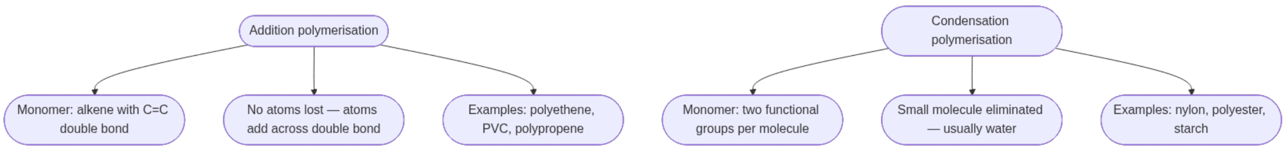
- Durable and long-lasting
- Lightweight
- Chemically resistant and corrosion-proof
- Inexpensive to produce at scale
- Versatile — can be moulded into any shape

Disadvantages

- **Non-biodegradable:** most synthetic plastics are not broken down by microorganisms. They persist in the environment for hundreds of years, accumulating in oceans, rivers, and landfill.
- **Pollution:** plastic waste fragments into microplastics that enter food chains and harm marine life.
- **Difficult disposal:** burning plastics can release toxic gases (e.g. HCl from PVC). Recycling requires sorting by polymer type.
- **Fossil fuel dependence:** most synthetic polymers are made from petrochemicals — a non-renewable resource.

Biodegradable Polymers

Research into biodegradable polymers — polymers that can be broken down naturally by microorganisms — aims to reduce plastic pollution. These include polylactic acid (PLA), made from plant sugars, which is used in compostable packaging and medical sutures.



Addition vs condensation polymerisation