Book 7

Topic 14
Materials Chemistry

Content

- **50.1** Green chemistry
- **50.2** The use of less hazardous chemical syntheses
- **50.3** The use of safer solvents and auxiliary substances
- **50.4** How green is a process?
- **Key terms**
- **Summary**
- **Unit Exercise**
- **Topic Exercise**

50.1 Green chemistry (p.135)

Chemistry has provided valuable materials in the form of medicines, food products, cosmetics, paints, synthetic polymers, and high-tech substances like liquid crystals and nanoparticles. Chemists have used their knowledge and skill to prepare a large number of new materials which are far better and more useful than natural ones. The processes on industrial scale involve many chemical reactions using huge quantities and wide varieties of reactants, solvents, etc. These chemical processes not only produce the required products but also large quantities of undesired and harmful substances. There is a pressing need to minimise chemical pollution.

50.1 Green chemistry (p.135)

Chemistry has provided valuable products

50.1 Green chemistry (p.135)

Sustainable development (可持續發展) has emerged as an alternative for overcoming activities (such as over-population, resource overconsumption, and environmental degradation) that have resulted in damage to the Earth’s environment and quality of life for this generation and future ones. The most widely cited definition states that sustainable development is development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs.

50.1 Green chemistry (p.135)

Green chemistry (綠色化學) involves the 'design of chemical products and processes to reduce or eliminate the use and generation of hazardous substances'.

Specifically, green chemistry can aid in achieving sustainability through:

- the development of economical renewable energy sources;
- the use of reagents derived from renewable materials; and
- replacing pollution-generating technologies with clean alternatives.

Green chemistry protects the environment, not by cleaning up, but by inventing new chemical processes that do not pollute.

There are twelve key principles of green chemistry (table on the next page).

50.1 Green chemistry (p.135)

Table 50.1 Green chemistry's 12 principles

1	Prevent waste handling	Design chemical syntheses to prevent waste. Leave no wastes to treat or clean up.
2	Maximise atom economy	Design syntheses that maximise the incorporation of the starting materials into the final product.
3	Design less hazardous chemical syntheses	Design syntheses that use and generate substances with little or no toxicity to either humans or the environment.
4	Design safer chemicals and products	Design chemical products that are fully effective yet have little or no toxicity.
5	Use safer solvents and auxiliary substances	Avoid using solvents, separation agents, or other auxiliary substances. If you must use these chemicals, use safer ones.
6	Increase energy efficiency	Run chemical reactions at room temperature and pressure whenever possible.
7	Use renewable feedstocks	Use starting materials (also known as feedstocks) that the renewable rather than depletable. The source of renewable feedstocks is often agricultural products; the source of depletable feedstocks is often fossil fuels or mining operations.

50.1 Green chemistry (p.135)

8	Avoid chemical derivatives	Avoid using blocking groups or any temporary modifications if possible. Derivatives use additional reagent and generate waste.
9	Use catalysts N2	Catalysts generally reduce energy usage and waste products.
10	Design chemicals and products to degrade after use	Design chemical products that break down to innocuous substances after use.
11	Analyse in real time to prevent pollution	Include in-process, real-time monitoring and control during syntheses to minimise or eliminate the formation of waste products.
12	Minimise the potential for accidents	Design chemicals and their physical forms (solid, liquid, or gas) that minimise the potential for chemical accidents including explosion, fire and release to the environment.

50.1 Green chemistry (p.135)

Benefits of green chemistry

Green chemistry offers many benefits to scientists, educators, businesses, policymakers, and the public.

- For scientists, it provides a platform for not only avoiding or eliminating hazards and waste, but also for creating new, innovative and efficient methodologies.
- For educators, it can be a tool for inspiring students to pursue scientific careers, providing context to a subject that is often abstract.

50.1 Green chemistry (p.135)

- For businesses, it can help realise cost savings through reduced waste disposal costs and reduced worker liability costs, while offering competitive advantage in existing markets, offering a greater value added to customers, and over all higher innovation potential that leads to the creation of new markets.

- For policymakers, it is projected to advance opportunities for environmental outcomes that go beyond what is now possible with existing regulatory policies and reduce social conflict around the trade-off between the environment and economic growth.

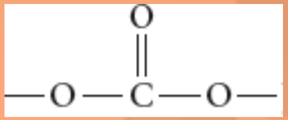
- For the public, it means a cleaner, safer environment, as well as greater economic opportunities.

50.2 The use of less hazardous chemical syntheses (p.139)

Whenever practicable, synthetic methodologies should be designed to use and generate substances that possess little or no toxicity to human health and the environment.

50.2 The use of less hazardous chemical syntheses (p.139)

Synthesis of polycarbonates

Polycarbonates (聚碳酸酯) are a group of thermoplastics containing carbonate groups () in their structures. Polycarbonates are used to produce a variety of products and are particularly useful when impact resistance and transparency are a product requirement (e.g. in bullet-proof glass). Compact discs, riot shields, water bottles, electronic components, safety helmets, headlamp lenses and greenhouses are all typical applications for polycarbonates.

50.2 The use of less hazardous chemical syntheses (p.139)

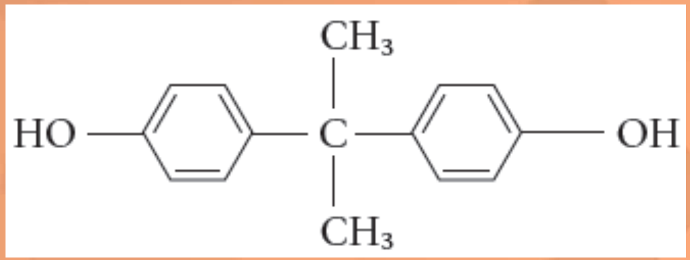
A compact disc made of polycarbonate

A water bottle made of polycarbonate

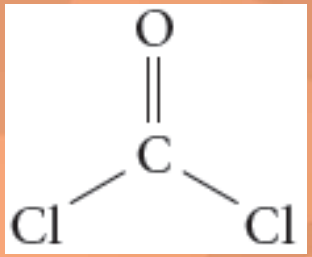
A greenhouse made of polycarbonate

50.2 The use of less hazardous chemical syntheses (p.139)

The polycarbonate most used has been produced by the reaction between bisphenol A and **phosgene (光氣)**.



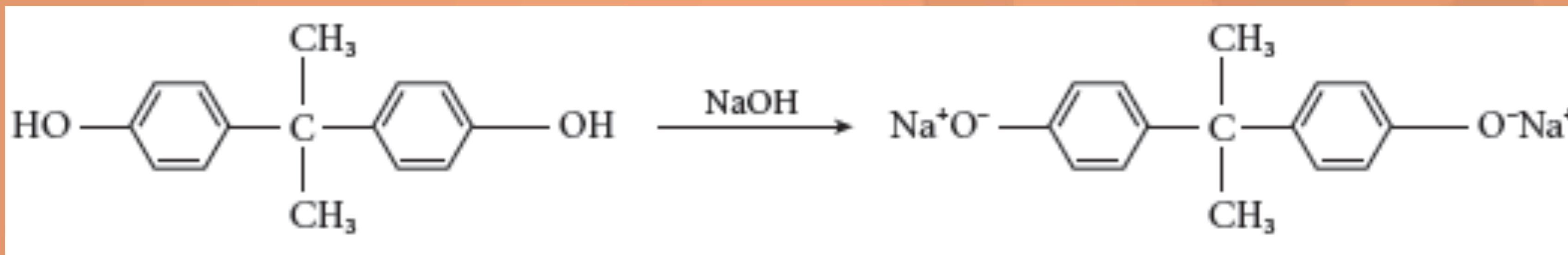
Bisphenol A



phosgene

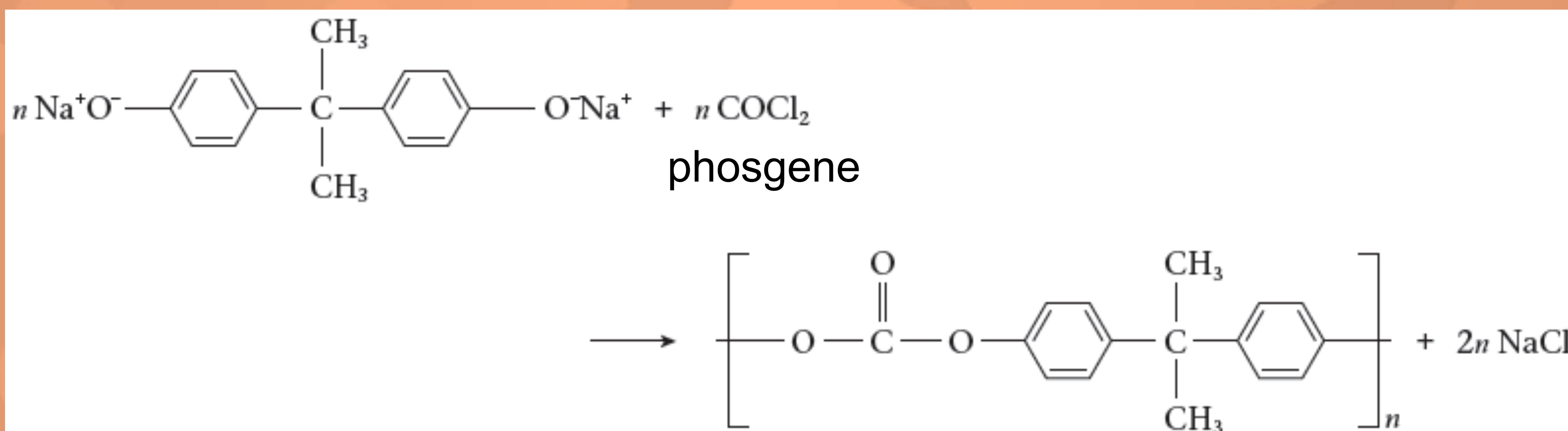
The process starts out with the reaction of bisphenol A with sodium hydroxide to form the disodium salt of bisphenol A. The disodium salt dissolved in water reacts with phosgene dissolved in a chlorinated organic solvent, such as CH_2Cl_2, to give the polycarbonate.

50.2 The use of less hazardous chemical syntheses (p.139)



bisphenol A

disodium salt of bisphenol A



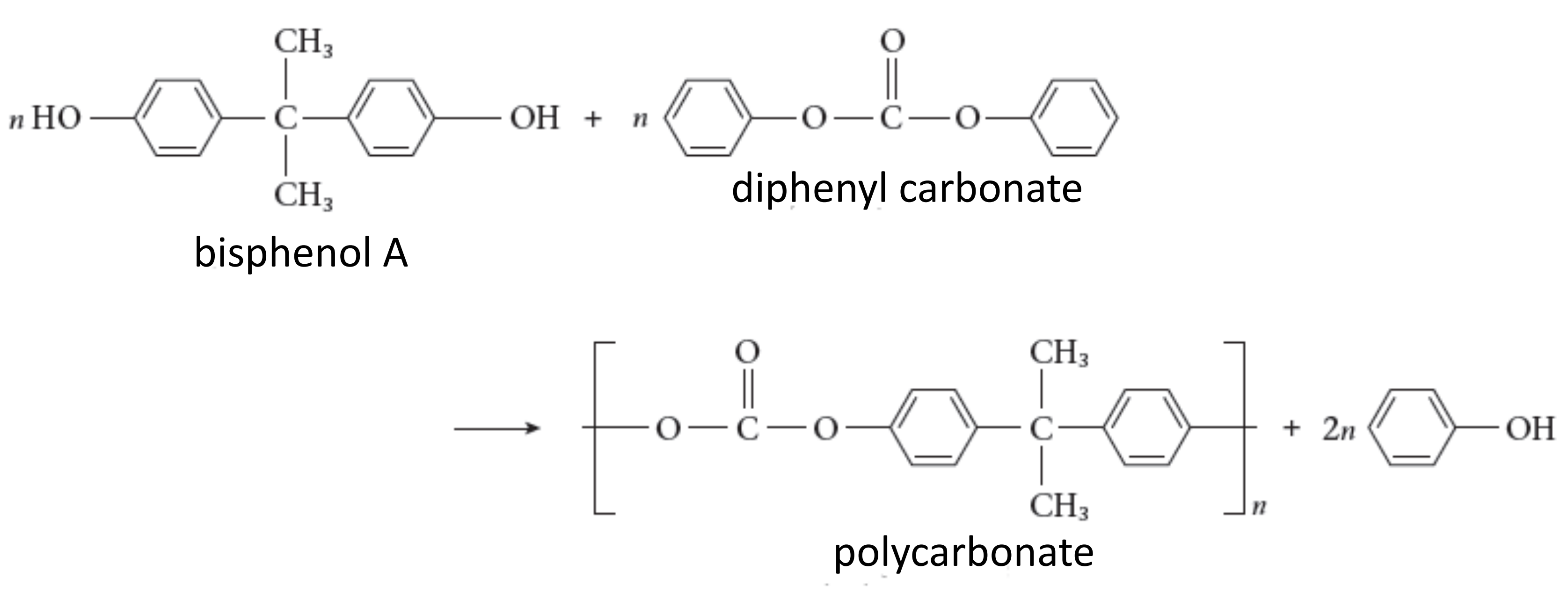
polycarbonate

50.2 The use of less hazardous chemical syntheses (p.139)

The phosgene process entails a number of drawbacks including the toxicity of phosgene, the use of chlorinated organic solvent, and the large quantity of waste water containing the organic solvent which must be treated. The concentrated sodium hydroxide solution adds the problem of corrosion of equipment.

A new non-phosgene process for polycarbonate production relies on the reaction of diphenyl carbonate with bisphenol A in a solvent-free condition.

50.2 The use of less hazardous chemical syntheses (p.139)



This non-phosgene process does not use the highly toxic phosgene. It also avoids the use of chlorinated organic solvent and the production of sodium chloride. This process has gradually replaced the phosgene process.

50.2 The use of less hazardous chemical syntheses (p.139)

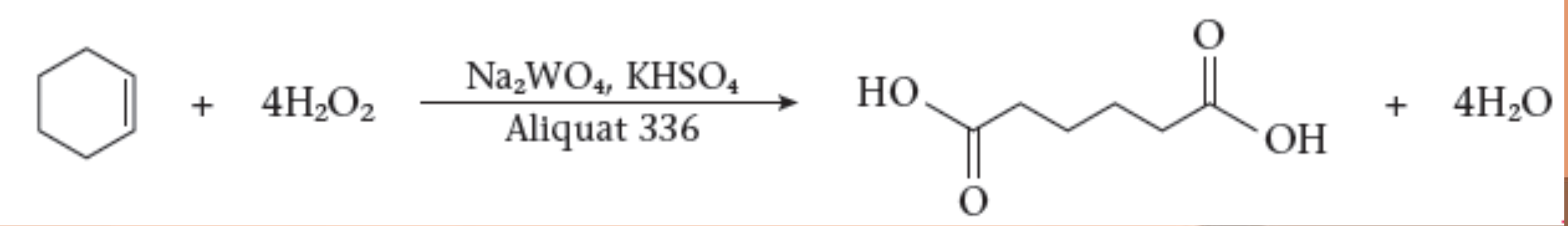
Catalytic oxidation of cyclohexene to hexanedioic acid

Hexanedioic acid is an industrially important compound. It is the monomer used in the manufacture of nylon-6,6. The industrial production of hexanedioic acid involves the oxidation of cyclohexanol or cyclohexanone by nitric acid. The by-product, dinitrogen monoxide (N_2O), is commonly thought to cause global warming and ozone depletion as well as acid rain and smog.

Preparing hexane-1,6-dioic acid by catalytic oxidation of cyclohexene in the presence of a phase-transfer catalyst *Ref.*

50.2 The use of less hazardous chemical syntheses (p.139)

Aqueous hydrogen peroxide solution is an ideal clean oxidising agent as it produces harmless water as the only by-product. Recent research shows that hexanedioic acid can be obtained by the oxidation of cyclohexene with 30% aqueous hydrogen peroxide solution in the resence of small amounts of sodium tungstate (Na_2WO_4), potassium hydrogensulphate and Aliquat 336 ($CH_3(C_8H_{17})_3N^+Cl^-$).



50.2 The use of less hazardous chemical syntheses (p.139)

In the reaction, hydrogen peroxide is used as the principal oxidising agent to substitute the environmentally hazardous nitric acid.

This process is much cleaner than the current method for producing hexanedioic acid. The commercial viability of this route rests on the long-term price and availability of hydrogen peroxide, but the potential is obvious.

50.3 The use of safer solvens and auxiliary substances (p.143)

One of the key principles of green chemistry promotes the use of safer solvents and auxiliary substances. If possible, the use of solvents should be avoided, or if they cannot be eliminated, use safer ones.

Reactions that occur in the gas phase are preferable as they avoid the use of solvents to bring the reactants together. The manufacture of ammonia in the Haber process is an example.

50.3 The use of safer solvens and auxiliary substances (p.143)

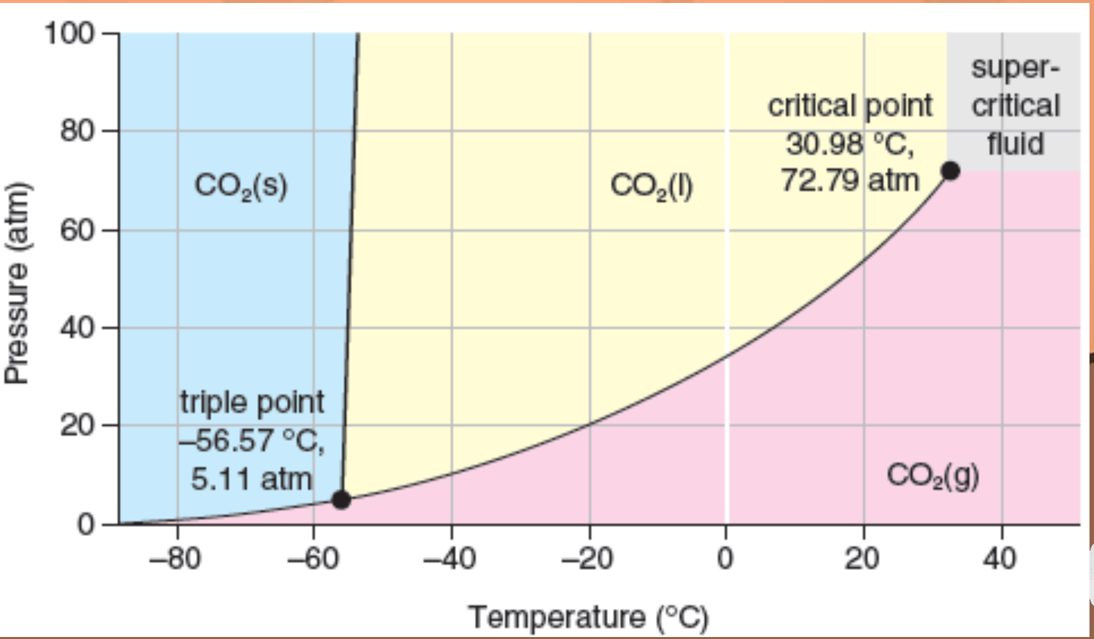
Yet solvents are necessary for many reactions to occur and are also used in the workup process (i.e. extraction, recrystallisation, etc.). Many widely used solvents are toxic and volatile, like alcohols, benzene (known carcinogen), trichloromethane and dichloromethane, that makes these solvents hazardous. These are now gradually replaced by safer green solvents like supercritical carbon dioxide, water and also solvent-free systems.

50.3 The use of safer solvens and auxiliary substances (p.143)

Supercritical carbon dioxide

A pure substance may exist in solid, liquid or gas state. The state of the substsance is decided by its temperature and pressure. Defining state by these two quantities is usually visualised in a so-called phase diagram — example of such a diagram for carbon dioxide is shown in the figure below.

Phase diagram of carbon dioxide



50.3 The use of safer solvens and auxiliary substances (p.143)

The phase diagram consists of discrete regions that represent the different phases exhibited by carbon dioxide. Each region corresponds to the range of combinations of temperature and pressure over which that phase is stable.

The curves in the phase diagram correspond to the combinations of temperature and pressure at which two phases can coexist in equilibrium. The curves meet at a so-called **triple point (三相點)**, where the substance coexists in all three phases in equilibrium.

50.3 The use of safer solvens and auxiliary substances (p.143)

As can be seen in the figure in front, the gas-liquid equilibrium curve ends in a so-called **critical point (臨界點)**, which is characterised by critical pressure and critical temperature. At temperatures and pressures greater than the critical values, the substance is in a state that is neither liquid nor gas, usually called a **supercritical fluid (超臨界流體)**.

Supercritical carbon dioxide has interesting hybrid properties: it exhibits gas-like diffusivity, surface tension and viscosity, but also resembles a liquid in density and dissolving properties. Supercritical carbon dioxide is chemically inert, non-toxic, non-flammable and readily available at high purities and at low costs.

50.3 The use of safer solvens and auxiliary substances (p.143)

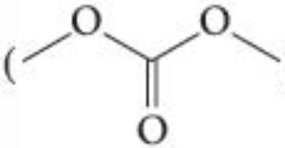
Dichloromethane (CH_2Cl_2) is a suspected carcinogen but is widely used in syntheses and extractions. It was previously used to extract caffeine from coffee, but now decaffeination is performed using supercritical carbon dioxide.

Tetrachloroethene (CCl_2CCl_2) is also a suspected carcinogen and is the main solvent used in dry cleaning processes. A technology making use of supercritical carbon dioxide for dry cleaning clothes has been developed. Dry cleaning machines have now been developed using this technique.

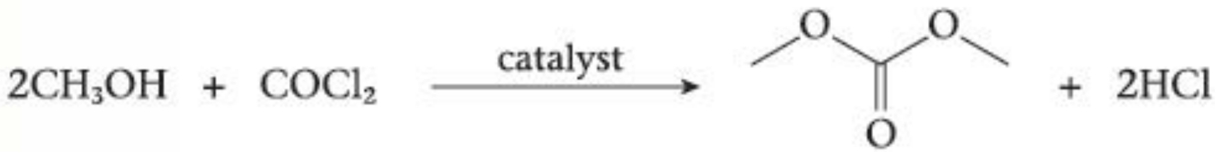
50.4 How green is a process? (p.145)

Some processes and products seem more environmentally friendly than others. Often this is because you see only part of the process. An overall environmental impact analysis should take into account not only the chemical reactions, but also the hazards and consequences of acquiring and transporting the starting materials. Besides, the overall energy demand should also be considered.

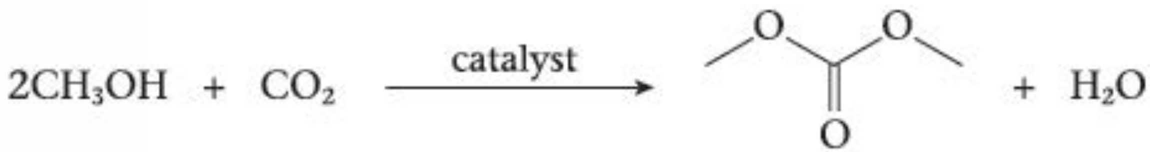
50.4 How green is a process? (p.145)

Q Dimethyl carbonate () is a non-toxic intermediate used in the production of polycarbonates, lubricants, solvents and other products.

Traditionally, dimethyl carbonate is prepared by the reaction between methanol and phosgene ($COCl_2$):



A new production method involving methanol and carbon dioxide is currently in research phase:



Suggest why the new method is considered to be greener than the traditional method.

50.4 How green is a process? (p.145)

Answer

The carbon dioxide used in the new method is less hazardous when compared with phosgene used in the traditional method.

The carbon dioxide used in the new method is available from flue gas. Depletion is not a problem.

The by-product H_2O produced in the new method is environmentally friendly when compared with the by-produce HCl produced in the traditional method.

Key terms (p.148)

Sustainable development	可持續發展	Green chemistry	綠色化學
Phase-transfer catalyst	相轉移催化劑	Phase diagram	相圖
Triple point	三相點	Critical point	臨界點
Supercritical fluid	超臨界流體		

Summary (P.148)

1) Sustainable development is development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs.

2) Green chemistry involves the ‘design of chemical products and processes to reduce or eliminate the use and generation of hazardous substances’.

Summary (P.148)

3) Examples of applying green chemistry practices in the production of synthetic materials include:

- the use of less hazardous chemical syntheses;
- the use of catalysts, such as phase-transfer catalysts;
- the use of safer solvents and auxiliary substances, such as using supercritical carbon dioxide and water as solvents.

Unit Exercise (p.149)

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

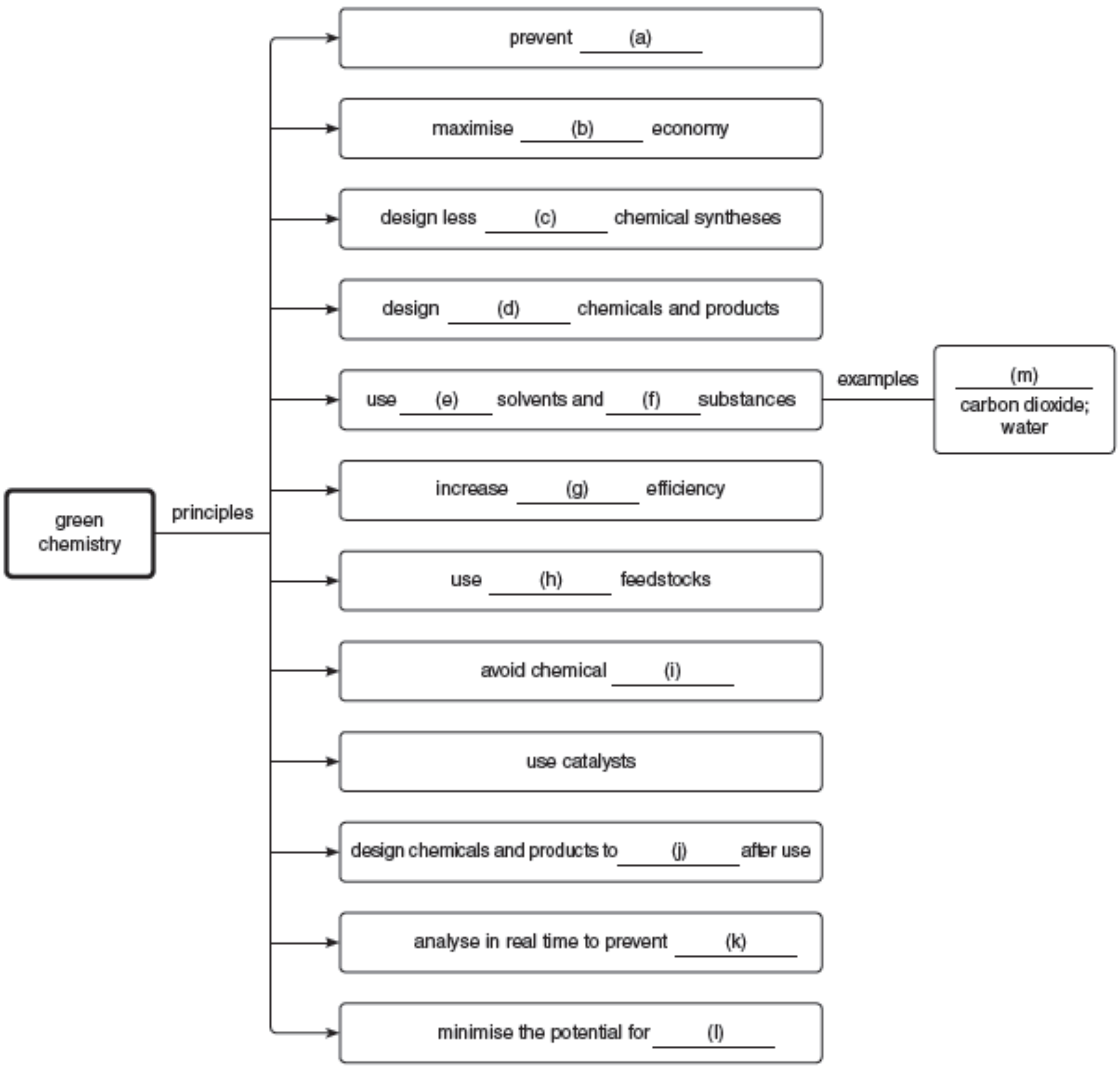
question targeted at level 3 and above;
question targeted at level 4 and above;
question targeted at level 5.

Unit Exercise (p.149)

PART I KNOWLEDGE AND UNDERSTANDING

1 Complete the following concept map.

Unit Exercise (p.149)



a) waste handling
b) atom
c) hazardous
d) safer
e) safer
f) auxiliary
g) energy
h) renewable
i) derivatives
j) degrade
k) pollution
l) accidents
m) supercritical

Unit Exercise (p.149)

PART II MULTIPLE CHOICE QUESTIONS

2 Which of the following statements about supercritical carbon dioxide is correct?

A It shows the properties of both a solid and a liquid.

B It can dissolve most polar carbon compounds.

C It can react with many catalysts.

D Its viscosity is lower than that of common liquid organic solvents.

Answer: D

Unit Exercise (p.149)

3 Which of the following is / are advantage(s) of using water as a solvent in chemical reactions?

(1) The reactions would become exothermic.

(2) Water is readily available.

(3) Water can dissolve most organic reactants.

A (1) only

B (2) only

C (1) and (3) only

D (2) and (3) only

Answer: B

Unit Exercise (p.149)

4 Which of the following statements about catalysts are correct?

(1) They speed up chemical processes.

(2) They reduce the energy requirement of chemical processes.

(3) They increase the percentage yield of products in chemical processes.

A (1) and (2) only

B (1) and (3) only

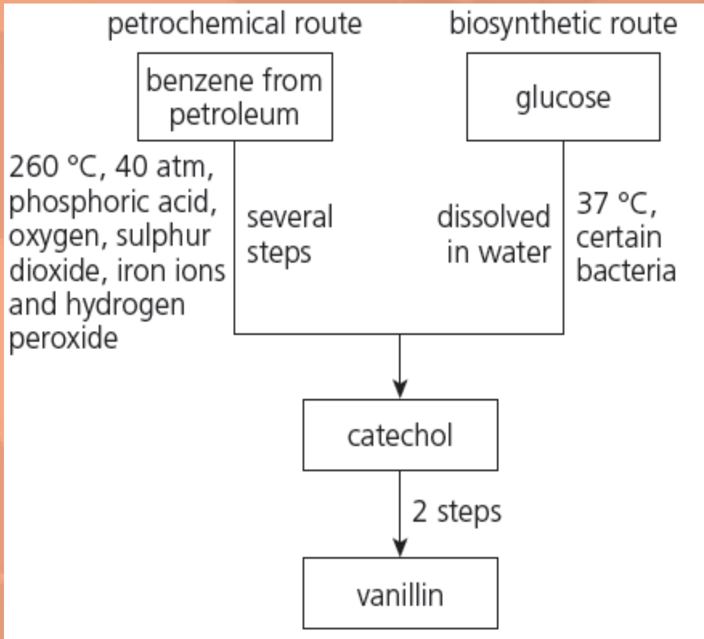
C (2) and (3) only

D (1), (2) and (3)

Answer: A

Unit Exercise (p.149)

5 The following diagram shows two routes for the synthesis of the flavouring vanillin.



The biosynthetic route is 'greener' than the petrochemical route because
(1) a renewable starting material is used.
(2) atmospheric pressure is used.
(3) no toxic chemical is used.

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

Answer: D

Unit Exercise (p.149)

Answer: B

6 Ammonia is manufactured by the Haber process.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

The Haber process is considered to be an example of green chemistry because
(1) no solvent is required for the process.
(2) no catalyst is required for the process.
(3) the raw material nitrogen is available in large amount in the atmosphere.

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

Unit Exercise (p.149)

PART III STRUCTURED QUESTIONS

7 Give a reason, from the perspective of green chemistry, why scientists often seek new catalysts for established chemical processes.

Any one of the following:

- To allow lower pressures / temperatures. (1)
- Use recyclable catalysts — needs qualifying / longer lasting / less toxic catalysts. (1)

Unit Exercise (p.149)

8) A new method for producing phenol (C6H5OH) is by reacting benzene with dinitrogen monoxide in the presence of a solid catalyst.

$$C_6H_6 + N_2O \rightarrow C_6H_5OH + N_2$$

The reaction is carried out in a gas phase at around 400 °C. Suggest TWO reasons why the above reaction is considered to be green.

Unit Exercise (p.149)

8 (continued)

Any two of the following:

- The process uses a solid catalyst, which can easily be separated from the gaseous products (thus saving energy). (1)
- The only other product of the reaction is gaseous nitrogen, which is non-toxic / safe / not a harmful product. (1)
- A relatively moderate operating temperature reduces overall costs. (1)
- High atom economy (1)

Unit Exercise (p.149)

9 Maleic anhydride ($C_4H_2O_3$) is widely used in the manufacture of polyester resins and paints.

There are two synthetic routes to produce maleic anhydride: the benzene route and the butane route.

Route 1 Benzene reacts with oxygen in air in the presence of V_2O_5 and MoO_3 catalysts.

$$2C_6H_6 + 9O_2 \rightarrow 2C_4H_2O_3 + 4H_2O + 4CO_2$$

Route 2 Butane reacts with oxygen in air in the presence of $(VO)_2P_2O_5$ catalyst.

$$2C_4H_{10} + 7O_2 \rightarrow 2C_4H_2O_3 + 8H_2O$$

Which route is 'greener'? Explain your choice.

Route 2 is 'greener'.

Route 1 uses a carcinogenic / toxic feedstock — benzene, *Route 2* uses a safer feedstock — butane. (1)

The atom economy of *Route 2* is higher than that of *Route 1*. (1)

Unit Exercise (p.149)

10 The following chemical equation shows how vinyl acetate can be obtained.

$$2CH_3COOH + 2CH_2{=}CH_2 + O_2 \xrightarrow{Pd} 2CH_3COOCH{=}CH_2 + 2H_2O$$

vinyl acetate

Give TWO reasons why this reaction can be considered as green.

(HKDSE, Paper 2, 2018, 2(a)(i))

Unit Exercise (p.149)

11) Butyl ethanoate is an ester used as a pineapple flavouring. It can be synthesised from butan-1-ol by two different processes.

Process 1 is a one-step process.

$CH_3CH_2CH_2CH_2OH + CH_3COOH \rightleftharpoons CH_3COOCH_2CH_2CH_2CH_3 + H_2O$

Process 2 is a two-step process.

$CH_3COOH + SOCl_2 \rightarrow CH_3COCl + SO_2 + HCl$

$CH_3CH_2CH_2CH_2OH + CH_3COCl \rightarrow CH_3COOCH_2CH_2CH_2CH_3 + HCl$

a) In an experiment, a chemist produced 22.4 g of butyl ethanoate from 21.0 g of butan-1-ol.

i) Suggest the conditions required for the reaction.

Acid catalyst Heat/reflux (1)

ii) Calculate the percentage yield of butyl ethanoate.

(Relative atomic masses: H = 1.0, C = 12.0, O = 16.0)

ii) Theoretical yield of ester $= 21.0\ g \times \frac{116.0\ g\ mol^{-1}}{74.0\ g\ mol^{-1}}$

Percentage yield of ester $= \frac{22.4\ g}{32.9\ g} \times 100\% = 68.1\%$ (1)

Unit Exercise (p.149)

11 (continued)

b) Which process would you choose for the manufacture of butyl ethanoate? Explain your choice.

b) Process 1

Any two of the following:

- Higher atom economy (1)
- Less toxic reactants / less toxic products / less hazardous reactants / less hazardous products (1)
- Cheaper starting materials / more readily available starting materials (1)
- Fewer steps / one step rather than two steps (1)

Unit Exercise (p.149)

12 Ethanoic acid, CH_3COOH, is used to make esters. Some information about two of the processes used to make ethanoic acid is given below.

Process 1

This is a one-step process that involves the reaction of methanol with carbon monoxide.

$$CH_3OH + CO \longrightarrow CH_3COOH$$

The conditions used are 180 °C and 30 atmospheres pressure. A rhodium / iodine catalyst is used.

The percentage yield for this process is 99%.

Process 2

This involves the oxidation of naphtha, a fraction obtained from crude oil.

Liquid naphtha is oxidised using air at a temperature of 180 °C and 50 atmospheres pressure. No catalyst is needed.

A large variety of other products are also formed in this oxidation.

Suggest THREE advantages of making ethanoic acid using *Process 1* rather than *Process 2*.

(OCR Advanced Subsidiary GCE, Chem. A, F322, Jan. 2012, 2(a))

Unit Exercise (p.149)

12 (continued)

Any three of the following:

- *Process 1* has a high atom economy. (1)
- *Process 1* has a very efficient conversion of reactants to products / not much waste of starting material. (1)
- *Process 1* uses a lower pressure. (1)
- *Process 1* uses up toxic carbon monoxide. (1)
- *Process 1* uses methanol which can be produced from biomass. (1)

Topic exercise (p.153)

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.**

Topic exercise (p.153)

PART I MULTIPLE CHOICE QUESTIONS

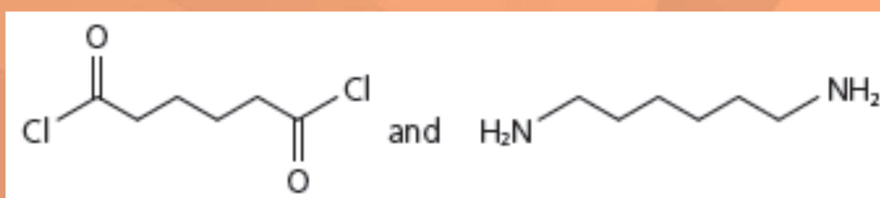
1 The formula of the repeating unit of a polymer is

$$-\!\!\left[\, OC(CH_2)_4CONH(CH_2)_6NH \,\right]\!\!-$$

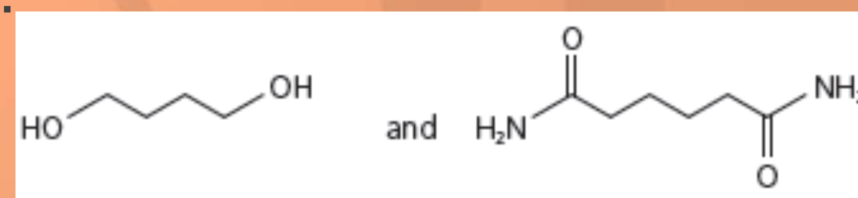
Answer: A

The polymer is formed by the reaction of

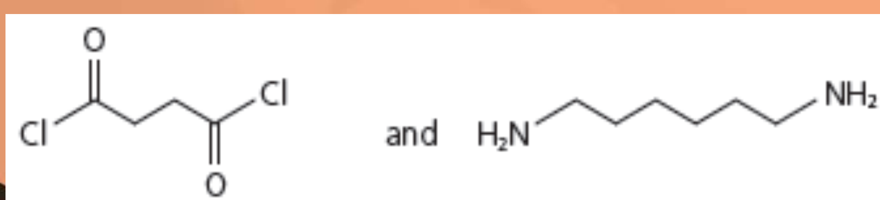
A.



B.



C.



D.

(Edexcel GCE, Unit 5, 6CH05/01, Jun. 2017, 17)

Topic exercise (p.153)

2 During vulcanisation, sulphur reacts with the polymer chains in the rubber. How does this reaction increase the hardness of rubber?

A It makes the polymer chains shorter.
B It lowers the melting point of rubber.
C It pushes the polymer chains further apart.
D It forms strong bonds between the polymer chains.

Answer: D

Topic exercise (p.153)

3 Which of the following fabrication processes is commonly used to make chocolate box trays?

A Blow moulding

B Compression moulding

C Injection moulding

D Vacuum forming

Answer: D

Topic exercise (p.153)

4 Which of the following statements concerning thermosetting plastics and thermoplastics is correct?

A Thermosetting plastics contain strong covalent bonds while thermoplastics do not.

B Thermosetting plastics do not soften on heating while thermoplastics do.

C Thermosetting plastics conduct electricity while thermoplastics do not.

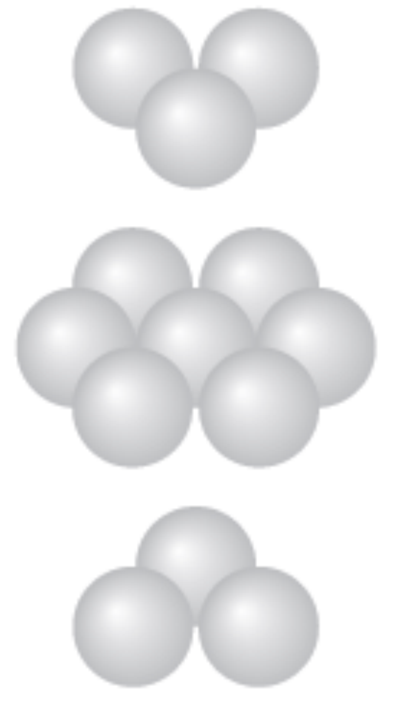
D Thermosetting plastics are biodegradable while thermoplastics are not.

Answer: B

Topic exercise (p.153)

Answer: D

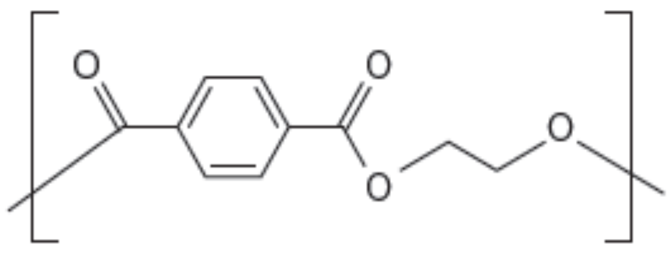
5 The following diagram shows an expanded view of the arrangement of atoms in a metal.
What is the coordination number of each metal atom in the structure?



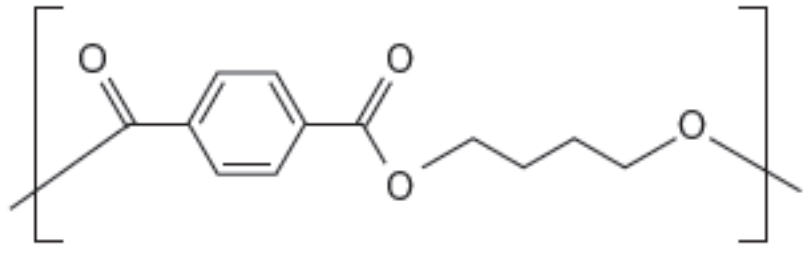
A 4
B 6
C 8
D 12

Topic exercise (p.153)

6 The repeating units of polymers X and Y are shown below.



polymer X



polymer Y

Which of the following statements concerning polymers X and Y are correct?

(1) They are both condensation polymers.
(2) They are both thermosetting plastics.
(3) Polymer X is more flexible than polymer Y.

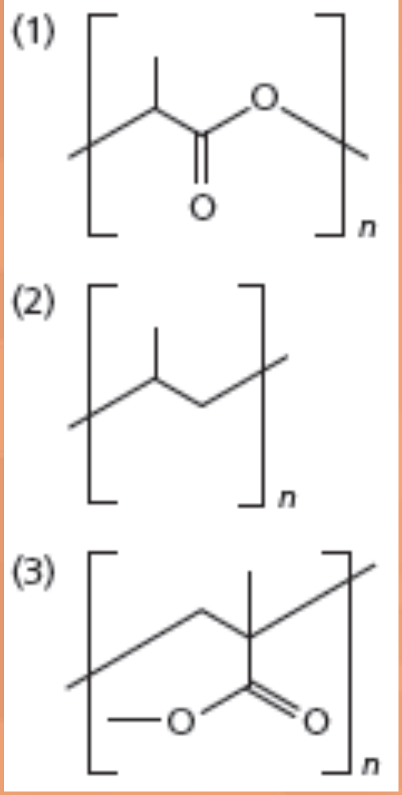
A (1) only
B (2) only
C (1) and (3) only
D (2) and (3) only

Answer: A

(3) There are less dipole-dipole interactions between molecules of polymer Y. Thus, polymer Y is more flexible.

Topic exercise (p.153)

7 Which of the following polymers is / are biodegradable?



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

Answer: B

Topic exercise (p.153)

8 Which of the following statements concerning brass are correct?

(1) It is harder than pure copper.
(2) Its melting point is higher than that of pure copper.
(3) It is a substitutional alloy.

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

Answer: A

Topic exercise (p.153)

Directions: *Each question (Questions 9–10) consists of two separate statements. Decide whether each of the two statements is true or false; if both are true, then decide whether or not the second statement is a correct explanation of the first statement. Then select one option from A to D according to the following table :*
A Both statements are true and the 2nd statement is a correct explanation of the 1st statement. B Both statements are true but the 2nd statement is NOT a correct explanation of the 1st statement. C The 1st statement is false but the 2nd statement is true. D Both statements are false.

Topic exercise (p.153)

9 1st statement
Urea-methanal has cross-links among polymer chains.

2nd statement
Urea-methanal is a condensation polymer.

Answer: B

Topic exercise (p.153)

10 1st statement

Stainless steel is commonly used to make surgical tools

2nd statement

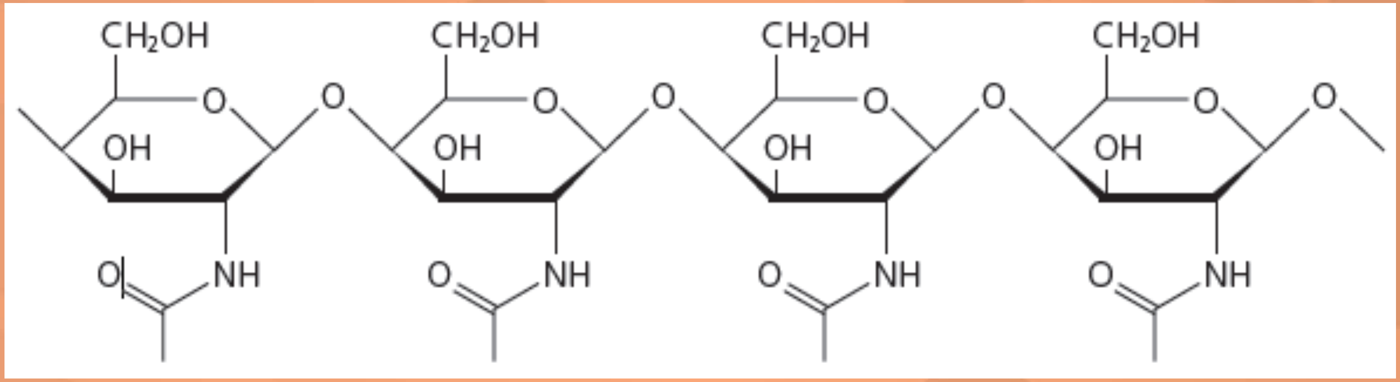
Stainless steel is strong and very corrosion resistant.

Answer: A

Topic exercise (p.153)

PART II STRUCTURED QUESTIONS

11 Substance W is the component of the exoskeleton of crabs. Part of the structure of W is shown below:



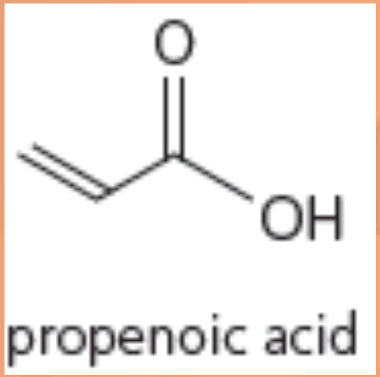
a) Name W.

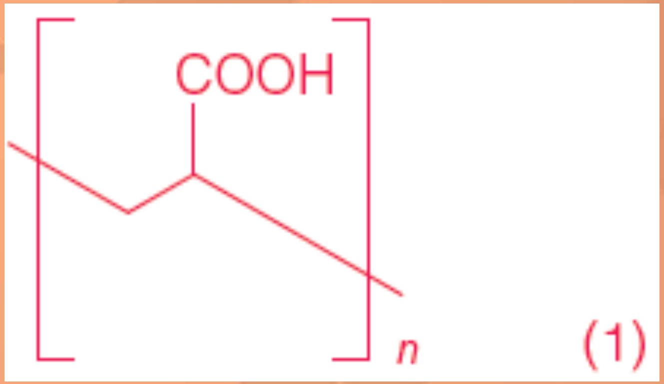
b) With reference to the above structure, suggest why the exoskeleton of crabs is very hard.

(HKDSE, Paper 2, 2018, 2(a)(ii))

Topic exercise (p.153)

12) In recent years, there has been a lot of interest in polymers in the form of gels that absorb aqueous materials. One of the largest uses of these polymers is in baby diapers. The gel which is used in this case is a polymer of propenoic acid.





a) Draw the structure of the polymer formed from propenoic acid.

b) Account for the water absorbing property of the polymer.

The polymer contains a large number of <u>–COOH groups</u>. (1)

These groups can <u>form hydrogen bonds with water</u>. (1)

Topic exercise (p.153)

12 (continued)

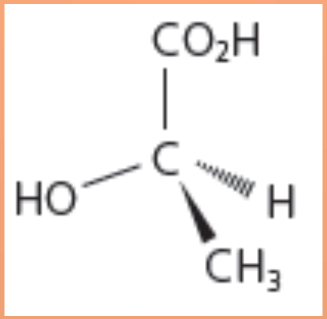
c) For some baby diapers, the monomer is a mixture of propenoic acid and sodium propenoate.
Suggest and explain how the difference in the structure of this polymer compared to one formed only from propenoic acid might affect the water absorbing property of the polymer.

c) Increase water absorbing property
The polymer has ionic side-chains. (1)

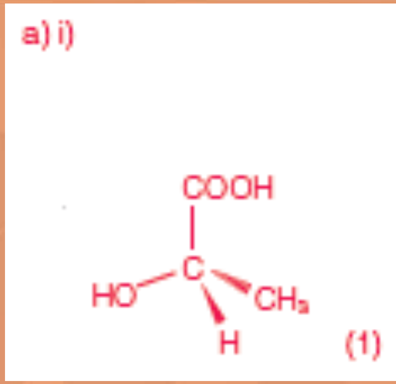
Topic exercise (p.153)

13 The increasing awareness of the diminishing supply of petroleum has resulted in a number of initiatives to replace petroleum-based polymers with those derived from natural products. One such polymer, polylactide (PLA), is produced from corn starch and has a range of applications.

a) The raw material for the polymer, lactic acid, is formed by the fermentation of corn starch using enzymes from bacteria. The structure of lactic acid is shown below.



Topic exercise (p.153)



13 (continued)

ai) Lactic acid exists in two stereoisomeric forms.
Draw the other form.

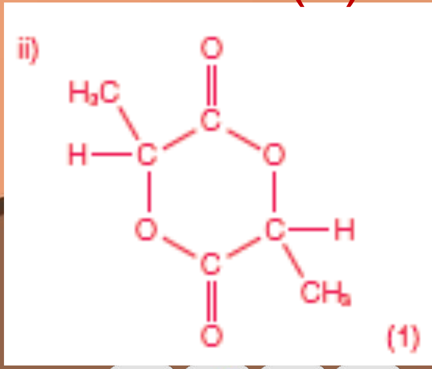
ii) When heated strongly, lactic acid forms a cyclic 'diester'.
Draw the structure of the cyclic diester.

b) i) PLA can be classified as polyester.
Formation of polyesters often involves condensation.
Give a feature of condensation.

Small molecules (H_2O) would be eliminated in the reaction. (1)

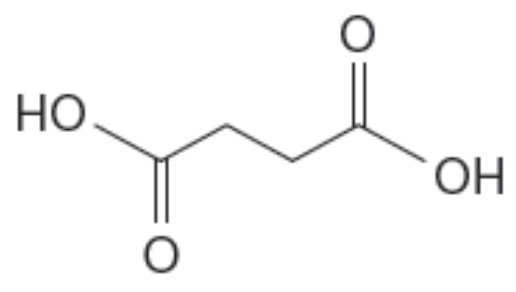
ii) PLA is used to make stitches.
It breaks down after several days.
Explain how PLA breaks down.

The ester links in PLA are hydrolysed in the presence of acids / alkalis. (1)



Topic exercise (p.153)

14 Polymers made using succinic acid and ethane-1,2-diol were first synthesised in 1863. In the 1930s, these polymers were further investigated by Wallace Carothers as possible alternatives to silk. He later abandoned the project in favour of researching polyamides, which he thought would be stronger.



succinic acid

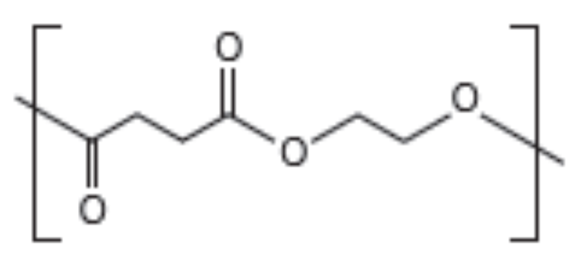
Topic exercise (p.153)

14 (continued)

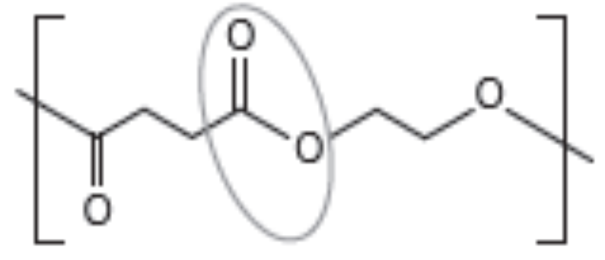
a) i) Draw the structural formula of the repeating unit of the polymer produced using succinic acid and ethane-1,2-diol.

ii) Give the name of this type of condensation polymer.

iii) Circle in your repeating unit the group of atoms responsible for this type of polymer.

14ai)  (1)

14aii) Polyester (1)

14aiii)  (1)

Topic exercise (p.153)

14 (continued)

b) Suggest why Carothers thought that polyamides would form stronger fibres than the polymer in (a)(i).
In your answer, refer to ALL the types of intermolecular forces present in the two types of polymer.

(OCR Advanced GCE, Chem. B (Salters), F334, Jun. 2016, 4)

Intermolecular forces in polyester

Van der Waals' forces (1)

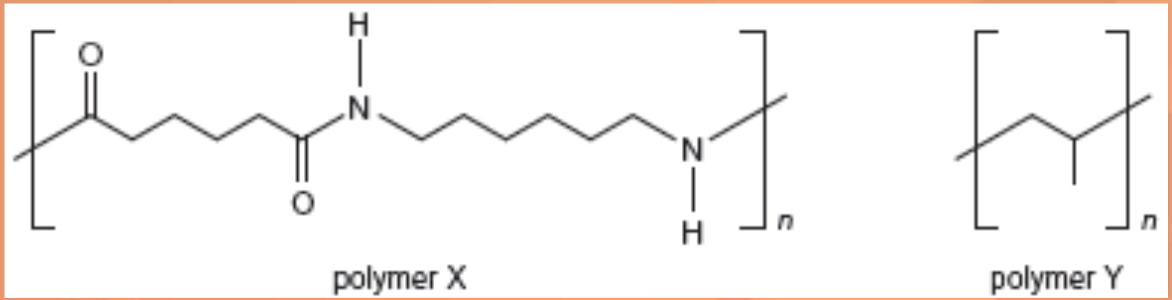
Intermolecular forces in polyamide

Van der Waals' forces and hydrogen bonds (1)

Hydrogen bonds are stronger than van der Waals' forces. (1)

Topic exercise (p.153)

15 The structures of two polymers, X and Y, are shown below.



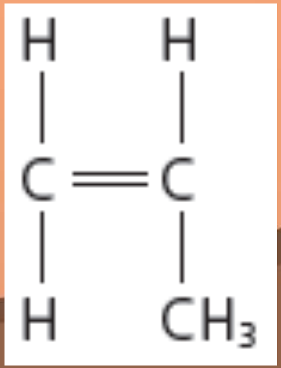
a) For each polymer,

i) draw the structure(s) of the monomer(s);

a) i) Monomers of polymer X

$H_2N–(CH_2)_6–NH_2$ (1) and $HOOC–(CH_2)_4–COOH$ (1) or $ClOC–(CH_2)_4–COCl$ (1)

Monomer of polymer Y



(1)

Topic exercise (p.153)

15 (continued)

aii) state the type of polymerisation used to produce it.

b) Suggest why the density of polymer Y is lower than that of polymer X.

ii) Polymer X — condensation (1)
Polymer Y — addition (1)

b) Hydrogen bonds exist between molecules of polymer X. (1)
Only van der Waals' forces exist between the molecules of polymer Y. (1)
Hydrogen bonds are stronger than van der Waals' forces.
The molecules in polymer X are closer than those in polymer Y. (1)

Topic exercise (p.153)

16 Many shopper bags made of synthetic polymers are used and then thrown away.
Most of these bags are sent to landfills.
One way of reducing the amount of waste in landfills is recycling.
Describe the advantages and disadvantages of recycling products made of synthetic polymers.

Topic exercise (p.153)

16 (continued)

Advantages

Any two of the following:

- Saves raw materials / crude oil (1)
- Landfill sites do not fill up (1)
- As synthetic polymers are non-biodegradable (1)
- Less possible damage to animals from discarded waste (1)
- Less energy used (in recycling than in starting from crude oil) (1)

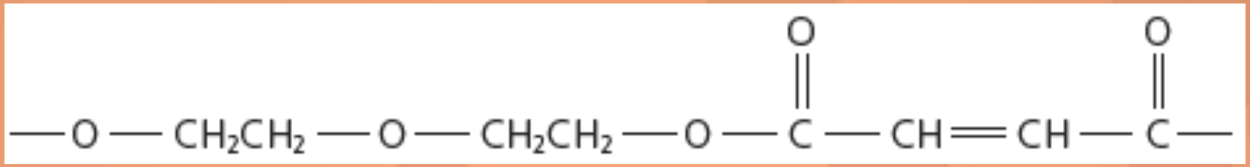
Disadvantages

Any two of the following:

- Transport to collection area / recycling point uses fuel. (1)
- Collection point may cause litter problem / eyesore etc. (1)
- Synthetic polymers need to be sorted. (1)

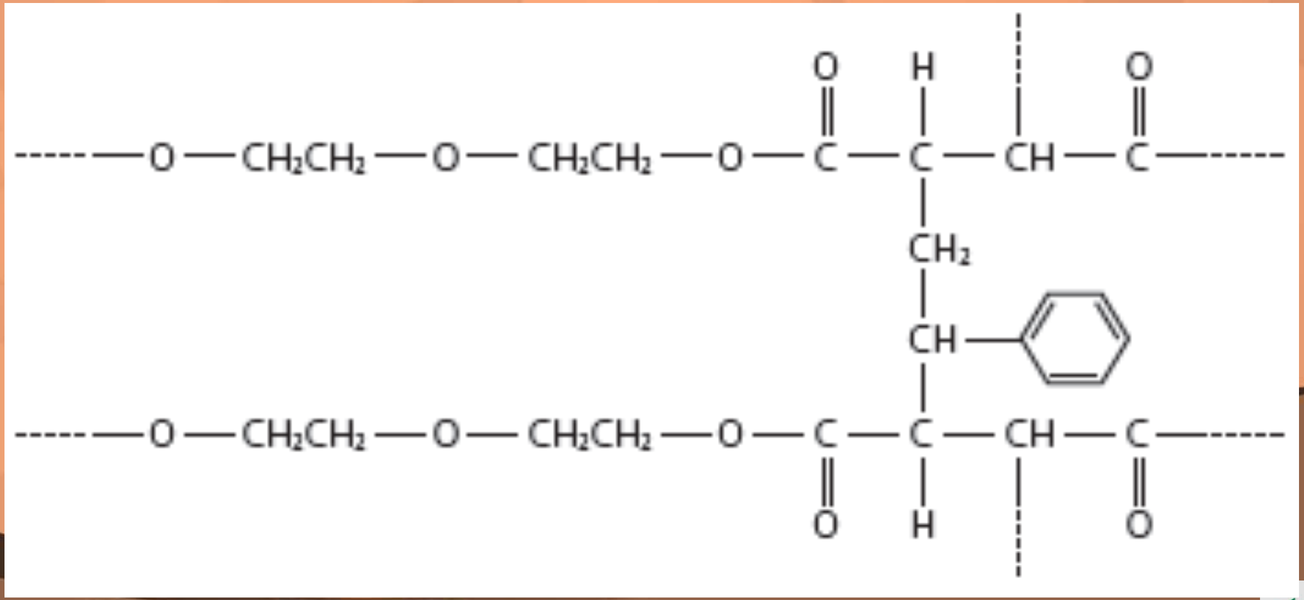
Topic exercise (p.153)

17 The repeating unit of a polymer X is shown below:



a) Draw the structures of the monomers of X.

b) Compound A joins molecules of X together to form Y. Part of the structure of Y is shown below:



Topic exercise (p.153)

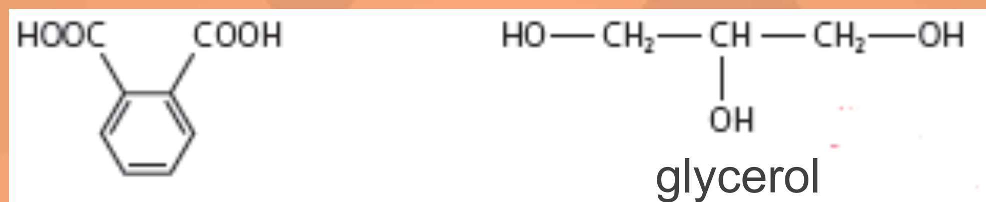
17 (continued)

bi) Draw the structure of A.
ii) Comment on the thermal property of Y.
iii) Suggest one way to control the rigidity of Y. Explain your answer.
c) Y is used to make the body of a boat.
i) Suggest a moulding method for making the body of the boat.
ii) Suggest one advantage of using Y over iron in making the body of a boat.

(HKDSE, Paper 2, 2018, 2(c))

Topic exercise (p.153)

18 When phthalic acid reacts with glycerol, the reaction leads first to the formation of a fairly soft material, which on further heating yields a material which is hard and does not melt on heating. Explain the above observations.



Phthalic acid

The reaction between phthalic acid and glycerol leads initially to molecules that are either linear, branched or both. (1)
But since glycerol is tri-functional, crosslinking ultimately takes place between these molecules leading to a material which is hard and does not melt on heating. (1)

Topic exercise (p.153)

19 a) Throwing away items made from synthetic polymers after use is a major environmental concern. Suggest TWO main reasons.

b) For each reason suggested in (a), give a strategy that has been adopted to reduce the concern.

19 a) Any two of the following:

- Synthetic polymers are non-biodegradable. (1)
- Synthetic polymers are made from crude oil. (1)
- Synthetic polymers produce toxic gases on burning. (1)

b) Any one of the following:

- Develop biodegradable polymers. (1)
- Recycle polymer waste / use renewable resources. (1)

Topic exercise (p.153)

20 Feeding bottles for babies can be made with polypropene. Briefly describe the fabrication process involved in the production of feeding bottles from polypropene beads.

20
- Make a polypropene hollow tube by extrusion moulding. (1)
- Clamp the hollow tube in semimolten state between the two halves of an open two-part mould. (1)
- Close the mould.
- Blow compressed air into the polypropene tube, forcing the tube walls to conform to the contours of the mould. (1)
- Remove the finished product from the mould when the polypropene cools to a solid. (1)

Topic exercise (p.153)

21 Chromium and other elements are introduced into iron to form stainless steel.

a) Name ONE of the other elements introduced.

Carbon/nickel (1)

b) Explain why chromium is introduced into iron.

Increase the corrosion resistance of iron (1)

c) The unit cell of chromium is shown below:

i) Name the type of unit cell of chromium

Body-centred cubic structure (1)

Topic exercise (p.153)

21 (continued)

cii) Calculate the number of atoms present in ONE unit cell of chromium.

Number of atoms in one unit cell = 1+ $\left(8\times\frac{1}{8}\right)=2$ (1)

iii) Given that the edge length of a unit cell of chromium is 2.96 x 10^{-10} m, calculate the density of solid chromium, in g cm^{-3}.
(Relative atomic mass: Cr = 52.0; Avogadro constant = 6.02 x 10^{23} mol^{-1})

iii) Edge length of unit cell of chromium = 2.96 x 10^{-8} cm

Volume of one unit cell of chromium = (2.96 x 10^{-8} cm)^3=2.59x10^{-23} cm^3

Mass of one atom of chromium = $\frac{Molar\ mass}{Avogadro\ constant}=\frac{52.0\ g\ mol^{-1}}{6.02\times10^{23}mol^{-1}}$

= 8.64 x 10^{-23} g

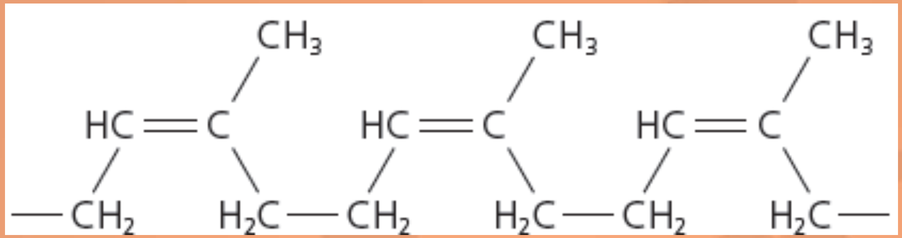
Mass of chromium atom in one unit cell = 2 x 8.64 x 10^{-23} g

Density of solid chromium = $\frac{Mass\ of\ one\ unit\ cell}{Volume\ of\ one\ unit\ cell}=\frac{2\times8.64\times10^{-23}g}{2.59\times10^{-23}cm^3}$ (1)

= 6.67 g cm^{-3} (1)

Topic exercise (p.153)

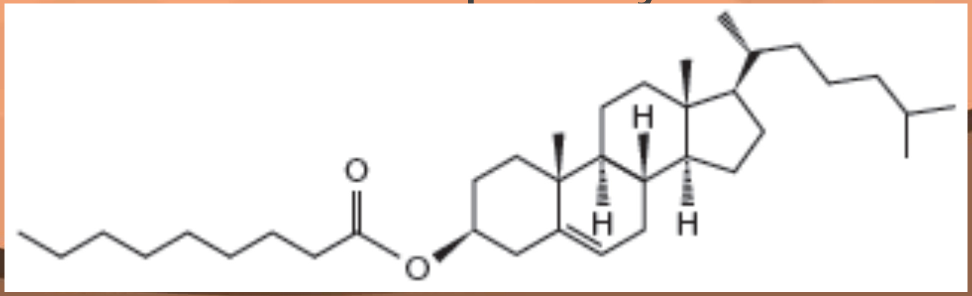
22 a) A portion of the structure of natural rubber is shown below:



Suggest why natural rubber becomes hardened when it is heated with sulphur.

b) In terms of molecular structure, explain why high density polyethene (HDPE) molecules are more closely packed than low density polyethene (LDPE) molecules.

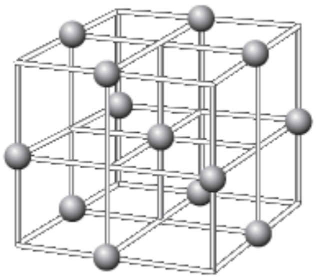
c) The structure of compound A is shown below: Explain whether A would exhibit liquid crystal behaviour.



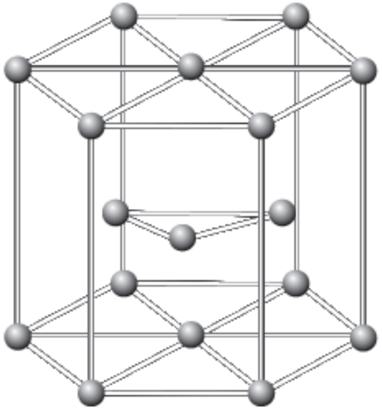
Topic exercise (p.153)

22 (continued)

d) The diagrams below show the unit cell of copper crystal and a portion of the structure of zinc crystal:



copper crystal



zinc crystal

i) Refer to the unit cell of copper crystal.

I) State the coordination number of a copper atom.

II) Deduce the number of copper atoms in the unit cell.

Topic exercise (p.153)

22 (continued)

dii) Refer to the portion of the structure of zinc crystal.

I) Name the type of packing.

II) State one similarity between the packing of copper crystal and that of zinc crystal.

III) Discuss the difference between the packing of copper crystal and that of zinc crystal.

iii) Name an alloy containing copper and zinc that can be used to make water taps.

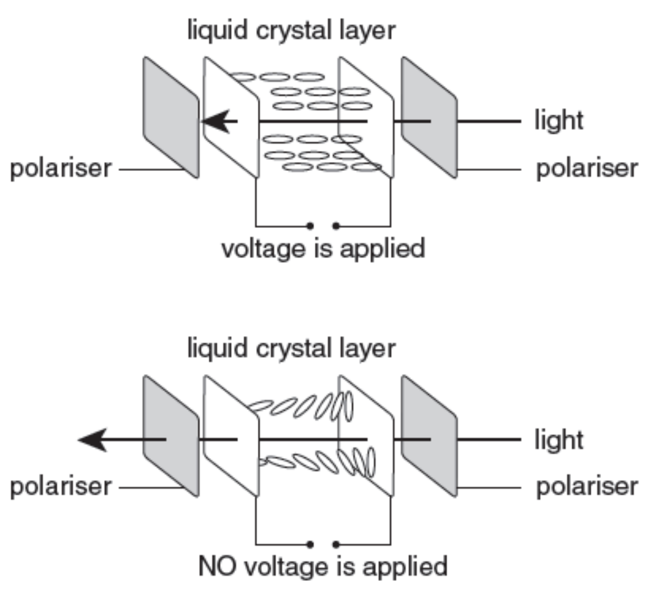
(HKDSE, Paper 2, 2017, 2(a)–(b))

Topic exercise (p.153)

23 Liquid crystals can be used to make displays for mobile phones.

a) How do molecules arrange in the smectic phase of liquid crystals?

b) The following diagram illustrates the basic working principle of one pixel in liquid crystal displays.



Explain why the pixel appears dark when a voltage is applied to the liquid crystal layer.

Topic exercise (p.153)

23 (continued)

c) Some scientists suggested that the use of nanomaterials may increase the resolution of displays.

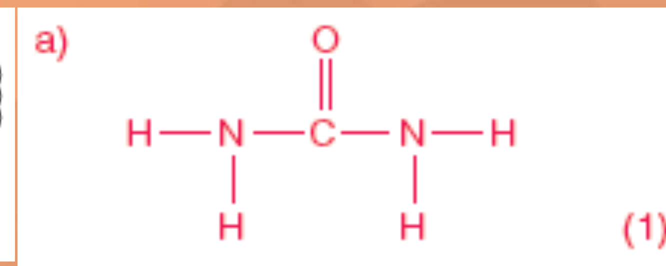
i) State the meaning of the term 'nanomaterials'.

ii) Suggest why the use of nanomaterials may increase the resolution of displays.

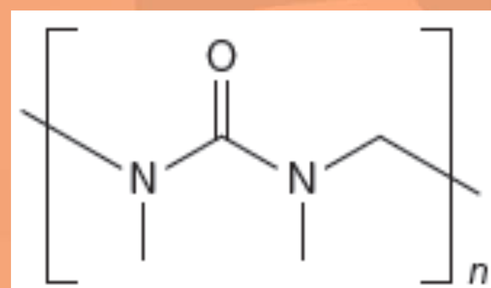
(HKDSE, Paper 2, 2015, 2(c))

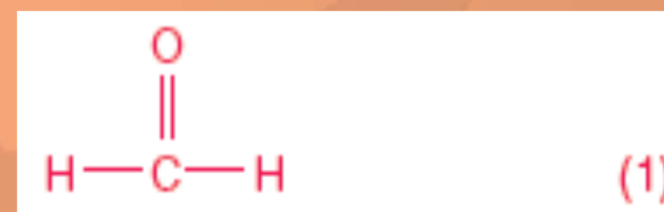
Topic exercise (p.153)

24 The tableware shown below are made of urea-methanal.



The structure of urea-methanal is shown below.





a) Draw the structures of monomers of urea-methanal.

b) Name the type of reaction for the formation of urea-methanal from its monomers.

Condensation polymerisation (1)

Topic exercise (p.153)

24 (continued)

c) Deduce the thermal property of urea-methanal.

Urea-methanal is highly cross-linked. (1)

It does not melt upon heating. / It is a thermosetting plastic. (1)

d) Suggest a moulding method for making the tableware shown.

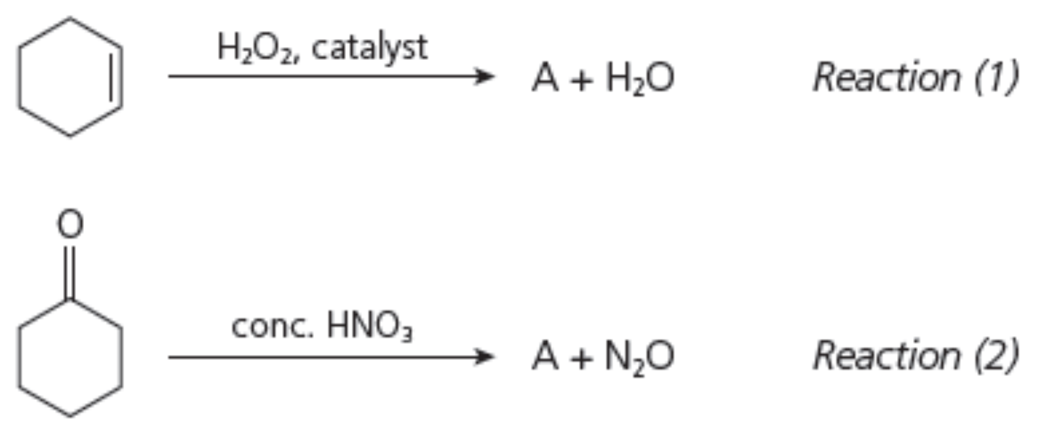
Compression moulding (1)

e) Urea-methanal is considered NOT to be a green polymer.

It is non-biodegradable. It will persist in the environment. (1)

Topic exercise (p.153)

25 Compound A is one of the monomers for making nylon-6,6 in industry. The following equations show two reactions that can produce A:



a) Draw the structure of A.

b) *Reaction (1)* is considered to be greener than *Reaction (2)*. Suggest THREE reasons.

c) In what aspect are both reactions considered as NOT green?

(HKDSE, Paper 2, 2012, 2(a)(ii))

