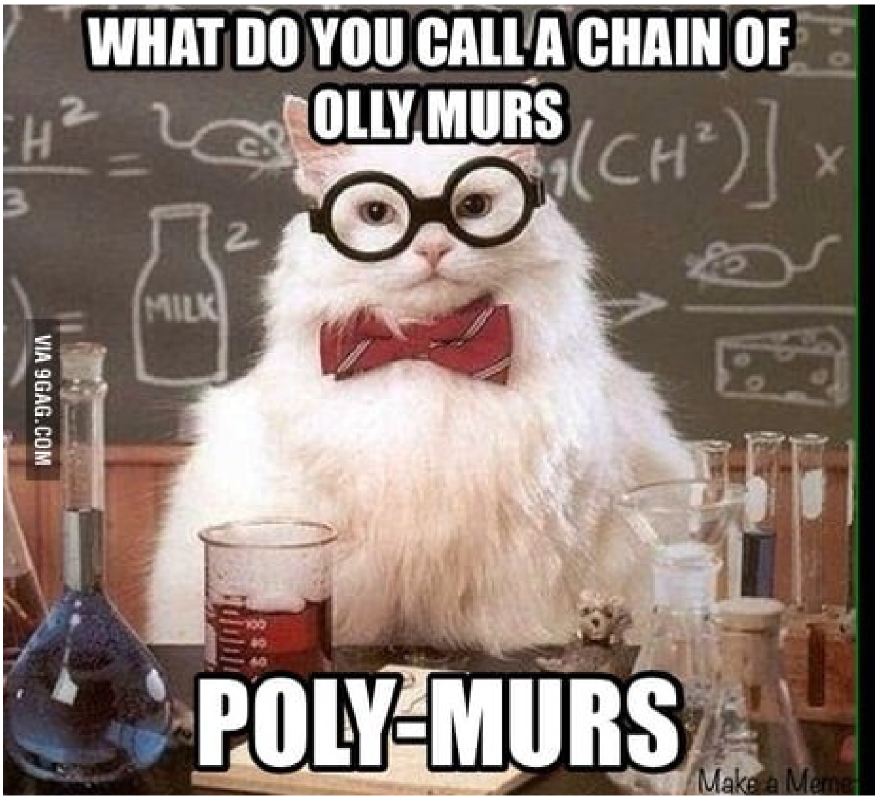
NAME:

Ch 8. Polymers and society 2023



KEY KNOWLEDGE

- the formation of polymers from monomers including addition polymerisation of alkenes
- the distinction between linear (thermoplastic) and cross-linked (thermosetting) polymers with reference to structure, bonding and properties including capacity to be recycled
- the features of linear polymers designed for a particular purpose including the selection of a suitable monomer (structure and properties), chain length, degree of branching, percentage crystalline areas and addition of plasticisers
- the advantages and disadvantages of the use of polymer materials.

Unit 1 Chemistry - Chapter 8 Polymers

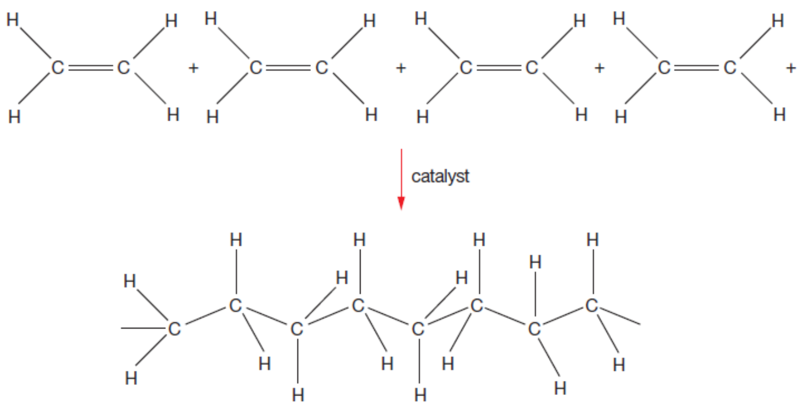
Polymers are given the general term 'plastics'. A substance is described as plastic if it can be moulded into different shapes readily.

FIGURE 10.1.3 A plastic basket has plastic properties, whereas a polymer frying pan handle does not.

Formation of Polyethene

In this reaction, Ethene reacts with itself to form a long chain. This is known as

____, and is how **polymers** are formed.



$$nC_2H_4(g) \xrightarrow{\text{catalyst}} (C_2H_4)_n$$

1. Polymers

Polymers are long chain covalent molecules. They can have >10,000 molecules in the chain.

<u>Natural polymers</u>: Wool, cotton, linen, hair, skin, nails, rubber and flesh are all naturally occurring polymers.

<u>Synthetic polymers</u>: Synthetic polymers are commonly referred to as plastics. 'Plastic' means pliable or able to be moulded, and this is true of these synthetics, at least during their production.

2. Formation of Polymers

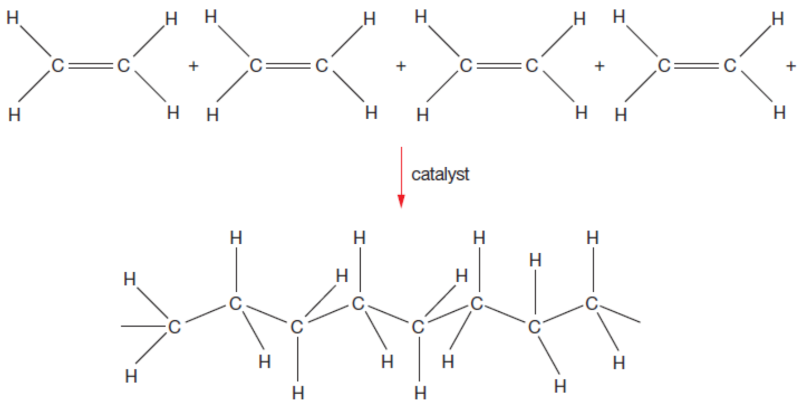
There are two types of polymerization techniques:
Addition Polymerisation and Condensation polymerisation

TABLE 10.1.1 Monomer and polymer names

Monomer	Polymer
Ethene	Polyethene
Propene	Polypropene
Tetrafluoroethene	Polytetrafluoroethene

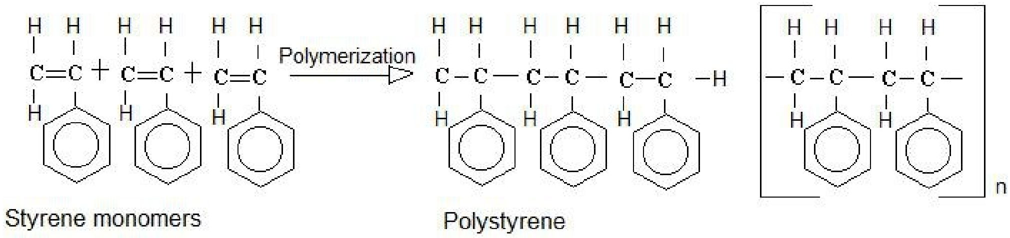
<u>Addition Polymerisation</u>:

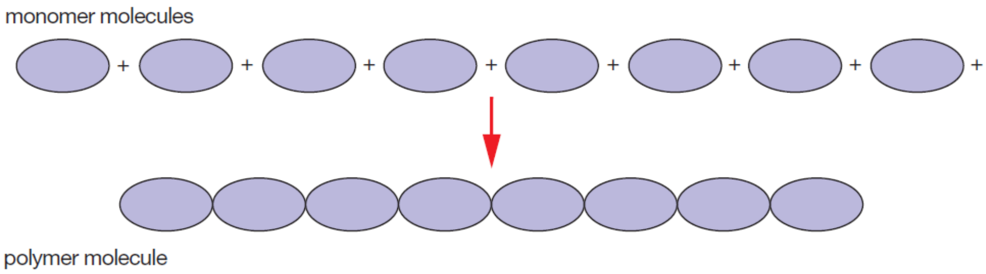
Addition polymers are formed through the addition reaction of many smaller molecules, called monomers. The monomers are the building blocks of a polymer. This is called addition polymerisation. The monomer contains an unsaturated carbon to carbon bond, which breaks and allows each monomer in turn to add together.
Eg: Polyethene



$$nC_2H_4(g) \xrightarrow{\text{catalyst}} (C_2H_4)_n$$

Eg: Polystyrene





Fill in the following:

A ___________ is a large molecule formed of many smaller molecules covalently bonded in a repeating pattern. The small molecules which make up the polymer are called ___________. Polymers generally form either from an ______________ reaction or a condensation reaction and are often _______________ after the original monomer e.g. PVC – Polyvinyl Chloride.

An _________ **polymer** is a polymer formed by chain addition reactions between monomers that contain a double bond. Molecules of ethene can polymerize with each other under the right conditions to form the polymer called ______________.

Polyethene: An addition Polymer

Polyethene is usually written as: **(– CH2 – CH2 –)$_n$** (Where 'n' is very large, > 10,000.) Polyethene is the simplest of polymers as it only contains hydrogen and carbon atoms in the chain. It is addition polymer. There are two different types of Polyethene that can form (low density and high density) and this depends on the reaction conditions.

Reaction conditions

Low-density polyethene (LDPE)

- Polyethene made under high pressures and high temperatures (harsh conditions) has short branches off the main chain
- Presence of these branches impacts upon the properties of the polymer as the molecules cannot pack closely together→ weaker dispersion forces
- Disordered, non-crystalline arrangement

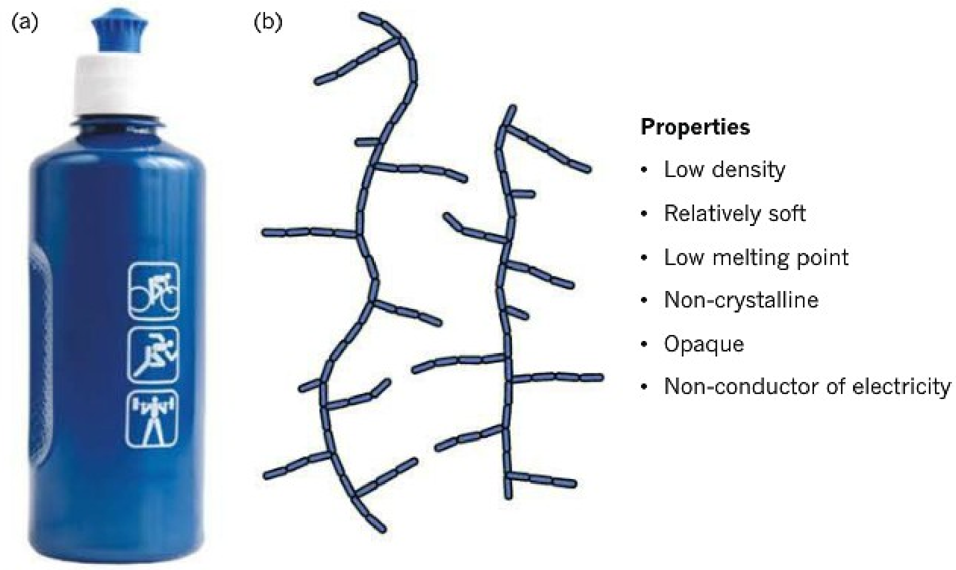
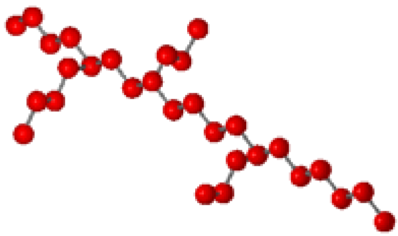


FIGURE 10.1.9 Low density polyethene. (a) A bottle made from LDPE. (b) LDPE branched structure.

High-density polyethene (HDPE)



- Polyethene made under low-pressure (milder conditions) with specialised transition metal catalysts (Ziegler-Natta catalysts)
- Very few branches → molecules pack together tightly → increasing density and hardness of polymer
- More ordered, crystalline sections

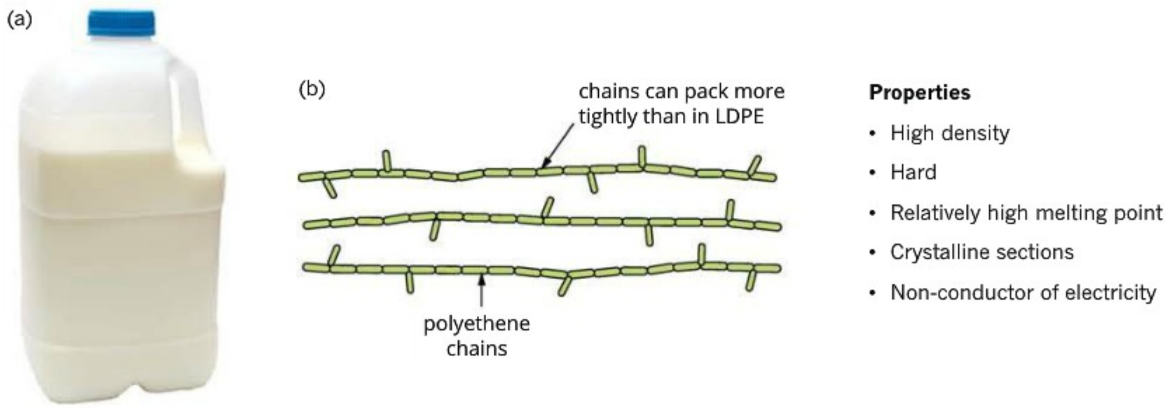
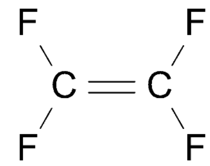


FIGURE 10.1.10 Properties and structure of HDPE. (a) A bottle made from HDPE. (b) HDPE structure.

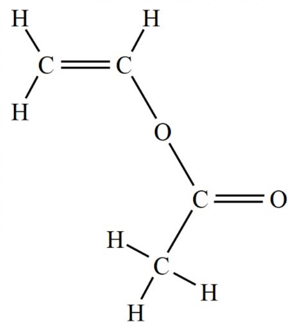
Exercises

1. The monomer tetrafluoroethene has the structural formula shown at right. Draw a polymer containing 3 monomer units



Name the polymer formed.

2. The monomer vinyl acetate has the structural formula shown at right. Draw a polymer containing 3 monomer units.



Name the polymer formed.

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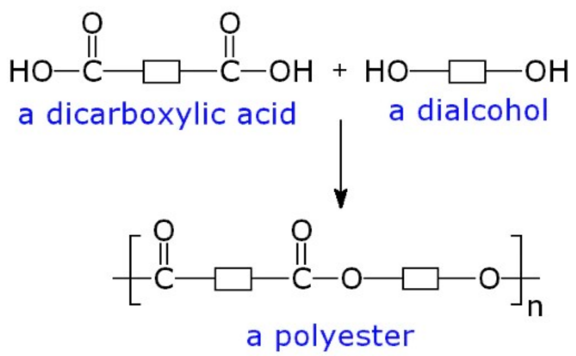
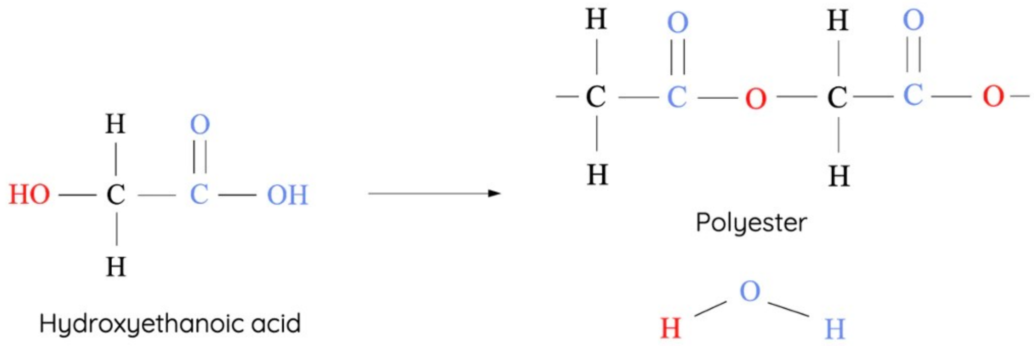
Look at Sample Problem 1
Complete Practice problem 1

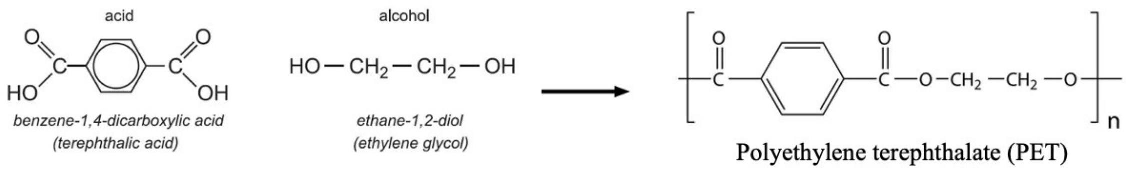
Condensation Polymerisation:

Condensation polymers are formed through the removal of a small molecule, usually water, from the combination of two functional groups on different monomers. The monomers are the building blocks of a polymer. This is called condensation polymerisation. The monomer contains functional groups on either end of a carbon chain which react forming a linkage and eliminating one small molecule per linkage. This allows each monomer in turn to add together.

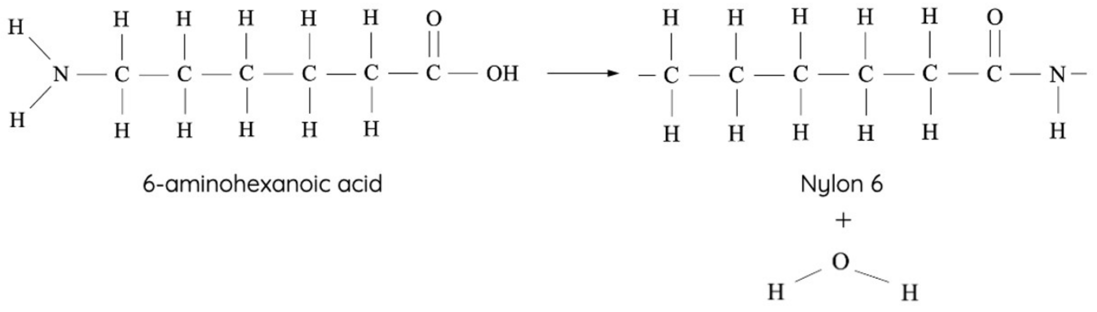
Eg: Polyester







- **Nylon 6** is a common polyamide produced from 6-aminohexanoic acid (monomer)



● **Nylon 66** is another common polyamide produced from two monomers: hexandioic acid (adipic acid) and hexan-1,6-diamine.

Structure of nylon 66

Properties of Nylon	Uses of Nylon
● High tensile strength ● Can be drawn into fibres ● Abrasion-resistant ● Elastic ● Thermoplastic ● Absorbs moisture	● Clothing: Lingerie, tights, raincoats and swimwear ● Carpets, drapes and bedding ● Seat belts ● Ropes, nets, sleeping bags, tents

Condensation Polymerisation animation + video

http://www.dynamicscience.com.au/tester/solutions1/chemistry/foodchemistry/condensationpolymers.htm

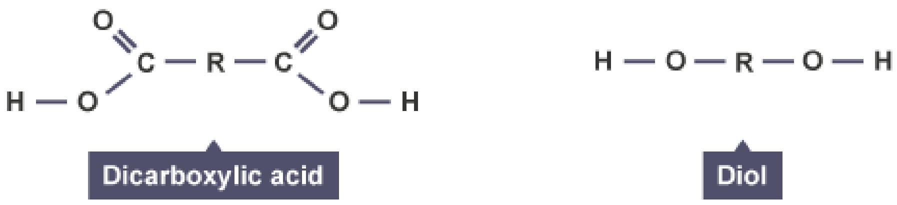
https://www.youtube.com/watch?v=SgSFx3mAFjo

Questions:

1. **Describe what is meant by a condensation polymer**

2. **Which small molecule is most commonly formed in a condensation reaction.**

3. **Draw a section of a condensation polymer from the following monomer.**



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Complete 8.2 - Quick Quiz
Complete 8.2 Exercise

<u>8.3 Linear and Cross linked polymers</u>

<u>Thermoplastic and Thermosetting Polymers</u>: Polymers may be classified on the basis of their thermal behaviour. Plastics that may be repeatedly melted, reshaped and hardened by cooling are called **thermosoftening/thermoplastic** plastics or thermoplastics. An example of a thermoplastic polymer is polystyrene.
Plastics that do not melt but char when heated are called **thermosetting** plastics. These plastics must be moulded or shaped during their manufacture. Bakelite is an example of a thermosetting plastic material.

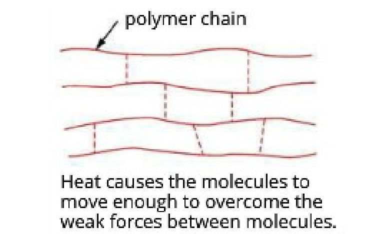


FIGURE 10.1.13 A thermoplastic polymer has weak bonds between the chains.

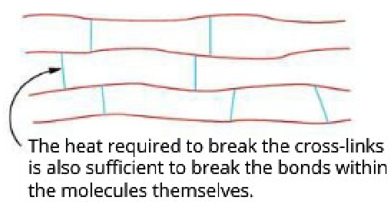


FIGURE 10.1.14 A thermosetting polymer has strong covalent bonds between the chains.

Thermoplastic polymers
Thermoplastic polymers soften when heated and can be remoulded or recycled. The bonds between long polymers are H-bonds, dipole-dipole bonds or weak dispersion forces. When heated, molecules have enough energy to overcome intermolecular forces and become free to move.

Thermosetting polymers
Thermosetting polymers decompose or burn when heated. They don’t soften because bonds between chains are very strong covalent bonds (cross-links). Cross-links limit

movement between polymer molecules, making them rigid, hard, and heat-resistant. They are difficult to recycle.

Elastomers

Elastomers only occasionally have cross-links present. The chains in polymers can still move past each other when stretched but cross-links return chains to original positions, when stretching force is released. e.g. in elastic bands and rubber items. Cross-links stop elastomers from completely melting when heated making recycling difficult (e.g. in car tyres)

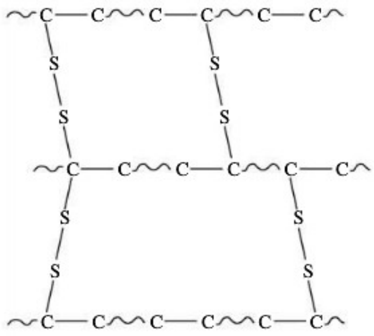


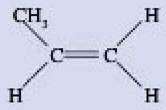
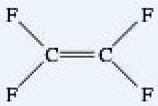
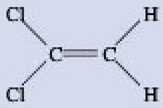
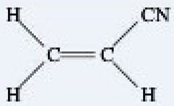
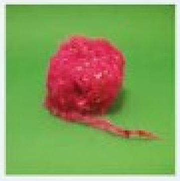
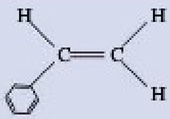
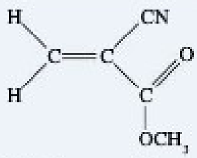
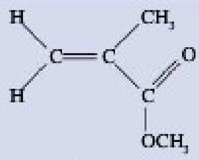
FIGURE 10.1.15 The elastomer chains in rubber car tyres are cross-linked by sulfur atoms.

<u>Extensive Cross-linking</u>

- Giant covalent network lattice
- Polymers, once formed they are rigid and hard
- When sufficient heat is applied the covalent bonds between the polymer molecules will break causing the thermosetting polymer to break and char rather than melt

<u>Occasional Cross-linking</u>

- Called elastomers, regain their shape after stretching
- Cross-links prevent the chains from sliding past each other and pulls the material back to its original shape.
- Vulcanisation is the process of making rubber.

Monomer	Poylmer	Properties	Examples	Application
 Propene	Polypropene (polypropylene)	Durable, cheap	Artificial grass, dishwasher-safe plastic, ice-cream containers, rope	
 Tetrafluoroethene	Polytetrafluoroethene (PTFE, Teflon)	Non-stick, high melting point	Frying pan and iron coatings, plumber's tape, Gore-Tex fabric	
 Dichloroethene	Polyvinylidene chloride (PVDC)	Sticks to self, transparent, stretchy	Food wrap	
 Propenenitrile	Polypropenenitrile (acrylic)	Strong, able to form fibres	Acrylic fibres, fabrics	
 Phenylethene (styrene)	Polyphenylethene (polystyrene)	Hard, brittle, low melting point	Toys, packaging, expanded foams	
 Methylcyanoacrylate	Polymethylcyanoacrylate	Polymerises on contact with water	Super glue	
 Methyl 2-methylpropenoate	Polymethyl methacrylate (Perspex)	Transparent, strong	Perspex (a glass substitute)	

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Complete 8.3 - Quick Quiz
Complete 8.3 Exercise

8.4 Polymer selection, Structure, Properties and Applications

The most important properties of polymers are tensile strength and melting temperature. Tensile strength is a measure of the materials resistance to breaking under tension. It determines the structural uses of the polymer and affects how the polymer can be moulded.

Softening temperature and Tensile strength are determined by the strength of the forces between the molecules. They are affected by:

- Degree of branching
- Nature of atoms or groups are attached to the carbon chain
- How the groups are arranged along the chain
- Amount of crosslinking

Degree of Branching

e.g. Polyethene

Polyethene: Polymer Chain Length and Branching

Chain Length
Ultra-high molecular weight polyethene (UHMWPE) consists of extremely long polymer molecules. The dispersion forces between chains are much stronger than in shorter chains.

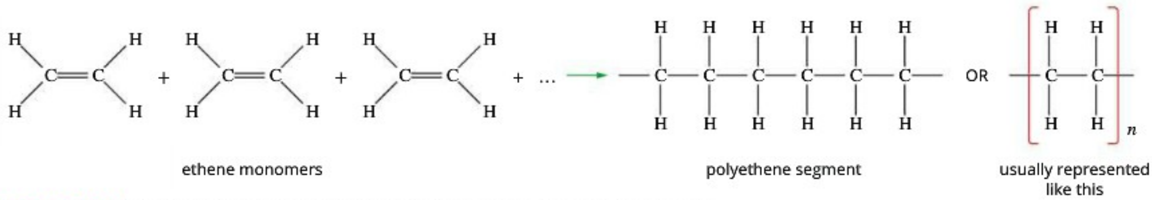


FIGURE 10.1.4 Thousands of ethene monomers join together to make one chain of polyethene. The standard notation shown simplifies the drawing of such a large chain.

Extent of branching
Amount of branching in polyethene can be varied (HDPE, LDPE).

- HDPE
  - % crystallinity as high as 95%
  - Excellent mechanical properties (pipes, buckets, food containers)
- LDPE
  - % crystallinity only 65%
  - Softer and more flexible (cling wrap, insulating cables)

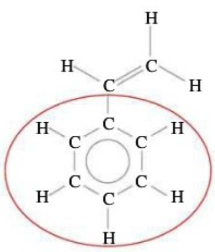
HDPE – A polymer with less branching can pack more tightly together (higher density) so is much stronger and less flexible.

- Used for pipes, toys, containers etc
- LDPE – A polymer with more branching is unable to pack closely together (low density) therefore is softer and more flexible.
- Used for insulating cables, cling wrap etc

Nature of side groups

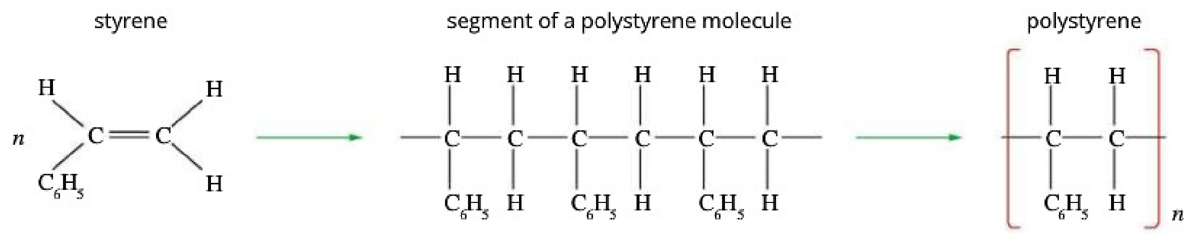
Size of side group on monomer

The bulky ring in polystyrene prevents chains from stacking close together therefore it has a very low density. It is quite brittle and so is usually mixed with a gas to give the material we know.



Bulky side groups make it difficult for chains to slide over one another or stack closely together. They prevent the formation of crystalline regions that refract light therefore an amorphous material is produced.

e.g. Polystyrene
The side group of styrene is a flat ring of six C atoms (benzene ring). When styrene polymerises, benzene rings are covalently bonded to every second C atom in the polymer chain. Styrene is a hard but brittle plastic with low density.



e.g. Polymethyl methacrylate (PMMA)
Polymethyl methacrylate has large side groups. The absence of crystalline regions that refract light means the substance is transparent. It is much lighter than glass, more malleable and less prone to shattering. It is used for car headlamps, safety glasses, safety shields.

FIGURE 10.2.19 Polymethyl methacrylate is an amorphous material that is used in safety glasses and shields used by riot police.

Arrangement of side groups

Polypropene: Arrangement of side groups

<u>Atactic Polypropene</u>

- Has the side groups (CH_3) randomly distributed which prevents the chains from stacking well together and forming crystalline regions. It is very soft and useful only as grease.

<u>Isotactic Polypropene</u>

- Have the side groups all on the one side producing more uniform chains which can stack together more closely. Isotactic Polypropene can be used to make babies bottles and strong fibres and ropes.

Addition polymer made from monomer propene (CH_2=$CHCH_3$)

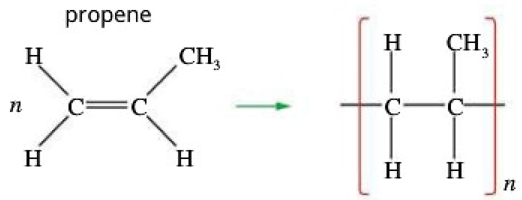
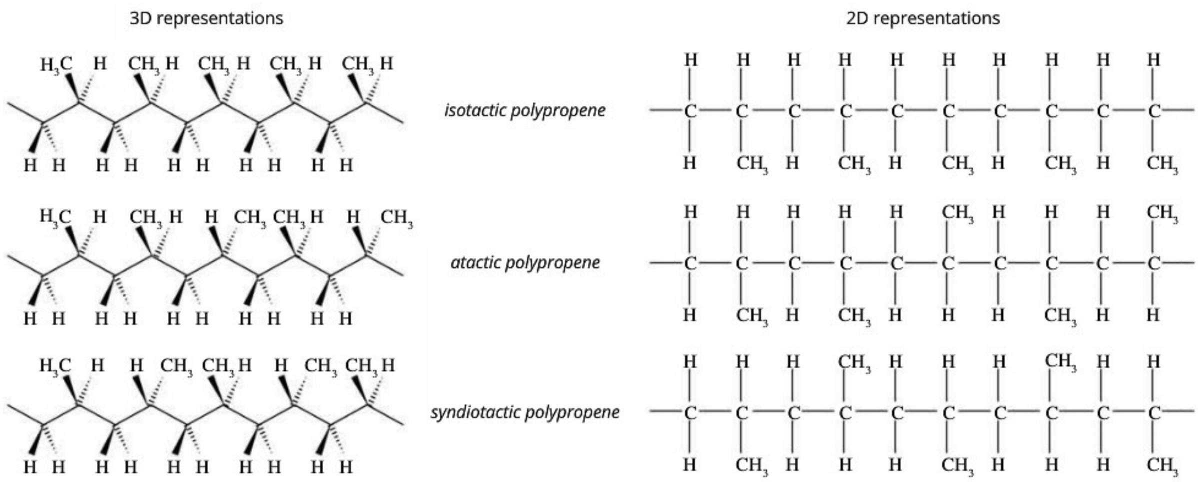


FIGURE 10.2.14 Propene undergoes addition polymerisation to form polypropene.

The way the methyl side groups are arranged along polymer chains have significant effect on properties and uses of this polymer.



Additives

Most polymers include additives that improve or extend the properties of the polymer. These include pigments for colour, UV stabilisers (to prevent deterioration in sunlight) and plasticisers.

e.g. Plasticisers
Plasticisers are small molecules added to polymers. Polymer molecules are forced slightly further apart, weakening forces between chains, making material softer and more flexible. PVC chains are held together by strong dipole-dipole bonds (due to polar C-Cl bond) and are quite rigid. The addition of plasticisers between the chains allow the chains to slide past, making the polymer softer and more flexible. By varying amount of plasticisers, PVC of a wide range of flexibilities can be produced.

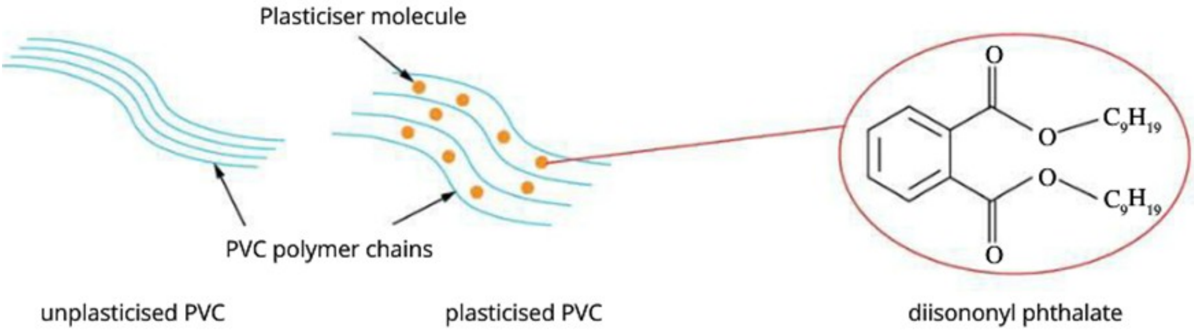


FIGURE 10.2.20 The presence of a plasticiser between the polymer chains weakens the attractive forces.

e.g. Foamed polymers
Foamed polymers are formed by blowing a gas through melted polymer materials. It can drastically change physical properties of a polymer material. Polystyrene foam is produced by introducing pentane into melted polystyrene beads. The beads swell up to produce lightweight, insulating, shock-absorbing foam.

Advantages and Disadvantages of Polymers

TABLE 10.2.2 Some advantages and disadvantages of using polymers

Advantages	Disadvantages
Available in an enormous variety of different forms, with distinctive properties	Many are derived from petroleum, a non-renewable resource
Generally biologically inert, chemical resistant, corrosion resistant	Microorganisms cannot break down most synthetic polymers (they are not biodegradable)
Easy to process by moulding	Thermoplastic polymers have a limited thermal stability
Low density	Some plastic products crack, scratch or break easily
Good mechanical strength	Many plastics produce toxic gases, such as hydrogen chloride, hydrogen cyanide and dioxins, when burned
Properties can be modified, e.g. by foaming or adding plasticisers	Some plasticisers can leach out of containers or wraps and pose a health risk
Many can be recycled	Thermosetting polymers are currently difficult to recycle

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Look at Sample Problem 2,3
Complete Practice problem 2,3
Complete 8.4 - Quick Quiz
Complete 8.4 Exercise

8.5 Plastic recycling and innovations in design

There is huge importance on the reduction of polymer waste by using **biodegradable** polymers or recyclable polymers. Changes in monomer structure, length of polymer chains, amount of branching, and addition of other substances to the polymer can modify polymer properties.

FIGURE 10.2.1 (a) Apples packaged in biodegradable plastic. (b) Waste plastic waiting to be recycled.

Plastic waste

Disposal of waste polymer material is a serious issue. Plastics are durable, chemically resistant and lightweight. There are serious environmental effect as biodegradation of plastics is slow. Plastic may persist for hundreds of years after being discarded. Synthetic polymers (low density) take up more volume and occupy limited space available in landfills. Burning plastics raises concerns as it releases harmful by-products of combustion.

Biodegradable plastics

Biodegradable materials break down naturally by action of microorganisms. Most are condensation polymers made of corn and starch. The use of additives like transition metals, promote degradation of polymer chains to smaller, biodegradable compounds.
e.g. polyvinyl alcohol has hydroxyl side groups that form H-bonds with water molecules, making polymer soluble in water

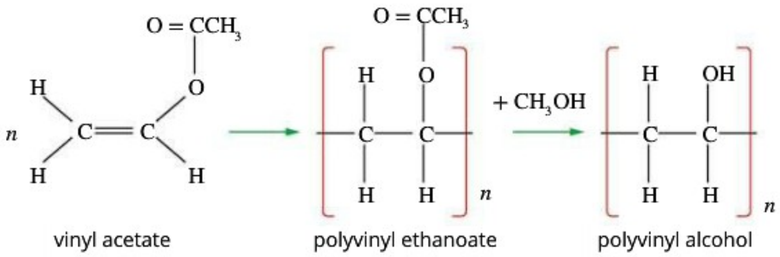

FIGURE 10.2.23 Polymerisation of vinyl ethanoate produces polyvinyl ethanoate, which is then reacted with an alcohol to produce polyvinyl alcohol.

Recycling plastics

Two methods:

- Reprocessing
  - Shredding, melting, reshaping used plastic into new, clean products
  - Can be used only with thermoplastic polymers
- Depolymerisation
  - Polymers are broken down into monomers
  - Monomers are then used to make new polymers
  - Depolymerisation requires a large amount of energy and yield is usually low, therefore it is less economically viable than reprocessing

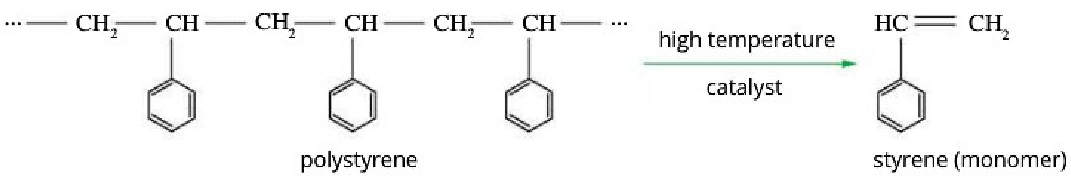

FIGURE 10.2.25 Depolymerisation of polystyrene at high temperature with a catalyst re-forms styrene monomers.

There is a numbering scale used to identify plastics for recycling:

1 PETE	2 HDPE	3 PVC	4 LDPE	5 PP	6 PS	7 OTHER
Polyethene terephthalate	High density polyethene	Polyvinyl chloride	Low density polyethene	Polypropene	Polystyrene	Includes polycarbonates, ABS, Teflon, various copolymers, nylon and other condensation polymers
bottles for soft drinks, water, shampoo, take-away food containers	garbage bins, fuel tanks, hard hats, banners, water pipes, food storage containers	plastic wrap, cordial bottles, electrical wire covers, water pipes, floor tiles	plastic wrap, squeeze bottles, plastic tubing, shopping bags	rope, clothing, ice-cream containers, flip-top bottle lids	yoghurt containers, fridge shelves, drink cups, insulating beads, packaging	

FIGURE 10.2.26 International number code used to identify recyclable plastics.

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Complete 8.5 - Quick Quiz
Complete 8.5 Exercise