

Book 7

Topic 14 Materials Chemistry





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48.1 What determines the properties of a polymer? (p.56)

The properties of a polymer, such as its strength and flexibility, are determined by the structural features of its molecules. For example, in general, the longer the chains, the stronger the polymer is.

The presence of polar groups results in stronger attraction between polymer chains, making the polymer stronger.

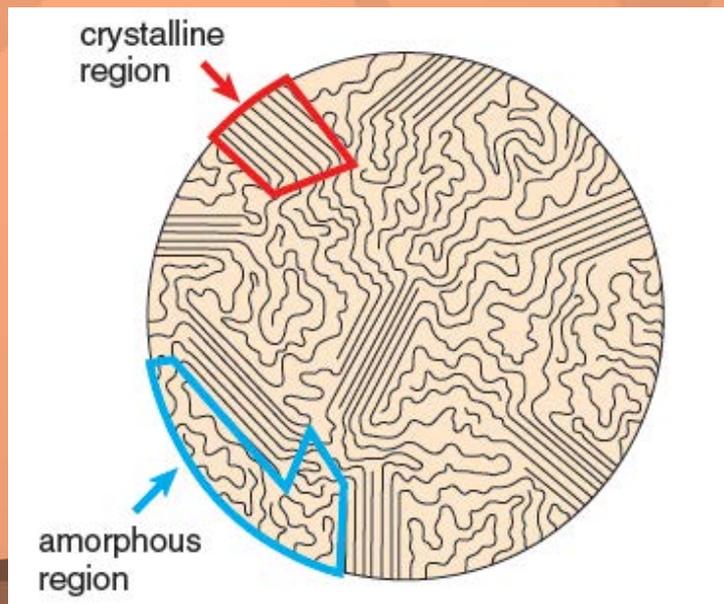
In the following sections, you are going to study the effect of structures of polymers on properties such as density, rigidity, elasticity and biodegradability.



48.2 Low density polythene (LDPE) and high density polythene (HDPE) (P.56)

Polymer chemists use the term crystalline to describe the areas in a polymer where the chains are packed in a regular way. Many polymers have a mixture of crystalline (ordered) regions and amorphous (unordered) regions in which the chains are further apart and have more freedom to move. A single polymer chain may have both crystalline and amorphous regions along its length.

Crystalline (晶狀的) regions and amorphous (無定形的) regions of a polymer



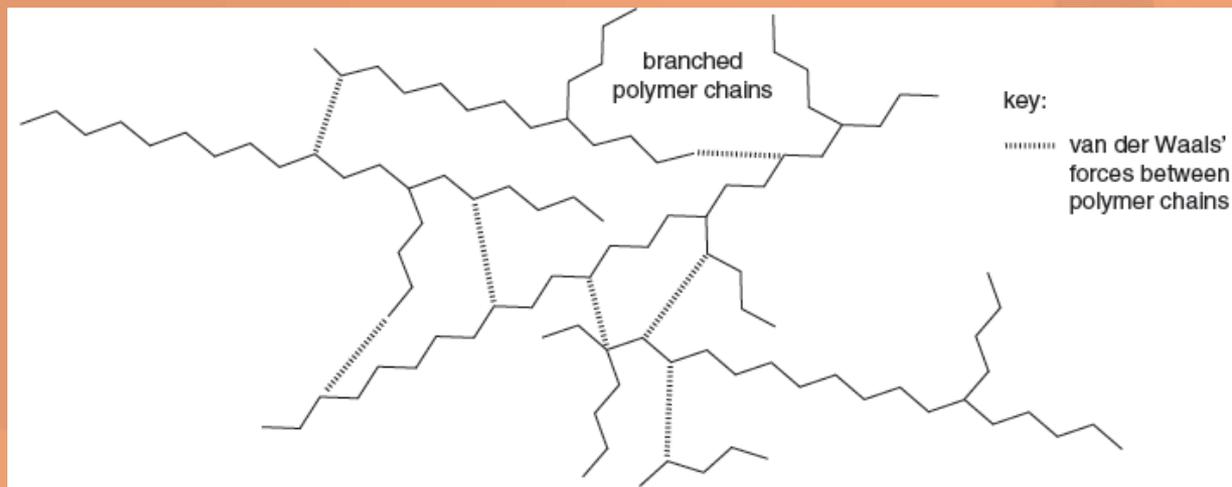


48.2 Low density polythene (LDPE) and high density polythene (HDPE) (P.56)

If ethene is polymerised at very high pressures, the reaction proceeds by a free radical mechanism. Branched polymer chains are produced (on the next page) with many rather short branches and a few longer ones. The polythene chains cannot pack closely together in a regular way. Only about 50–60% of the polymer is crystalline. The van der Waals' forces between the chains are relatively weak.

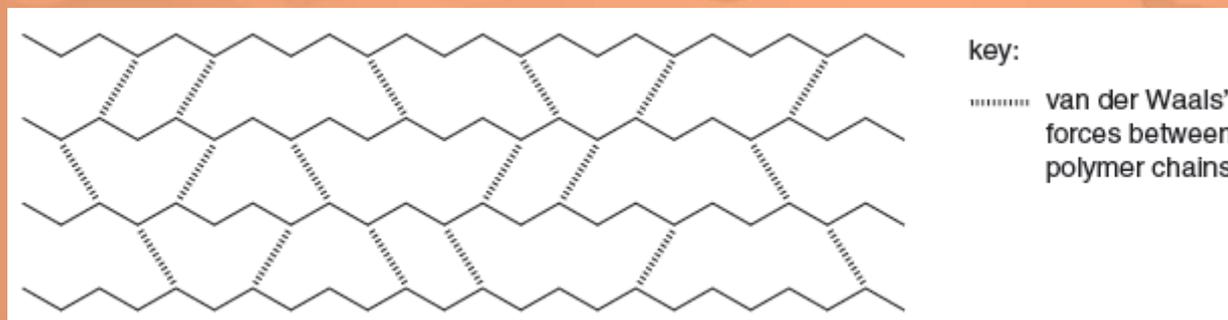


48.2 Low density polythene (LDPE) and high density polythene (HDPE) (P.56)



(a) low density polythene (LDPE)

The branched nature of the chains in LDPE makes it a flexible plastic



(b) high density polythene (HDPE)

The unbranched chains in HDPE make it a more crystalline structure and a more rigid plastic



48.2 Low density polythene (LDPE) and high density polythene (HDPE) (P.56)

This low density polythene (density $0.91\text{--}0.94\text{ g cm}^{-3}$) has a low melting point (about $100\text{ }^{\circ}\text{C}$) and is a flexible polymer. This kind of polythene is mainly used for making films for food packaging and damp-proofing membranes, but it also finds use in items such as food packaging, bags and squeezable bottles.



48.2 Low density polythene (LDPE) and high density polythene (HDPE) (P.56)

More linear and less branched form of polythene is formed by using Ziegler-Natta catalyst at lower temperatures. These linear chains can pack together better than the branched chains of LDPE and over 90% of the polymer is crystalline. The van der Waals' forces between the chains are relatively strong.

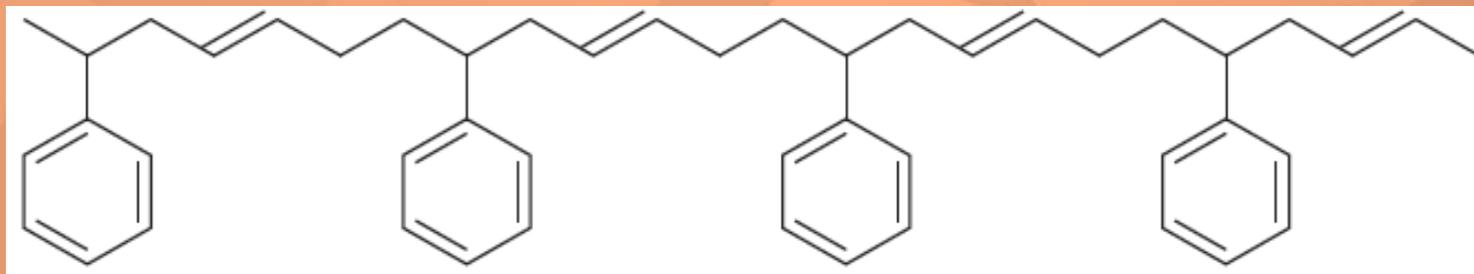
This high density polythene (density $0.95\text{--}0.97\text{ g cm}^{-3}$) has a higher melting point (about $115\text{ }^{\circ}\text{C}$) and is more rigid than LDPE. This polythene is used to make toys, water pipes, containers and buckets.



48.2 Low density polythene (LDPE) and high density polythene (HDPE) (P.56)

Practice 48.1

A part of the structure of a copolymer formed from styrene and buta-1,3-diene is shown below. The copolymer has benzene rings attached at intervals of approximately 6 carbon atoms, as well as double bonds in the carbon chain at intervals of approximately 6 carbon atoms.

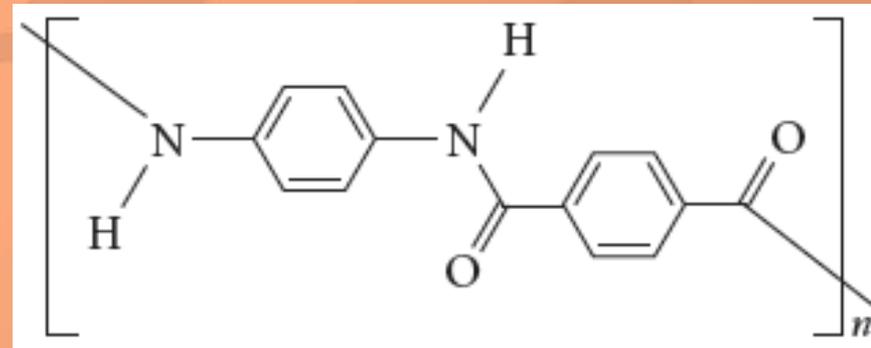
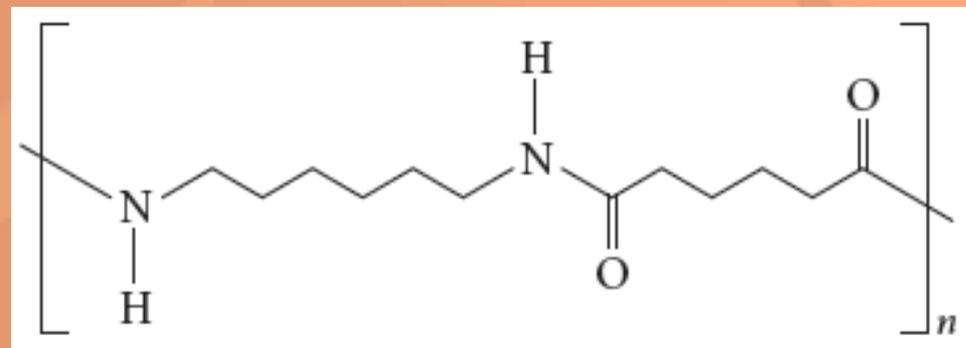


Explain why this copolymer is not as rigid as high density polythene. The extra bulk of the benzene rings makes it impossible for the polymer molecules to pack as close as those in polythene. The intermolecular attractions between the polymer molecules of this copolymer are weaker than that in polythene.



48.3 Nylon and Kevlar (P.59)

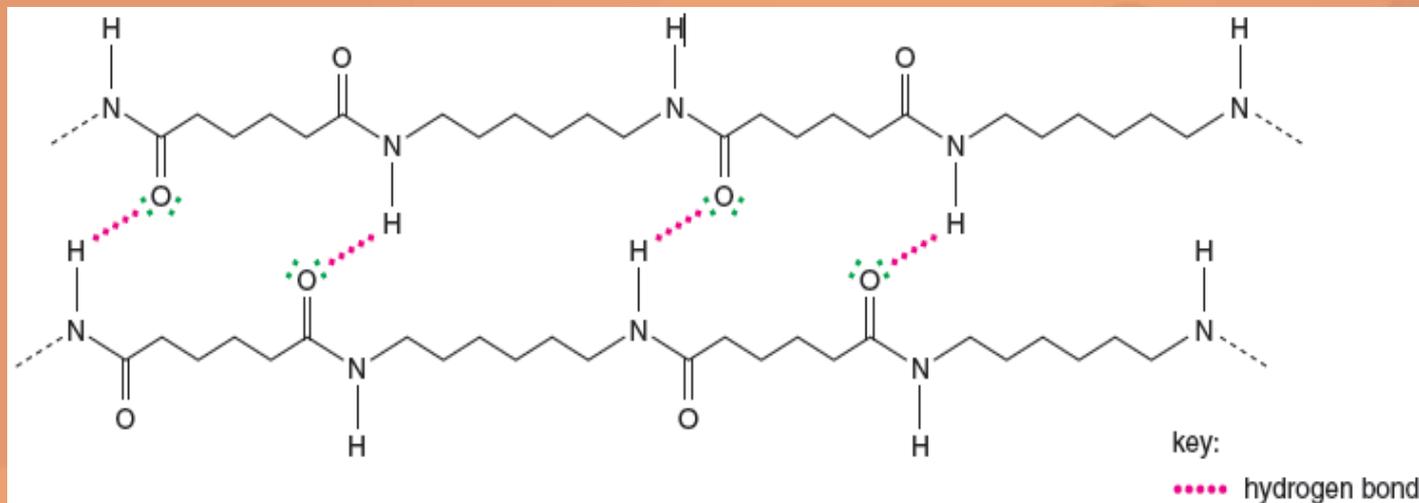
Both nylon-6,6 and Kevlar contain amide linkages. Due to the presence of C=O and N–H groups in the polymer chains, hydrogen bonding is possible between the chains of both polymers.



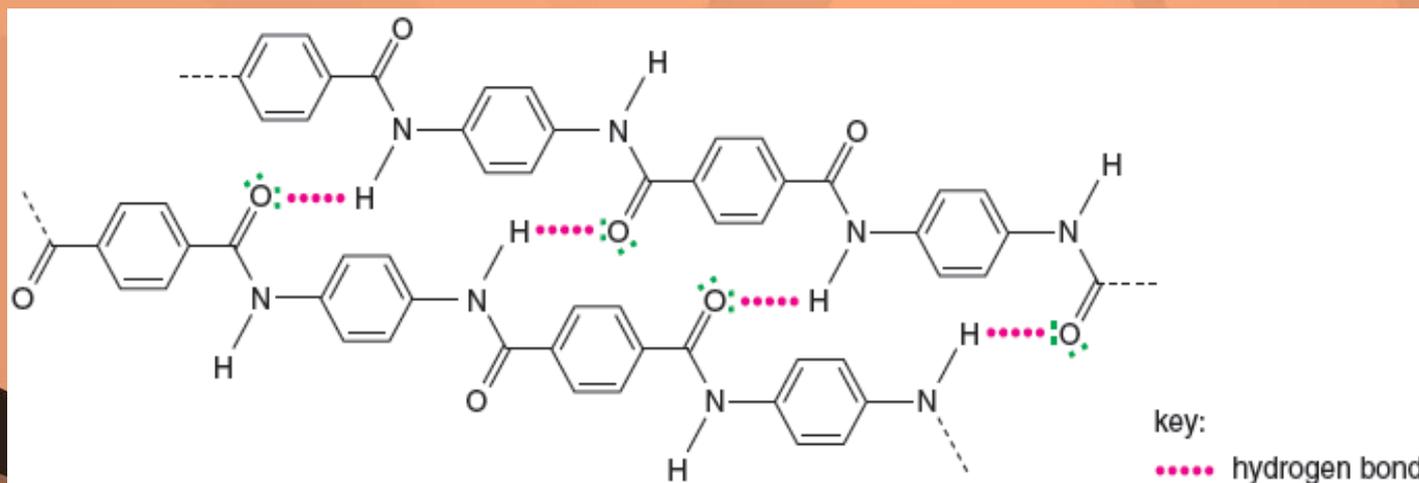
Nylon-6,6 (left) and Kevlar (right) contain amide linkages



48.3 Nylon and Kevlar (P.59)



hydrogen bonding
between nylon-6,6
polymer chains



hydrogen bonding
between Kevlar
polymer chains



48.3 Nylon and Kevlar (P.59)

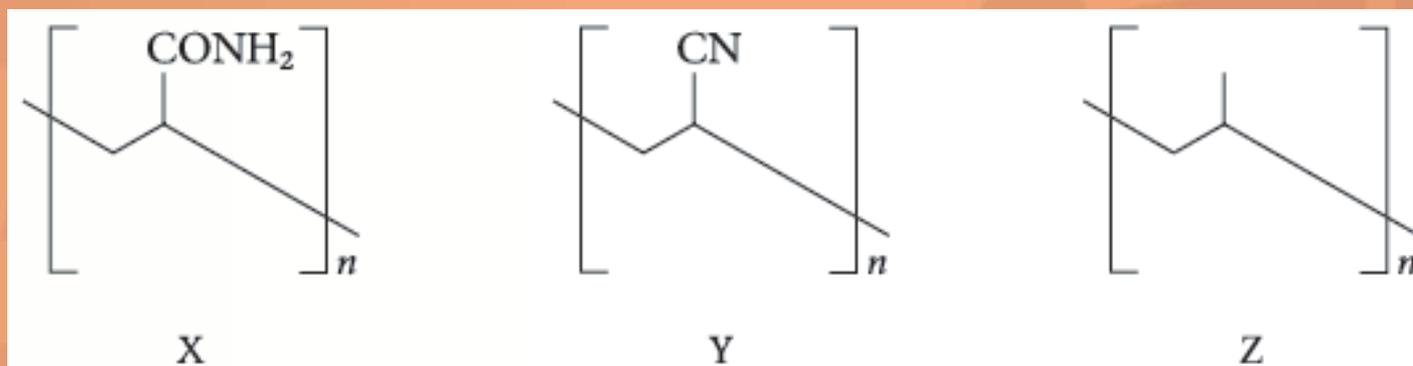
The flexibility of chain molecules arises from rotation around single bonds in the 'backbone' of the chains. In nylon-6,6, ease of rotation around single bonds in the 'backbone' of the polymer chains makes the chains quite flexible. Kevlar is much stronger than nylon-6,6 because the benzene groups make the polymer chains very rigid.



48.3 Nylon and Kevlar (P.59)

Q (Example 48.1)

The structures of three addition polymers are shown below.



The strength of these polymers is in the order.

$$X > Y > Z$$

Explain this order.



48.3 Nylon and Kevlar (P.59)

A

Polymer X contains both C=O and NH₂ groups.

Hydrogen bonds exist between molecules of polymer X.

Polymer Y contains polar C≡N groups. Dipole-dipole interactions exist between molecules of polymer Y.

Only van der Waals' forces exist between the non-polar molecules of polymer Z.

The strength of the forces between molecules of these polymers is in the order

Hydrogen bonds > dipole-dipole interactions > van der Waals' forces

Hence the strength of these polymers is in the order

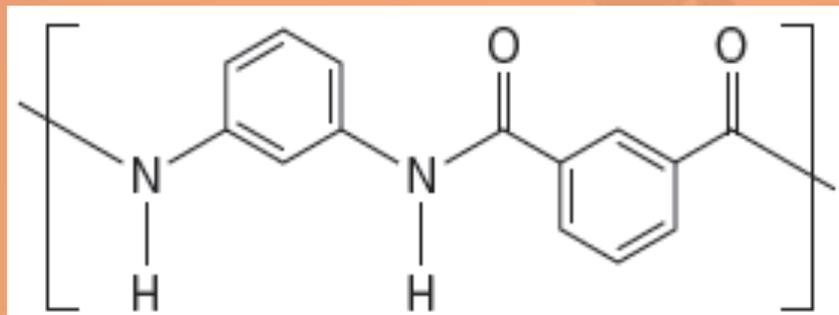
$$X > Y > Z$$



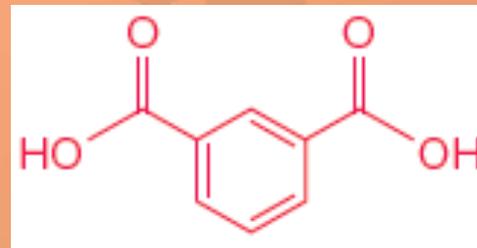
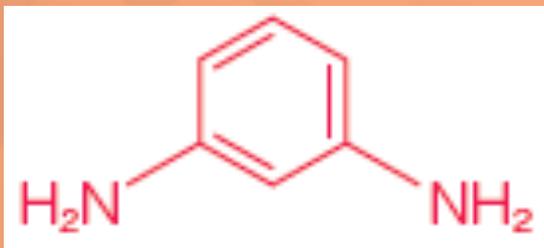
48.3 Nylon and Kevlar (P.59)

Practice 48.2

The repeating unit of a polymer Nomex is shown below:



- a) Draw the structures of the two monomers needed to make Nomex.

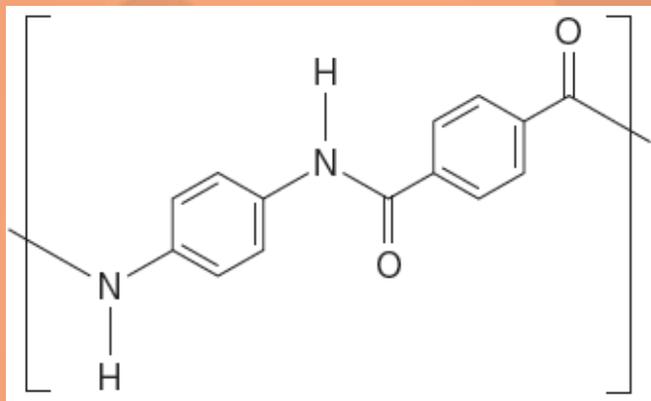




48.3 Nylon and Kevlar (P.59)

Practice 48.2

- b) The repeating unit of Kevlar is shown below:
Nomex has a lower strength than Kevlar. Suggest a reason why.



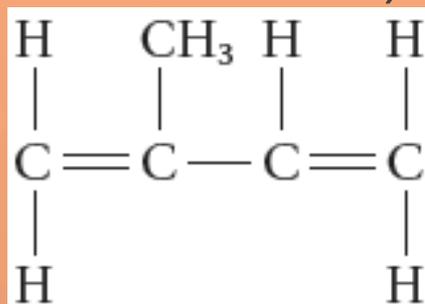
Nomex has a lower strength than Kevlar. Suggest a reason why.
Compared with Kevlar, the polymer molecules of Nomex cannot be aligned as closely for maximising hydrogen bonding between adjacent molecules.



48.4 Vulcanisation of rubber (P.62)

Natural rubber is made from a runny, milky white liquid called **latex** (膠漿) that oozes from certain plants when you cut into them. Although there are something like 200 plants in the world that produce latex, over 99% of the world's natural rubber is made from the latex that comes from a tree species called *Hevea brasiliensis*, widely known as the rubber tree.

Natural rubber is an addition polymer of isoprene (also known as 2-methylbuta-1,3-diene).

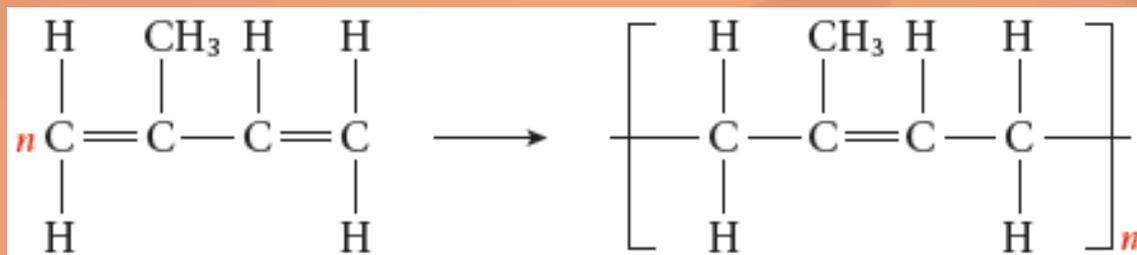


Isoprene (2-methylbuta-1,3-diene)

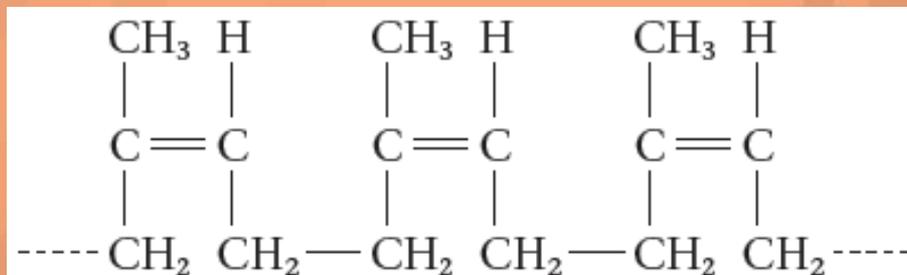


48.4 Vulcanisation of rubber (P.62)

Natural rubber is formed via addition polymerisation.



On average, a molecule of rubber contains 5 000 monomer units. Notice that when the diene undergoes addition polymerisation, carbon-carbon double bonds are still present in the product. The figure below shows a part of the structure of natural rubber. All the carbon-carbon double bonds are in the *cis* configuration.



A part of the structure of natural rubber



48.4 Vulcanisation of rubber (P.62)

Elasticity is the ability of a substance to stretch when pulled and return to the original shape when forces are lifted. Natural rubber has a low elasticity as it cannot revert when forces are released.

Vulcanisation(硫化作用) is the process in which liquid rubber is heated with sulphur. Sulphur reacts with some of the carbon-carbon double bonds in the polymer chains of rubber, forming cross-links between the polymer chains. Each cross-link is a chain of one to about four sulphur atoms.



48.4 Vulcanisation of rubber (P.62)

Vulcanised rubber is stronger and harder than natural rubber. With the cross-links, the polymer chains cannot slide over each other easily.

However, vulcanised rubber is still very elastic. When it is stretched and released, the cross-links will pull the chains back to their original arrangement.

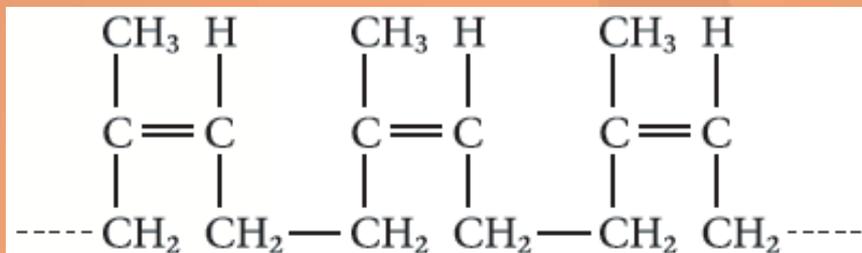
The number of cross-links (or the amount of sulphur added) determines the stiffness of vulcanised rubber. Low sulphur additions leave the rubber soft and flexible, as in elastic bands or rubber gloves. Increasing the sulphur content makes the rubber harder and more stiff, as in rubber used for motor mounts.



48.4 Vulcanisation of rubber (P.62)

Q (Example 48.2)

A part of the structure of natural rubber is shown below.



Natural rubber needs to be heated with Sulphur before it can be used in making car tyres.

- Name this treatment process. **a) Vulcanisation**
- Explain why natural rubber becomes hardened when it is heated with Sulphur.
 - Sulphur reacts with some of the carbon-carbon double bonds in the polymer chains, forming cross-links between the polymer chains. With the cross-links, the polymer chains cannot slide over each other easily.**

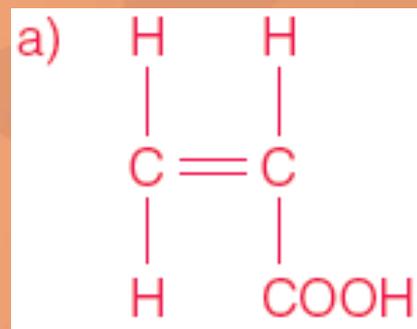
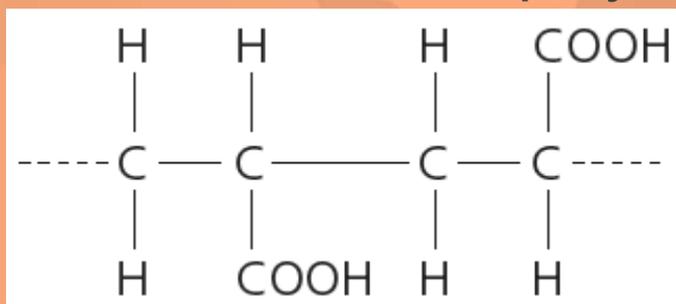


48.4 Vulcanisation of rubber (P.62)

Practice 48.3

Super-absorbent polymers have the ability to absorb 200–300 times their own mass of water. One of the largest uses of these polymers is in disposable nappies.

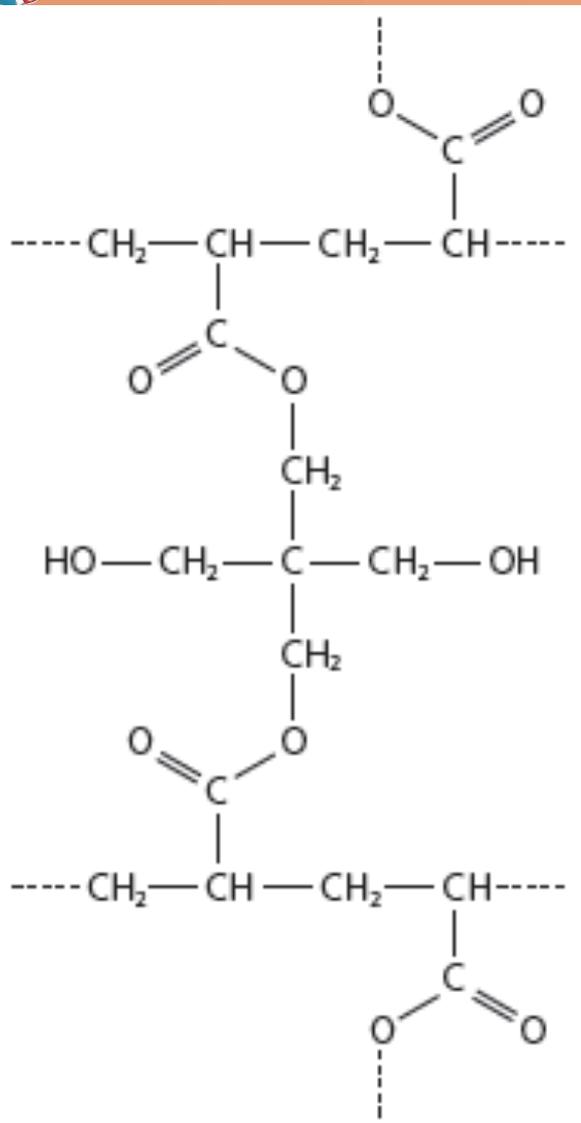
Part of the structure of one such polymer P is shown below:



- Draw the structure of monomer of polymer P.
- Chains of polymer P can be cross-linked by using compound X. Part of the structure of the cross-linked polymer is shown below.



48.4 Vulcanisation of rubber (P.62)



i) Draw the structure of compound X used to cross-link the chains of polymer P.

$C(CH_2OH)_4$

ii) During the cross-linking, small molecules are formed. Identify these small molecules.

Water

iii) The polymer becomes stronger if more cross-linking takes place. Explain why.

The polymer molecules are more strongly / tightly held.



48.5 Biodegradable plastics (P.66)

Most household plastic waste that you dump as refuse simply goes into landfill sites. This is both wasteful on natural resources and damaging to the environment since most of the plastic waste is nonbiodegradable. This means that it is not broken down naturally by microorganisms in the environment.

Much research attention has been given to the development of biodegradable plastics. **Biodegradable (生物可降解的)** plastic is a plastic that decomposes naturally in the environment. This is achieved when microorganisms in the environment metabolise and break down the structure of the plastic.

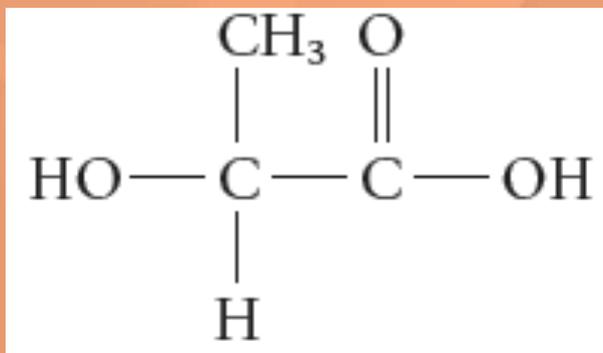


48.5 Biodegradable plastics (P.66)

Polyactide (PLA) – a biodegradable polymer

Polyactide 聚乳酸 (PLA) has generated great interest as one of the most innovative materials being developed for a wide range of applications.

It is a biodegradable thermoplastic derived from **lactic acid(乳酸)** (2-hydroxypropanoic acid).



lactic acid
(2-hydroxypropanoic acid)



Making polyactide [Ref.](#)



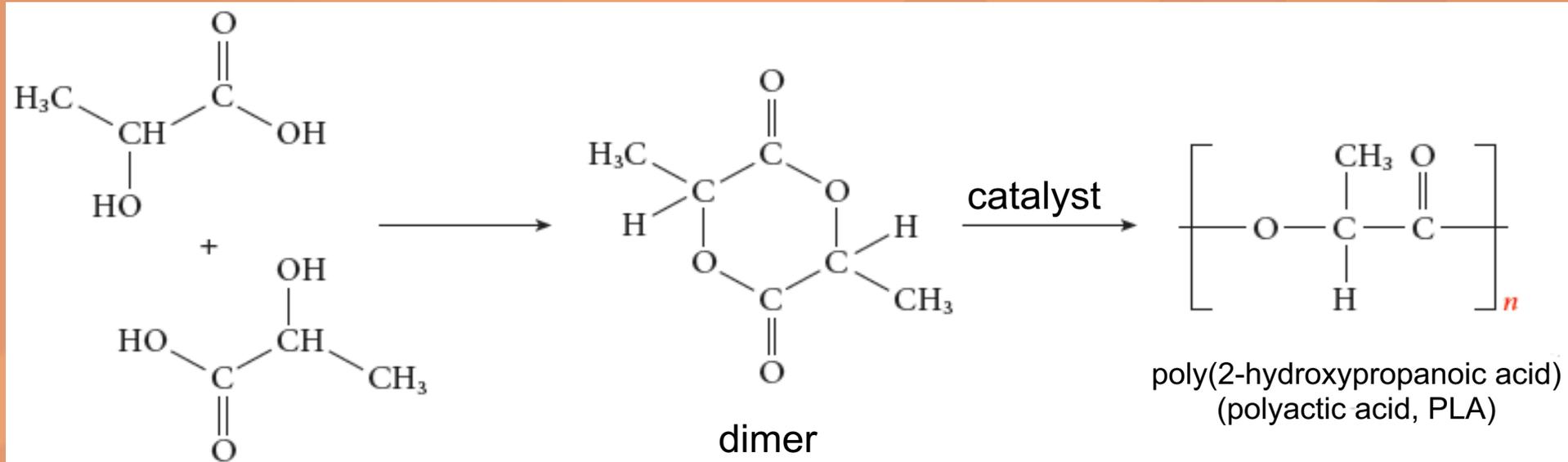
48.5 Biodegradable plastics (P.66)

The lactic acid, traditionally made from ethanal and hydrogen cyanide, is now being increasingly produced by an alternative method, the fermentation of sugars from maize (corn syrup) and cane sugar (molasses) using the lactobacillus bacterium.

However, the acid cannot be polymerised directly as the water produced prevents the polymerisation process proceeding to high enough relative molecular masses. The acid is therefore first dimerized by strong heat. The dimer undergoes ring opening polymerisation in the presence of a catalyst. This method avoids the formation of water during polymerisation.



48.5 Biodegradable plastics (P.66)



2-hydroxypropanoic acid
(lactic acid)

Poly lactide is manufactured from renewable sources and is biodegradable, addressing problems in solid waste disposal and lessening the dependence on petroleum-based raw materials.



48.5 Biodegradable plastics (P.66)

Uses of polylactide (PLA)

Polylactide has characteristics similar to polythene, polypropene and polystyrene. It can be broken down by the hydrolysis of the ester linkages.

Short-term applications such as food containers, water bottles, and disposable cutlery are popular uses for polylactide.

Polylactide is widely used in the medical field due to its ability to degrade into non-toxic lactic acid. Medical implants such as screws, rods, pins and mesh have been made using polylactide. Inside the patient's body, these implants completely break down in six months to two years, eliminating the need for further surgery.



48.5 Biodegradable plastics (P.66)

Poly lactide can be made into thin fibres with significant mechanical strength. These fibres have been used to manufacture casual sports apparel, upholstery material, hygiene products and diapers.

Poly lactide is more expensive than petroleum-based plastics, but its price has been falling as production increases.

A huge benefit of poly lactide is that it naturally degrades when exposed to the environment. For example, a poly lactide bottle left in the ocean would typically degrade in 6 to 24 months.



48.5 Biodegradable plastics (P.66)

In industrial composting (堆肥) facilities, polylactide is exposed to temperatures higher than $60\text{ }^{\circ}\text{C}$ and relative humidity higher than 90% for approximately 60 to 80 days; after which it composts into carbon dioxide, water, inorganic compounds and biomass as below.



A PLA bottle within 80 days in industrial composting facilities



48.6 Plastics fabrication processes (P.71)

There are a variety of different fabrication processes used to convert synthetic polymers into finished products. The process used for a polymer depends to a large extent on its nature — in particular, whether it is a thermoplastic or thermosetting plastic.

The greatest variety of methods are used for thermoplastics. The polymer is heated to near or above the melting temperature so that it becomes rubbery or liquid. The polymer is then shaped and cooled while maintaining the required shape.



48.6 Plastics fabrication processes (P.71)

Fewer fabrication processes are used for thermosetting plastics. Fabrication of a thermosetting plastic is accomplished in two stages. First comes the preparation of a linear polymer as a liquid, having a low relative molecular mass. This material is converted into the final hard and stiff product during the second stage, which is carried out in a mould having the desired shape. A cross-linked structure forms. The finished product may be removed from the mould while still hot.



48.6 Plastics fabrication processes (P.71)

Injection moulding

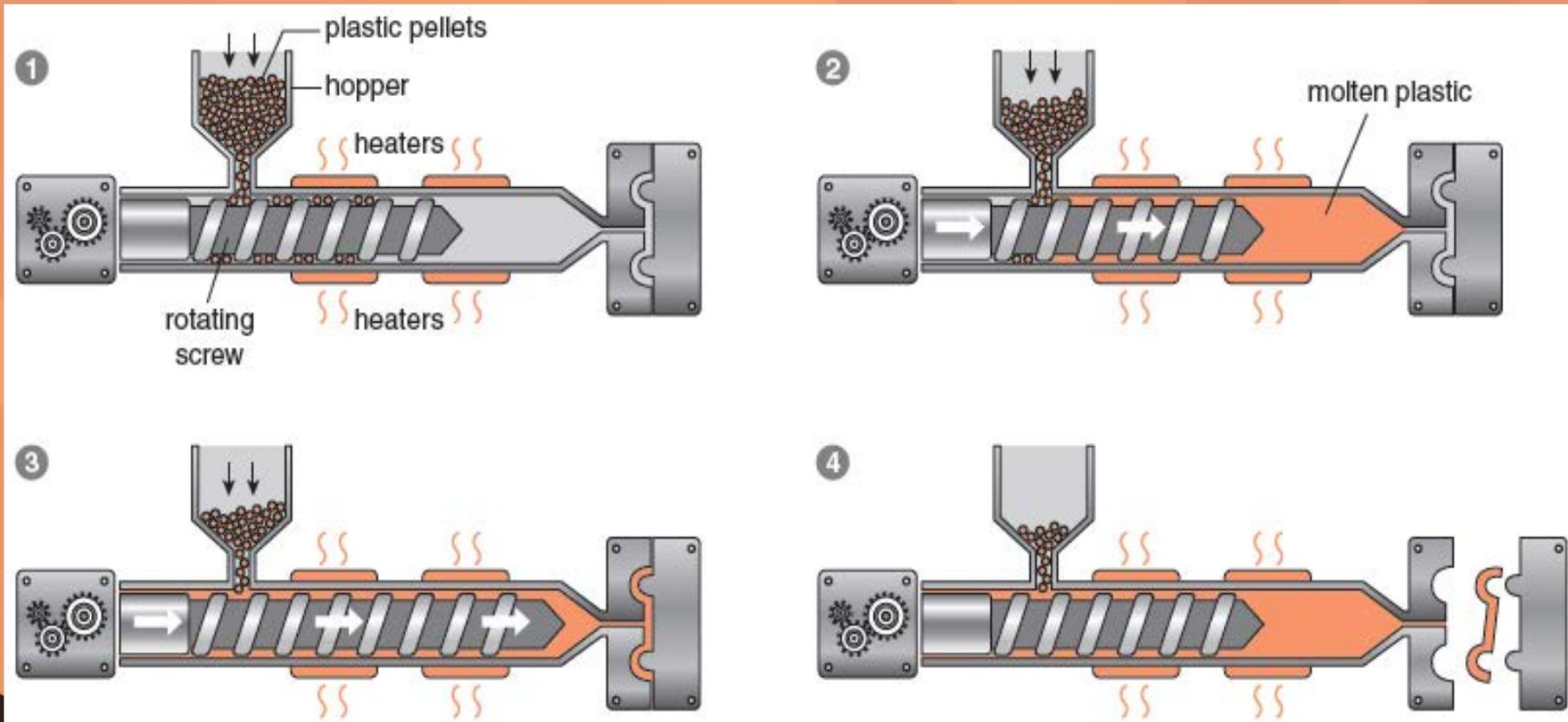
Injection moulding can produce intricate three-dimensional parts of high quality. It is predominately used for thermoplastics but some thermosetting plastics are also processed by injection moulding.

- 1 The plastic, in granule form, is fed into the moulding machine via the hopper.
- 2 A rotating screw pushes the plastic through the heated chamber in which the material is melted.
- 3 The screw injects the molten plastic into a closed cold mould.
- 4 When the plastic cools to a solid, the mould opens and the finished product is ejected.



48.6 Plastics fabrication processes (P.71)

The figure below show the four steps in the process:





48.6 Plastics fabrication processes (P.71)

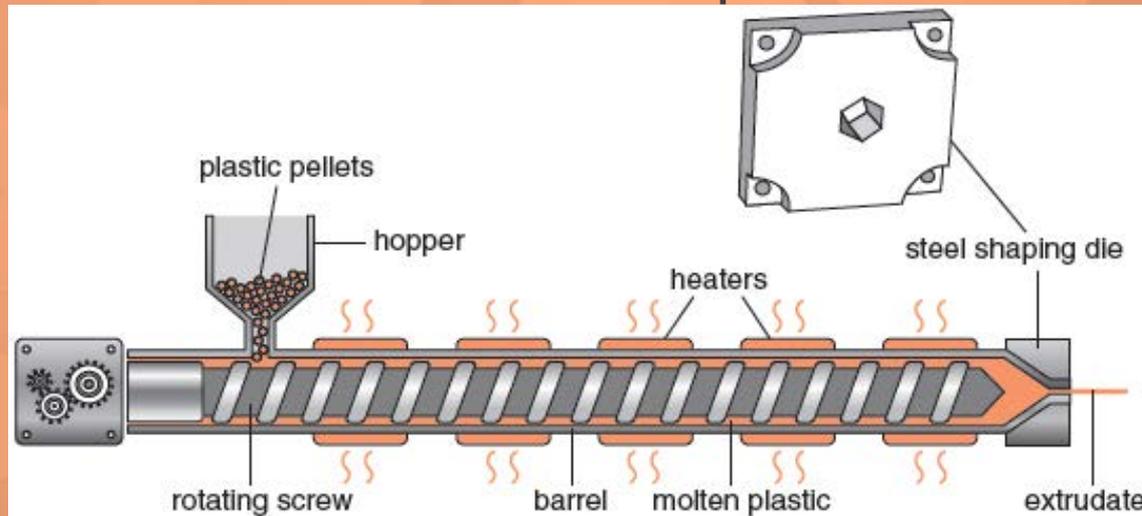
Many of the objects you come across everyday are made by injection moulding, including

- casings for computers and other electronic products;
- dustbins;
- cases for CDs and DVDs;
- lids of all sorts, such as plastic bottle caps and plastic cup lids;
- bumpers of vehicles;
- plastic construction kits.

48.6 Plastics fabrication processes (P.71)

Extrusion moulding

Extrusion moulding (擠塑法) is used to produce films, sheets, tubes and pipes. Thermoplastic, in granule form, is loaded into a hopper and then fed into a long heated chamber through which it is moved by the action of a rotating screw. At the end of the heated chamber, the molten plastic is forced out through a small opening called a die to form the shape of the finished product.

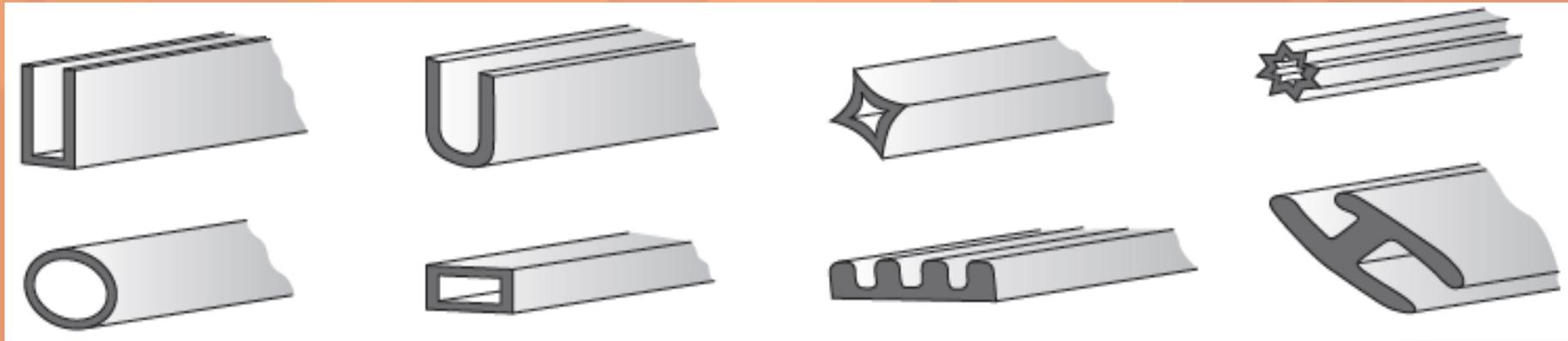


Process of extrusion moulding



48.6 Plastics fabrication processes (P.71)

The extrusion is cooled as it leaves the die and is finally cut to the required length. The shape of the die can be varied from a simple hole with a centrally supported core to produce tubes such as pipes, to very complex sections for curtain tracks or hollow window frames. The figure below shows typical shapes of extrusions.



Typical shapes of extrusions



48.6 Plastics fabrication processes (P.71)

Examples of extruded products include

- lawn edgings;
- pipes;
- films;
- insulation on electric wires;
- guttering and down spouting; and
- window frames.



Pipes are extruded products

 48.6 Plastics fabrication processes (P.71)

Blow moulding

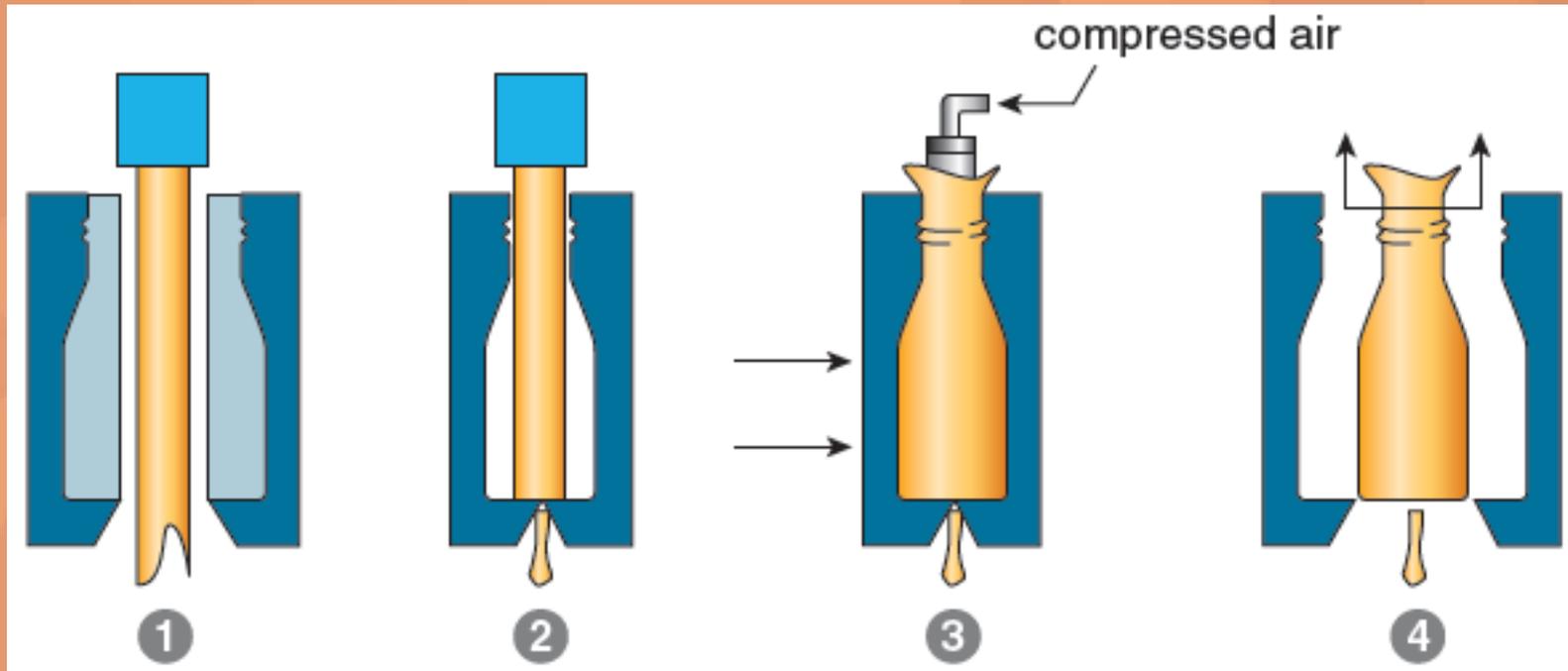
Blow moulding (吹塑法) is the most popular way of producing hollow products such as bottles, drums and other vessels out of thermoplastics.

Blow moulding is accomplished in the steps below:

- 1 Clamp a thermoplastic hollow tube in semimolten state between the two halves of an open two-part mould.
- 2 Close the mould.
- 3 Blow compressed air into the plastic tube, forcing the tube walls to conform to the contours of the mould.
- 4 Remove the finished product from the mould when the plastic cools to a solid.



48.6 Plastics fabrication processes (P.71)



Process of blow moulding



48.6 Plastics fabrication processes (P.71)

The hollow plastic tube used in blow moulding is formed by either of two processes: injection or extrusion moulding.

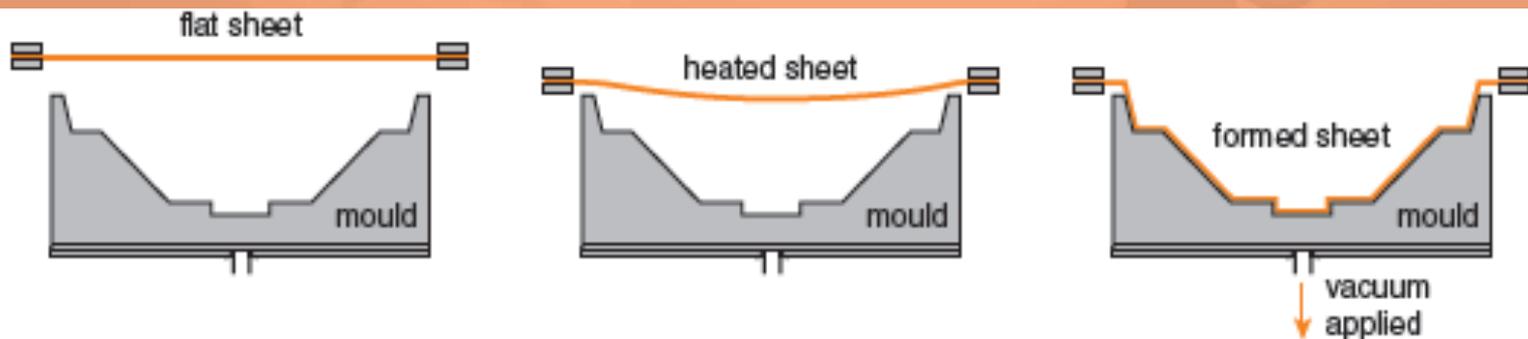
Blow moulding is used to make hollow plastic containers such as bottles and jars. Milk containers, shampoo and soda bottles, and watering cans are examples of products that are typically blow moulded.

 48.6 Plastics fabrication processes (P.71)

Vacuum forming

Vacuum forming (真空成型法) is a very common fabrication process used, for example, to make a range of plastic packaging. Think of the sandwich boxes, or the liner in a chocolate box, or your acrylic bath.

The figure below shows what happens in vacuum forming. Clamp a flat thermoplastic sheet in place and heat it until it softens. Use a vacuum pump to draw out the air between the mould and the plastic sheet. Atmospheric pressure forces the plastic sheet into the mould. **Process of vacuum forming**



 48.6 Plastics fabrication processes (P.71)

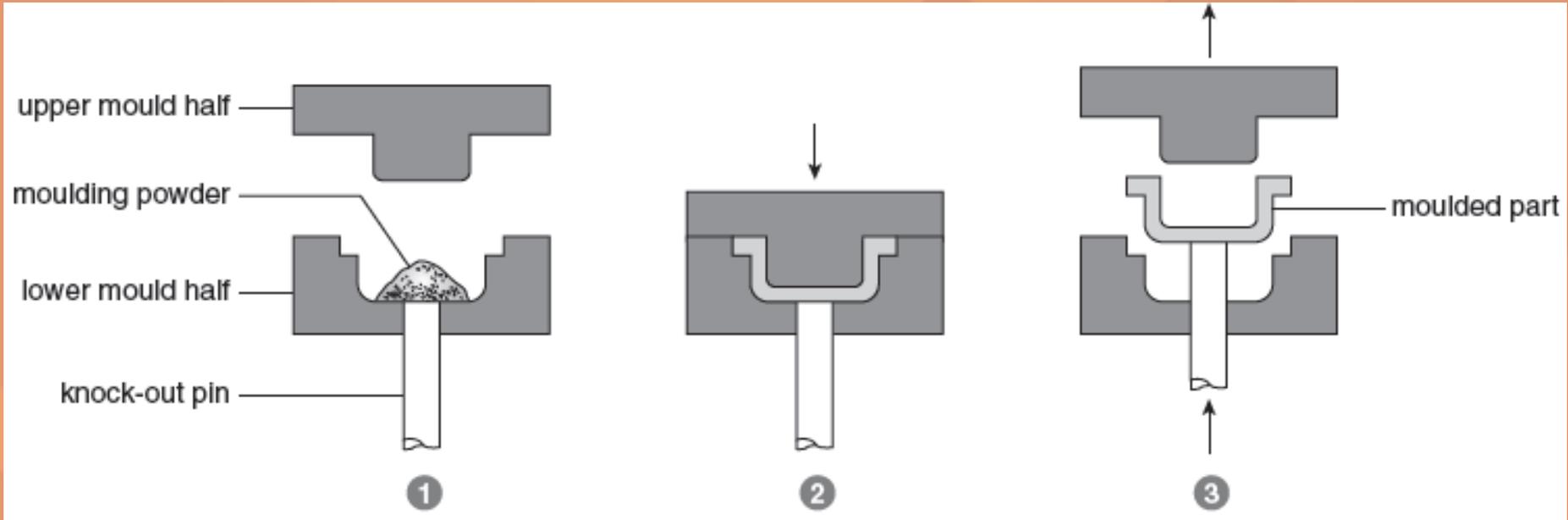
Compression moulding

Compression moulding (壓塑法) is a technique mainly used for thermosetting plastics. The process involves the following steps.

- 1 Place the moulding powder in the lower half of a heated mould. The powder becomes soften.
- 2 The upper half of the mould moves downwards, pressing on the material and forcing it to fill the mould. Cross-links form between the polymer chains due to the heat and pressure applied. The plastic hardens into the final shape.
- 3 Open the mould and remove the finished product by means of the knock-out pin.



48.6 Plastics fabrication processes (P.71)



Process of compression moulding

Compression moulding is commonly used for manufacturing electric parts, tableware, gears, buttons, buckles, knobs, handles, electronic device cases, appliance housing and large containers.



48.7 The environmental impact of the use of synthetic polymers (P.77)

There are many factors that have to be considered when discussing the environmental impact of the use of synthetic polymers. It is far from a simple debate and you cannot simply say that synthetic polymers are bad for the environment. Some relevant points are summarised below.



Synthetic polymer waste in landfill sites remains unchanged for years



48.7 The environmental impact of the use of synthetic polymers (P.77)

- Synthetic polymers are made from petroleum, which is a finite resource.
- Most synthetic polymers are non-biodegradable. When synthetic polymer waste is buried in landfill sites, it remains unchanged for many years. An alternative to dumping is incineration, with the possibility of making use of the heat generated. However, some synthetic polymers burn with the formation of toxic gases, for example, hydrogen chloride or dioxins from PVC, and incinerators must be designed to remove these gases from the exhaust.



48.7 The environmental impact of the use of synthetic polymers (P.77)

- Many synthetic polymer containers need less energy to make than an equivalent one in glass or aluminium.
- The use of synthetic polymers in making insulation materials reduces energy loss.
- Synthetic polymer containers are light and less energy is needed to transport them.
- Synthetic polymer packaging prevents food from spoiling and so can reduce food wastage.



48.7 The environmental impact of the use of synthetic polymers (P.77)

- Synthetic polymer pipes for water, gas, sewage and communication cables do not rust and therefore do not have to be replaced as often.
- Synthetic polymer waste in the environment can cause harm to birds and marine animals.



Synthetic polymer pipes for sewage



Synthetic polymer waste in the environment causes harm to marine animals



48.8 Recycling of synthetic polymers (P.78)

Recycling rather than disposal into a landfill or incineration is an obvious way of reducing the environmental impact of synthetic polymers. However, there are significant challenges to successfully recycling synthetic polymers at low cost.

Thermosetting plastics cannot be melted down and recycled — they will decompose before melting if heated. Another major difficulty is that since different synthetic polymers have different properties, waste of mixed synthetic polymers is of limited use. The waste needs to be sorted and separated.



48.8 Recycling of synthetic polymers (P.78)

In order to facilitate efficient recycling, a set of seven identification codes has been established. These codes are stamped on the bottoms of widely-distributed products.

Resin identification code	Examples of uses	
 PET Poly(ethylene terephthalate)	carbonated drink bottles, water bottles	
 HDPE High density polythene	milk containers, toiletry bottles	
 PVC Polyvinyl chloride	drain pipes, bottles, floor tiles, shower curtains	

Application of the seven resin identification codes to various examples of uses



48.8 Recycling of synthetic polymers (P.78)

 <p>04 LDPE Low density polythene</p>	<p>packaging films, dry cleaning bags, bread bags, wash bottles</p>	
 <p>5 PP Polypropene</p>	<p>ketchup bottles, margarine tubs, medicine bottles</p>	
 <p>6 PS Polystyrene</p>	<p>CD cases, disposable containers and cutlery</p>	
 <p>7 OTHER Other plastics</p>	<p>3 and 5 gallon reusable water bottles, baby feeding bottles</p>	

Application of the seven resin identification codes to various examples of uses



Key terms (p.80)

Crystalline	晶狀的	Amorphous	無定形的
Vulcanisation	硫化作用	Biodegradable	生物可降解的
Polyactide	聚乳酸	Lactic acid	乳酸
Fabrication process	加工過程	Injection moulding	注塑法
Extrusion moulding	擠塑法	Blow moulding	吹塑法
Vacuum forming	真空成型法	Compression moulding	壓塑法



Summary (P.81)

1 The following table compares the structures and properties of low density polythene and high density polythene.

	Low density polythene	High density polythene
Structures	<ul style="list-style-type: none"> • branched polymer chains with many short branches • the chains cannot pack close together in regular way, more amorphous regions • van der Waals' forces between the chains are relatively weak 	<ul style="list-style-type: none"> • more linear and less branched • chains can pack together better, more crystalline regions • van der Waals' forces between the chains are relatively stronger
Properties	<ul style="list-style-type: none"> • lower melting point • flexible 	<ul style="list-style-type: none"> • higher melting point • more rigid

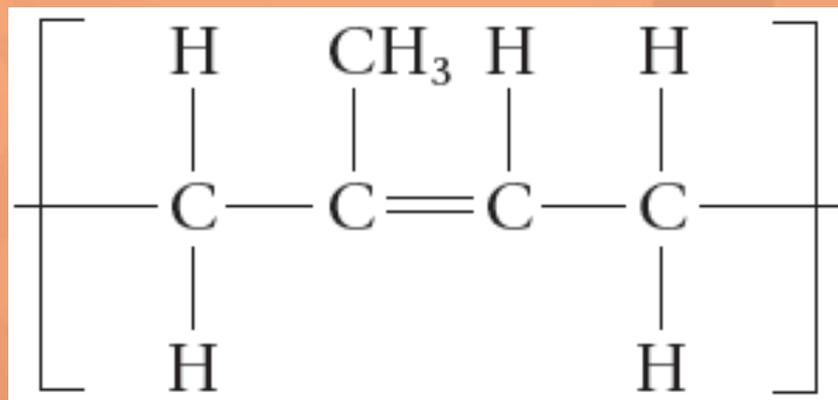


Summary (P.81)

2 The following table compares the structures and properties of nylon-6,6 and Kevlar.

	Nylon-6,6	Kevlar
Similarity	Both of them have C=O groups and N-H groups in the polymer chains. Hydrogen bonding is possible between the chains.	
Difference	Ease of rotation around single bond in the 'backbone' of the polymer chain makes the chain quite flexible.	Benzene groups make the polymer chains very rigid.

3 a) The repeating unit of natural rubber is



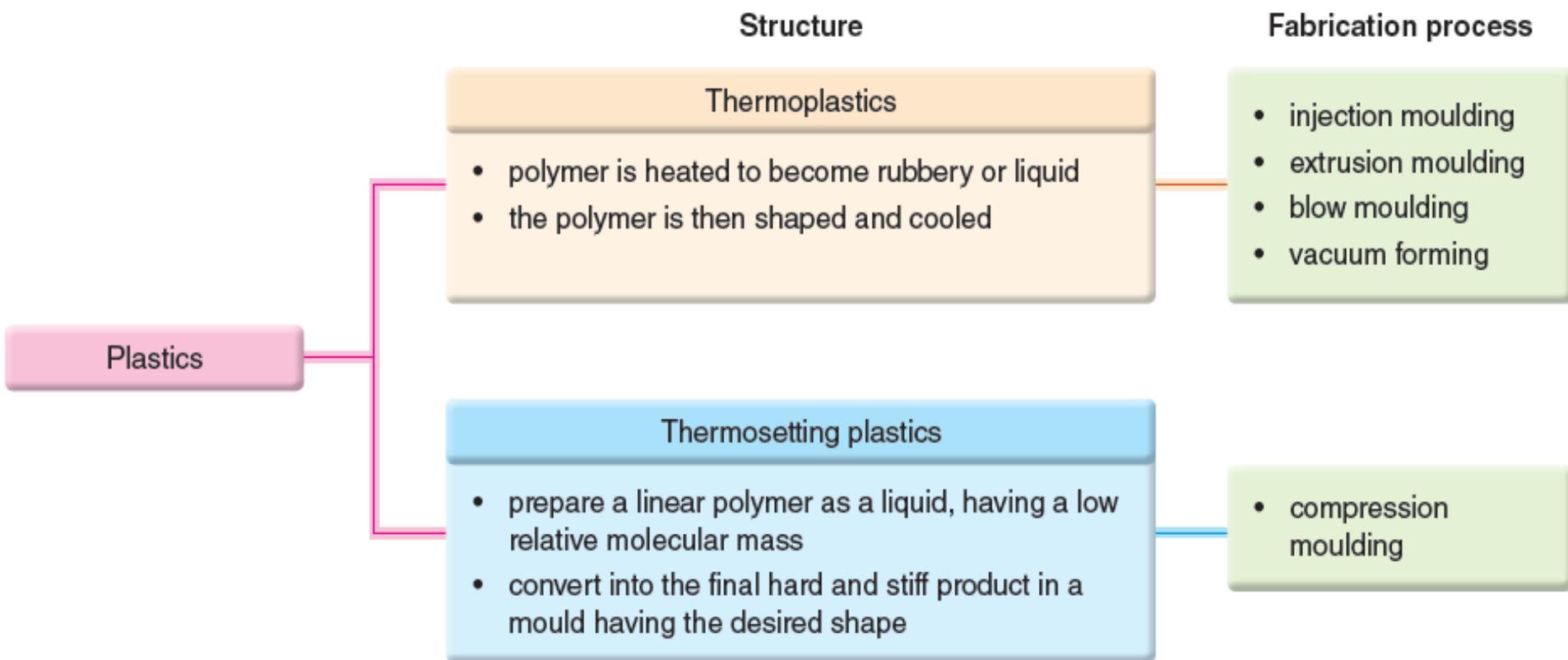


Summary (P.81)

- 3 b) Vulcanised rubber is stronger and harder than natural rubber. With the cross-links, the polymer chains cannot slide over each other easily.
- 4 a) Biodegradable plastic is a plastic that decomposes naturally in the environment.
 - b) Polylactide (PLA) is a biodegradable thermoplastic derived from lactic acid (2-hydroxypropanoic acid).
 - c) Lactic acid can be produced by the fermentation of sugars from maize and cane sugar.

Summary (P.81)

5 The following diagram summarises information about the structures and fabrication processes of thermoplastics and thermosetting plastics.





Summary (P.81)

6 Three common methods for treating plastic waste are:

- a) landfilling;
- b) incineration; and
- c) recycling.





Unit Exercise (p.83)

Note: Questions are rated according to ascending level of difficulty (from 1 to 5):

 **question targeted at level 3 and above;**

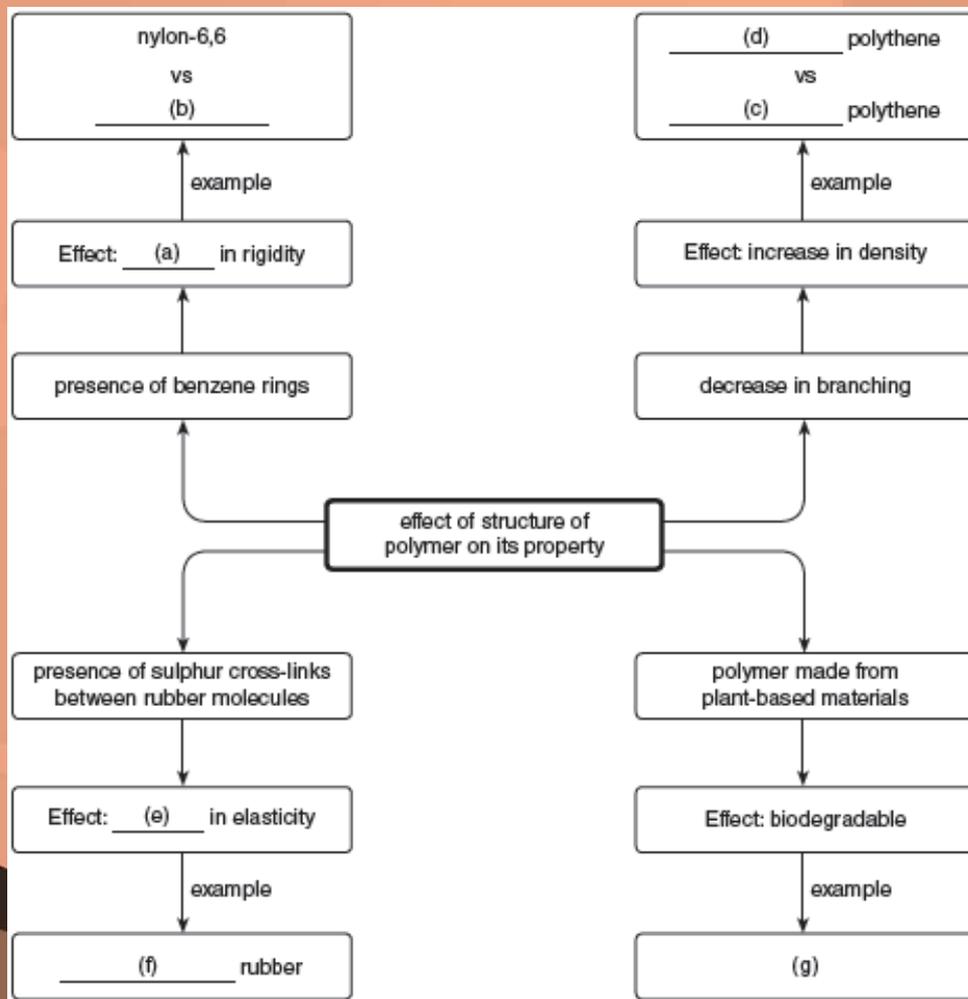
 **question targeted at level 4 and above;**

 **question targeted at level 5.**

Unit Exercise (p.83)

PART I KNOWLEDGE AND UNDERSTANDING

1 Complete the following concept map.



- a) increase
- b) Kevlar
- c) high density
- d) low density
- e) increase
- f) vulcanised
- g) polylactide



Unit Exercise (p.83)

PART II MULTIPLE CHOICE QUESTIONS

2 Which of the following comparisons between thermoplastics and thermosetting plastics is correct?

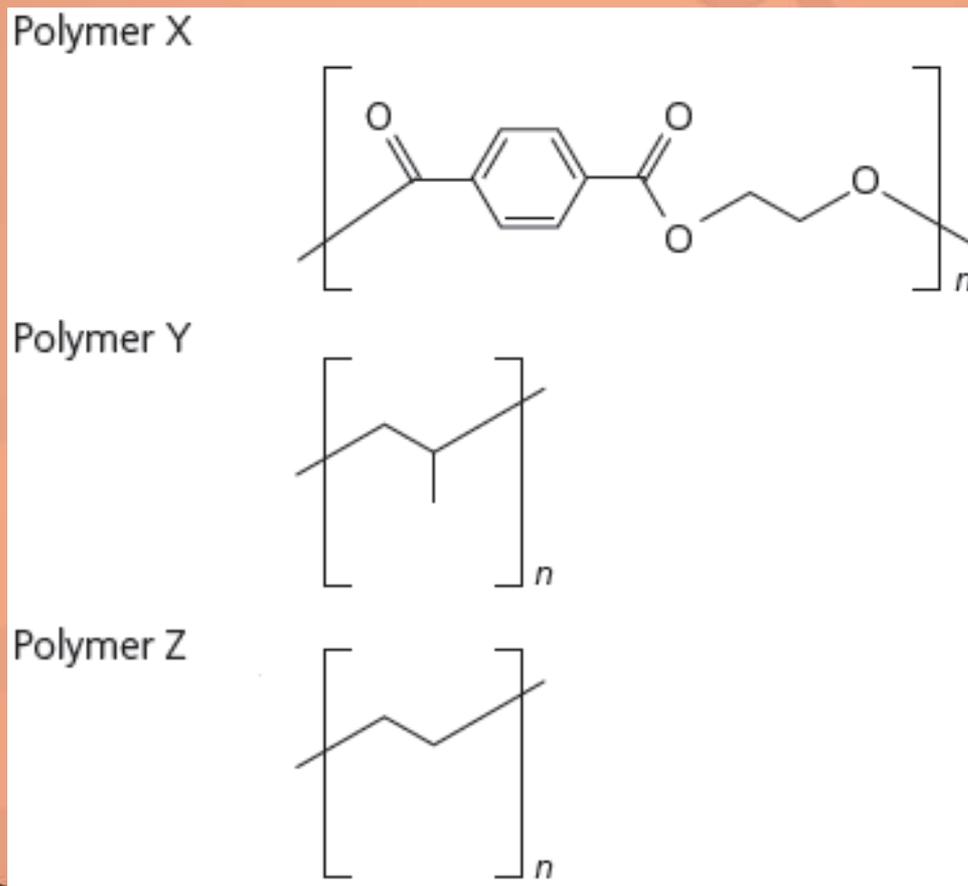
- A Thermoplastics have higher densities than thermosetting plastics.
- B Thermoplastics are usually less flexible than thermosetting plastics.
- C Thermoplastics are more flammable than thermosetting plastics.
- D Thermoplastics can be moulded only once while thermosetting plastics can be remoulded easily.

Answer: C



Unit Exercise (p.83)

Directions: Questions 3 and 4 refer to the structures of three polymers given below.





Unit Exercise (p.83)

- 3 Which of the polymers is / are condensation polymer(s)?
- A X only
 - B Y only
 - C X and Z only
 - D Y and Z only

Answer: A

**Polymer X is a condensation polymer.
It is formed from two monomers.**



Unit Exercise (p.83)



4 Which of the following lists the polymers in increasing order of tensile strength?

A $X < Z < Y$

B $Y < X < Z$

C $Y < Z < X$

D $Z < Y < X$

Answer: D

- Polymer X contains C=O groups. Dipole-dipole interactions exist between the polymer molecules. Van der Waals' forces exist between non-polar molecules of polymers Y and Z.
- Dipole-dipole interactions are stronger than van der Waals' forces between non-polar molecules. Thus, the strength of polymer X is higher than that of polymers Y and Z.
- The size of molecules of polymer Y are larger than those of polymer Z. Thus, the van der Waals' forces in polymer Y are stronger than those in polymer Z.
- The strength of polymer Y is higher than that of polymer Z.



Unit Exercise (p.83)

- 5 Which of the fabrication processes is commonly used to make polypropene bottles?
- A Blow moulding
 - B Compression moulding
 - C Injection moulding
 - D Vacuum forming

Answer: A



Unit Exercise (p.83)

6 Which of the following fabrication processes is commonly used to make plastic drain pipes?

- A Blow moulding
- B Compression moulding
- C Extrusion moulding
- D Injection moulding

Answer: C



Unit Exercise (p.83)

- 7 Which of the following fabrication processes is commonly used to make thermosetting plastic tableware for children?
- A Blow moulding
 - B Compression moulding
 - C Extrusion moulding
 - D Vacuum forming

Answer: B



Unit Exercise (p.83)

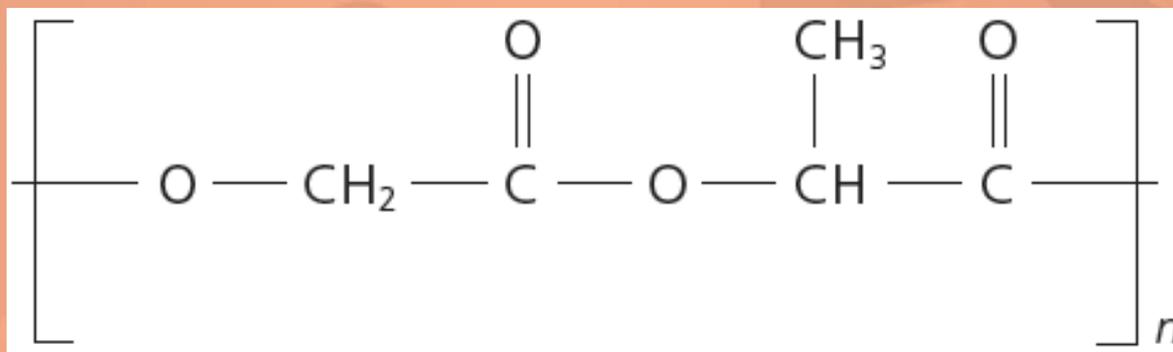
- 8 Which of the following fabrication processes is commonly used to make plastic bottle caps?
- A Compression moulding
 - B Extrusion moulding
 - C Injection moulding
 - D Vacuum forming

Answer: C



Unit Exercise (p.83)

Directions: Questions 9 and 10 refer to the polymer X shown below. It is often used to stitch cuts and wounds.



Polymer X is made via polymerisation between glycolic acid (HOCH_2COOH) and one other monomer M.



Unit Exercise (p.83)

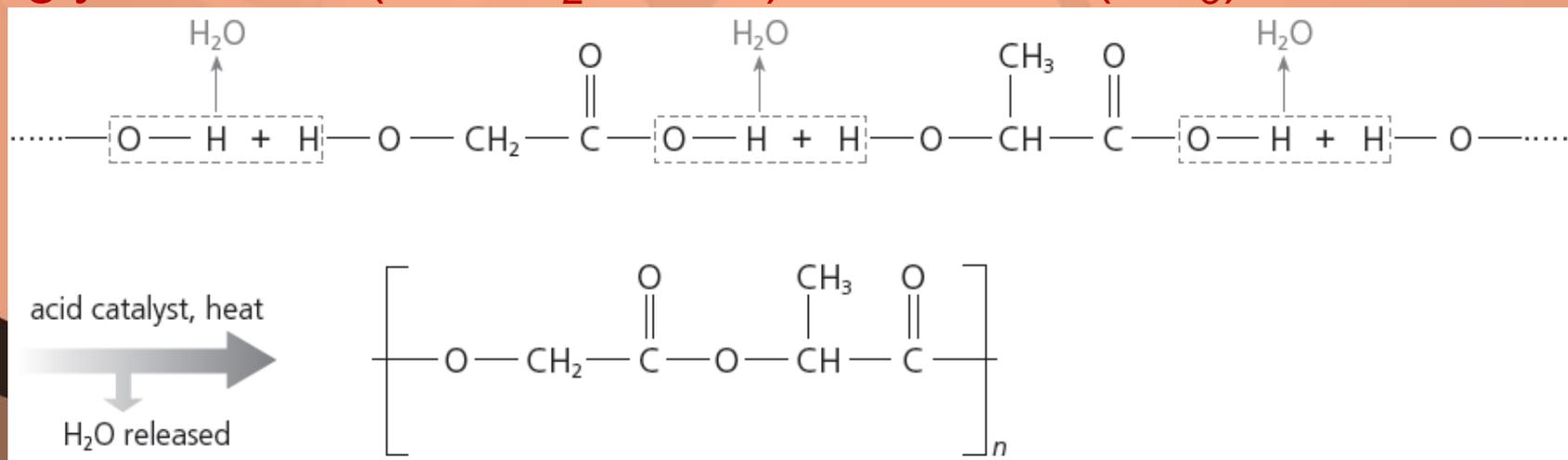


9 What is the structure of monomer M?

- A $\text{HOOCCH}(\text{CH}_3)\text{COOH}$
- B $\text{HOCH}_2\text{CH}_2\text{OH}$
- C $\text{HOCH}(\text{CH}_3)\text{COOH}$
- D $\text{HOCH}_2\text{CH}_2\text{COOH}$

Answer: C

Polymer X is made via condensation polymerisation between glycolic acid (HOCH_2COOH) and $\text{HOCH}(\text{CH}_3)\text{COOH}$.





Unit Exercise (p.83)

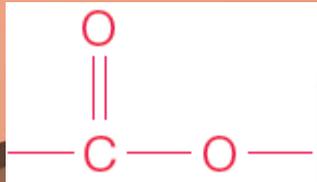
10 Which of the following statements about polymer X are correct?

- (1) It is a thermoplastic.
- (2) It is an addition polymer.
- (3) It can be hydrolysed by water in the body.

- A (1) and (2) only
- B (1) and (3) only
- C (2) and (3) only
- D (1), (2) and (3)

Answer: B

(2) Polymer X is a condensation polymer.

(3) The ester linkage () can be hydrolysed by water in the body.

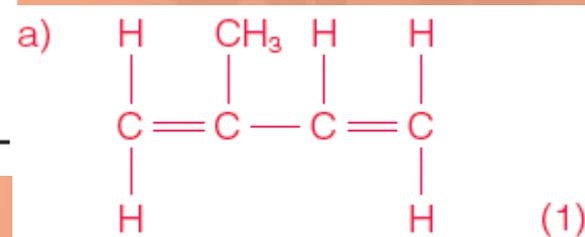
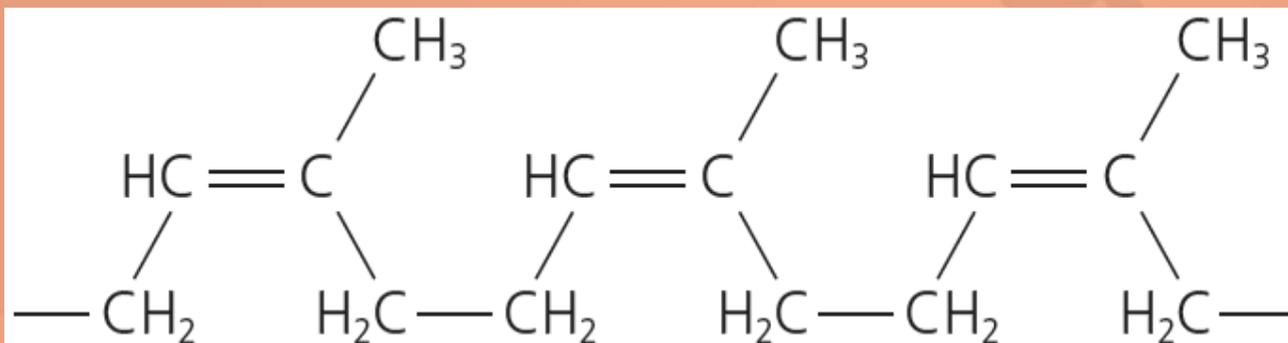


Unit Exercise (p.83)

PART III STRUCTURED QUESTIONS



11 A part of the structure of natural rubber is shown below:

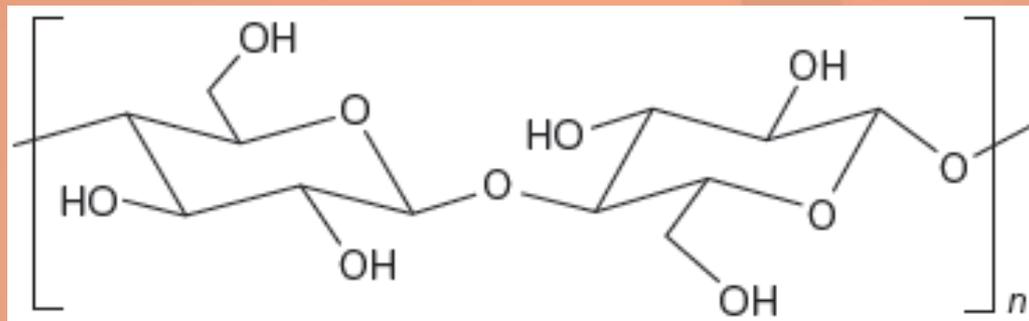


- a) Draw the structure of the monomer of natural rubber.
- b) What is the role of sulphur in the vulcanisation of natural rubber?
Sulphur reacts with some of the C=C bonds in the polymer chains, forming cross-links between the polymer chains. (1)
- c) Explain why natural rubber becomes hardened upon vulcanisation.
With the cross-links, the polymer chains cannot slide easily over each other. (1)



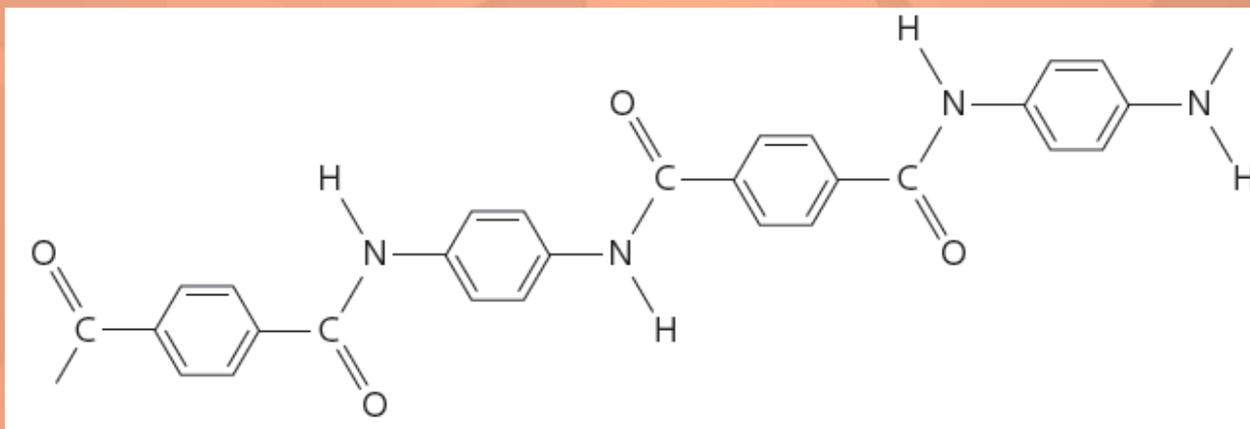
Unit Exercise (p.83)

12 a) Cellulose is a natural polymer and its structure is shown below:



Explain why cellulose is considered to be environmentally friendly.

b) A portion of the structure of Kevlar is shown below:



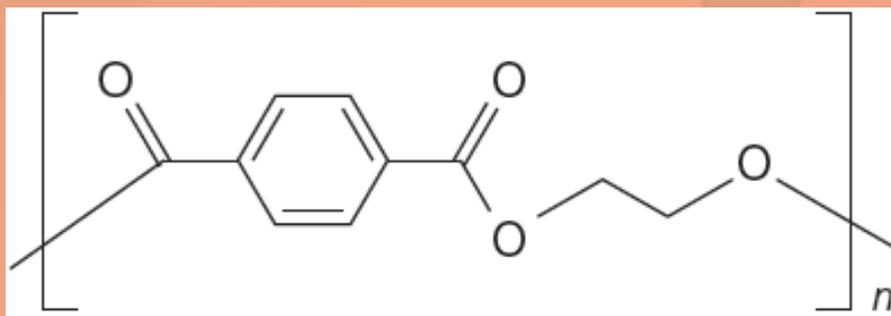
With reference to the above structure, give TWO reasons why Kevlar is rigid.

(HKDSE, Paper 2, 2016, 2(a)(i), (iii))



Unit Exercise (p.83)

13 PET is a polyester with the structure shown below:



- a) State the types of intermolecular forces which hold polyester chains together.

Dipole-dipole interactions (1)

- b) A student heats PET under reflux with an excess of NaOH(aq). From the mixture the student isolates a solid salt and an organic liquid.

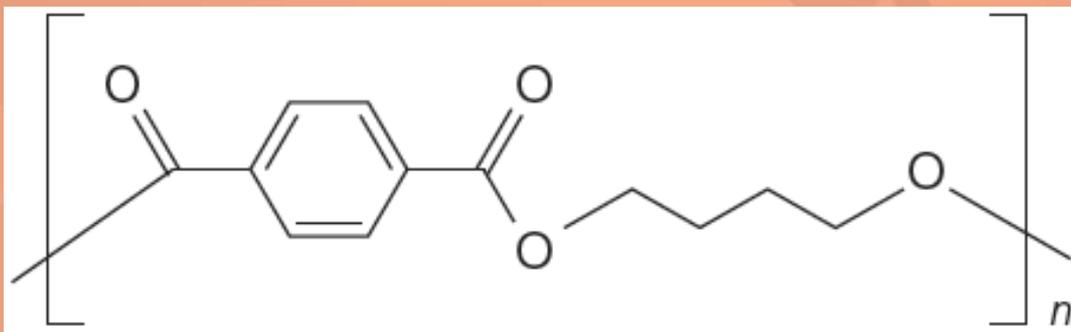




Unit Exercise (p.83)

13 (continued)

c) The structure of PBT is shown below.



Explain why PBT is more flexible than PET.

Dipole-dipole interactions exist between the C=O groups of polymer molecules of PBT and PET.

PBT contains less C=O groups per unit length than PET. (1)

There are less dipole-dipole interactions between the polymer molecules of PBT. (1)

The polymer molecules of PBT can slide over each other more easily. (1)



Unit Exercise (p.83)

14 Arrange the following synthetic polymers in increasing order of strength.



nylon-6,6

polythene

polyvinyl chloride

Explain your answer in terms of intermolecular forces between polymer molecules.

Order of strength:

nylon-6,6 > polyvinyl chloride > polythene (1)

Nylon-6,6 contains both C=O and NH₂ groups. Hydrogen bonds exist between molecules of nylon-6,6. (1)

Polyvinyl chloride contains polar C–Cl groups. Dipole-dipole interactions exist between molecules of polyvinyl chloride. (1)

Only van der Waals' forces exist between the non-polar molecules of polythene. (1)

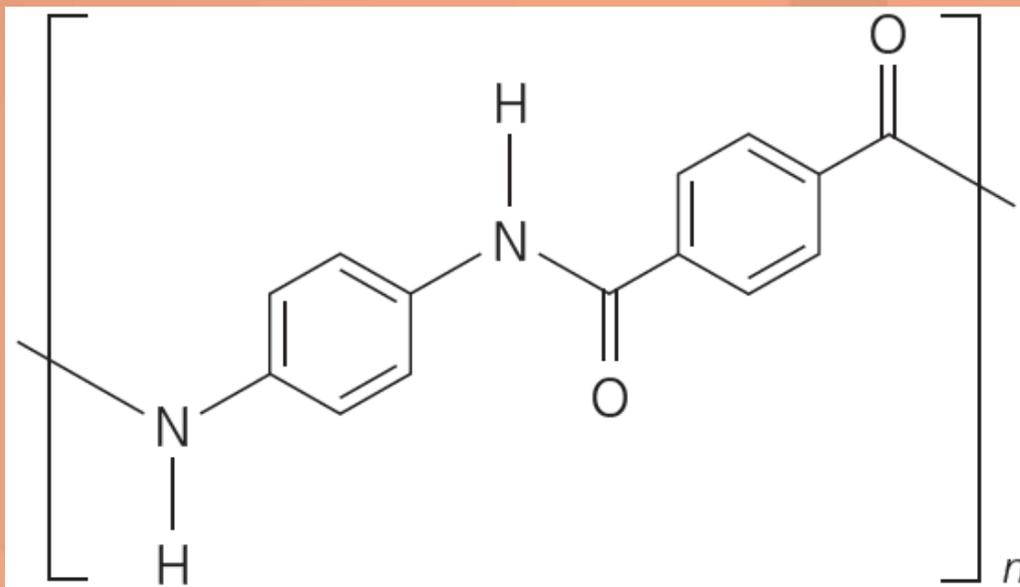
The strength of the forces between molecules of these polymers is in the order hydrogen bonds > dipole-dipole interactions > van der Waals' forces (1)



Unit Exercise (p.83)



15 The structure of Kevlar is shown below.



- Draw the structures of the monomers for making Kevlar.
- What reaction conditions are needed to break the amide linkages in Kevlar?

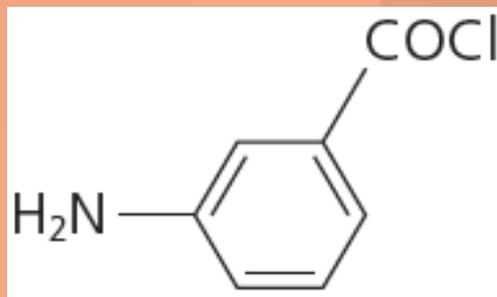
a)



- Warm / heat / reflux with dilute H_2SO_4 or NaOH (1)

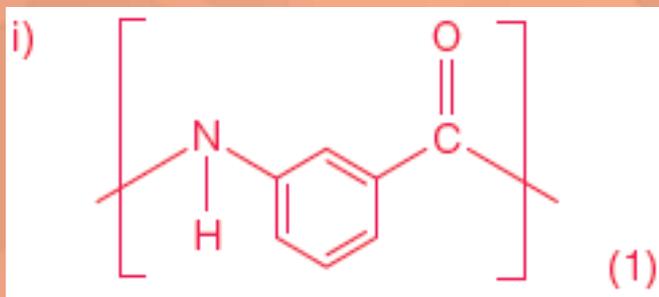
 Unit Exercise (p.83)15 (continued)

c) Polymer P is formed from the monomer shown below.



i) Draw the repeating unit of polymer P.

ii) Suggest why Kevlar is much stronger than polymer P.



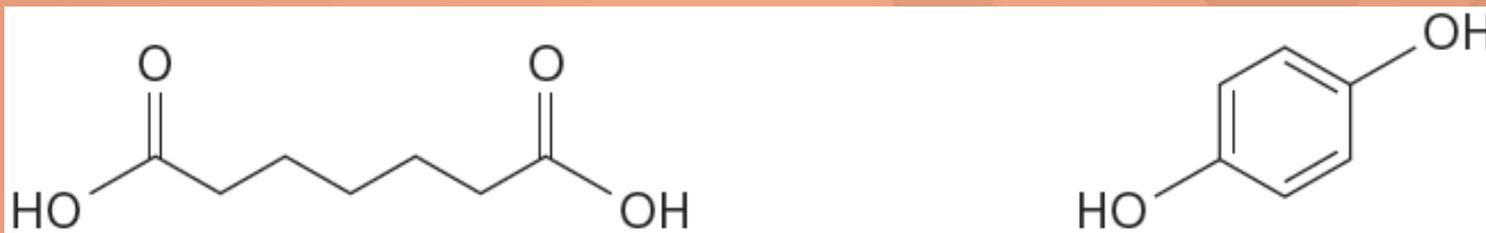
ii) The polymer chains of Kevlar are more rigid. Hydrogen bonds between the polymer chains will be stronger. (1)



Unit Exercise (p.83)



16 Polymer P is formed from the following two monomers.

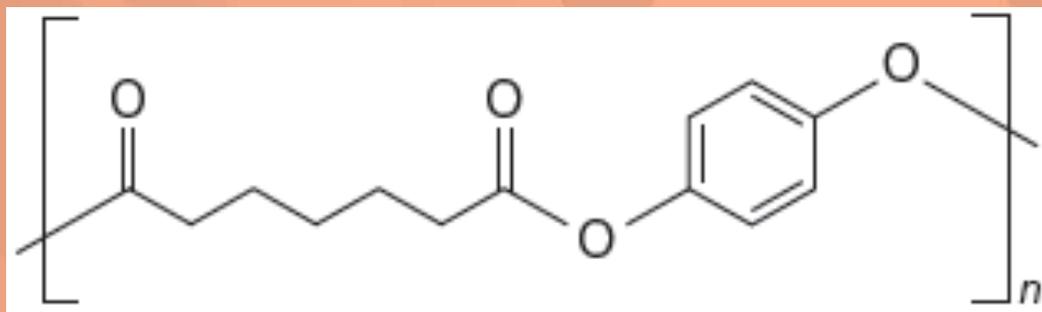


- a) The two monomers react by condensation polymerisation. What other molecule is formed in this reaction?

Water

(1)

- b) Draw the structure of polymer P.



(1)



Unit Exercise (p.83)

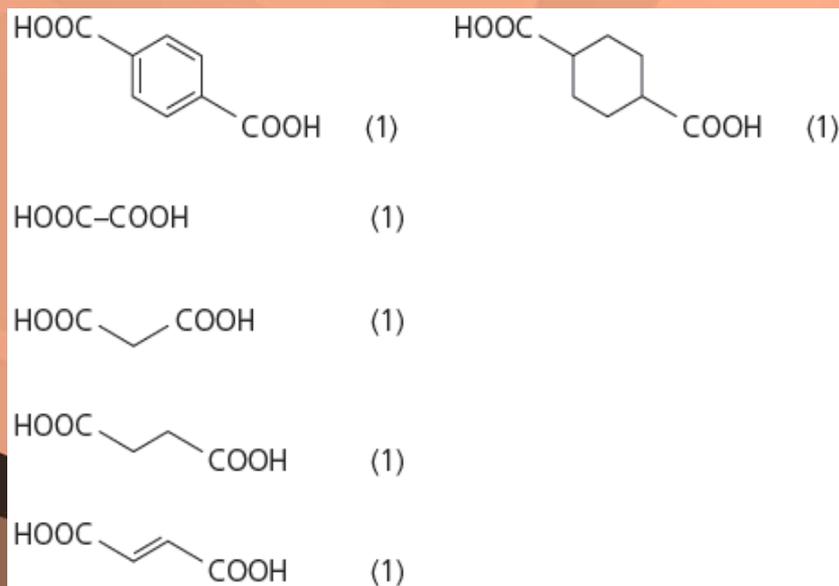
16 (continued)

- c) One of the monomers could be changed to make a more rigid polymer Q of a similar chemical type to polymer P.
State which monomers could be changed, and suggest a structure for the new monomer.

The acid should be changed to something less flexible. (1)

Examples

Any one of the following:

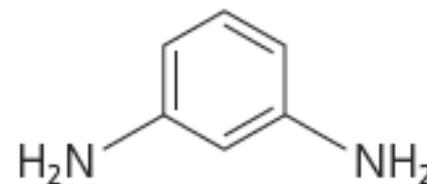
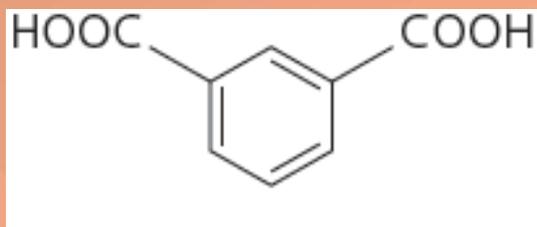


(length of chain is the important feature)

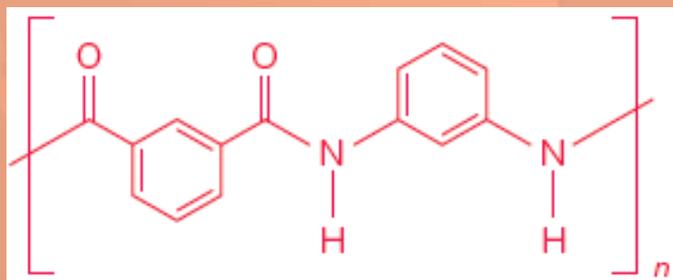


Unit Exercise (p.83)

17 The two monomers shown below undergo polymerisation to make a condensation polymer, Nomex.



a) Draw the structure of Nomex.



(1)

b) What is the meaning of the term 'condensation polymer'?

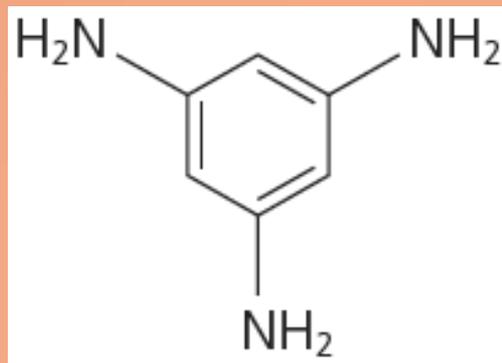
A condensation polymer is formed when many monomer molecules join together via condensation reactions, with the elimination of simple molecules, such as water. (1)



Unit Exercise (p.83)

17 (continued)

c) Some of the diamine monomer is now replaced with 1,3,5-triaminobenzene. A hard and rigid plastic material is produced.



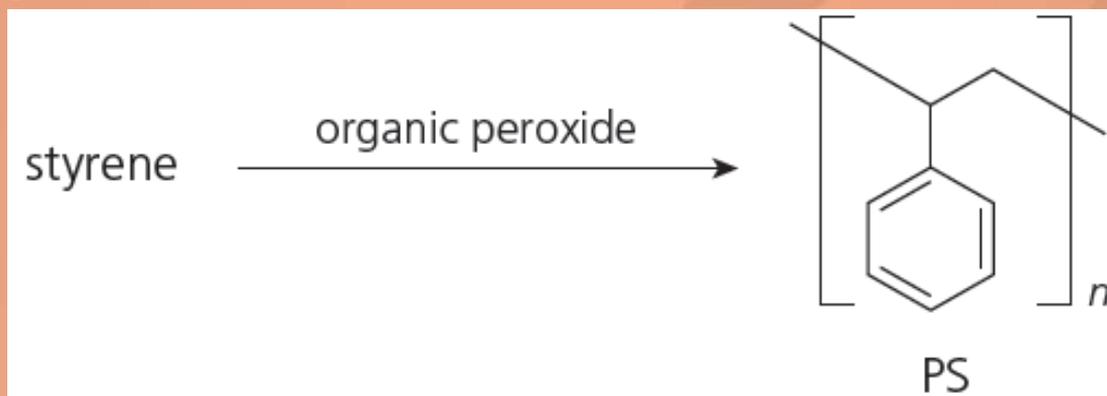
Deduce the thermal property of this plastic material.

c) The plastic material has cross-links between the polymer chains.(1)
As the plastic material has a giant covalent network structure, it does not melt upon heating. (1)



Unit Exercise (p.83)

18 The equation below shows the formation of polystyrene (PS) from styrene.



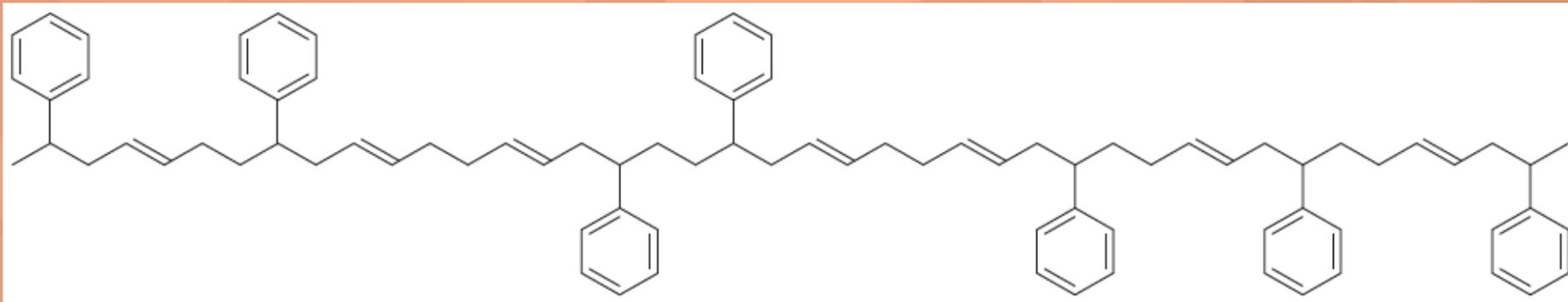
- Draw the structure of styrene.
- Name the type of polymerisation involved in forming PS.
- Expanded PS is commonly used in making disposable cups for containing hot drinks.
 - Explain why expanded PS has good heat insulating property.
 - Suggest a moulding method for making expanded PS cups.
 - State TWO problems in recycling objects made from expanded PS.



Unit Exercise (p.83)

18 (continued)

- d) Styrene can polymerise with buta-1,3-diene to give a high impact polystyrene (HIPS) in which the monomers randomly join together. A portion of the structure of a certain HIPS is shown below:



Suggest why the hardness of HIPS is lower than that of PS.

(HKDSE, Paper 2, 2015, 2(b))

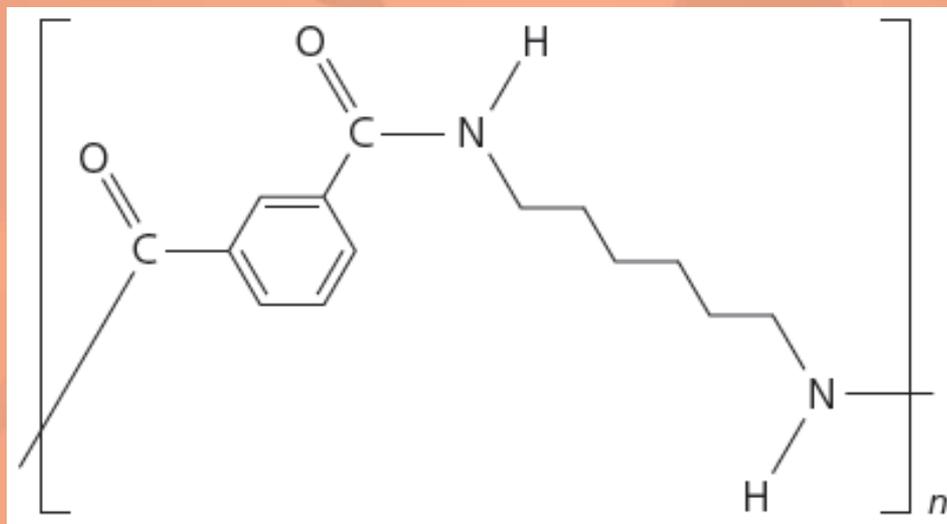


Unit Exercise (p.83)



19 To combat the security problems of metal cutlery on aircraft, chemists have developed a polymer known as PPA. This polymer, a polyamide, is strong enough to replace stainless steel cutlery for in-flight use.

The structure of PPA is shown below:



Unit Exercise (p.83)

19 (continued)

a) Draw the structures of two monomers that could be used to form PPA.

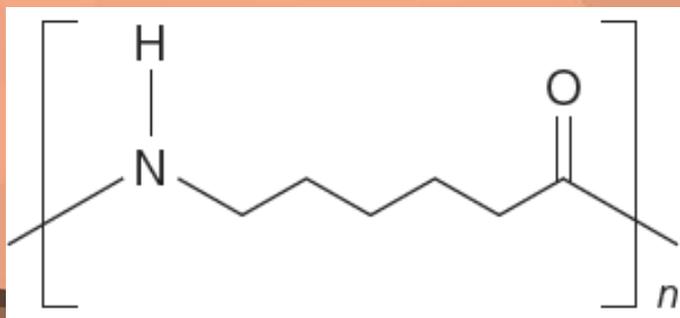


b) PPA is a condensation polymer.

What is the meaning of the term 'condensation polymer'?

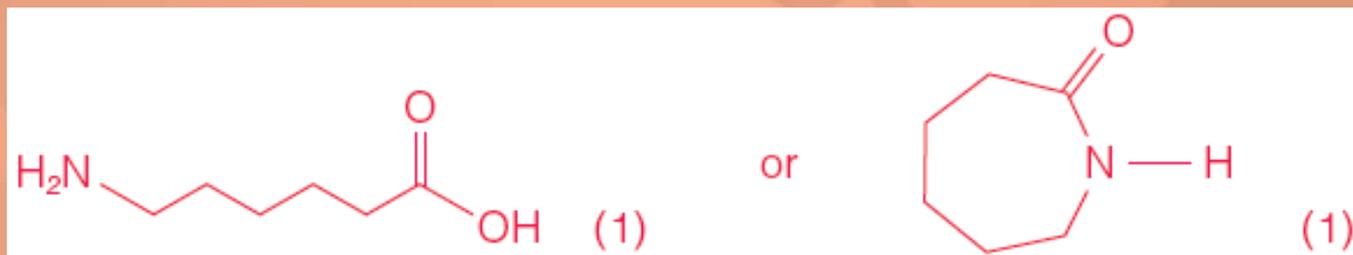
b) A condensation polymer is formed when many monomer molecules join together via condensation reactions, with the elimination of simple molecules, such as water. (1)

c) Nylon-6 is a polyamide that can be made from a single monomer. Its structure is shown below:



 Unit Exercise (p.83)19 (continued)

i) Draw the structure of the monomer that could be used to form nylon-6.



ii) PPA has more crystalline areas than nylon-6. This gives PPA a higher melting temperature than nylon-6. Explain this higher melting temperature in terms of the intermolecular forces involved.

ii) The polymer chains of PPA are closer than those in nylon-6. (1)

So, the intermolecular forces in PPA are stronger. (1)

To melt PPA, more heat is needed to overcome the stronger intermolecular forces.



Unit Exercise (p.83)

19 (continued)

d) State the difference in the biodegradability of objects made of PPA to those made of polyalkenes. Explain this difference.

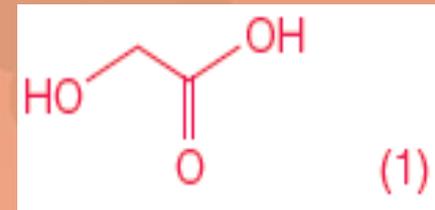
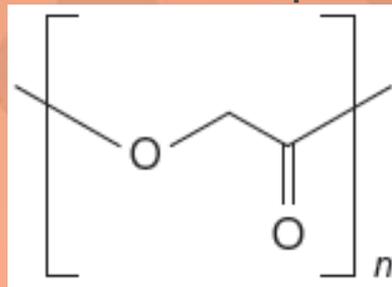
d) Objects made of PPA are biodegradable while those made of polyalkenes are not. (1)

PPA is a polyamide that is readily hydrolysed by acids / bases / enzymes. (1)

Unit Exercise (p.83)

20 Polyglycolic acid (PGA) is a polymer that is developed as an inner coating for plastic bottles.

The structure of PGA is shown below.



- Draw the structure of the monomer of PGA, glycolic acid.
- Identify the other product formed in the polymerisation process and explain why this polymerisation is called a condensation reaction.

H_2O (1)

A small molecule/ H_2O is eliminated (1)

- Explain, in chemical terms, why the disposal of PGA poses less harm to the environment than that of hydrocarbonbased synthetic polymers.

Any one of the following:

- Polyester hydrolyses steadily in the presence of acid or alkali. (1)
- PGA is biodegradable. (1)
- PGA has a lower amount of carbon content, it burns more completely during incineration. (1)



Unit Exercise (p.83)

21 The diagram below shows a plastic bottle for cough syrup made from polythene (PE):



- Suggest a moulding method for making this plastic bottle.
- Give the TWO common types of PE. Explain, from molecular level, which type of PE is more suitable in making this plastic bottle.
- Explain, from molecular level, why bottles made from poly(ethylene terephthalate) (PET) would generally be harder than bottles made from PE.

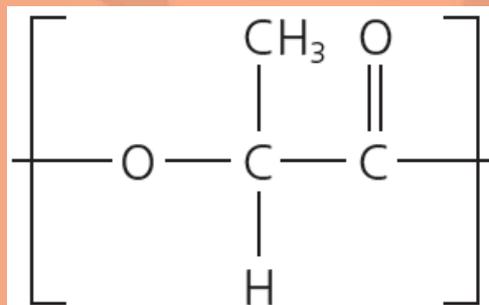
(HKDSE, Paper 2, 2014, 2(c))



Unit Exercise (p.83)

21 (continued)

d) Some people suggest, from the perspective of environmental protection, switching from using PE and PET to using polylactide (PLA) in making this type of plastic bottles. The repeating unit of PLA is shown below:



- It is known that PLA can be produced from the polymerisation of lactic acid through esterification. Give the structure of lactic acid.
- Explain why the switching might be environmentally friendly.
- Suggest a potential problem of widely replacing PE and PET by PLA.

(HKDSE, Paper 2, 2014, 2(c))

Unit Exercise (p.83)

22 Suggest a suitable fabrication process for each of the following plastic items.



- a) Vacuum forming
- b) Injection moulding
- c) Extrusion moulding
- d) Compression moulding
- e) Blow moulding