SAMPLE CHAPTER

INTERNATIONAL GCSE (9–1)

GRAHAM HILL
ROBERT WENSLEY

Chemistry

for Edexcel International GCSE

SECOND EDITION

DYNAMIC LEARNING

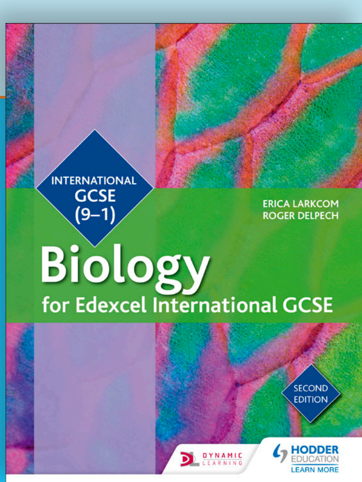
HODDER EDUCATION
LEARN MORE

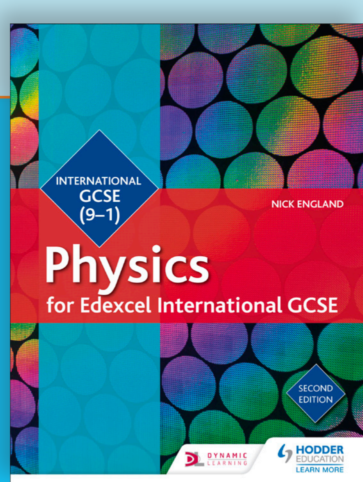
Ensure complete coverage of the latest Edexcel International GCSE (9–1) Science Specifications, with affordable student books and workbooks written by expert authors and teachers.

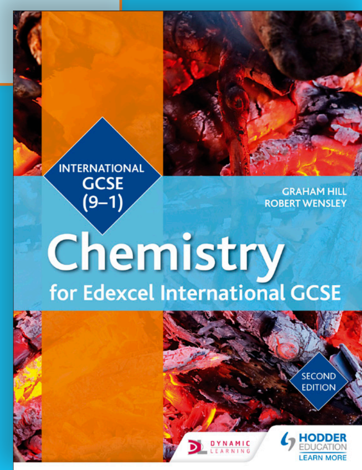
The following titles will be entered into Edexcel's endorsement process:

Edexcel International GCSE Biology Student Book Second Edition	9781510405196	£21.99	May 2017
Edexcel International GCSE Chemistry Student Book Second Edition	9781510405202	£21.99	April 2017
Edexcel International GCSE Physics Student Book Second Edition	9781510405189	£21.99	May 2017
Edexcel International GCSE Biology Student eTextbook	9781510405103	see below	June 2017
Edexcel International GCSE Chemistry Student eTextbook	9781510405134	see below	May 2017
Edexcel International GCSE Physics Student eTextbook	9781510405172	see below	June 2017

Visit www.hoddereducation.co.uk/igcsescience to pre-order your class sets or to sign up for your Inspection Copies or eInspection Copies.



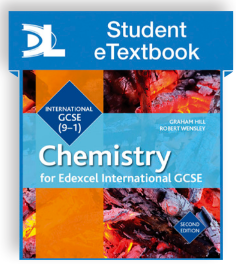




Also available:

Our Student Books will also be available as Student eTextbooks via Dynamic Learning. Student eTextbooks provide a downloadable version of the printed textbook that you can assign to students so they can:

- Download and view on any device or browser
- Add, edit and synchronise notes across any two devices
- Complete interactive, self-check questions.



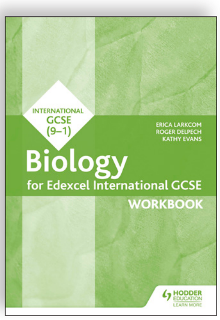
Price: £14.66 for 1 year's access
£21.99 for 2 year's access
Publishing: from May 2017

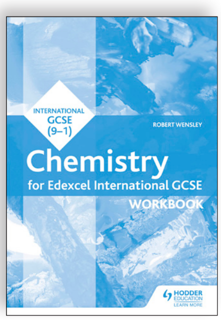
Supporting resources:

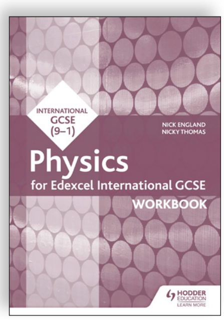
Edexcel International GCSE (9–1) Science Workbooks

Maximise every student's performance with exam-style questions, sample answers and examiner comments, written to support and enhance the content of the Edexcel International GCSE Student Books.

Price: £5.99
Publishing: July 2017







Contents

Section 2 Inorganic Chemistry

Section 3 Physical Chemistry

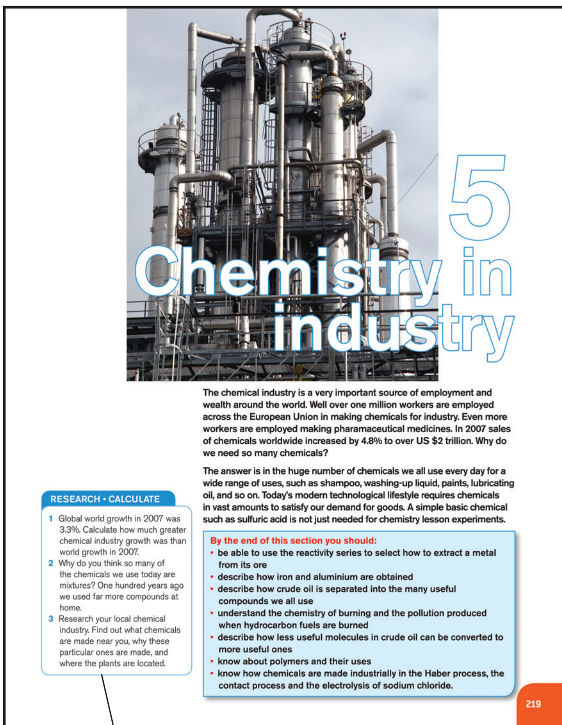
Getting the most from this book

At the start of each Section you will find the learning objectives for that Section.

Welcome to the Edexcel International GCSE Chemistry Student Book. This book has been divided into four Sections, following the structure and order of the Edexcel Specification, which you can find on the Edexcel website for reference. Section 1 has been divided into two parts to help you structure your learning.

Each Section has been divided into a number of smaller Chapters to help you manage your learning.

The following features have been included to help you get the most from this book.



5

Chemistry in industry

The chemical industry is a very important source of employment and wealth around the world. Well over one million workers are employed across the European Union in making chemicals for industry. Even more workers are employed making pharamaceutical medicines. In 2007 sales of chemicals worldwide increased by 4.8% to over US $2 trillion. Why do we need so many chemicals?

The answer is in the huge number of chemicals we all use every day for a wide range of uses, such as shampoo, washing-up liquid, paints, lubricating oil, and so on. Today's modern technological lifestyle requires chemicals in vast amounts to satisfy our demand for goods. A simple basic chemical such as sulfuric acid is not just needed for chemistry lesson experiments.

RESEARCH • CALCULATE

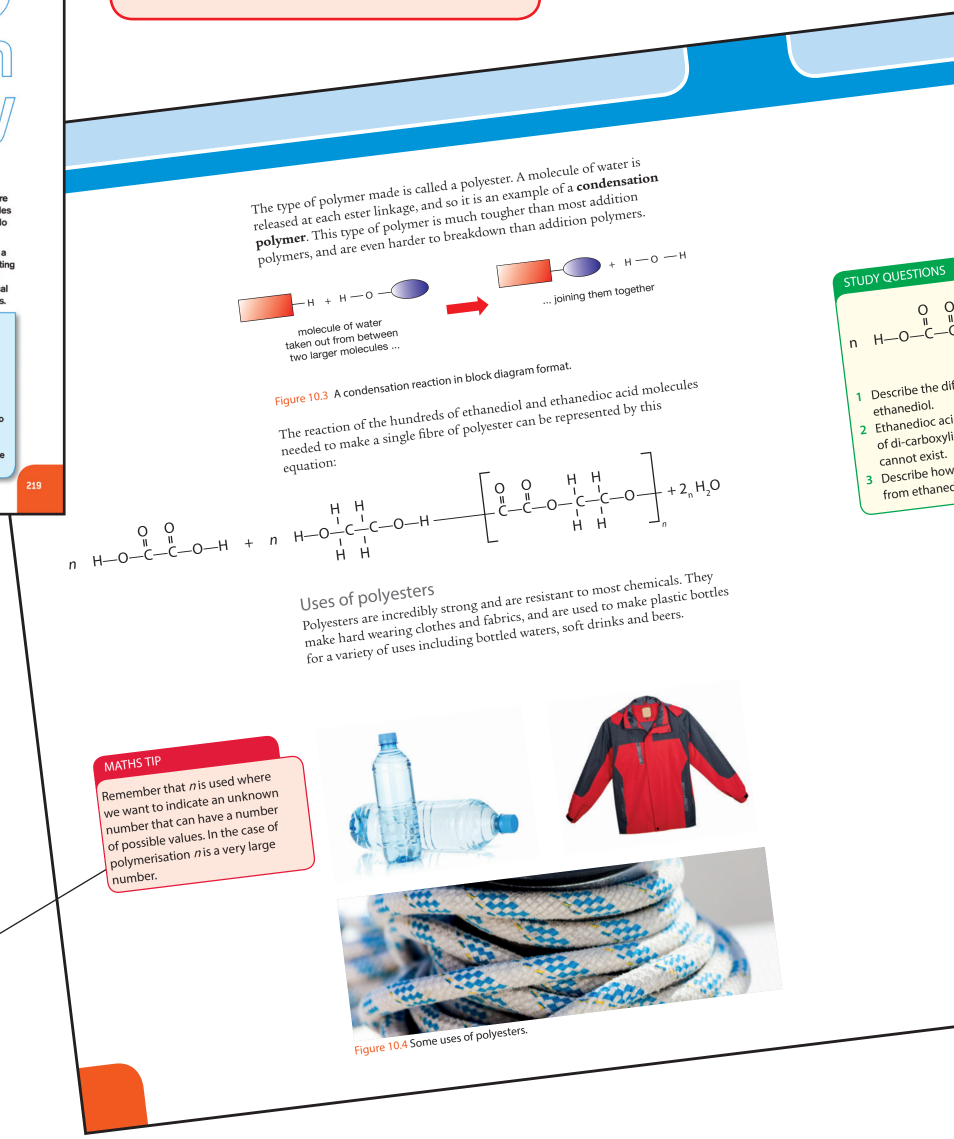
1 Global world growth in 2007 was 3.3%. Calculate how much greater chemical industry growth was than world growth in 2007.
2 Why do you think so many of the chemicals we use today are mixtures? One hundred years ago we used far more compounds at home.
3 Research your local chemical industry. Find out what chemicals are made near you, why these particular ones are made, and where the plants are located.

By the end of this section you should:
- be able to use the reactivity series to select how to extract a metal from its ore
- describe how iron and aluminium are obtained
- describe how crude oil is separated into the many useful compounds we all use
- understand the chemistry of burning and the pollution produced when hydrocarbon fuels are burned
- describe how less useful molecules in crude oil can be converted to more useful ones
- know about polymers and their uses
- know how chemicals are made industrially in the Haber process, the contact process and the electrolysis of sodium chloride.

219

PRACTICAL

Practical boxes tell you whether the practical work is required or suggested by the exam board, and include links to the specification.



The type of polymer made is called a polyester. A molecule of water is released at each ester linkage, and so it is an example of a **condensation polymer**. This type of polymer is much tougher than most addition polymers, and are even harder to breakdown than addition polymers.

Figure 10.3 A condensation reaction in block diagram format.

The reaction of the hundreds of ethanediol and ethanedioc acid molecules needed to make a single fibre of polyester can be represented by this equation:

Uses of polyesters

Polyesters are incredibly strong and are resistant to most chemicals. They make hard wearing clothes and fabrics, and are used to make plastic bottles for a variety of uses including bottled waters, soft drinks and beers.

MATHS TIP

Remember that *n* is used where we want to indicate an unknown number that can have a number of possible values. In the case of polymerisation *n* is a very large number.

Figure 10.4 Some uses of polyesters.

STUDY QUESTIONS

RESEARCH • CALCULATE

Try the activity before you start, and then have a look at it again once you have completed the Section to see if your responses are different before and after learning more about the topics.

MATHS TIP

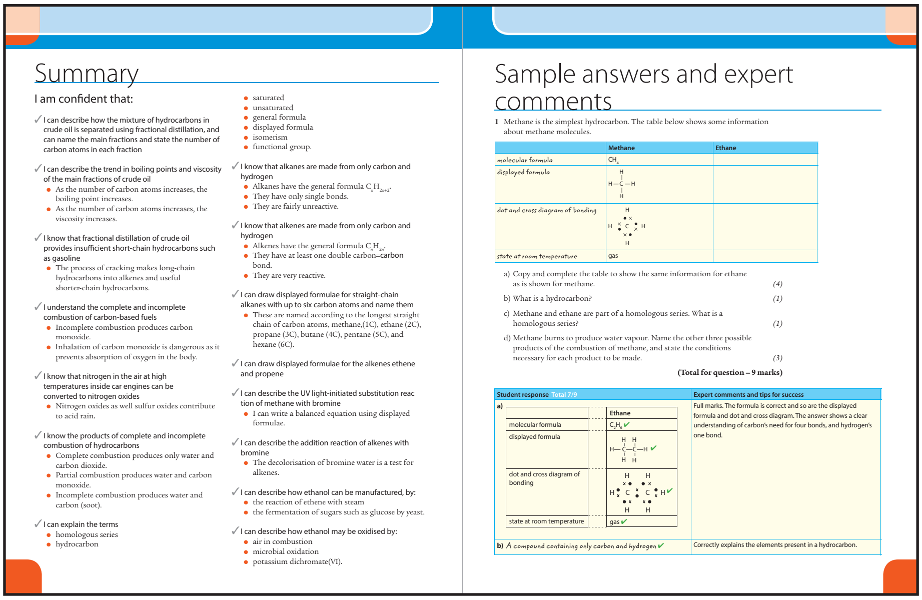
Maths tips give you additional help with the maths in the book so you can avoid losing valuable marks in the exam.

EXAM TIP

Exam tips throughout the book will guide you in your learning process.

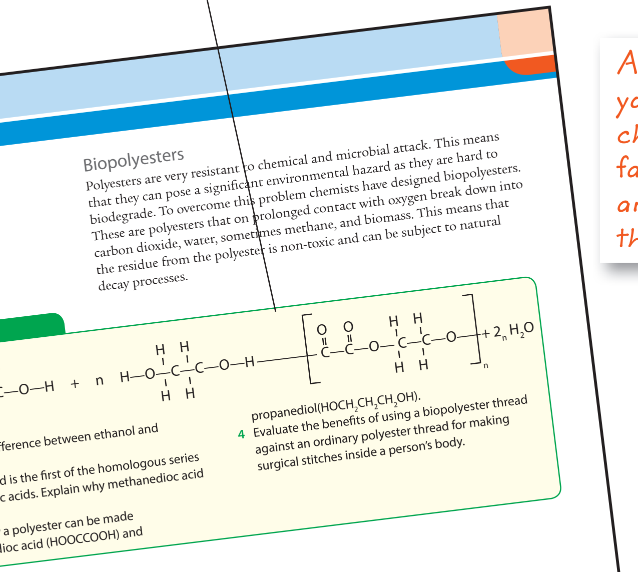
STUDY QUESTIONS

At the end of each Chapter you will find Study Questions. Work through these in class or on your own for homework. Answers are available online.



Summary

Sample answers and expert comments



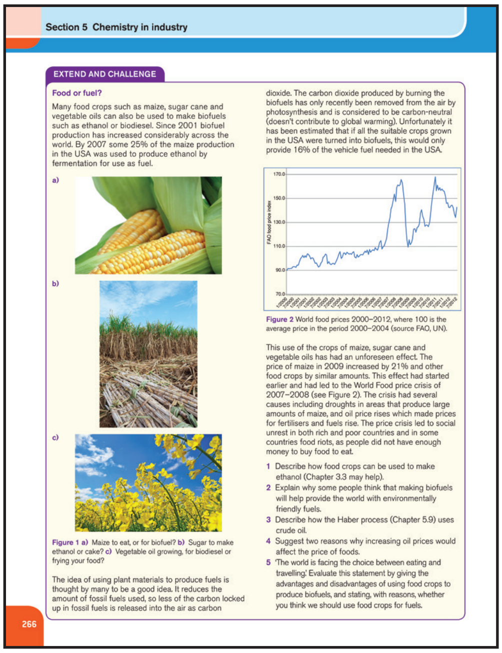
Biopolyesters

At the end of each Section, you will find a summary checklist, highlighting the key facts that you need to know and understand, and key skills that you learnt in the Section.

Before you try the exam-style questions, look at the sample answers and expert comments to see how marks are awarded and common mistakes to avoid.

EXTEND AND CHALLENGE

When you have completed all the Exam-style questions for the Section, try the extension activity.



Section 5 Chemistry in industry

EXTEND AND CHALLENGE

Food or fuel?

You will find Exam-style questions at the end of each Section covering the content of that section and the different types of questions you will find in an examination.

ANSWERS

Answers for all questions and activities in this book can be found online at www.hoddereducation.co.uk/igcsechemistry

4.6 Alcohols

When people talk about alcohol, they really mean *ethanol*. Ethanol is the substance which makes alcoholic drinks intoxicating. It is also the major constituent in methylated spirits (meths). After water, ethanol is the most widely used industrial solvent.

Figure 6.1 Foam in a copper brewery tank. What causes the foam?

Manufacturing ethanol

At one time, all ethanol, including methylated spirits, was produced by fermentation of sugars. Today, fermentation is still important in brewing and wine making, but most industrial ethanol and methylated spirits is manufactured from ethene.

Manufacturing ethanol by fermentation

The starting material for fermentation is a glucose solution. In countries where sugar beet and sugar cane grow well and are readily available, industrial alcohol is manufactured from sugar extracted from these plants. The starting material in winemaking is a sugary solution of grape juice and in beer making it is a sugary solution of malted barley.

Natural yeasts in the plant materials and, in some cases, added yeast, contain enzymes that break down the sugar. The first product is glucose, which is then broken down to ethanol and carbon dioxide (Figure 6.2). The process takes place at about 30 °C.

$$\underset{\text{glucose}}{C_6H_{12}O_6} \rightarrow \underset{\text{ethanol}}{2CH_3CH_2OH} + \underset{\text{carbon dioxide}}{2CO_2}$$

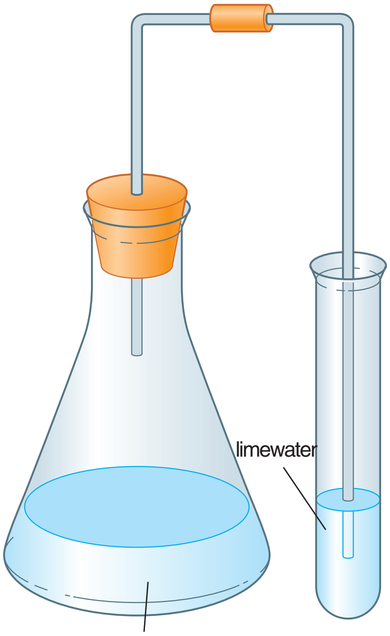
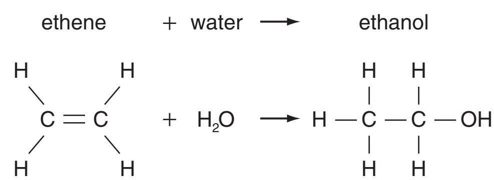


Figure 6.2 Making ethanol by fermentation on a small scale. Leave the apparatus in a warm place for five days. Why does the limewater go milky? Then filter the solution in the conical flask and separate ethanol from the filtrate by fractional distillation. The first few drops of distillate will burn like ethanol.

Fermentation can only produce a weak solution of ethanol in water because the yeasts are killed if the solution is more than 15% ethanol. But fermentation is ideal for winemaking (about 12% ethanol) and beer (about 3% ethanol). Fractional distillation is used to obtain higher concentrations of ethanol for industrial use and for producing whisky, gin and vodka. These drinks contain about 40% ethanol.

Manufacturing ethanol from ethene

Most industrial ethanol and methylated spirits is manufactured by an addition reaction between ethene and steam (water). The ethene is obtained from crude oil by cracking (Chapter 4.3). Ethene and steam are passed over a catalyst of phosphoric acid at 300 °C and a pressure of 60–70 atm.



A reaction like this, which involves the addition of water, is described as **hydration**.

Large quantities of ethanol are used in industry as solvents for paints, dyes, glues and soaps. Ethanol is miscible with both oils and water so it can be used with a wide range of solutes. It also evaporates quickly which makes it useful as a solvent for perfumes and aftershave lotions.

Figure 6.3 Methylated spirits is used as a solvent in table polishes to spread the polish and obtain a smooth, shiny surface.

Most of the ethanol used in industry and in our homes is sold as methylated spirits (meths). This contains about 90% ethanol, 5% water and 5% methanol. The methanol gives the meths a bitter taste and makes it unfit to drink.

Evaluating methods of ethanol production

The two methods of producing ethanol are compared in Table 1. The key factor in deciding which method to use for industrial ethanol is usually the relative availability of sugar cane and crude oil.

Table 1 Comparing the methods of producing ethanol.

	Fermentation	Hydration of ethene
Type of process	batch process using fixed amounts of sugary solution	continuous process – ethene and steam fed in continually
Raw material	sugar (or starch) – a renewable resource	ethene from cracking crude oil – a non-renewable resource
Rate of reaction	slow – process takes days at about 30 °C	fast – process is catalysed at 300 °C and 60–70 atm
Quality of product	% of ethanol is low, flavour is usually more important	100% ethanol can readily be produced
Main use of product	alcoholic drinks – beers, wines and spirits	industrial solvent and fuel
Cost	batch process and slow reaction – expensive	continuous process and fast reaction – cheaper

Table 2 The homologous series of alcohols.

CH_3OH	methanol
CH_3CH_2OH	ethanol
$CH_3CH_2CH_2OH$	propanol
$CH_3CH_2CH_2CH_2OH$	butanol

Alcohols form a homologous series like alkanes and alkenes (see Table 2). They have similar chemical properties which show a gradual change from one alcohol to the next as the molecular formula increases by units of CH_2.

Notice from Table 2 that alcohols have names derived from the alkanes with the same number of carbon atoms (i.e. methanol from methane, ethanol from ethane, etc.).

STUDY QUESTIONS

1 Explain the words:
fermentation; enzyme; alcohol.

2 a) Why is fermentation important?
b) What are the main products of the fermentation of glucose with yeast?
c) What causes the fermentation process?
d) Why are there two important and viable methods for the production of ethanol?

3 a) If an alcohol has *n* carbon atoms, how many hydrogen atoms will it have?
b) Write a general formula for the family of alcohols.

4 Look at the formula of butanol in Table 2.
a) Draw the structural formula of another isomer of butanol which is also an alcohol.
b) Use molecular models to construct butanol and its isomer from part (a).

5 a) Write a balanced chemical equation for the burning of ethanol with oxygen.
b) Describe two ways that ethanol may be converted into ethanoic acid.

4.7 Carboxylic Acids

In many countries pickling is used as a method of preserving foods. The cabbage, beetroot, onions, vegetables, fish and meat are covered in vinegar and the container is sealed. The vinegar is a solution of a weak acid called ethanoic acid (or acetic acid). The acid kills microbes and so prevents the food rotting. It also gives the food a sharp acid taste. Why is it safe to eat foods pickled in ethanoic acid, but not in a strong acid such as sulfuric acid?

Figure 7.1 Pickled onions will remain edible longer than if they were left out in the open.

Carboxylic acids

The active ingredient in vinegar is ethanoic acid. It is one of a group of organic compounds called carboxylic acids.

Carboxylic acids have a –COOH **functional group** attached to a carbon chain. They are named like other organic molecules, using the longest chain of carbon atoms to give the 'methan-', or 'ethan-' number of carbon atoms. The name is completed by '-oic acid'.

Table 1 The first four carboxylic acids.

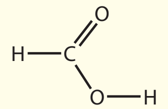
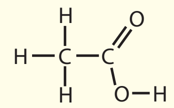
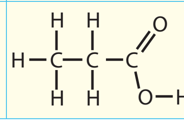
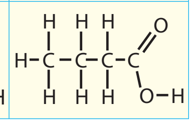
Name	Methanoic acid	Ethanoic acid	Propanoic acid	Butanoic acid
Molecular formula	HCO_2H	CH_3CO_2H	$C_2H_5CO_2H$	$C_3H_7CO_2H$
Displayed formula				

Table 1 shows the molecular and displayed formulae of the first four carboxylic acids. Each carbon atom has four covalent bonds attached to it. Note that the carbon atom which is part of the carboxylic acid functional group has one bond to the carbon chain, a double bond to one oxygen atom, and then a single bond to an oxygen atom with a hydrogen atom attached to it.

Like alkanes, alkenes and alcohols, carboxylic acids are a homologous series. They have the general formula $C_nH_{2n}O_2$. The formula is often expanded to show that the carboxylic acid functional group is present, like this: CH_3CO_2H or CH_3COOH.

Why is the carboxylic acid group an acid?

The hydrogen atom attached to the oxygen atom in the carboxylic acid group can be easily detached from the molecule as a hydrogen ion.

$$CH_3COOH(aq) \rightleftharpoons CH_3COO^-(aq) + H^+(aq)$$

The hydrogen ion is the particle that gives solutions of molecules containing the carboxylic acid group their acidic properties. It is not as easy to remove the hydrogen ion from a carboxylic acid as it is to remove it from an acid such as sulfuric acid, so carboxylic acids are weak acids (see Section 2.14).

Reaction of carboxylic acids with metals

Carboxylic acids are weak acids. They have the same reactions as strong acids but they do not react as vigorously. When reacted with reactive metals, such as sodium and iron, carboxylic acids produce hydrogen gas. This reaction is far slower than the reaction of reactive metals with hydrochloric acid.

sodium + ethanoic acid → sodium ethanoate + hydrogen gas

$$2Na(s) + 2CH_3COOH(aq) \rightarrow 2CH_3COO^-Na^+(aq) + H_2(g)$$

The salt produced by the reaction of ethanoic acid is called an ethanoate.

Table 2 Naming the salts made from carboxylic acids.

Carboxylic acid	Carboxylate salt
methanoic acid	methanoate
ethanoic acid	ethanoate
propanoic acid	propanoate
butanoic acid	butanoate
pentanoic	pentanoate

Reaction of carboxylic acids with metals carbonates

Metal carbonates react vigorously with acids such as sulfuric acid. They produce carbon dioxide gas, water and the salt of the acid used. The same applies to carboxylic acids. They react with metal carbonates to produce the carboxylic acid salt, carbon dioxide and water. This is the reaction of sodium carbonate with propanoic acid:

sodium carbonate + propanoic acid → sodium propanoate + carbon dioxide gas + water

$$Na_2CO_3(s) + 2C_2H_5COOH(aq) \rightarrow 2C_2H_5COO^-Na^+(aq) + CO_2(g) + H_2O(l)$$

Copper carbonate also reacts with carboxylic acids:
copper carbonate + ethanoic acid → copper ethanoate + carbon dioxide gas + water

$$CuCO_3(s) + 2CH_3COOH(aq) \rightarrow (CH_3COO^-)_2Cu^{2+}(aq) + CO_2(g) + H_2O(l)$$

Each copper ion needs two ethanoate ions to balance copper's two positive charges.

STUDY QUESTIONS

1. Draw the displayed formula of pentanoic acid ($C_4H_9CO_2H$).
2. Write a chemical equation to show how propanoic acid can produce a hydrogen ion in water?
3. Explain why butanoic acid is an acid.
4. Suggest the name of the salt formed by pentanoic acid.
5. Describe the reaction of propanoic acid with lithium metal.
   Write a balanced chemical equation and name the products. Describe a test to identify the gas given off.
6. Describe the reaction of potassium carbonate with methanoic acid. Write a balanced chemical equation and name the products. Describe a test to identify the gas given off.

4.8 Esters

Figure 8.1 Where does perfume get its smell from?

In earlier times perfumes were made from two sources; either plant extracts or from the scent glands of animals. Today, the large quantities of perfumes manufactured mean that for all but the most expensive perfumes these sources are unable to produce enough to meet demand. Instead, manufacturers use a range of compounds, many of them known as **esters**. Esters are made from alcohols and carboxylic acids. They also are used as artificial flavours in foods.

Making an ester from an alcohol and a carboxylic acid

Mix 1 cm^3 of ethanol and 1 cm^3 of anhydrous ethanoic acid in a test tube. Add 3 drops of concentrated sulfuric acid to the test tube and warm the mixture for 10 minutes in a water bath. The test tube will now contain some of the ester ethyl ethanoate. Pour the reaction mixture into 10 cm^3 of sodium carbonate solution to neutralise any unused ethanoic acid. Carefully smell the solution. It should have a fruity aroma from the ethyl ethanoate.

$$\text{ethanoic acid} + \text{ethanol} \rightleftharpoons \text{ethyl ethanoate} + \text{water}$$

$$CH_3COOH(l) + HOC_2H_5(l) \rightleftharpoons CH_3COOC_2H_5(l) + H_2O(l)$$

The reaction is an equilibrium and can be easily reversed. The concentrated sulfuric acid is used as a catalyst for the reaction and is not included in the equation.

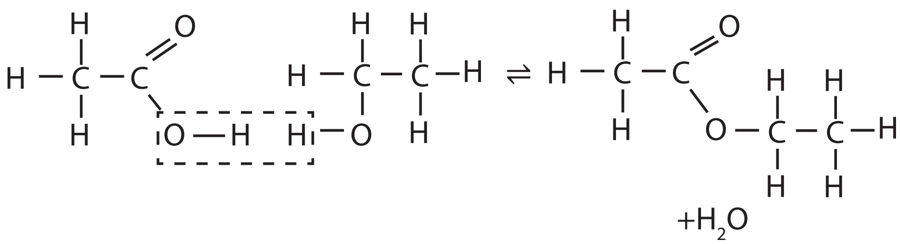
REQUIRED PRACTICAL

This required practical relates to specification point 4.43C.
When warming the mixture of ethanol and ethanoic acid you should remember that both liquids are flammable and keep them away from flames.

Esterification

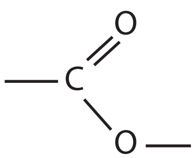
This type of reaction is called an esterification. This is how the two molecules react:

ethanoic acid + ethanol ⇌ ethyl ethanoate + water



The carboxylic acid loses its –OH group and the alcohol loses the hydrogen from its –OH group to produce the molecule of water, and the two molecules join together linked by the oxygen atom from the alcohol. As the reaction produces water, often as steam, this is known as a **condensation reaction**.

This linkage is the functional group of esters:



Naming esters

Most alcohols and carboxylic acids can react together in an esterification reaction. The name of the ester formed is always based on the name of the alcohol used (see Chapter 4.6, Table 2) and on the name of the salt produced from the carboxylic acid (see Chapter 4.7, Table 2). If ethanol is used, the alcohol's name is changed to ethyl in the name of the ester. Table 1 shows how the first part of the ester's name is based on the alcohol used.

Table 1 Naming an ester.

	Number of carbon atoms in alcohol	First part of ester's name from the alcohol
methanol	1	methyl
ethanol	2	ethyl
propanol	3	propyl
butanol	4	butyl
pentanol	5	pentyl
hexanol	6	hexyl

Figure 8.2 The pear flavour in pear drops is produced by the ester ethyl ethanoate.

Esters are volatile compounds that easily vaporise. Their distinctive smells can easily travel through the air to our noses. Inside our mouths they readily stimulate our taste buds. This is why they are used as artificial flavourings in foods and are also used as perfumes. Ripening fruits produce these esters to attract animals to the fruit and encourage them to eat the fruit, so dispersing the seeds of the plant widely.

STUDY QUESTIONS

1 Draw the functional group of an ester.
2 Draw the structural formula of the ester ethyl methanoate.
3 Draw the displayed formula of the ester propyl ethanoate.
4 Draw the displayed structure of $CH_3COOC_4H_9$. Name the ester.
5 Name the ester formed by each of these reactions.
   a) ethanol and pentanoic acid
   b) propanol and ethanoic acid
   c) butanol and methanoic acid
   d) pentanol and propanoic acid

4.9 Addition Polymers

Figure 9.1 Clingfilm is made from PVC (polyvinylchloride).

Ethene is a very valuable substance for the chemical industry. Ethene, propene and other alkenes are used to make important polymers because they are so reactive. These important polymers include polythene, polypropene, polyvinylchloride (PVC), polystyrene and perspex.

Poly(ethene)

Ethene and other alkenes contain reactive carbon-to-carbon double bonds (C═C).

If the conditions are right, molecules of ethene will undergo **addition reactions** with each other to form **poly(ethene)** (sometimes shortened to polythene). Double bonds break, leaving single bonds as the molecules join together (Figure 9.2).

'Poly' means 'many'. So, poly(ethene) means 'many ethenes' joined together.

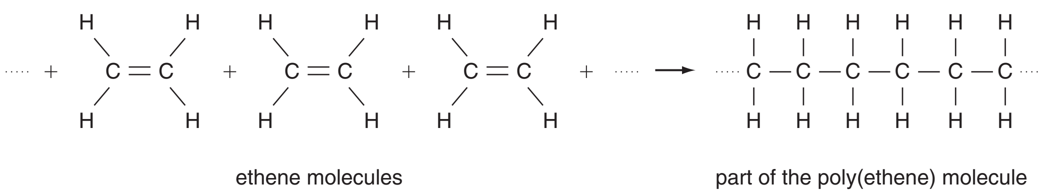
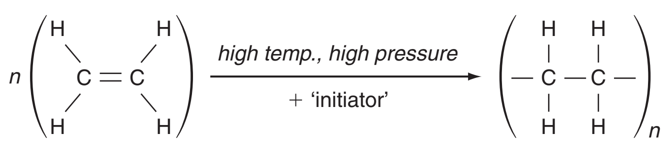


Figure 9.2 Molecules of ethene can undergo addition reactions with each other.

Making poly(ethene)

Poly(ethene) is an addition polymer. It is manufactured by heating ethene at high pressure with special substances called **initiators**. Initiators start (initiate) the reaction by helping the double bonds in some ethene molecules to 'open up'. Carbon atoms in separate ethene molecules can then join together to form poly(ethene).

When ethene forms poly(ethene), very long chains are produced containing between 1000 and 5000 carbon atoms. The equation for this is usually summarised as:



In the structure of polythene, *n* is between 500 and 2500.

Addition polymerisation

Processes like this are called **addition polymerisations**.

During addition polymerisation, small molecules, like ethene, add to each other to form a giant molecule.

Poly(ethene) is

- tough
- light
- flexible
- easily moulded
- transparent
- easily coloured
- a good insulator
- resistant to water, acids and alkalis

Figure 9.3 The properties of poly(ethene).

The giant molecule is called a **polymer**.

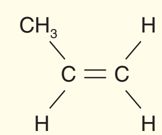
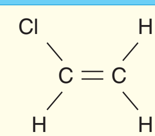
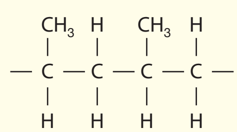
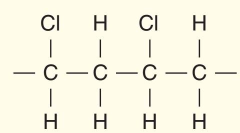
The small molecules, like ethene, which add to each other are called **monomers**.

Figure 9.3 lists the properties of poly(ethene). These have led to many different uses. Poly(ethene) is the most important plastic at present. It is used as thin sheets in plastic bags and boxes. It is moulded into beakers, buckets and plastic bottles. It is used to insulate underwater cables.

Other addition polymers

The two most useful and most commonly used polymers after poly(ethene) are **poly(propene)** and **poly(chloroethene)**, better known as **PVC**. These are also manufactured by addition polymerisation. The structure and uses of these two polymers are shown in Table 1.

Table 1 The structure and uses of poly(propene) and poly(chloroethene), PVC.

	Poly(propene)	Poly(chloroethene) (or polyvinylchoride, PVC)
Name and displayed formula of monomer	 propene	 chloroethene (vinyl chloride)
Section of polymer structure showing two repeat units		
Major uses	tough, easily moulded and easily coloured – used for crates and ropes	tough, rigid, water resistant – used in rainwear, insulation on electric cables, guttering, drain pipes and clingfilm

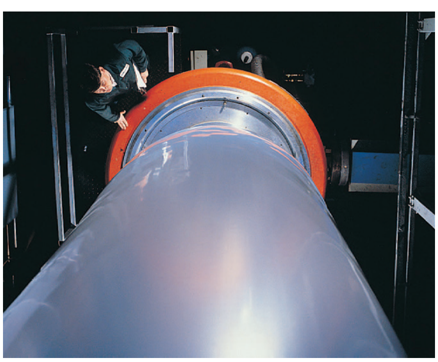


Figure 9.4 Polythene tubing emerging from an extrusion machine. The plastic is extruded from the container in which it is formed by hot pressurised air.

Making things from polymers

Polythene, poly(propene) and PVC are soft, flexible and slightly elastic. They are often called **plastics**. Once a plastic has been produced, it is then turned into a useful article.

This is usually done by:

- **moulding** the warm, soft plastic under pressure, or
- **extruding** (pushing out) the warm, soft plastic into different shapes by forcing it through nozzles or between rollers.

Figure 9.5 A biodegradable plastic bag.

Most plastics consist of molecules with very long, thin chains. Sometimes, however, the long polymer molecules can form bonds with each other at points along the chain. This produces cross-linked three-dimensional structures which are harder and more rigid. Melamine, resins and superglues (epoxyglues) are examples of these cross-linked plastics.

Addition polymers are hard to dispose of

The main raw material for all plastics is crude oil. Although these products have provided us with many new materials, they have one big disadvantage. They are **non-biodegradable**. This means that, unlike wood and paper, they are not decomposed by micro-organisms (bacteria). So plastic rubbish lies around for years, littering the environment. In the last few years, biodegradable plastics have been developed and used for bags, wrappings, bottles and other containers (Figure 9.5).

When addition polymers are burnt they can produce toxic gases. This can be caused by the polymer chains reacting with other molecules that are being burnt at the same time, or because the monomer unit contains other elements or groups of atoms that produce toxic substances when burnt.

In 2011 the Welsh Assembly introduced a 5p charge for plastic bags. In 2014 Scotland introduced the charge, and in 2015 so too did England. This has led to a dramatic 85% reduction in the number of new plastic carrier bags being manufactured.

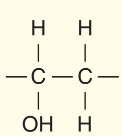
STUDY QUESTIONS

1 Explain the following: polymer, addition polymerisation, non-biodegradable.

2 a) How is ethene manufactured?
   b) Why is ethene important in industry?

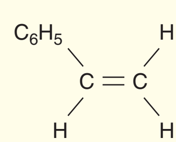
3 a) Give one use of plastic rubbish.
   b) Give one disadvantage of plastic rubbish.

4 An addition polymer has a repeat unit with this structure:



Draw the displayed structure of its monomer.

5 Look at the displayed formulae of the monomers in Table 1.
   a) Which part of their displayed formulae do they have in common?
   b) What happens when these monomers polymerise to form polymers?
   c) Polystyrene is made from the following monomer.



Draw a section of polystyrene showing six carbon atoms in the chain.

4.10 Condensation polymers

Figure 10.1 A polyester drinks bottle is an example of a synthetic condensation polymer.

Most common plastics are addition polymers formed by addition reactions. However, monomers can also be joined together by condensation reactions, and polymers produced in this way are called condensation polymers. The best known examples of synthetic condensation polymers are polyester and nylon.

Condensation reactions

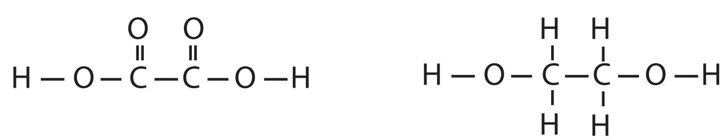
In a **condensation reaction**, two larger molecules join together with the release of a small molecule from between them (Figure 10.2). The small molecule is usually water.

This is what happens when an ester is made (see Chapter 4.8). The ester is made from an alcohol and a carboxylic acid. The –OH group of the alcohol reacts with the –COOH group of the carboxylic acid to produce the ester link.

Making polyesters

If the carboxylic acid has a –COOH group at each end of the molecule, as shown in Figure 10.2, it could form ester links at both ends of the molecule and join with two alcohols. A carboxylic acid with two –COOH groups is called a **dicarboxylic acid**.

If the alcohol molecule has –OH groups in two places in the molecule, as is also shown in Figure 10.2, it too could form two ester links and join with two carboxylic acids. An alcohol with two –OH groups is called a **diol**.



ethanedioc acid ethanediol

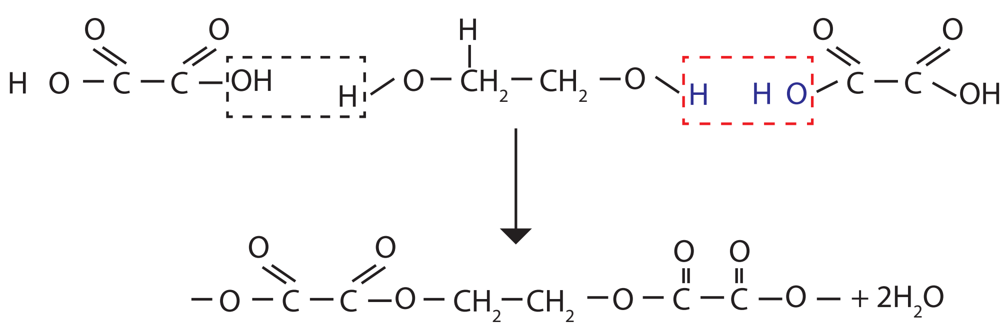


Figure 10.2 Ethanedioc acid and ethanediol react to make a condensation polymer, a polyester.

The type of polymer made is called a polyester. A molecule of water is released at each ester linkage, and so it is an example of a **condensation polymer**. This type of polymer is much tougher than most addition polymers, and are even harder to breakdown than addition polymers.

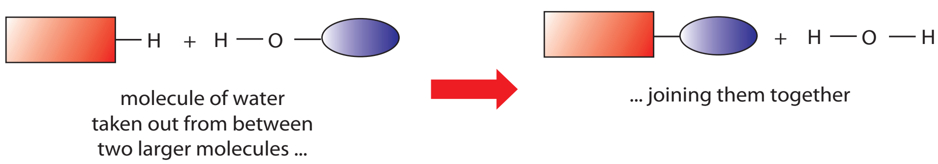
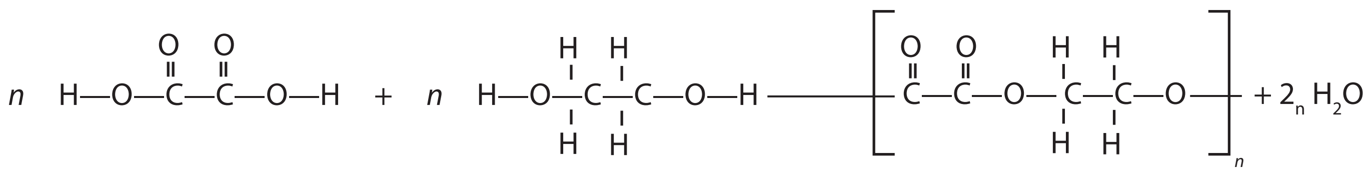


Figure 10.3 A condensation reaction in block diagram format.

The reaction of the hundreds of ethanediol and ethanedioc acid molecules needed to make a single fibre of polyester can be represented by this equation:



Uses of polyesters

Polyesters are incredibly strong and are resistant to most chemicals. They make hard wearing clothes and fabrics, and are used to make plastic bottles for a variety of uses including bottled waters, soft drinks and beers.

MATHS TIP

Remember that *n* is used where we want to indicate an unknown number that can have a number of possible values. In the case of polymerisation *n* is a very large number.

Figure 10.4 Some uses of polyesters.

Biopolyesters

Polyesters are very resistant to chemical and microbial attack. This means that they can pose a significant environmental hazard as they are hard to biodegrade. To overcome this problem chemists have designed biopolyesters. These are polyesters that on prolonged contact with oxygen break down into carbon dioxide, water, sometimes methane, and biomass. This means that the residue from the polyester is non-toxic and can be subject to natural decay processes.

STUDY QUESTIONS

1. Describe the difference between ethanol and ethanediol.
2. Ethanedioc acid is the first of the homologous series of di-carboxylic acids. Explain why methanedioc acid cannot exist.
3. Describe how a polyester can be made from ethanedioc acid (HOOCCOOH) and propanediol ($HOCH_2CH_2CH_2OH$).
4. Evaluate the benefits of using a biopolyester thread against an ordinary polyester thread for making surgical stitches inside a person's body.

Summary

I am confident that:

✓ I can describe how the mixture of hydrocarbons in crude oil is separated using fractional distillation, and can name the main fractions and state the number of carbon atoms in each fraction

✓ I can describe the trend in boiling points and viscosity of the main fractions of crude oil
- As the number of carbon atoms increases, the boiling point increases.
- As the number of carbon atoms increases, the viscosity increases.

✓ I know that fractional distillation of crude oil provides insufficient short-chain hydrocarbons such as gasoline
- The process of cracking makes long-chain hydrocarbons into alkenes and useful shorter-chain hydrocarbons.

✓ I understand the complete and incomplete combustion of carbon-based fuels
- Incomplete combustion produces carbon monoxide.
- Inhalation of carbon monoxide is dangerous as it prevents absorption of oxygen in the body.

✓ I know that nitrogen in the air at high temperatures inside car engines can be converted to nitrogen oxides
- Nitrogen oxides as well sulfur oxides contribute to acid rain.

✓ I know the products of complete and incomplete combustion of hydrocarbons
- Complete combustion produces only water and carbon dioxide.
- Partial combustion produces water and carbon monoxide.
- Incomplete combustion produces water and carbon (soot).

✓ I can explain the terms
- homologous series
- hydrocarbon

Some material from this page has been removed for the purposes of producing this marketing sample.
The missing material will be reinstated in the published book.

- saturated
- unsaturated
- general formula
- displayed formula
- isomerism
- functional group.

✓ I know that alkanes are made from only carbon and hydrogen
- Alkanes have the general formula C_nH_{2n+2}.
- They have only single bonds.
- They are fairly unreactive.

✓ I know that alkenes are made from only carbon and hydrogen
- Alkenes have the general formula C_nH_{2n}.
- They have at least one double carbon=carbon bond.
- They are very reactive.

✓ I can draw displayed formulae for straight-chain alkanes with up to six carbon atoms and name them
- These are named according to the longest straight chain of carbon atoms, methane,(1C), ethane (2C), propane (3C), butane (4C), pentane (5C), and hexane (6C).

✓ I can draw displayed formulae for the alkenes ethene and propene

✓ I can describe the UV light-initiated substitution reaction of methane with bromine
- I can write a balanced equation using displayed formulae.

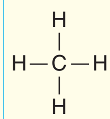
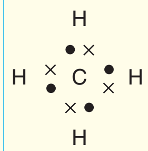
✓ I can describe the addition reaction of alkenes with bromine
- The decolorisation of bromine water is a test for alkenes.

✓ I can describe how ethanol can be manufactured, by:
- the reaction of ethene with steam
- the fermentation of sugars such as glucose by yeast.

✓ I can describe how ethanol may be oxidised by:
- air in combustion
- microbial oxidation
- potassium dichromate(VI).

Sample answers and expert comments

1 Methane is the simplest hydrocarbon. The table below shows some information about methane molecules.

	Methane	Ethane
molecular formula	CH_4	
displayed formula		
dot and cross diagram of bonding		
state at room temperature	gas	

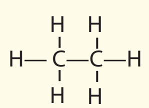
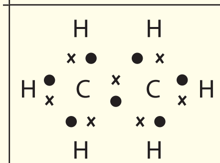
a) Copy and complete the table to show the same information for ethane as is shown for methane. [4]

b) What is a hydrocarbon? [1]

c) Methane and ethane are part of a homologous series. What is a homologous series? [1]

d) Methane burns to produce water vapour. Name the other three possible products of the combustion of methane, and state the conditions necessary for each product to be made. [3]

[Total for question = 9 marks]

Student response Total 7/9		Expert comments and tips for success
a)	**Ethane**	Full marks. The formula is correct and so are the displayed formula and dot and cross diagram. The answer shows a clear understanding of carbon's need for four bonds, and hydrogen's one bond.
molecular formula	C_2H_6 ✔	
displayed formula	 ✔	
dot and cross diagram of bonding	 ✔	
state at room temperature	gas ✔	
b) *A compound containing only carbon and hydrogen* ✔		Correctly explains the elements present in a hydrocarbon.

c) *A group of compounds where each compound is different to the next by the same amount.* ✔ *In this case CH_2.*	Gives the correct definition, for 1 mark. The two named examples are used to give the repeat unit of the alkane homologous series.
d) *Carbon dioxide when there is lots of oxygen.* ✔ *Carbon monoxide when there is no oxygen.* O	Only 1 mark out of 3. Read the question carefully to find the number of answers wanted. Carbon dioxide and the conditions are right, but the conditions for carbon monoxide are wrong. There has to be some oxygen present for the methane to burn to make carbon monoxide and carbon.

2 Crude oil is separated by fractional distillation into hydrocarbon fractions. A hydrocarbon is a compound that contains only hydrogen and carbon. A fraction is a mixture of hydrocarbons that contains molecules with a similar number of carbon atoms. The table gives some information about four fractions.

Common name of fraction	Average number of carbon atoms in the molecules	Average boiling point of fraction in °C	Time for ignition after flame applied in s
refinery gases	3	40	0
gasoline	8	110	1
kerosene	10	180	3
diesel	14	250	5

a) Explain why the table uses the average number to describe the number of carbon atoms in the molecules of a fraction. [2]

b) Describe the relationship between the average number of carbon atoms in a fraction and the average boiling point of the fraction. [1]

c) Explain why diesel is the most viscous of the fractions in the table. Use information from the table and your knowledge of hydrocarbons in your answer. [2]

d) Fuel oil and bitumen are two more fractions. Bitumen has more than 50 carbon atoms in its molecules and fuel oil has on average 35 carbon atoms. Explain which of the six fractions will be hardest to ignite. [2]

[Total for question = 7 marks]

Student response Total 7/7	Expert comments and tips for success
a) *Each fraction is made up of lots of different molecules.* ✔ *The molecules have similar boiling points as they have similar numbers of carbon atoms* ✔*, so it's best to use the mean value for the carbon atoms.*	A good answer using information from the table and question with a clear explanation of why is it useful to give the average number of carbon atoms for a fraction.
b) *The higher the number of carbon atoms, the higher the boiling point.* ✔	This answer clearly relates the boiling point to the number of carbon atoms.
c) *Diesel has the highest boiling point which means the molecules are most strongly attracted to each other* ✔*. So the molecules will find it harder to slip past each other* ✔ *making it more viscous.*	You should use the data in this way. Refer to the data, then use your knowledge to explain the information and its relevance to the question.
d) *Bitumen.* ✔ *The trend from the table shows increasing difficulty to ignite with more carbon atoms, so as it is the largest* ✔*, bitumen is hard to light.*	1 mark for the correct choice. The trend from the table is given and then used to support the answer.

Exam-style questions

1 Crude oil is an important resource. It was formed over millions of years from the remains of dead plants and animals that were buried in sediments.

a) The oil industry uses fractionating towers to split crude oil into more useful fractions.

i) How does the boiling point change as the number of carbon atoms in these fractions increases? [1]

ii) Explain how the process of fractional distillation separates crude oil into more useful fractions. [2]

b) Octadecane, $C_{18}H_{38}$, is found in the diesel oil fraction.

i) Octadecane can be **cracked** into smaller molecules. One way is shown in the equation.

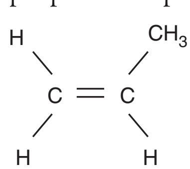
$$C_{18}H_{38} \rightarrow C_8H_{16} + C_8H_{18} + C_2H_4$$

octadecane → octene + ______ + ______

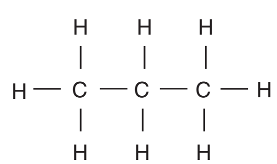
Copy and finish the word equation for this reaction. [1]

ii) Explain why cracking long-chain compounds such as octadecane enables oil companies to make more profit. Use the equation in part (b) i) to help you with your answer. [2]

c) The refinery gases fraction from crude oil contains propene and propane.



propene



propane

i) Describe a chemical test which you could use to distinguish between propene and propane. [2]

ii) Explain why propene can be polymerised, but propane cannot. [2]

iii) Write an equation to summarise the polymerisation of propene. [2]

2 In some countries the exhaust gases from older cars must be tested each year. These exhaust gases contain carbon monoxide, unburned hydrocarbons and smoke.

a) Look at the results below from an exhaust test.

Use these results to answer the questions.

Item	Test result	Maximum limit
carbon monoxide	4.0%	3.5%
unburned hydrocarbons	297 ppm	1200 ppm
idle speed	pass	
smoke level	pass	

i) What is the maximum limit of carbon monoxide allowed? [1]

ii) This car failed its test. Why? [1]

b) Why is carbon monoxide dangerous? [2]

c) As well as carbon monoxide, unburned hydrocarbons, smoke and water, car exhausts contain other gases. One of these gases may cause a change in the Earth's climate.

Name this gas and explain why it can affect the climate. [3]

3 Ethene, C_2H_4, and methane, CH_4, are the first members of two different homologous series.

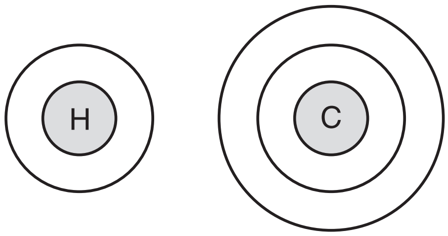
a) One characteristic of a homologous series is that all its members have the same general formula.

i) State **two** other characteristics of a homologous series. [2]

ii) What is the name of the homologous series to which methane belongs? [1]

iii) What is the general formula of this homologous series? [1]

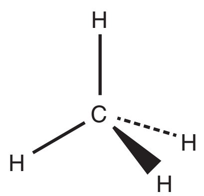
b) i) Use the Periodic Table on page 267 to help you copy and complete the diagrams to show the electronic configuration of hydrogen and of carbon.



[2]

ii) Draw a dot and cross diagram to show the covalent bonding in a methane molecule. [2]

iii) The shape of a methane molecule is shown in the following diagram.



What name describes this shape? [1]

c) The alkane C_4H_{10} exists as two isomers.

i) What are isomers? [2]

ii) Draw the displayed formula of each isomer. [2]

4 Alkenes are unsaturated hydrocarbons.

a) State the general formula of all alkenes. [1]

b) Draw the displayed formula of ethene. [1]

c) Alkenes can be shown to be unsaturated using bromine water. Describe the colour change that occurs when an alkene reacts with bromine water.

5 Ethanol is manufactured in two ways.

a) By the fermentation of a carbohydrate.

i) What must be present in the solution of carbohydrate to make fermentation occur? [1]

ii) What process is used to separate ethanol from the fermentation mixture? [1]

b) By the hydration of ethene.

i) Write a balanced chemical equation, including state symbols, for the hydration of ethene to produce ethanol. [2]

ii) State the conditions for this reaction. [2]

c) Country A is a relatively poor country with no oil reserves. The climate is ideal for growing crops.

Country B is relatively rich and has its own oil reserves.

Explain which method of ethanol production (fermentation or hydration) is likely to be used in each country. [2]

d) Ethene can be prepared by dehydrating ethanol using aluminium oxide.

i) Copy and complete the equation for this process.

$$C_2H_5OH \rightarrow C_2H_4 + [\ \ ]$$ [1]

ii) Calculate the maximum volume of ethene, at room temperature and atmospheric pressure, that can be obtained from 2.30 g of ethanol. (C = 12, H = 1, O = 16)

(1 mol of gas occupies 24.0 dm^3 at room temperature and pressure) [3]

6 Many useful substances are produced by the fractional distillation of crude oil.

a) Bitumen, fuel oil and gasoline are three fractions obtained from crude oil. There are several differences between these fractions. Which of these three fractions has:

i) the highest boiling point range [1]

ii) molecules with the fewest carbon atoms [1]

iii) the darkest colour? [1]

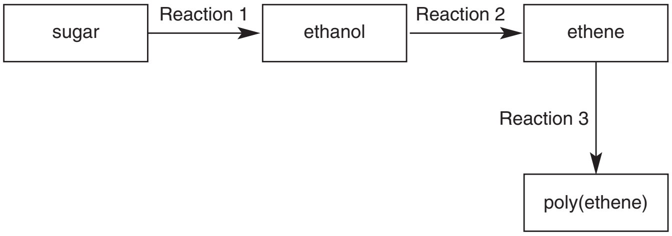
b) Some long-chain hydrocarbons are converted into more useful products by a chemical process. Name this process and describe how it is carried out. [3]

c) Some hydrocarbons, such as methane, are used as fuels. When methane undergoes incomplete combustion, carbon monoxide is formed.

i) Write a chemical equation for this reaction. [2]

ii) Explain why it is dangerous to breathe air containing carbon monoxide. [2]

7 Sugar can be converted into poly(ethene) as follows:



a) State the type of reaction occurring in:

i) Reaction 1 [1]

ii) Reaction 2 [1]

iii) What type of polymerisation occurs in Reaction 3? [1]

b) State **two** conditions used in the conversion of sugar to ethanol in Reaction 1. [2]

c) Write a chemical equation for Reaction 2. [2]

d) Draw the displayed formula of ethanol. [1]

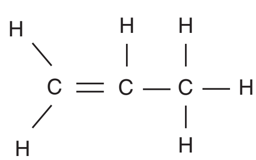
e) Many thousands of ethene molecules combine to form a poly(ethene) molecule. Draw that part of the structure of a poly(ethene) molecule that forms from **three** ethene molecules. [2]

f) Polyester is made by a different type of polymerisation. Name this type of polymerisation and describe how it is different from the type of polymerisation used to make poly(ethene). [3]

8 a) Describe briefly how crude oil was formed. [3]

b) Propene and propane can be produced from crude oil.

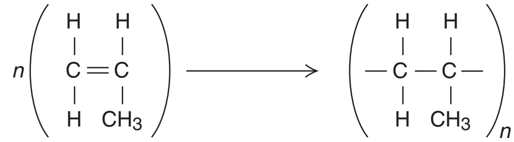
i) A propene molecule (C_3H_6) can be represented by the display formula below.



Draw a similar displayed formula for the structure of a propane molecule (C_3H_8). [1]

ii) Which molecule, propene or propane, is unsaturated? Explain your answer. [2]

c) The equation below summarises the polymerisation of propene.



i) Name the polymer produced by this reaction. [1]

ii) Explain the meaning of the term **polymerisation**. [1]

9 Ethanoic acid is a carboxylic acid. It has the molecular formula CH_3COOH.

a) Draw the structural formula of ethanoic acid. [1]

b) Ethanoic acid is a weak acid. The equation shows how it reacts with sodium carbonate.

$$2CH_3COOH(aq) + Na_2CO_3(aq) \rightarrow$$
$$2Na^+CH_3COO^-(aq) + H_2O(l) + CO_2(g)$$

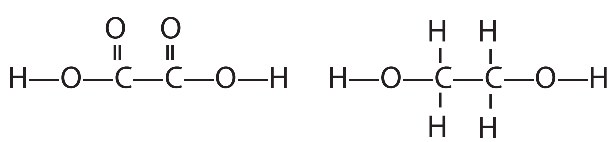
Name the sodium salt made. [1]

c) Ethanoic acid can also react with an alcohol such as ethanol (CH_3CH_2OH) to make an ester.

Draw and name the ester made by ethanoic acid and ethanol. [2]

d) Explain why esters are used in the food industry. [2]

10 Polyesters are polymers that are very tough and hardwearing. They are highly resistant to chemical and bacterial attack. A polyester can be made from these two monomers.

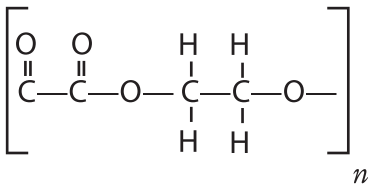


monomer A monomer B

a) What is a monomer? [1]

b) Monomer A is called ethanedioc acid. What is monomer B called? [1]

c) When monomer A and monomer B polymerise they make this repeat unit of polymer.



Explain why this type of polymerisation is known as condensation polymerisation. [2]

d) Some scientists have developed a type of polyesters known as biopolyesters. Suggest why these biopolyesters have been developed. [2]

EXTEND AND CHALLENGE

Measuring enthalpy changes really accurately

When you try to measure enthalpy changes in the laboratory by measuring the increase or decrease in temperature of the reactants and products, there are all sorts of problems. Heat energy is transferred to and from the environment and the apparatus used. So how do chemists obtain results that are both reproducible and accurate?

The answer is the bomb calorimeter. Originally made from a bomb casing, which gives the apparatus its name, it is an ingenious device to ensure that virtually all the energy released by a burning fuel can be measured. How is it done?

The sample is burned in a crucible inside the calorimeter (Figure 1) and the temperature of the water is monitored and a graph produced. The crucible is then replaced with a heating coil, and the water allowed to cool to its original starting temperature. The current is then switched on, and sufficient current is supplied to produce a graph curve identical to the original curve. By measuring the current used during the heating by the coil it is possible to find the exact same amount of energy that heated the water as the fuel did. This must be the energy that was produced.

1 Describe the differences between the bomb calorimeter and the apparatus for measuring enthalpy change shown in Figure 7.2 in Chapter 4.7.
2 Suggest what the purpose is of the following parts of the bomb calorimeter:
   a) the stirrer
   b) the air jacket
   c) the data logger.
3 Suggest why there is no need to know the specific heat capacity of the water or the apparatus.
4 Explain how the differences you have given in question 1 could improve the reproducibility of the results obtained in the bomb calorimeter.
5 Explain why the results from the bomb calorimeter will be more accurate.

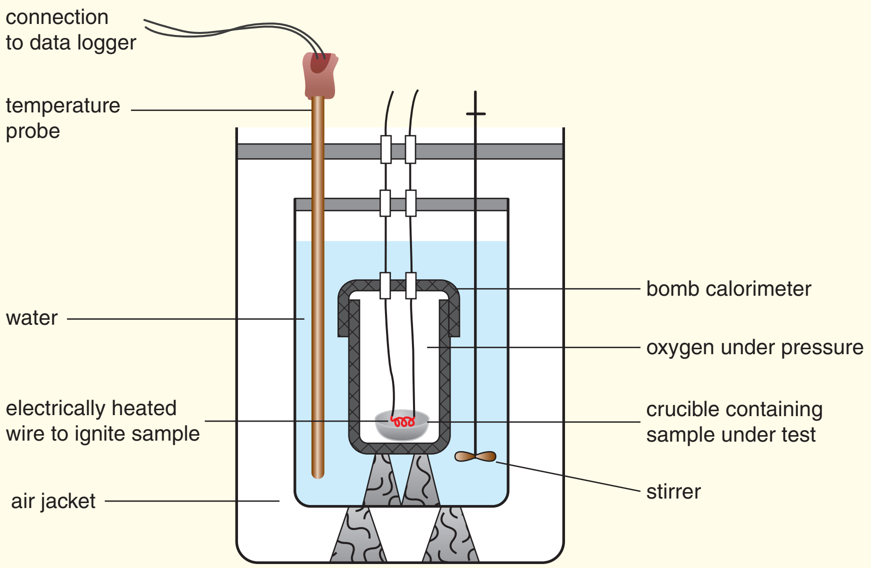


Figure 1 A bomb calorimeter.

The Publisher would like to thank the following for permission to reproduce copyright photographs:

l = left, r = right, c = centre, t = top, b = bottom

p. 6 t © Giuseppe Porzani – Fotolia.com; p. 7 t © Tree of Life – Fotolia.com, c © Patrick – Fotolia.com, b © meryll – Fotolia.com; p. 8 © Cultura Creative / Alamy; p. 9 © cantor pannatto – Fotolia.com; p. 11 © Mohamed Asama / 123rf.com; p. 14 © Maitree Laipitaksin / 123rf.com; p. 16 © tobi / 123rf.com; p. 17 © Evgeny Litvinov – Fotolia.com; p. 18 © JAMES HOLMES/ZEDCOR/SCIENCE PHOTO LIBRARY; p. 19 © Global Warming Images / Alamy; p. 20 © serezniy / 123rf.com; p. 21 t l © karandaev / 123rf.com, t r © Viktor Nikitin / 123rf.com, b © shopartgallerycom / 123rf.com

INTERNATIONAL GCSE (9–1)

Chemistry

for Edexcel International GCSE

SECOND EDITION

First teaching from September 2017

This sample chapter is taken from Edexcel International GCSE (9–1) Chemistry Student Book Second Edition, which has been selected for the Edexcel endorsement process.

Provide your students with complete coverage of the new Edexcel International GCSE Science specifications, with these affordable student books written by expert authors and teachers; testing knowledge and building practical skills throughout.

- Build students' confidence with in-depth yet accessible scientific content
- Test knowledge and understanding with study questions throughout the book
- Improve students' grades with practice questions for every section
- Challenge higher-ability students with extension activities
- Build practical skills with coverage of all required practicals plus further suggested experiments
- Enable the student to check their own progress with answers to all activities freely available online
- Enhance and maximise learning with supporting workbooks for each subject

ALSO AVAILABLE

Dynamic Learning

Edexcel International GCSE (9–1) Chemistry

Powered by Dynamic Learning the Student eTextbooks are downloadable versions of the printed textbook that teachers can assign to students so they can:

- Download and view on any device or browser
- Add, edit and synchronise notes across 2 devices,
- Access their personal copy on the move

To request Inspection Copies or eInspection Copies, trial the Student eTextbooks or pre-order your class sets visit **www.hoddereducation.co.uk/igcsescience**

Textbook subject to change due to Edexcel endorsement process.

HODDER EDUCATION

www.hoddereducation.co.uk