

**Salters Advanced Chemistry
Module 1 Activities Booklet**

Chemistry for Life

2850



**EL The Elements of Life
DF Developing Fuels**



Chemistry for Life Activities

Module 1 - 2850 - Activities Booklet

| <i>The Elements of Life</i> | | |
|-----------------------------|---|----|
| EL1 | How do we know the formula of a compound? | 1 |
| EL2.1 | How much iron is in a sample of an iron compound? | 3 |
| EL2.2 | Making the most of your study of chemistry | 6 |
| EL3.1 | Investigating the chemistry of Group 1 and Group 2 elements | 8 |
| EL3.2 | How do the physical properties of elements change across a row in the Periodic Table? | 11 |
| EL3.3 | Check your notes on <i>The Elements of Life</i> (Part 1) | 12 |
| EL4.1 | How do we know about atoms? | 13 |
| EL4.2 | Isotopic abundance and relative atomic mass | 14 |
| EL4.3 | Investigating a spectroscopic technique | 16 |
| EL4.4 | Radon in the rocks | 17 |
| EL5 | Balloon molecules | 20 |
| EL6 | Check your notes on <i>The Elements of Life</i> (Part 2) | 21 |

| <i>Developing Fuels</i> | | |
|-------------------------|--|----|
| DF1.1 | Which fuel for the future? | 25 |
| DF1.2 | Measuring the enthalpy change of combustion of different fuels | 26 |
| DF1.3 | Comparing the enthalpy changes of combustion of different alcohols | 28 |
| DF2.1 | Using spreadsheets to calculate enthalpy changes of combustion | 30 |
| DF2.2 | Making notes | 32 |
| DF3.1 | How do physical properties change along the alkane series? | 33 |
| DF3.2 | Comparing winter and summer petrol blends | 34 |
| DF3.3 | Auto-ignition in a test-tube | 35 |
| DF4.1 | Modelling and naming alkanes | 37 |
| DF4.2 | The octane numbers of different alkanes | 41 |
| DF4.3 | Using zeolites | 42 |
| DF4.4 | Cracking alkanes | 46 |
| DF4.5 | A closer look at alcohols | 49 |
| DF4.6 | Blend your own | 52 |
| DF4.7 | Why do hydrocarbons mix? | 54 |
| DF4.8 | Petrol – pulling it together | 55 |
| DF5 | What happens to the sulphur? | 56 |
| DF8 | Check your notes on <i>Developing Fuels</i> | 60 |

How do we know the formula of a compound?

This activity allows you to find the formula of a compound from your own experimental data. It also helps you to think about the uncertainties in your measurements and it gives you practice at converting mass to amount of substance.

Requirements

- copper strip (approximately 15 cm × 1 cm)
- emery paper
- dry filter paper
- access to a balance
- iodine crystals (0.3 g)
- boiling tube
- Bunsen burner



CARE Eye protection must be worn.



Introduction

You know for a fact that the formula of water is H_2O . But did you know that, like every fact in chemistry, it has been experimentally determined; it has come from observation and measurement?

One way to determine the formula of water is to break it down into its elements – hydrogen and oxygen – in an electrolysis experiment:



The hydrogen and oxygen formed can be collected and the volume of each gas measured. The mass of each gas produced can be calculated from the volumes and then converted to the amount in moles. The simplest ratio of moles of atoms can be found and thus the empirical formula of water.

Table 1 gives the results of three experiments. Use these data to find the empirical formula of water. The relative atomic masses of hydrogen and oxygen are 1 and 16 respectively (A_r : H, 1; O, 16). (If you are not sure how to do this refer to **Chemical Ideas 1.1**.)

The rest of this activity will help you to find experimentally the formula of another compound – a yellow compound formed when copper reacts directly with iodine vapour. In the water example above the compound was broken down into its elements. In this example, you will *make* a compound from its elements.

The exact masses which react together (reacting masses) can be measured and then used to find the empirical formula of the compound.

| Experiment | Mass of hydrogen/g | Mass of oxygen/g |
|------------|--------------------|------------------|
| 1 | 0.020 | 0.168 |
| 2 | 0.017 | 0.139 |
| 3 | 0.021 | 0.157 |

Table 1 Results from the electrolysis of water

What you do

- 1 Clean a strip of copper with emery paper and wipe it with a piece of dry filter paper. Weigh the copper strip.
- 2 You need to use about 0.3 g of iodine crystals so first weigh a dry boiling tube. (You may find it helpful to stand the boiling tube in a beaker so that it does not roll.) Add a small quantity of iodine to the boiling tube and reweigh it. (**CARE** Iodine is harmful. Avoid skin contact and do not inhale the vapour.) Keep adding iodine crystals until you have about 0.3 g in the tube. It is not necessary to know the exact mass of iodine in the tube, so you do not need to record the mass of the tube or the iodine.
- 3 Bend one end of the copper strip so that it fits over the lip of the boiling tube and the other end of the copper is about 2 cm above the iodine crystals (Figure 1).
- 4 Gently heat the copper nearest to the iodine. *This should be done in a fume cupboard.*
- 5 Continue heating until no more iodine vapour is seen but do not heat so strongly that iodine vapour escapes from the tube. Keep moving the tube in and out of the flame to avoid overheating it.
- 6 Allow the tube to cool. Carefully remove the copper strip and reweigh it.
- 7 Remove the yellow coating of copper iodide from the surface of the copper by scraping gently with a spatula onto a piece of scrap paper and reweigh the copper strip.

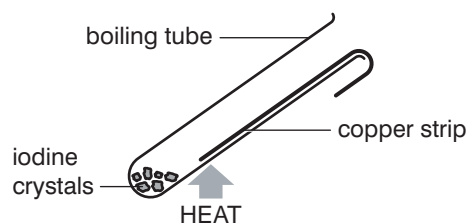


Figure 1 The reaction of copper with iodine vapour

Record your results

| | |
|--------------------------------------|---|
| Initial mass of copper strip | g |
| Mass of copper strip + copper iodide | g |
| Final mass of copper strip | g |

Using your results

- 8 What mass of copper has reacted with the iodine?
- 9 What mass of iodine did it react with?
- 10 How many moles of copper atoms reacted? (A_r : Cu, 63.5)
- 11 How many moles of iodine atoms reacted? (A_r : I, 127)
- 12 How many moles of iodine atoms combine with one mole of copper atoms?
- 13 What formula does this indicate for the copper iodide?

Evaluating your results and procedures

As a matter of routine, on completing an experiment you should review and evaluate the procedures you used so that you can identify any that could have been sources of error. Where your experiment involves measurements, you should consider whether the sources of error in your procedure would tend to make your values larger or smaller. For example, if it was difficult to remove all of the copper iodide then the final mass of copper would be too high.

As well as evaluating your procedures it is also important to bear in mind that when any physical measurement is made there is always some kind of **uncertainty** associated with the value obtained. This is sometimes referred to as **experimental error**, although it is not a mistake.

A source of uncertainty is the precision of the instrument being used. Every measuring instrument is designed to measure to a certain level of precision. For example, the copper iodide activity involves several weighings using a balance. The commonest balance you will use reads to 2 decimal places but there is an uncertainty associated with the second place.

For example, a reading of 11.46 means that the mass is between 11.455 g and 11.465 g. This can be written as 11.46 ± 0.005 .

± 0.005 is the **precision error** of the balance.

To compare the importance of the precision errors for different measurements they are usually expressed as **percentage errors**.

$$\text{Percentage error} = \frac{\text{error} \times 100}{\text{reading}}$$

$$\text{In this case, the percentage error} = \frac{0.005 \text{ g} \times 100}{11.46 \text{ g}} = 0.04\%.$$

Generally the limit of precision is taken to be half a division on either side of the smallest unit on the scale you are using.

QUESTIONS

- a What was the percentage error for each of the three weighings that you did?
- b How is the percentage error related to the value of the mass recorded?
- c If you wanted to reduce the percentage error for the initial mass of copper, would you use a smaller or larger piece of copper?
- d Identify stages in your *procedure* which could have led to errors. How would these errors have influenced the answer you obtained in 12?
- e Look at all the sources of error associated with weighing and with carrying out your experiment. Which one(s) do you think had the greatest effect on your final result?
If you were to repeat the experiment, write down any changes you would make to how you would carry it out. With which parts of the procedure you would take extra care?

How much iron is in a sample of an iron compound?

This activity introduces you to the technique of titration – one method of quantitative analysis. You will learn how to perform a titration and make use of accurately calibrated apparatus. Titration will be used in later units.

Requirements

- a sample of hydrated iron(II) ammonium sulphate (5 g)
- weighing bottle
- glass rod
- sulphuric acid, 1 mol dm⁻³ (250 cm³)
- potassium manganate(VII) solution, 0.010 mol dm⁻³ (100 cm³)
- 250 cm³ conical flask
- 250 cm³ volumetric flask
- burette
- 100 cm³ beakers (2)
- 25 cm³ pipette
- pipette filler
- small filter funnel
- 10 cm³ measuring cylinder
- wash bottle and distilled water
- mortar and pestle
- access to a balance

sulphuric acid



IRRITANT

CARE Eye protection must be worn.



WEAR EYE PROTECTION

CARE Take care when pouring potassium manganate(VII) solution as it stains the hands. Wear protective gloves if necessary.

Titration

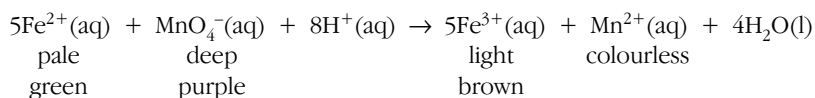
Measuring the concentration of iron in blood has to be carried out under strictly controlled conditions in medical laboratories. Because of this you are going to find the percentage of iron in an iron(II) salt, rather than blood, in this experiment.

You are going to carry out a **quantitative** investigation: trying to answer as accurately as possible a question which begins, 'How much ...'. A **titration** is a method of quantitative analysis which can be used when two solutions react together. One solution of a known concentration is placed in a burette. The second solution is placed in a conical flask. The solution in the burette is run into the flask until just enough has been added for the reaction to be complete. Often an indicator is added to show when the reaction has finished, but this is not necessary if the reaction is accompanied by a very obvious colour change. An analysis involving a titration is sometimes called a **volumetric analysis**.

How it works

In this investigation, you are going to find out how much iron there is in a solution of an iron(II) salt by titrating the solution with potassium manganate(VII) solution.

The salt is called hydrated iron(II) ammonium sulphate. You will learn more about names like this in **From Minerals to Elements** but, as its name suggests, iron(II) ammonium sulphate contains Fe²⁺ ions. These react with the MnO₄⁻ ions in the potassium manganate(VII), as shown in the equation below:



This looks rather complicated, but it tells you that the colour of the potassium manganate(VII) disappears as it reacts with the Fe²⁺(aq) ions. This provides a way of deciding when the titration is complete because, when all the Fe²⁺(aq) ions are gone, just *one drop* extra of potassium manganate(VII) solution will make the titration mixture turn pale purple.

What you do

- 1 Accurately weigh a weighing bottle. Add approximately 5 g of iron(II) ammonium sulphate to the bottle and record the mass of the bottle plus crystals. Tip the crystals into a clean 100 cm³ beaker. Carefully rinse out the bottle two or three times with 1 mol dm⁻³ sulphuric acid (**CARE** Irritant), transferring the washings to the beaker each time. It is important that all of the solid goes into the beaker.
- 2 Pour about a further 25 cm³ of sulphuric acid into the beaker but do not fill the beaker more than half full. Stir the acid and the solid together with a glass rod until you are sure all of the solid has dissolved.
- 3 Transfer the contents of the beaker through a small funnel into a 250 cm³ volumetric flask. Rinse the beaker and glass rod twice with small quantities of the dilute sulphuric acid and transfer the washings to the volumetric flask. Then rinse the funnel with a small volume of acid. This technique ensures that all the iron compound from the beaker is transferred to the volumetric flask.
- 4 Finally, add dilute sulphuric acid to the volumetric flask until it is about 1 cm below the graduation mark. Now add the acid slowly from a *clean* dropping pipette until the bottom of the meniscus is just touching the graduation mark. Stopper the flask and invert it several times to mix the solution.
- 5 Use a pipette and pipette filler to withdraw 25.0 cm³ of the solution from the volumetric flask and transfer it to a conical flask.
- 6 Use a clean, dry 100 cm³ beaker to fill a burette with the potassium manganate(VII) solution. Run a little of the solution out of the burette into the beaker to make sure the jet is full of solution. (Ask your teacher for help if an air bubble stays in the jet.) Be careful how you turn the burette tap: some burettes have tapered keys which leak if they are used wrongly. (If you are not sure, ask your teacher for advice on how to use a burette correctly.)
- 7 Record the volume reading on the burette before starting the titration. Read the burette to the nearest 0.05 cm³.
- 8 Add potassium manganate(VII) solution in small volumes to the solution in the conical flask, swirling the flask after each addition. The purple colour of the MnO₄⁻(aq) ions will disappear as they react with the Fe²⁺(aq) ions. The end-point of the titration is when you *first* get a faint purple colour from excess manganate(VII) ions.
- 9 Record the final burette reading and calculate the volume of solution you have run out into the flask.
- 10 Your first attempt will be a rough titration but it will give you a general idea of where the end-point comes. Do several more titrations until you have three volumes which agree to within 0.1 cm³.

Record your results

Record your results in tables similar to those shown below.

| | |
|-----------------------------------|---|
| mass of weighing bottle and solid | g |
| mass of weighing bottle | g |
| mass of solid | g |

| Titration | rough | 1 | 2 | 3 | 4 | 5 |
|-------------------------|-------|---|---|---|---|---|
| final burette reading | | | | | | |
| initial burette reading | | | | | | |
| titre | | | | | | |

Average titre = _____ cm³

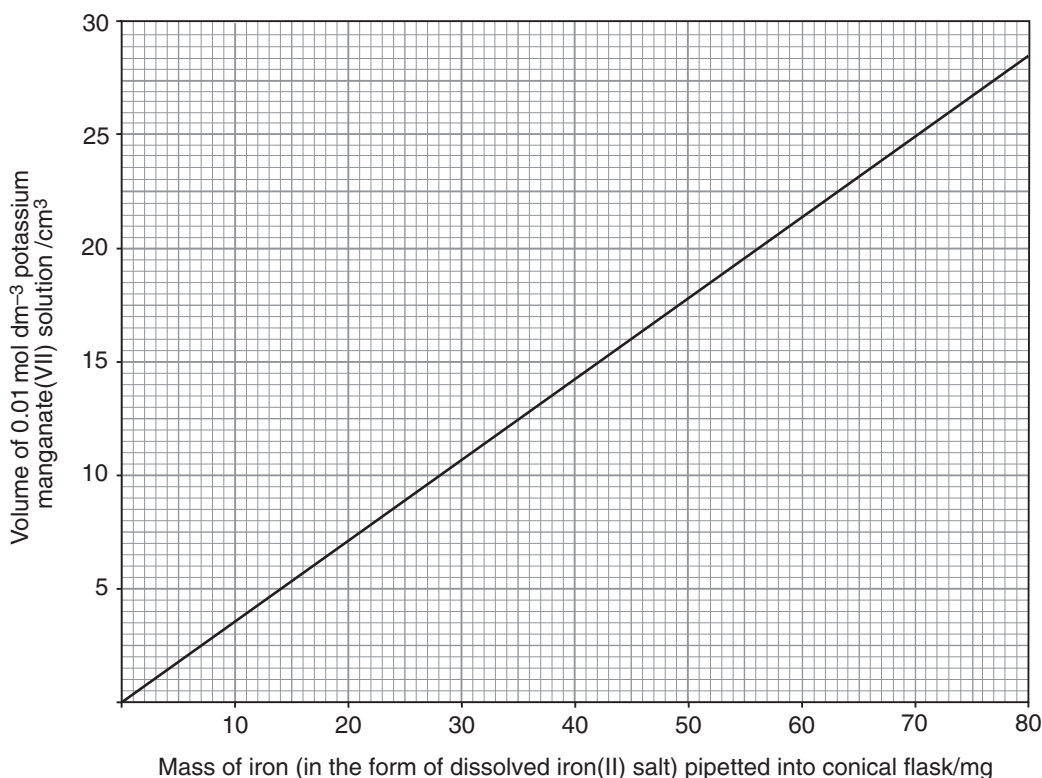


Figure 1 Conversion graph for iron(II) analysis

Using your results

- 11 Work out the average of your three closest figures for the volume of potassium manganate(VII) used in a titration. Correct this to 1 decimal place.
- 12 Use the conversion graph in Figure 1 to find an average value for the mass of iron which was pipetted into the conical flask each time.
- 13 Calculate how much iron was in the 250 cm³ of solution in the volumetric flask.
- 14 Calculate how much iron must have been in the mass of hydrated iron(II) ammonium sulphate that you used.
- 15 Calculate the percentage of iron in the hydrated iron(II) ammonium sulphate crystals.
- 16 Look up the formula of hydrated iron(II) ammonium sulphate and compare your result for the percentage of iron in the compound to the theoretical result calculated from the formula.

Evaluating your results and procedures

In any analysis involving a titration there are errors or uncertainties related to the precision of the equipment used. The glassware has been designed so that, if it is used appropriately, the precision errors are as follows:

Volumetric or standard flask (class B)

When a 250 cm³ volumetric flask is filled correctly, i.e. the bottom of the meniscus rests on the calibration line, the error is 0.2 cm³ or 0.08%

Burette (class B)

One drop from a burette has a volume of approximately 0.05 cm³. All burette readings should include 2 decimal places in which the second figure is either 0 or 5. An error of one drop in a volume of 25.00 cm³ gives a percentage error of 0.2% for each reading.

Pipette (class B)

When a 25 cm³ pipette is used correctly, i.e. it is allowed to drain and retain the last drop, the error is 0.06 cm³ or 0.24%.

Procedural errors can arise if your practical technique is not good. A good technique would include the following:

- the solution in the volumetric flask needs thorough mixing
- the burette and pipette should be washed out with the solutions being used
- the conical flask should be thoroughly washed out with distilled water between titrations
- the end-point of a titration can only be determined accurately if the solution from the burette is added drop by drop, with swirling, as the end-point is reached
- when an indicator is used in a titration only the minimum number of drops is added each time.

$$\text{Percentage error} = \frac{\text{error} \times 100}{\text{reading}}$$

It is important to repeat a titration several times to check that your results are reliable. After calculating the average titre, you should correct the value to 1 decimal place.

QUESTIONS

- a Fill in the following table for your experiment.

| Quantity measured | % error |
|--|---------|
| Mass of iron compound weighed on balance | |
| 250 cm ³ solution made up in volumetric flask | |
| 25 cm ³ solution delivered by pipette | |
| Your average titre delivered by burette | |

- b Estimate the percentage error when using the conversion graph.
- c Which of the stages in your *procedure* do you think could have led to errors? In each case, say whether it would make the result higher or lower.
- d Which of all the sources of error that you have identified are likely to have most impact on your overall result?

Getting a good grade at the end of your chemistry course should be important to you. Your chances of getting the best grade you can are much higher if, from the very beginning, you make an effort to develop good study habits and study skills. This activity should help you to begin to do this.

Effective study

Good **study habits** include being organised about the way you tackle your work and making sure that your working environment is suitable for study. Examples of good study habits are:

- don't leave things to the last minute
- think carefully about your work before you start
- spread your work out – don't try to do it all in one long session
- keep a diary of what you have to do, and for when
- make sure you have all the things you need
- work where you will be least disturbed and can concentrate best.

Study skills include being able to:

- make a summary of the key points in what you read or hear
- get at information quickly
- organise your notes
- record information clearly
- write your notes in a way that helps you learn and understand them
- cope with exams.

Make a summary

- 1 Go through 'A calcium story' in **Storyline EL2** and note down what you consider to be the key words or phrases. Do not pick out too much information – being able to select the most important points is part of the skill.
- 2 Work with three other people from your chemistry group and compare your summary with theirs.
 - Have you got all the important points?
 - Have you written down anything which is not important?
 - What are the best features of each summary?
 - Would you change your summary in any way?
- 3 Now turn your group of four into two pairs. Decide with your partner who will speak and who will listen. Then, using only your summary for reference, either you or your partner should describe as much as you can about 'A calcium story'.
 - How much did you remember? As a result of this process of making a summary, you will probably recall more than just the summary of words and phrases.
 - Was your account clear and concise? Would it have been easily understood by you in several months' time when exams are near?

Good notes should allow you to remember the important aspects of the course, and they should organise the information in a clearly structured way. It's no good just putting the pages of the units into your files – they contain too much information, and they have been written by someone else.

You need to develop your *own* style – one that is best for you. And that needs practice – practice at selecting material and recording it. In fact, everything you do, except copying out or writing down dictated notes, will involve using study skills. So you should have plenty of opportunities for practice throughout this course.

Techniques of recording information

The summary you just made probably listed the key points in a *linear* way. Often that will be a good way of note-taking, but it doesn't show you the *structure* of 'A calcium story' very well.

Sometimes *branching* notes may be better. The text begins with introductory points and then branches into different sections. Look at the way this is made clearer in the notes in Figure 1:

OSTEOPOROSIS: A CALCIUM STORY

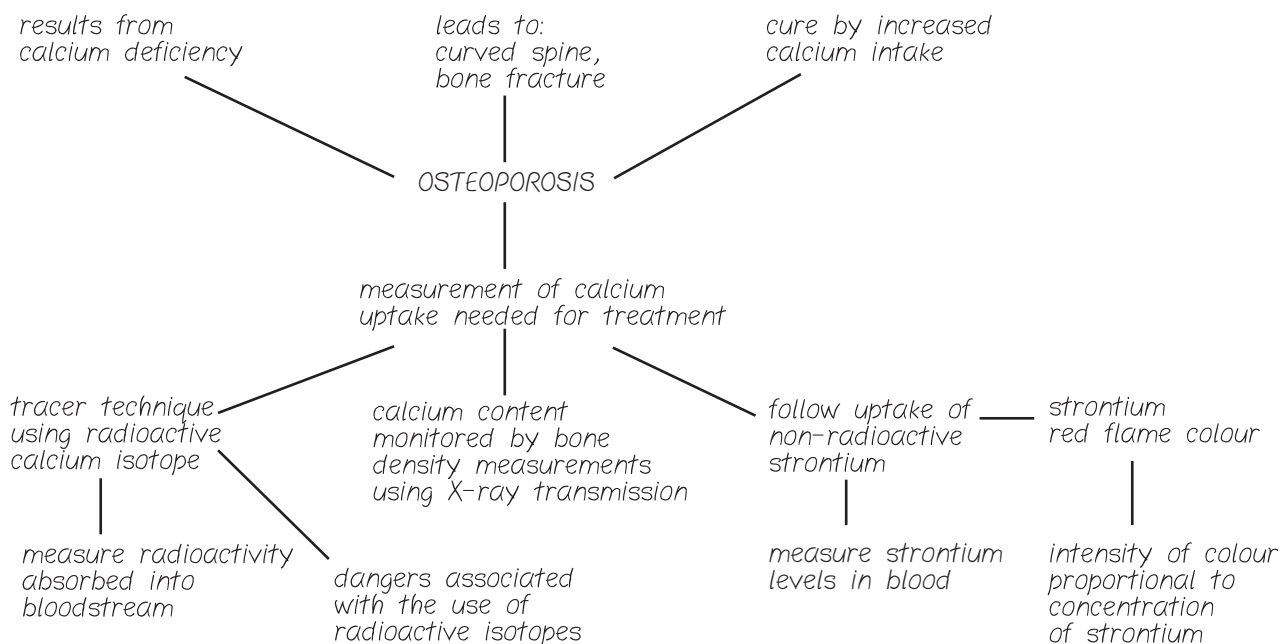


Figure 1

Chemists use several other techniques, besides linear and branching notes, for recording information clearly and concisely. Here are some examples:

- lists
- tables
- bar charts
- graphs
- chemical equations
- annotated diagrams.

You will come across examples of all these in this unit. You should keep experimenting with these techniques to find the *blend* which best suits you. Then you will be making really good notes.

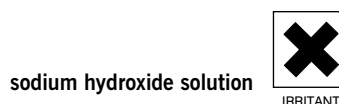
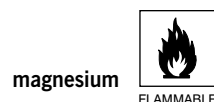
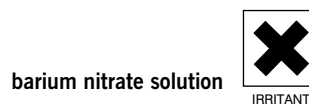
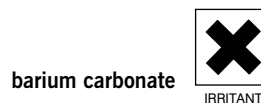
Investigating the chemistry of Group 1 and Group 2 elements

This activity introduces you to some of the chemistry of these elements and gives you practice at spotting patterns and looking for generalisations in your results.

Part 1: Chemistry of Group 2 elements, magnesium, calcium, strontium and barium

Requirements

- test-tubes
- angled glass delivery tube with bung to fit test-tube
- 100 cm³ beakers
- Universal Indicator solution
- tweezers
- filter paper
- small pieces of:
 - magnesium
 - calcium
 - barium
- magnesium carbonate
- calcium carbonate
- strontium carbonate
- barium carbonate
- magnesium nitrate solution, 0.1 mol dm⁻³ (10 cm³)
- calcium nitrate solution, 0.1 mol dm⁻³ (10 cm³)
- strontium nitrate solution, 0.1 mol dm⁻³ (10 cm³)
- barium nitrate solution, 0.1 mol dm⁻³ (10 cm³)
- sodium hydroxide solution, 1 mol dm⁻³ (10 cm³)
- sodium carbonate solution, 1 mol dm⁻³ (10 cm³)
- limewater (15 cm³)



CARE Eye protection must be worn.



Reaction of the elements with water

- 1 Half fill a 100 cm³ beaker with water. Use a pair of tweezers to select a small piece of calcium metal (**CARE** Avoid skin contact) and add it to the water.
- 2 Observe what happens to the contents of the beaker. When reaction seems to be over, test the pH of the mixture using Universal Indicator solution. Make a note of your observations.
- 3 Repeat the experiment with a piece of magnesium; and then with barium. (**CARE** Barium and its compounds are harmful; do not swallow any. Barium is kept under oil. You will need to dry your piece of metal on filter paper before using it.)
 - a Use a reference book to find out what the products are in these reactions. Then summarise your results in a table like the one below.

| Metal | Observation when metal added to water | Chemical equation | pH of mixture produced |
|-----------|---------------------------------------|-------------------|------------------------|
| magnesium | | | |

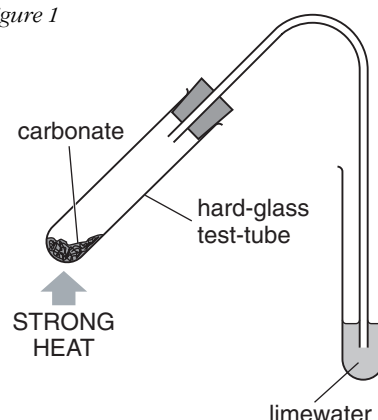
- b Make a note of any common properties of these metals and the compounds produced from them.

- c Make a note of any patterns you can spot in your results where properties change gradually from one element to the next.

Thermal stabilities of the carbonates

- 4 Place about 0.5 cm depth of magnesium carbonate in the apparatus shown in Figure 1.
- 5 Heat the powder with a moderate flame for a few minutes. If nothing happens, change to a roaring flame. Note how quickly any gas is given off and the extent to which the limewater turns cloudy. (**CARE** Remove the delivery tube from the limewater before you stop heating. If the gas in the tube is allowed to cool, limewater will be sucked back and will shatter the hot glass.)
- 6 Repeat the experiment using the carbonates of the other three elements.
 - d Record the pattern for the thermal stabilities of these carbonates.
 - e Write a general equation, using MCO_3 to represent a carbonate, to illustrate the reaction which occurs in these experiments.
 - f Write an equation for what happens to the limewater in these experiments, and explain why it is a suitable substance to use to test for carbon dioxide. Limewater is an aqueous solution of calcium hydroxide, $\text{Ca(OH)}_2(\text{aq})$.

Figure 1



Solubilities of the hydroxides and carbonates

- 7 Think about and write down a plan to investigate the solubilities of Group 2 hydroxides and carbonates. The plan should be similar to the instructions that you normally read in your activity sheets and should contain enough detail so that another student could use it to carry out the experiment without further help.

The simplest way to investigate the solubilities of the hydroxides is to mix solutions of a Group 2 nitrate and sodium hydroxide. For example, if you mix solutions of barium nitrate and sodium hydroxide and observe that a precipitate (particles of a solid) is formed, then you can conclude that an insoluble substance has been formed. The reaction occurring is:

barium nitrate + sodium hydroxide \rightarrow barium hydroxide and sodium nitrate

The insoluble product must be barium hydroxide as all sodium salts are soluble.

Similarly, to investigate the solubilities of the carbonates, you can mix solutions of a Group 2 nitrate and sodium carbonate.

You need to decide:

- how much Group 2 nitrate solution to use
- what quantity of each of the other solutions to add
- what equipment to use to measure out and mix your solutions together
- bearing in mind that you are looking for evidence of solubility of the hydroxides and carbonates, what language you expect to use to describe your observations, eg precipitate (colour), milky, opaque, cloudy, moderate precipitate, heavy precipitate, slight precipitate, etc
- what such observations would mean in terms of solubility, eg soluble, insoluble, very insoluble, sparingly soluble, etc
- what form of table you will need for your results.

Your plan should include a **Risk Assessment** for your planned activity. Your teacher will help you carry out a Risk Assessment when you do this for the first time.

Remember if you change your plan you may need to change your Risk Assessment.

At the end of your plan, list the sources of information which have helped you to devise your plan and produce your Risk Assessment. The reason for listing references is so that someone who wishes to check your information could consult the original source that you used. So it is important that you give full details of the publication and on which page in the publication the information can be found.

Your teacher will check your plan and your Risk Assessment before you carry out the experiment.

- g What trends, if any, can you see in your results?

Part 2: Chemistry of Group 1 elements, lithium, sodium, potassium, rubidium and caesium

This activity will help you to revise and extend your knowledge of the elements from Group 1 of the Periodic Table. You can either draw your information from chemistry textbooks or from a computer database or Internet site. A computer will allow you to collect and process data more quickly.

Reaction of elements with water

- 8 Find out how Group 1 elements react with water. (You may have a Periodic Table application that allows you to use video clips of reactions.) Put the elements in order of increasing reactivity with water and try to write a general equation for the reactions, using **M** as the symbol for the metal.

Reaction of oxides and hydroxides with water and acids

- 9 Find out how Group 1 oxides and hydroxides react with water and acids (eg hydrochloric acid). Write a general equation for each group of reactions, using **M** as the symbol for the metal.

Part 3: Physical properties of elements from Groups 1 and 2

- 10 Plot graphs showing how each of the following properties of the elements varies as you go down each of Groups 1 and 2:

- melting point
- density
- first ionisation enthalpy.

Describe and try to explain any trends you can see in these properties.

How do the physical properties of elements change across a row in the Periodic Table?

This activity helps you to identify patterns in the physical properties of elements as you go across the Periodic Table.

You can either draw the information you need from a chemistry databook or a computer database/Periodic Table application. A computer will allow you to collect and process data more quickly.

You can divide the behaviour of an element into two areas:

- **its chemical properties** – these cover all of the ways in which the element reacts with other substances
- **its physical properties** – these cover characteristics such as: melting point, boiling point, first ionisation enthalpy and electrical conductivity.

In this activity you are going to concentrate on the physical properties of the elements.

Melting point, boiling point, first ionisation enthalpy and electrical conductivity

- a What is meant by the 'melting point' and 'boiling point' of a substance?
 - b Write an equation for the process whose energy (enthalpy) change is the first ionisation enthalpy of sodium.
 - c What is meant by the electrical conductivity of a substance? In what units is electrical conductivity measured?
- 1 Collect data on the melting points, boiling points, first ionisation enthalpy and electrical conductivity of the elements from H to Ar. Plot graphs showing how these properties vary with atomic number.
 - 2 On your graphs indicate which points come from Period 1, Period 2 and Period 3 elements.
 - d Describe any patterns you observe across each period.
 - e How do the patterns across Period 2 compare to those across Period 3?
 - f Explain how your graphs show *periodicity*.
 - g What elements occur at:
 - i the peaks,
 - ii the troughs
 on the melting point and boiling point graphs? To which groups do these elements belong?
 - h What elements occur at:
 - i the peaks
 - ii the troughs
 on the first ionisation enthalpy graph? To which groups do these elements belong? Try to relate the chemical reactivity of these elements to their first ionisation enthalpies.
 - i Metals have high values for electrical conductivity. Non-metals usually have low values. Use the graph displaying the electrical conductivity data to divide the elements (from H to Ar) into metals and non-metals. Which elements are difficult to classify? Which element exists in two different forms, each with quite different electrical conductivities?

Check your notes on The Elements of Life (Part 1)

This activity helps you get your notes in order.

Make sure that your notes cover the following points. The points are listed in the order in which they are dealt with in the unit. Remember that you will be coming back to many of the ideas in later units.

Most of the points are covered in the **Chemical Ideas**, with supporting information in the **Storyline** or **Activities**. However, if the *main* source of information is the Storyline or an Activity, this is indicated.

- The use of the concept of amount of substance to perform calculations involving: masses of substances, empirical and molecular formulae and percentage composition.
- The procedure for carrying out a titration (**Activity EL2.1**).
- Writing balanced chemical equations.
- The reaction of the Group 2 elements magnesium, calcium, strontium and barium with water.
- The reaction of the oxides and hydroxides of these elements with water and with acid.
- The solubilities of the hydroxides and carbonates of the Group 2 elements.
- The thermal stability of the carbonates of the Group 2 elements.
- An outline of the historical development of the Periodic Table (**Storyline EL3**).
- The arrangement of the elements in the Periodic Table in terms of atomic (proton) number and common properties.
- An outline of the periodic trends in the properties of the elements in the Periodic Table (eg melting point and boiling point, electrical conductivity and ionisation enthalpy).
- How the trends in a group of the Periodic Table are used to predict properties of an element, given suitable data.

There is at least one *Check your notes* activity for each unit of the course. Some of the lists of points are much longer than the one above so it is important that you develop a method of working with these lists. They provide an essential summary of

the units but they do not provide easily assimilated overviews of the units. It can help if you develop these yourself.

You can start by grouping the points. For example, the above list could be grouped under the headings:

- amount of substance
- doing a titration
- Group 1 and Group 2 elements
- Periodic Table.

The next step could be to develop each heading into a branching summary, similar to that used for 'A calcium story' in **Activity EL2.2**. Figure 1 shows an example.

Try producing a branching summary for each of the overview headings. These overviews could be the first thing you look at when revising this unit. Even though at first you might not know all the detail, if you know and understand these summaries it will give you confidence.

Now you need to check your notes against the summaries. Look back at the styles of note-making listed at the end of **Activity EL2.2**. Do any of the styles seem particularly appropriate for the points covered by each of the branching summaries?

For example in the titration, it is the sequence of steps which is important, so a list of bullet points in the correct order may be best. You might want to highlight key words in each step.

In your work on Group 1 and Group 2 elements you were looking for patterns and trends. Perhaps some form of table would be best for these.

The section on the Periodic Table covers a number of different things about the table that you need to know and understand. These could be recorded in the form of an annotated diagram. You could arrange a series of notes around a copy of the table and, where appropriate, use lines to link the notes to particular parts of the table.

There is no single correct way of working with the list of points covered in a unit. It is up to you to develop the way that suits the unit and you best. Check that your notes for Part 1 of **The Elements of Life** cover the points listed and are in appropriate forms.

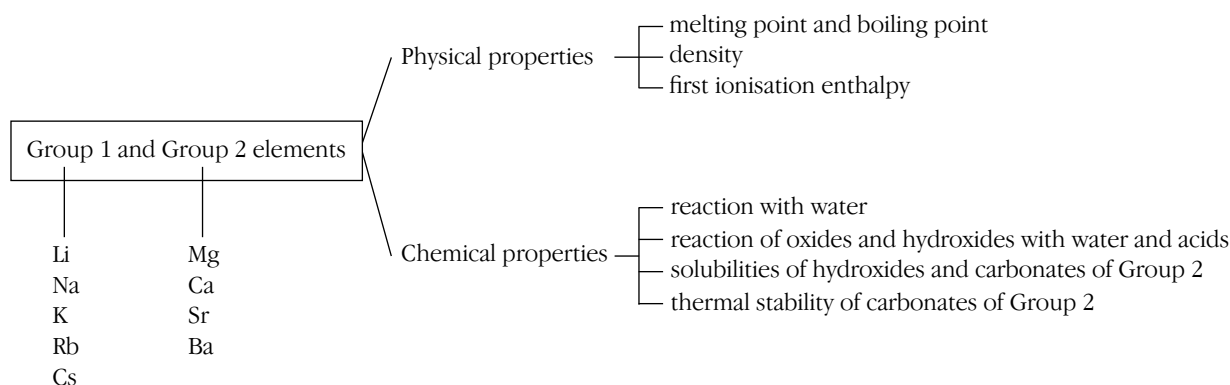



Figure 1 An example of a branching summary for Part 1 of **The Elements of Life**


Investigating a spectroscopic technique


In this activity you will have an opportunity to view the visible emission spectra of several metals in some of their compounds. The spectra you will see are line spectra emitted by metal atoms.


Requirements

- direct-vision spectroscope
 - nichrome wire fixed into a cork
 - Bunsen burner
 - concentrated hydrochloric acid
 - solid samples of chlorides of:
 - barium
 - calcium
 - potassium
 - sodium
 - strontium
 - 100 cm³ beaker
 - watch-glasses, one for each sample
- CARE** Work in a well-ventilated laboratory.

barium chloride 
TOXIC

calcium chloride 
IRRITANT

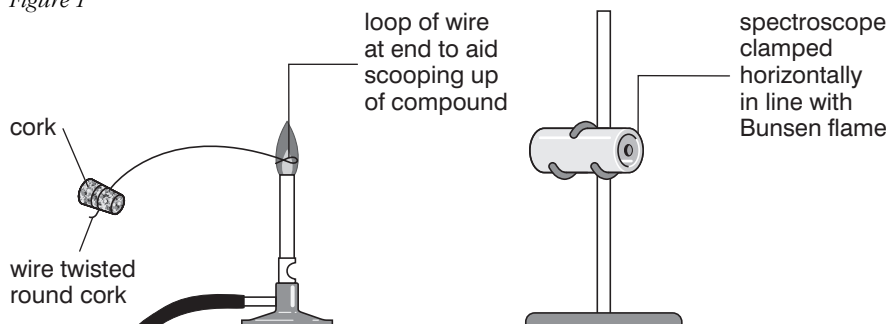
concentrated hydrochloric acid 
CORROSIVE

CARE Eye protection must be worn. 
WEAR EYE PROTECTION

What you do

- 1 Have a look through the spectroscope at light coming in through a window. We call this **white light**.
 - a What do you notice about the spectrum of white light?
- 2 Clamp the spectroscope as shown in Figure 1.

Figure 1



- 3 Clean the end of the nichrome wire by heating it strongly, then dipping it into a little concentrated hydrochloric acid in a 100 cm³ beaker. (**CARE** Hydrochloric acid is corrosive.) Repeat this process until the tip of the wire no longer gives a colour to the Bunsen burner flame.
- 4 Then dip the tip of the wire into one of the metal chlorides. Hold the sample in the edge of a non-luminous Bunsen flame. Look at the flame directly, and then through the spectroscope. (**CARE** The vapours produced in this activity can be harmful. Work in a well-ventilated laboratory and avoid inhaling the fumes.)
- 5 Repeat this procedure for each of the metal chlorides, cleaning the wire by heating it and dipping it in concentrated hydrochloric acid between successive tests.
 - b How do the spectra from the flames differ from the white-light spectrum?
 - c Briefly explain how this technique could be used to identify strontium in a sample of bone sent for medical analysis.
 - d Make a summary of your observations, noting the flame colour which is characteristic of each element.

It helps if these experiments are carried out in a darkened room.

What do atoms look like?

No one yet has been able to look inside atoms to see what they are really like. The picture of an atom we have in our mind is neither 'the truth' nor 'the right answer', but a good working **model** which helps explain many phenomena.

Much evidence has been gathered to support the present model of an atom. As more evidence comes to light, the model may change, and it is very likely to become more detailed.

We can sometimes explain things using only a simplified model of the atom. Thinking of atoms as tiny spheres is sufficient to explain states of matter (the properties of solids, liquids and gases), but this model is not detailed enough to explain why metals tend to react with non-metals. Models can be simple or elaborate, depending on the job they need to do. Keep this in mind as your ideas and understanding of chemistry develop.

How has the current model of the atom developed?

You will need to work in a group of four for this part of the activity.

Each of you is going to take the part of a scientist, or group of scientists, who collected some of the evidence which has contributed to the current model of the atom. You are going to prepare a report on the scientist you have chosen, and present it to the rest of your group.

Your presentation should be 2–3 minutes in length and could be illustrated with overhead projector transparencies, diagrams or by using a presentation package (eg Powerpoint). It should cover the following points:

- who you are
- when you did the work you are about to describe
- what you already knew about the atom
- what you did
- what you found
- what conclusions you drew from your results.

Use suitable textbooks, magazine articles or the Internet to help you find the information you need. You could start by searching the Salters Advanced Chemistry web site.

The scientists/groups of scientists are:

- 1 Joseph J. Thomson (key discovery 1897–1899)
- 2 Hans Geiger, Ernest Marsden and Ernest Rutherford (key discovery 1909)
- 3 Henry Moseley (key discovery 1913)
- 4 James Chadwick (key discovery 1932)

Make sure you present your reports in chronological order.

At the end of the activity you will need notes on the presentations. Each group should use a word processor or presentation package (eg Powerpoint) to prepare a brief summary of their presentation. At the end of the presentations ensure that the whole class has a copy of each summary.

Isotopic abundance and relative atomic mass

This activity shows how a mass spectrometer can be used to give information about isotopes. You will use mass spectra data to determine the relative abundances of the isotopes of an element and then calculate its relative atomic mass. You will also meet an application of isotopic abundance determination.

The naturally occurring form of some elements is made up of a mixture of isotopes of the element. For example, natural chlorine is made up of the isotopes ^{35}Cl and ^{37}Cl in the ratio of 75% to 25%. This means that for every 100 atoms of chlorine,

75 have mass number 35 and
25 have mass number 37

$$\begin{aligned}\text{so the relative atomic mass of chlorine} &= \frac{(75 \times 35) + (25 \times 37)}{100} \\ &= 35.5\end{aligned}$$

The relative atomic mass of a naturally occurring element (the form of the element that normally takes part in chemical reactions) is a weighted mean of the mass numbers of the stable isotopes of the element. The mass numbers and relative abundances of the stable isotopes can be found from the mass spectrum of the element.

Mass spectrum of an element

The mass spectrum of natural krypton, see Figure 1, shows that it has five stable isotopes at mass numbers 80, 82, 83, 84, and 86.

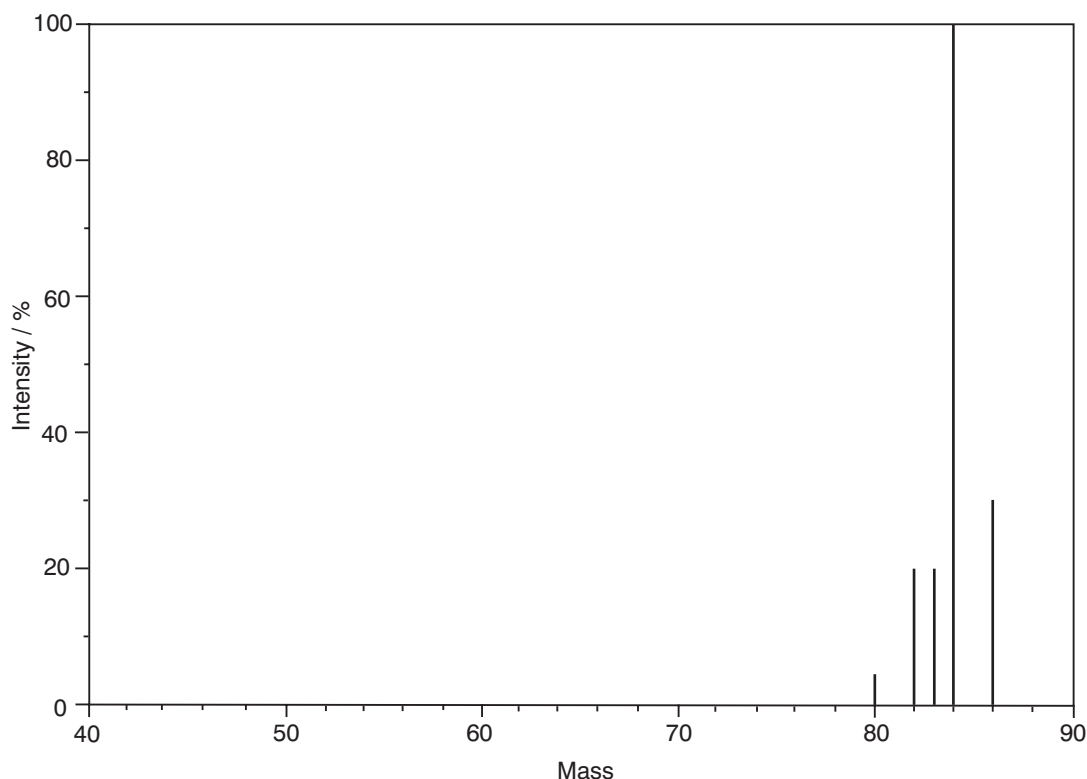


Figure 1 The mass spectrum of krypton

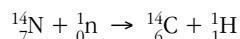
The peak heights of a mass spectrum are always adjusted so that the most abundant ion is given a relative intensity of 100% so that maximum differentiation between the peak intensities is achieved.

- 1 Measure the peak height for each isotope of krypton and calculate its relative abundance in natural krypton. Use these data and the mass numbers of the isotopes to calculate the relative atomic mass of krypton.
- 2 Draw the mass spectrum you would expect to obtain for naturally occurring chlorine.

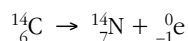
An element of life that 'decays' after death

The element carbon is found in all living material. It finds its way into the food chain via green plants which absorb carbon dioxide from the atmosphere during photosynthesis. The carbon in atmospheric carbon dioxide is made up of three isotopes, ^{12}C (about 99%), ^{13}C (about 1%) and a very small proportion of ^{14}C .

In the upper atmosphere neutrons are produced by the action of cosmic rays on atoms. These neutrons react with nitrogen atoms to form carbon-14.



Carbon-14 is a radioactive isotope which decays with a half-life of 5730 years. It decays to nitrogen-14 by the emission of an electron (β -decay).



This means that carbon-14 continually forms and decays, resulting in a fairly constant ratio of carbon-14 to carbon-12 in the atmosphere. This in turn results in the ratio in all living organisms (plants and animals) remaining fairly constant until they die. In the dead organism, the concentration of carbon-14 begins a slow decline as the isotope decays and is no longer replaced.

The rate of decay of carbon-14 is ideal for dating material that was once living up to about 40 000 years ago. If the ratio of ^{14}C to ^{12}C can be found it can be compared to the ratio in living organisms, which is $1 : 1 \times 10^{12}$. From this you can make an estimate of the age of the object based on the half-life of carbon-14.

Mass spectrometry may appear to be the obvious way of finding the relative abundances of ^{14}C and ^{12}C in an archaeological specimen but the ^{12}C peak is about 1×10^{12} times higher than the ^{14}C peak. Using a normal spectrometer the ^{14}C peak would be so small it would not be visible. However, a new form of mass spectrometer called an *accelerator mass spectrometer* has been developed which can separate ^{14}C ions from other ions and count them.

This means that very small samples can be used to date material. For example, a 50 mg sample of linen from the Shroud of Turin has been used to show that it dates from about AD 1250.

QUESTIONS

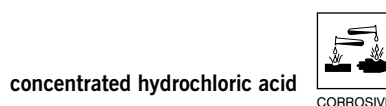
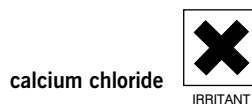
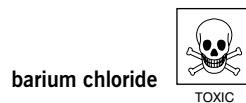
- a What fraction of a half-life of ^{14}C has elapsed since the linen of the Turin Shroud was first made?
 - b What will the ratio of ^{14}C to ^{12}C be today in a sample of wood that was used to make an object 5730 years ago?
 - c An accelerator mass spectrometer was used to measure the ratio of ^{14}C to ^{12}C in a sample of a human skeleton and it was found to be $1 : 4 \times 10^{12}$. How many years have elapsed since the person died?
-


Investigating a spectroscopic technique

In this activity you will have an opportunity to view the visible emission spectra of several metals in some of their compounds. The spectra you will see are line spectra emitted by metal atoms.

Requirements

- direct-vision spectroscope
 - nichrome wire fixed into a cork
 - Bunsen burner
 - concentrated hydrochloric acid
 - solid samples of chlorides of:
 - barium
 - calcium
 - potassium
 - sodium
 - strontium
 - 100 cm³ beaker
 - watch-glasses, one for each sample
- CARE** Work in a well-ventilated laboratory.

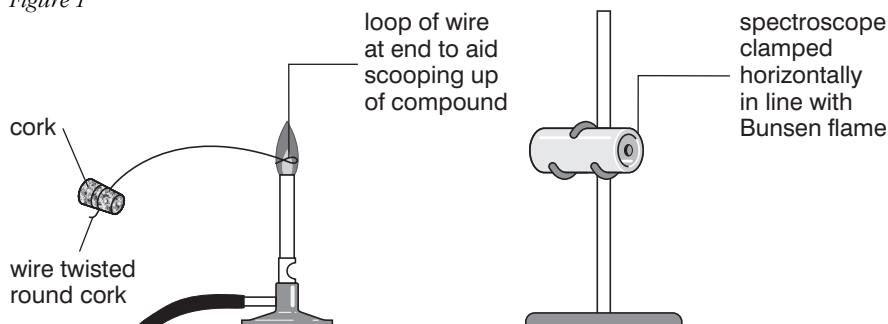


CARE Eye protection must be worn. 
WEAR EYE PROTECTION

What you do

- 1 Have a look through the spectroscope at light coming in through a window. We call this **white light**.
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Figure 1



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 - d Make a summary of your observations, noting the flame colour which is characteristic of each element.

It helps if these experiments are carried out in a darkened room.

This activity should help extend your understanding of radioactive decay and the hazards associated with ionising radiation. You will need to make use of the study skills you learned about in Activity EL2.2, associated with identifying the key points in a piece of text.

The article which follows is based on one written by Paul Phillips, Tony Denman and Stephen Barker which was published in *Chemistry in Britain* in January 1997.

What you do

- 1 Read the article carefully and make a note of the key points contained in it.
- 2 Now imagine that you work for an independent organisation, the Radiation Advice Bureau, which has been set up to give people unbiased information about issues involving radioactivity. Design a leaflet to be delivered to every home in your area, to explain:

- what radon is, how it is formed by radioactive decay and how it finds its way into buildings
- the possible danger to health if radon exceeds the 'action level'
- how people can decide whether they are at risk
- how to seek help and, if necessary, treat the problem.

The article will give you the facts about radon gas. Your school or college may also be able to provide you with other sources of information and you may find further information on the Internet.

You may produce your leaflet by hand or you may like to use this as an opportunity to practise your IT skills.

The radon problem

Radon is a colourless, odourless and tasteless gas found in Group 0 of the Periodic Table. It has a density of 9.25 g dm^{-3} , a boiling point of -62°C and a melting point of -71°C . The most abundant isotope, ^{222}Rn , contributes about 50 per cent of an individual's annual Rn dose and is produced by the decay of ^{226}Ra , which is part of the ^{238}U series. Another isotope, ^{220}Rn (also known as Thoron), contributes a further 4 per cent, and forms via the thorium decay series.

^{222}Rn decays with a half-life of 3.82 days into ^{218}Po , which in turn decays to ^{214}Pb , ^{214}Bi and ^{214}Po . These radionuclides are collectively called Rn daughters or radon progeny and, because they are solids, once formed they become attached to aerosol particles in the air and can be breathed into the lungs, where they settle. The isotopes ^{222}Rn , ^{218}Po and ^{214}Po all emit α -particles as they decay. Like other ionising radiation, α -particles can damage biological molecules, increasing the likelihood of cancers, genetic defects and accelerated ageing, even at low doses.

Alpha-particles are high linear energy transfer (LET) radiation and as such their energy is lost over a very short range. Thus when an α -particle passes through a cell it causes considerable damage. For these reasons, it is the radon daughters that deliver most of the radiation dose, but Rn gas concentrations (often referred to as 'levels') are the ones normally measured in a room. These are usually quoted in Bq m^{-3} (1 Bq = one decay per second). Average indoor Rn levels are about 20 Bq m^{-3} , while the action level for homes (the concentration above which the National Radiological Protection Board, NRPB, recommends measures to keep radon out of houses) is 200 Bq m^{-3} .

Silent, but deadly

In 1992 *Chemistry in Britain* published an article¹ on the health implications of elevated levels of radon (^{222}Rn) in domestic dwellings. At that time Rn had just become an

emotive public issue in certain regions of England that had been shown to have relatively high levels of the gas. Local newspapers and television regularly reported on *Shock report reveals new radon crisis* and *Focusing firms on radon fears*.

The public were looking to the scientific community for guidance and answers. Could Rn really cause lung cancer? How long must you live in high levels before cancer develops? Are children more vulnerable? How can we securely Rn-proof our house at low cost? Is there Rn in my area?

Although there was no direct evidence, a clear link was beginning to emerge between elevated Rn levels and incidences of lung cancer. In 1992 the US Environmental Protection Agency (EPA) estimated that the number of deaths from Rn in the US was somewhere between 7000 and 30 000. Compared with around 23 000 fatalities from drink driving, 4400 from fires and 1000 from aeroplane crashes, such a figure was certainly a cause for concern.

So what has happened since then? How has the scientific community responded to the public's alarm about this new environmental hazard; one that they cannot see, smell or easily avoid?

In 1994, the results of a large Swedish survey yielded further evidence to support the conclusion that residential exposure to Rn is an important cause of lung cancer in the general population². The study included 586 women and 774 men with lung cancer that was diagnosed between 1980 and 1984, who were compared with 1380 female and 1467 male 'controls'. Rn was measured in the 8992 houses that these people had occupied since 1947, and information was gathered on a range of other possible environmental hazards. The results were clear – the risk of lung cancer increased in relation to estimated cumulative exposure to Rn.

Back in the UK, in 1990 the NRPB advised that areas of the UK where 1 per cent or more of houses exceed the action level of 200 Bq m^{-3} should be classified as 'affected areas'. The 1992 article in *Chemistry in Britain* reported on early

recommendations to designate Cornwall and Devon, and shortly afterwards parts of Derbyshire, Northamptonshire and Somerset, as affected areas.

By 1993, the list also included some regions of Scotland and Northern Ireland, and in 1996 the NRPB had measured Rn levels in about 250 000 homes in England,³ advising that parts of Avon, Dorset, Lincolnshire, Oxfordshire and Shropshire that were once thought to be Rn free should adopt affected area status. Of the 100 000 homes most at risk, roughly 20 000 are in regions not known to be affected in 1992. Mapping still continues and more affected areas have been designated in Flintshire, Denbighshire, Powys, Anglesey and Pembrokeshire. Figure 1 shows one of the most recent maps of Rn levels in different regions of England.

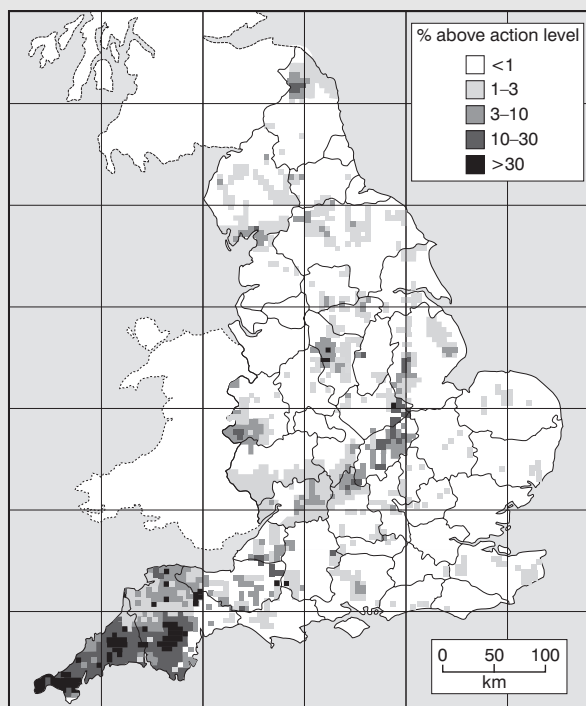


Figure 1 Estimated proportion of homes in England exceeding the action level in each 5 km² grid (courtesy of NRPB)

The NRPB has subdivided each of these affected areas according to Rn levels. For the highest level regions (>10 per cent of homes affected), new houses have to have primary (Rn-proof barrier) and secondary (Rn sump and extract pipe from ventilated sub-floor void) protection measures. In regions of lower risk, new dwellings should include secondary measures, while in regions of little risk no measures are necessary. Full preventative measures installed at the time of building cost about £250, compared with less than £100 for secondary protection – a small amount to protect health.

There are no regulations covering older houses and it is left to individual owners to seek testing and to decide on Rn protection measures if levels are above the action level. The cost of protecting an older house can vary dramatically; installing an efficient sump system costs from £500 to above £1000.

Geology and Rn

So important has the Rn problem become that the British Geological Survey (BGS) has just published a map and technical report⁴ illustrating the relationship between regional geology and Rn levels. Geological Rn mapping takes account

not just of measured Rn levels in buildings, but also of Rn levels in soil and the underlying geology. The resulting Rn potential map shows the susceptibility of soil to Rn emission in relation to the percentage of houses above the action level:

very high (>10 per cent), high (3–10 per cent), moderate (1–3 per cent), low (<1 per cent) and unclassified.

Testing for Rn gas is a useful method for detecting uranium deposits in the ground. Because granites contain relatively high levels of uranium, the uranium-rich mineral deposits of Cornwall and Devon are prime sites for elevated Rn levels in above-ground buildings. But how can we explain the elevated Rn levels in places such as Northamptonshire, where the Jurassic geology is very different: Diana Sutherland and Glenn Sharman⁵ have recently put forward a plausible explanation. Northamptonshire is an area of sedimentary Jurassic rocks (only about 200 million years old). The highest regions of soil Rn production are found on Northampton sand ironstone, upper Lincolnshire limestone, glacial sand and gravel. The ironstone contains phosphorus (ca 0.7 per cent), which is often associated with uranium, and underneath is a layer of phosphorus-rich pebbles, which contain the highest concentration, up to 55 ppm, of uranium. The ironstone is also rich in thorium, which generates the shorter half-life isotope of Rn, ²²⁰Rn.

One other important factor in determining indoor Rn levels is the permeability of the rock. The ability of Rn to leave the ground and enter the air is a function of soil porosity. Northamptonshire soils are very porous, while in areas where there is a relatively impermeable surface layer of clay, there is little risk of high indoor Rn levels since the Rn diffuses slowly through this and radioactively decays before entering buildings.

A controversial issue

As our knowledge about Rn and its health threat has increased, several suggestions have been put forward about the likely environmental impact of Rn. As well as lung cancer, some workers have suggested that Rn may be implicated in leukaemia and motor neurone disease, though as yet there is no hard evidence to substantiate this claim.

The attitudes of national governments to the problem of Rn in buildings also vary enormously. Some countries have no guidance, some have suggested limits, and two have advisory levels and compulsory levels (Sweden and Switzerland).

Sweden has a big Rn problem because of the high percentage of uranium in the country's rocks (eg granitic) and soils. Elevated indoor Rn levels are probably responsible for between 300 and 1500 lung cancer cases per year, out of a population of only 8.5 m. This has prompted Swedish authorities to carry out an extensive testing programme, involving about 300 000 buildings, which led to about 25 000 of them requiring radon-proofing. When Rn levels are above 400 Bq m⁻³, home owners are eligible for a grant to cover half the cost of remediation. The Swedish authorities aim to reduce the average Rn levels in homes to 50 Bq m⁻³ – half the current value.

In some parts of the world, the problem of Rn in the air in buildings is not so much of a concern as the levels in water supplies. Recent studies indicate that there is a connection between high Rn levels in drinking water and gastric cancer mortality. In North Carolina, 67 per cent of homes using well-water had Rn levels above the EPA's proposed limit of 11 Bq l⁻¹ (of well-water), while in Swaziland, 54 per cent of wells tested had Rn levels above the EPA's limit. Throughout the world, a large proportion of the population drinks well-water – thankfully only a small percentage is likely to receive a large radiation dose.

Dealing with the problem

What then is being done to offer protection to the public? In its *Report on indoor pollution*, published in July 1991, the House of Commons Select Committee on the Environment drew attention to the need for detailed advice on Rn-proofing to be made available to householders. At about the same time, moves were afoot to form a voluntary regulatory body that would set acceptable minimum standards for those involved in Rn remedial work.

The Rn Council evolved from an exploratory meeting of interested organisations in October 1990. The list of organisations associated with the Rn Council includes the Building Research Establishment (BRE), the NRPB and the Health and Safety Executive. The council has recently published the second edition of its *Rn manual*⁶ which contains a clear Code of Practice for those involved in Rn remedial work. The council also publishes a list of recognised contractors so that members of the public can choose competent and well qualified companies to deal with any problems. The excellent work of the BRE has meant that a range of reasonably priced Rn reduction techniques are now available to the public.

What we have to tackle now is public complacency. Every new environmental danger sparks public interest for only a short

time. The challenge is to convince people that Rn is a real problem and that investing in remediation is worthwhile.

Paul Phillips is a senior lecturer in the department of environmental science at Nene College of Higher Education, Park Campus, Boughton Green Road, Northampton NN2 7AL; Tony Denman is head of medical physics and radiation protection adviser at Northampton General Hospital; and Stephen Barker is a postgraduate student supervised by them.

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2. G. Pershagen *et al.* *N. Engl. J. Med.*, 1994, **330**, 159.
3. *Documents of the NRPB*, vol 7, no. 2, 1996.
4. J. D. Appleton and T. K. Ball, *Rn and background radioactivity from natural sources: characteristics, extent and relevance to planning and development in Great Britain*. BOS technical report WP/95/2.
5. D. Sutherland and O. Sharman, *Geol. Today*, March-April 1996, p63.
6. P. S. Phillips *et al.* *The Rn Manual* 2nd edn. Shepperton, Middlesex: The Rn Council, 1995.

The shapes adopted by twisted balloons can closely resemble the shapes of molecules. You have to be careful if this modelling process is to work well.

Requirements

- sausage-shaped balloons (3) and a pin

What you do

- Blow up the balloons and tie the necks. Do not blow them up too hard or you will not be able to twist them.
- Twist one of the balloons in the middle. It now represents *two* electron pairs around a central atom (Figure 1). The space taken up by a lobe of the balloon resembles the space occupied by a pair of electrons, and the balloon lobes push each other out of the way just as electron pairs repel one another. You can see the 'balloon molecule' takes the linear shape you would expect (like BeCl_2).
- Twist a second balloon in the middle, then twist the middle of this balloon several times around the middle of the first balloon to represent *four* electron pairs (Figure 2). (It may help to put a few drops of glycerol on the twist to lubricate the join.)
 - What shape does the 'molecule' adopt? Give an example of a molecule with such a shape.
- Now get a third balloon, twist it in the middle and twist it around the middle of the 'molecule' you made in step 3. Again, make sure the balloons are twisted round each other several times. Now you have a representation of a molecule with *six* electron pairs round a central atom.
 - What shape does the 'molecule' adopt? Give an example of a molecule with such a shape.
- Now comes the exciting bit. Get a pin and pop one of the balloon lobes. If you did your twisting well, the air won't escape from the other half of the popped balloon, and you will have *five* 'electron pairs'.
 - What shape does the 'molecule' adopt? Give an example of a molecule with such a shape.
- Pop two more lobes to get *three* 'electron pairs'.
 - What shape does the 'molecule' adopt? Give an example of a molecule with such a shape.



Figure 1 Two electron pairs round a central atom

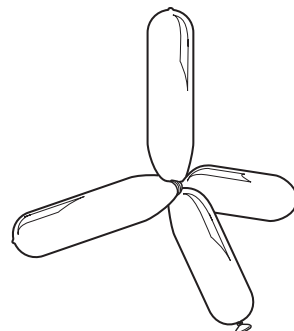


Figure 2 Four electron pairs round a central atom

Summary

Summarise your findings in a table like the one below. When you draw the diagrams, represent the electron pairs with lines or wedges as shown in **Chemical Ideas 3.3**.

| Number of electron pairs round central atom | Shape | Bond angles | Diagram | Example |
|---|-------|-------------|---------|---------|
| | | | | |

Check your notes on The Elements of Life (Part 2)

This activity helps you get your notes in order at the end of this unit.

Make sure that your notes cover the points below. Remember, you will find it easier to gain an overview of this part of the unit if you group the list of points under a number of headings. For example, the first three points are all concerned with *Atomic Structure*.

Decide how it would be helpful to group these points. You could produce branching summaries of the groups of points under each heading. Then check that your notes cover the summaries. Are they in forms which suit the subject matter and will you find them easy to understand next time you look at them? Remember that you will be coming back to many of the ideas in later units.

Most of the points are covered in the **Chemical Ideas**, with supporting information in the **Storyline** or **Activities**. However, if the *main* source of information is the Storyline or an Activity, this is indicated.

- The mass and relative charge of protons, neutrons and electrons.
- The structure of atoms in terms of protons, neutrons and electrons.
- The meaning of the terms: *atomic number*, *mass number*, *isotope*, *Avogadro constant*, *relative isotopic mass*, *relative atomic mass*, *relative formula mass* and *relative molecular mass*.
- The use of data from a mass spectrometer to determine relative atomic mass and the relative abundance of isotopes (**Activity EL4.2**).
- The principles underlying the operation of a mass spectrometer.
- The formation of elements in stars by nuclear fusion processes.
- Absorption and emission atomic spectra (make sure you know the difference).
- The atomic emission spectrum of hydrogen in terms of changes in electronic energy levels.
- The meaning of the term: *ionisation energy (enthalpy)*.
- The nuclei of some atoms are unstable, and these atoms are radioactive.
- The different properties of alpha, beta and gamma radiations.
- The use of nuclear symbols to write equations for nuclear processes, both fusion and radioactive decay.
- The use of radioactive tracers (**Storyline EL2**).
- The relationship between the position of an element in the Periodic Table and its electron structure (in terms of electron shells).
- The relationship between the ease of ion formation and ionisation enthalpy.
- Equations for the first and successive ionisation enthalpies of an element.
- The use of simple electron 'dot-cross' diagrams to describe how atoms bond through ionic, covalent and dative covalent bonds.
- A simple model of metallic bonding.
- The use of the electron pair repulsion principle to predict the shapes of simple molecules (such as CH₄, NH₃ and H₂O) and ions (such as NH₄⁺).
- Molecular shape in terms of bond angles.

Which fuel for the future?

The idea of this activity is to get you thinking about alternative fuels to replace petrol. It will help you appreciate the criteria needed for a good fuel, and you will have to bring together different aspects of your understanding of the chemistry of fuels. The activity will also allow you to practise and develop your skills in collecting information and in preparing and presenting an argument.

Although you are being given this briefing now, at the start of the unit, you will not actually be asked to give your presentation until you have *completed* **Developing Fuels**. By that time you will have learned a lot more about the chemistry of fuels.

What you will be asked to do

Your group is to prepare and present the case for the use of a particular fuel to replace petrol in motor vehicles. The fuels to be considered are:

- hydrogen
- methane (natural gas)
- liquefied petroleum gas (LPG), a liquid mixture mainly containing propane and butane
- methanol
- ethanol
- coal.

Your group will be assigned one of the above fuels to consider. You should bear the following points in mind when you prepare the case for your fuel:

- suitability for use in road transport
- availability and cost of supply
- energy density, in terms of the energy available per gram or litre
- whether existing engine technology could be readily adapted
- ease of storage and distribution and whether existing storage and distribution systems could be readily adapted
- effect on the environment
- safety in use.

Towards the end of your study of **Developing Fuels**, you will be asked to give a 5- to 10-minute presentation of the case for using your fuel. You should be prepared to answer questions on the content of your presentation.

Following your presentation and those of other groups, the class should work together to decide on the best overall strategy for replacing petrol as a fuel.

You will need to appoint a member of the class to chair the presentation sessions and the follow-up discussion. You may also wish to appoint a group to summarise these discussions and produce a short final report.

Sources of information

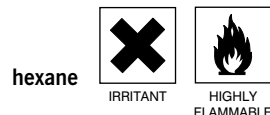
Much of the information you need about the criteria for a good fuel will be covered in some part of the **Developing Fuels** unit. You will also need to collect information about your particular fuel from other sources including the Internet, and you should start doing this now. Your teacher will be able to suggest some useful sources and you should also search the Salters Advanced Chemistry web site.

Measuring the enthalpy change of combustion of different fuels

In this activity you will use a simple, rather crude, method to measure the enthalpy change of combustion of different fuels. It's a method you may have used before, but you should use your skills in experimental design to improve its quantitative accuracy.

Requirements

- small copper can or other metal container to act as calorimeter (base diameter about 10 cm)
- 0–110 °C thermometer, or 0–50 °C thermometer if available
- 100 cm³ measuring cylinder
- spirit burners containing
 - (a) hexane
 - (b) methanol
- access to a balance
- Bunsen burner
- draught shielding



CARE Eye protection must be worn.



CARE Hexane and methanol are highly flammable liquids. Keep bottles stoppered when not in use and well away from naked flames. Avoid skin contact and do not breathe vapours. Do not open the spirit burner (eg to refill) in a laboratory with naked flames.

What you do

Figure 1 shows the basic apparatus, set up for a liquid fuel. You will burn the fuel and arrange for as much as possible of the energy to be transferred to the water by heating. Then you can use the fact that 4.2 J of energy are required to raise the temperature of 1 g of water by 1 °C.

Remember that the enthalpy change of combustion of the fuel is a measure of the energy transferred when *1 mole* of the fuel burns completely. You will need to measure the quantity of fuel burned in your experiment, then convert this to moles.

Here is a basic experiment that you can develop

- 1 Put 200 cm³ of cold water in a copper calorimeter and record its temperature.
- 2 Support the calorimeter over a spirit burner containing the liquid fuel you are going to test. Arrange a suitable draught exclusion system and any other features you can think of to reduce energy loss.
- 3 Weigh the spirit burner.
- 4 Replace the burner under the calorimeter and light the wick.
- 5 Use the thermometer to stir the water all the time it is being heated. Go on heating until the temperature has risen by about 15 °C–20 °C.
- 6 Extinguish the burner. Keep stirring the water and note the *biggest* temperature reached.
- 7 Weigh the burner to see what mass of fuel has been burned. (Again, think about how you can reduce inaccuracies.)

Use this basic experiment, developed as you see fit, to measure the enthalpy change of combustion (ΔH_c) for two different liquid fuels:

- hexane C₆H₁₄(l) (a component of petrol)
- methanol CH₃OH(l) (an alcohol, which can be used as an alternative fuel for cars, alone or blended with petrol).

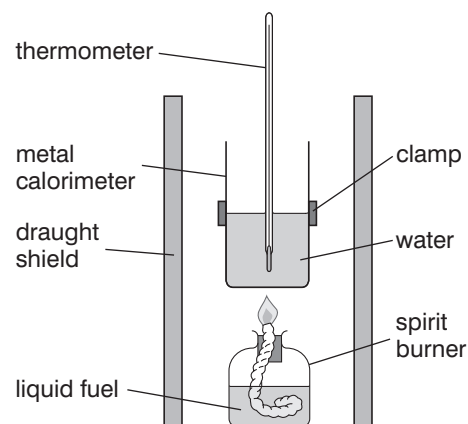


Figure 1 Simple apparatus for measuring the enthalpy change of combustion of a liquid fuel

Work out the enthalpy change using the following stages

- 8 Record your results in a suitable table.
- 9 Use your results to work out:
- the mass of water used
 - the temperature rise of water
 - the mass of fuel used.
- 10 Assuming that all the energy from the burning fuel is transferred to the water, we have:
- energy transferred to water by burning fuel =
 $(\text{mass of water} \times \text{temperature rise} \times 4.2) \text{ J}$
- (Remember: 4.2 J raises the temperature of 1 g of water by 1 °C.)
- Use this to work out the energy transferred to the water by the fuel burned.
- 11 You now need to find the energy that would be transferred to the water by burning 1 mole of fuel. Complete the following:
- | | | |
|--|---|----------------------|
| formula of fuel | = | |
| mass of 1 mole of fuel | = | |
| ⇒ number of moles of fuel used | = | |
| energy transferred by this number of moles of fuel (your answer from step 10) | = | J |
| ⇒ energy transferred by 1 mole of fuel | = | J |
| ⇒ enthalpy change of combustion | = | kJ mol ⁻¹ |

A more accurate method

In **Activity DF1.3** you can try one method for getting more accurate results from this basic experiment. You may also get an opportunity to use or see more sophisticated apparatus which can give more accurate results.

Evaluating your results and procedures

- a Fill in the following table which relates to your experiment.

| Quantity measured | % error |
|--|---------|
| volume of water using measuring cylinder | |
| mass of fuel using balance | |
| temperature change using thermometer | |

- b List the various stages in your procedure that could have led to errors and whether each source of error would have made your value higher or lower. For example, if the water was cooled by losing energy to the surroundings, this would lead to a smaller increase in temperature and in turn to a lower value for the enthalpy change of combustion.
- c Which of all the sources of error you have identified are likely to have had most impact on the accuracy of your final results?
- d Look up the values of ΔH_c for each fuel. (You can find these on the **Data Sheets**.) Calculate the percentage difference between each of the values you obtained and the quoted values. For which fuel was your value most accurate?
- e Suggest ways in which the accuracy of this basic experiment could be improved.

Precision and accuracy

The *accuracy* of a result means how close is it to the 'true' value.

The *precision* of each of the measurements you have made is indicated by the % error you calculated in **a** above. It is possible to take very precise measurements but still end up with an inaccurate result because of a weakness in the procedure or the equipment you have used. For example, you may record a temperature change very precisely, but it could be inaccurate because of energy losses to the surroundings.

DF1.3

Comparing the enthalpy changes of combustion of different alcohols

In this activity you will adapt the simple method of Activity DF1.2 to compare the enthalpy change of combustion of different alcohols. You will need to use your experimental skills to control the conditions so that an accurate comparison can be made.

Requirements

- spirit burners containing:
 - propan-1-ol
 - as many as possible of the following alcohols: methanol, ethanol, propan-2-ol, butan-1-ol
- small copper can or other metal container to act as a calorimeter
- 0–110°C thermometer
- 100 cm³ measuring cylinder
- access to a balance

CARE Alcohols are highly flammable liquids. Keep bottles stoppered when not in use and well away from naked flames. Avoid skin contact and do not breathe vapours. Do not open the spirit burner (eg to refill) in a laboratory with naked flames.

CARE Eye protection must be worn.



| | | |
|-------------|------------------|------------------|
| butan-1-ol | | |
| | HARMFUL | FLAMMABLE |
| ethanol | | |
| | HIGHLY FLAMMABLE | |
| methanol | | |
| | TOXIC | HIGHLY FLAMMABLE |
| propan-1-ol | | |
| | HIGHLY FLAMMABLE | |
| propan-2-ol | | |
| | HIGHLY FLAMMABLE | |

Background

The method you used in **Activity DF1.2** to measure the enthalpy change of combustion of fuels probably gave values in poor agreement with databook figures. Your results were inaccurate because of the cooling losses from the very simple apparatus you used.

However, you can use the same simple apparatus to make reasonably accurate *comparisons* of the enthalpy change of combustion of different fuels, provided you arrange things so that the cooling losses are the same in each case. You can do this by using the same quantity of water and the same temperature rise in all your experiments.

You can use a standard reference value for one of the alcohol fuels to find out the energy which must have been released from the amount you burned. In this experiment the standard you will use will be the alcohol propan-1-ol, CH₃CH₂CH₂OH:

$$\Delta H_c^\circ (\text{propan-1-ol}) = -2021 \text{ kJ mol}^{-1}$$

The same quantities of energy must have been released by the other alcohols if they heated the same quantity of water through the same temperature rise. Thus you can find their ΔH_c° values in kJ mol⁻¹.

You will be making comparisons with some other alcohols, probably including:

- methanol CH₃OH
- ethanol CH₃CH₂OH
- propan-2-ol CH₃CH(OH)CH₃
- butan-1-ol CH₃CH₂CH₂CH₂OH

Alcohols are a series of organic compounds which all contain the –OH group. They differ from each other by the length and structure of the carbon chain, and the position of the –OH group.

What you do

- 1 First make your measurements on the reference alcohol, propan-1-ol. You can do this using the basic experiment, steps 1–7, in **Activity DF1.2**.
- 2 Now repeat the experiment using a different alcohol. Keep *all conditions* the same as with the reference alcohol. Use the same apparatus, the same mass of water and the same starting temperature; and go on heating until you reach the same finishing temperature. The only thing that should be different is the mass of alcohol that is used up.
- 3 Repeat the experiment for as many alcohols as you have time for. You will probably need to share them around the class to make sure they all get done.

Working out the results

- 4 Look at your results for propan-1-ol. Work out the mass of propan-1-ol that you burned in the first part of the experiment. Use this to calculate the amount in moles of propan-1-ol that you burned.
- 5 The enthalpy change of combustion of propan-1-ol is $-2021 \text{ kJ mol}^{-1}$. Use this value, together with your answer in step 4, to calculate the quantity of energy, Q , released by the propan-1-ol when it burned. This is the quantity of energy required to raise the temperature of the mass of water from the starting temperature to the finishing temperature. You will be assuming that this is also the quantity of energy released when the other alcohols burn.
- 6 Look at your results for the next alcohol. Work out the mass of alcohol that you burned. Use this to calculate the amount in moles of the alcohol that you burned. This is the amount of the alcohol that released a quantity of energy Q when it burned.
- 7 Use your results from step 6 to work out the quantity of energy that would be released when 1 mole of the alcohol burned. This is the enthalpy change of combustion of the alcohol.
- 8 Repeat for any other alcohols.

Evaluating your results and procedures

- a If there are any, note clearly anomalous results and explain why you think they are anomalous.
- b Where possible calculate the percentage errors for each measurement and then comment on the relative importance of these errors.
- c Identify those parts of your procedure which could have led to errors and those which helped to minimise errors.
- d Explain which of the errors associated with either the measurements you made or with other aspects of your procedure you think had the greatest effect on the accuracy of your final results.

Using your results

- e Make out a table to compare your results with values from the **Data Sheets**. How accurate are your results?
- f Plot a graph of ΔH_c (vertical axis) against the number of carbon atoms for the different alcohols. If you are not confident using your own results, use values from the **Data Sheets**.
- g Interpret the important features of the graph.
 - i Use the graph to predict the enthalpy change of combustion of pentan-1-ol. Find out the **Data Sheet** value. How good is your estimate?
 - ii What is the significance of the intercept of the graph with the vertical axis? This is equivalent to ΔH_c when there are no carbon atoms in the molecule. Which compound does this correspond to? What would you expect ΔH_c for this compound to be?

Using spreadsheets to calculate enthalpy changes of combustion

In this activity you will use bond enthalpies to calculate the enthalpy change of combustion for some hydrocarbon fuels. It will give you an opportunity to practise using a computer spreadsheet program to perform a series of related calculations.

Requirements

- access to a computer with a standard spreadsheet package

Outline

The enthalpy change of combustion of a compound can be found from bond enthalpies. You just work out all the energy needed to break the bonds in the reactants, and all the energy released when the new bonds are made in the products. Then you add together the bond-breaking and the bond-making terms.

You do the same standard calculation to find the enthalpy change of combustion of *any* compound. It is quite easy to set up a standard spreadsheet to do the calculation for you. Try it, for a series of alkane fuels (general formula C_nH_{2n+2}), using your standard spreadsheet package.

What you do

Using the spreadsheet

- 1 Set up a spreadsheet to calculate enthalpy changes of combustion of alkanes. An example is given on the next sheet.
- 2 Use your spreadsheet to calculate the enthalpy change of combustion for the series of straight-chain alkanes, methane to nonane.
- 3 Plot a graph of enthalpy change of combustion against number of carbon atoms in the alkane. Compare the values you get with those in the **Data Sheets**. Comment on any differences you find. How can bond enthalpies be used to explain the shape of the graph?

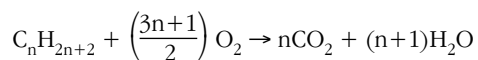
Extending the spreadsheet

- 4 Adapt the spreadsheet so that it can calculate the enthalpy change of combustion in kJ per *kilogram* and in kJ per dm^3 for the liquids. To do this you will need to include data on the relative molecular mass and density for each example you use.
- 5 Make a copy of the spreadsheet before altering it so that it will perform the calculations for alcohols instead of alkanes. You will need to start with writing a general equation for their combustion.

Example spreadsheet

Figure 1 shows an example spreadsheet. The spreadsheet calculates the enthalpy change of combustion for any non-cyclic alkane in kJ mol^{-1} . You will only have to enter the number of carbon atoms in the alkane molecule.

Using the general formula, $\text{C}_n\text{H}_{2n+2}$, the balanced equation for the enthalpy change of combustion of an alkane is:



Check that you can see how this equation balances.

Refer to the example spreadsheet in Figure 1.

- Cells A9 to A13 list the type of bonds in the reactants and products.
- Cells B9 to B13 list the bond enthalpies.
- Cells C9, C10 and C12 have formulae that express the number of moles of each bond broken in terms of the number of carbon atoms in the alkane (n). The value of n is held in cell B5 and can be altered.
- Cells D9, D10 and D12 have formulae calculating the energy required to break each type of bond (bond enthalpy \times number of moles of bonds broken).
- Cell D15 has a formula calculating the total energy required for bond breaking.
- Cells E11 and E13 have formulae that express the number of moles of each bond made in terms of the number of carbon atoms in the alkane.
- Cells F11 and F13 have formulae calculating the energy required to make each type of bond (bond enthalpy \times number of moles of bonds made).
- Cell F15 has a formula calculating the total energy required for bond making.
- Cell E17 has a formula calculating the enthalpy change for the reaction (total energy in – total energy out).

| | A | B | C | D | E | F |
|----|--|---|---|---------------------------------------|--|--|
| 1 | Enthalpy change of combustion of alkanes | | | | | |
| 2 | | | | | | |
| 3 | compound $\text{C}_n\text{H}_{2n+2}$ | | | | | |
| 4 | | | | | | |
| 5 | value of n | 1 | | | | |
| 6 | | | | | | |
| 7 | bond type | bond enthalpy (kJ mol^{-1}) | number broken | energy in (kJ mol^{-1}) | number made | energy out (kJ mol^{-1}) |
| 8 | | | | | | |
| 9 | C–C | 348 | =B\$5–1 | =B9*C9 | | |
| 10 | C–H | 411 | =(2*B\$5)+2 | =B10*C10 | | |
| 11 | C=O | 804 | | | =2*B\$5 | =E11*B11 |
| 12 | O=O | 498 | =((3*B\$5)+1)/2 | =B12*C12 | | |
| 13 | O–H | 463 | | | =2*(B\$5+1) | =E13*B13 |
| 14 | | | | | | |
| 15 | | | total energy in (kJ mol^{-1}) | =SUM(D9:D13) | total energy out (kJ mol^{-1}) | =SUM(F9:F13) |
| 16 | | | | | | |
| 17 | enthalpy change of combustion (kJ mol^{-1}) | | | | =D15–F15 | |

Figure 1 Example spreadsheet for calculating enthalpy changes of combustion of alkanes

This activity will help to ensure that your notes cover the main points arising from Storyline DF1 and DF2. This will allow you to develop your note-taking skills and practise making summaries.

Your aim

Storyline DF1 and **DF2** (and the associated **Chemical Ideas** sections, **1.3**, **4.1** and **4.2**) contain some important chemistry that you will need to use throughout the course. It is essential that you have a record of this work which you can refer back to when necessary.

You should get into the habit of making good summary notes as you go along (see **Activity EL2.2**). It is a waste of time to copy out the Storyline and Chemical Ideas sections. Your notes should be a *personal* record, *summarising* the main points in whatever form you find most helpful. You can put in references to places where you can look up the details if required.

Most people find that it helps to use a mixture of different ways of summarising information – lists, tables, annotated diagrams, branching ‘web’ diagrams, and so on.

Remember, the aim of your notes is to summarise the key points in as clear a manner as possible. This will help you to:

- organise your work, both mentally and on paper
- get at information quickly
- get an overview of the topic, free from detail
- see links between different sections of the course
- revise for examinations.

Of course, you should also keep records of your practical work and other activities in a systematic way, so that you can quickly find information. Your answers to assignments and problems will be useful when you come to revise this work.

All this needs *organisation* and *planning*. There is no one ‘best’ system for managing your work. Do what suits you best – but think about it *now*. Don’t wait until you are buried in paper!

One final tip – it is vital to number the pages in your notes ... just in case you drop your file!

Some help . . .

Make sure you understand and record the meaning of the following terms:

- exothermic
- endothermic
- enthalpy level diagram
- enthalpy change
- standard state
- standard enthalpy change for a reaction
- standard enthalpy change of combustion
- standard enthalpy change of formation
- Hess’s law
- bond enthalpy
- bond length

After completing **Storyline DF1** and **DF2** you should be able to:

- use a balanced chemical equation to work out reacting masses
- relate enthalpy changes to a balanced chemical equation
- discuss methods of measuring enthalpy changes and the precautions which must be taken to obtain accurate results
- calculate enthalpy changes from experimental results
- use an enthalpy cycle to find an enthalpy change indirectly
- interpret the enthalpy changes of combustion for successive members of a series of alcohols
- use bond enthalpies to calculate the enthalpy change for a reaction
- describe the relationship between bond enthalpy and the length and strength of a bond
- discuss some of the properties which make a good fuel.

DF3.1**How do physical properties change along the alkane series?**

In this activity, you will investigate the trends in melting point and boiling point as the number of carbon atoms in an alkane chain increases.

Alkanes form a **homologous series**. Each member of the series conforms to the general molecular formula C_nH_{2n+2} and members of the series show similar chemical properties. Physical properties, however, show a gradual change as the number of carbon atoms in the molecules increases.

Table 1 gives some properties of twelve alkanes.

| Name | Molecular formula | Relative molecular mass | Melting point/K | Boiling point/K |
|-------------|-------------------|-------------------------|-----------------|-----------------|
| methane | CH_4 | 16 | 91 | 112 |
| ethane | C_2H_6 | 30 | 90 | 184 |
| propane | C_3H_8 | 44 | 85 | 231 |
| butane | C_4H_{10} | 58 | 135 | 273 |
| pentane | C_5H_{12} | 72 | 143 | 309 |
| hexane | C_6H_{14} | 86 | 178 | 342 |
| heptane | C_7H_{16} | 100 | 182 | 371 |
| octane | C_8H_{18} | 114 | 216 | 399 |
| nonane | C_9H_{20} | 128 | 220 | 424 |
| decane | $C_{10}H_{22}$ | 142 | 243 | 447 |
| pentadecane | $C_{15}H_{32}$ | 212 | 283 | 544 |
| eicosane | $C_{20}H_{42}$ | 282 | 309 | 617 |

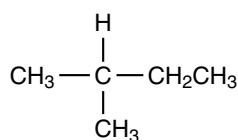
Table 1 Properties of some alkanes

What you do

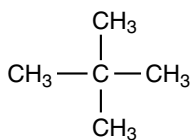
- 1 Use the information in the table to draw graphs to study the variation of melting points and boiling points with relative molecular mass. You can do this very effectively using a computer.
- 2 Summarise the trends you observe in each graph.

QUESTIONS

- a Which alkanes are gases at room temperature?
- b Predict the melting point and boiling point of the alkane $C_{26}H_{54}$.
- c How do these properties influence the use of alkanes as fuels?
- d Give the formula of a hydrocarbon which could be used for a solid fuel burner. Explain your choice.
- e There are weak attractive forces *between* the molecules in a liquid, which must be overcome before molecules can escape to form a gas. What can you say about the relative strengths of these forces in small and large alkane molecules?
- f The boiling points of two branched alkanes are given below:



boiling point 301 K



boiling point 283 K

Compare the boiling points of these compounds with those of the straight-chain alkane with the same relative molecular mass.

- i How does chain-branching affect the boiling point of alkanes?
- ii What does this suggest about the attractive forces between branched molecules compared with those between corresponding straight-chain molecules?
- iii Try to suggest a reason for the difference in ii.

Comparing winter and summer petrol blends

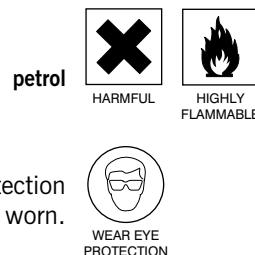
Oil companies change the blend of their petrol according to the season of the year. In this activity you will investigate how winter and summer blends differ.

Requirements

- test-tubes (2)
- identical balloons, new (2)
- 250 cm³ beaker
- unleaded petrol bought in summer*
- unleaded petrol bought in winter*
- supply of hot water (from tap or electric kettle)
- * Winter and summer petrols can be simulated, if necessary, using petroleum ether fractions (see the Teacher's and Technician's Guide).

CARE This is a potentially hazardous experiment because petrol is highly flammable. It is safe provided that you:

- work in a fume cupboard and avoid breathing petrol fumes
- make sure no naked flames are present at any time during the experiment.



CARE Eye protection must be worn.

What you do

- 1 Inflate the two balloons a few times to stretch the rubber.
- 2 Put about 1 cm³ of a summer petrol blend into a test-tube and cover the end of the tube with a balloon. There should be no air in the balloon.
- 3 Repeat with 1 cm³ of a winter petrol blend in a second test-tube, making sure that the balloons are identical.
- 4 Place the tubes in a beaker of warm water (40°C–60°C, from a tap or an electric kettle). **No naked flames.**
- 5 Compare the inflation of each balloon. Explain your observations.





Auto-ignition in a test-tube

This simple experiment illustrates the phenomenon of auto-ignition of petrol. Alkane vapour is introduced into a hot tube, and it 'pops' as it auto-ignites. You can use the experiment to compare the tendency of different alkanes to auto-ignite.

Requirements

- hard-glass boiling tubes (2)
- teat pipettes, each with a large teat and a long tube (2)
- Bunsen burners (2)
- bottles containing a **few drops only** of the following alkanes:
 - pentane
 - 2-methylbutane

CARE This is a potentially hazardous experiment because of the highly flammable nature of the two alkanes being used. It is safe **provided you make sure that all naked flames are extinguished before the alkanes are used.**

| | | |
|----------------|---|---|
| 2-methylbutane |  |  |
| | HARMFUL | HIGHLY FLAMMABLE |
| pentane |  |  |
| | HARMFUL | HIGHLY FLAMMABLE |

CARE Eye protection must be worn.



Background

In a car engine, a mixture of fuel vapour and air are compressed in the cylinder, before being ignited by an electric spark. As the fuel–air mixture is compressed, it heats up. (You may have noticed a similar heating effect if you have pumped up a bicycle tyre. The pump gets hot as you compress the air inside.) The heat produced by the compression can cause the fuel to ignite too soon, before the spark is passed. The fuel then burns unevenly and you can hear a 'knocking' sound from the engine.

In this experiment, you inject alkane vapour into a hot tube containing air, and investigate the tendency of the mixture to auto-ignite. It's not a direct comparison with what happens in a car, because the fuel–air mixture is not heated by compression. However, the results you obtain using different alkanes in the test tube experiment do reflect the way they behave in a car engine.

What you do

- 1 Before you start, practise filling a teat pipette with *vapour* from the pentane bottle – **vapour only, no liquid**. Pentane is very volatile (boiling point 38°C), so there is plenty of vapour in the space above the liquid in the bottle. Your bottle will contain only a few drops of the liquid.
- 2 Clamp a hard-glass boiling tube at an angle as shown in Figure 1a. Make sure all bottles of flammable liquids are well away, then start heating the tube very strongly. Go on heating until it is red hot (for about 2 minutes). You will need to use two Bunsens.
- 3 **Extinguish the flames**, then immediately get a pipette-full of pentane *vapour* and squirt it into the hot tube (Figure 1b). Do not squirt in any liquid.

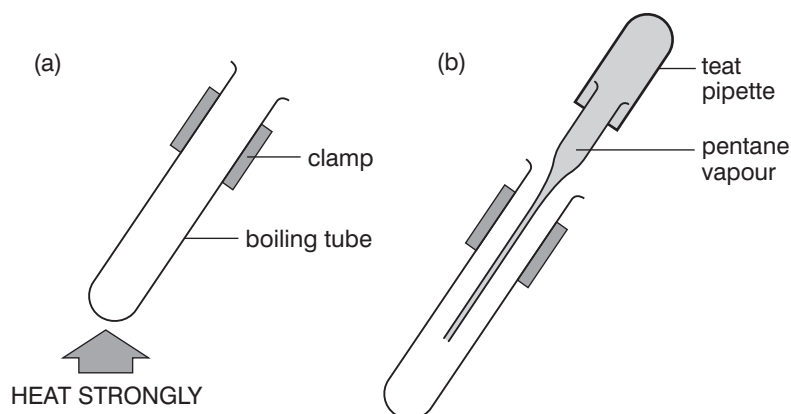
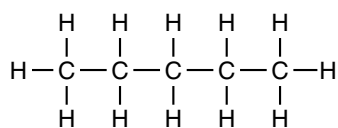


Figure 1 Auto-ignition in a test-tube

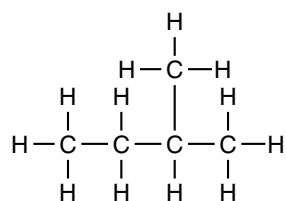
- 4 Continue squirting in vapour for as long as there are pops. Count the number of successful popping squirts. Speed is essential. (With skill, two or even three pops can be obtained from one pipette filling.)
- 5 Repeat the experiment two or three times to get an average answer for the number of pops.
- 6 Now repeat steps 2–5 using 2-methylbutane instead of pentane. (The boiling point of 2-methylbutane is 28 °C. It is very volatile, so keep the bottle stoppered.)

QUESTIONS

- a What is the average number of pops for
- i pentane,
 - ii 2-methylbutane?
- b The structural formulae for pentane and 2-methylbutane are given below:



pentane



2-methylbutane

Do your results fit the suggestion that branched alkanes have a lesser tendency towards auto-ignition than straight-chain alkanes?

In this activity, you will use molecular models to investigate the structure and shape of a variety of alkanes, and to look at the relationship between structural isomers. You will also learn how to name alkanes in a systematic way.

Requirements

- set of molecular models (Molymod or similar)

You may find it helpful to work in pairs or small groups for this activity. It is designed to be supported self-study, so the answers to the questions are provided at the end to enable you to check on your progress.

Straight-chain alkanes

Saturated hydrocarbons with the general molecular formula C_nH_{2n+2} are called **alkanes**. Each carbon atom in an alkane is bonded to four other atoms. Each hydrogen atom is bonded to one other atom.

- a** Draw out the structural formulae for the first two members of the alkane series, methane (CH_4) and ethane (C_2H_6).

Representing these structures in a two-dimensional way on paper can give a misleading picture of what the molecules look like.

- 1 Make models of the methane and ethane molecules. The covalent bonds are spaced as far apart as possible and each carbon atom is at the centre of a regular tetrahedron. If you have a computer molecular modelling program you may find it useful to create computer images of each alkane model you make. You will then be able to see how the image on the screen relates to the molecule in 'real' 3D.
- b** Draw three-dimensional structures for the methane and ethane molecules using the symbols —, ◀ and — — to represent the bonds (see **Chemical Ideas 12.1** if you have forgotten how to do this). Mark in the bond angles on your diagrams.
- c** Why are the bonds in methane spaced as far apart as possible?
- 2 Look again at your model of ethane. Try rotating one of the carbon atoms relative to the other. There are two extreme forms or **conformations** of ethane. These can be drawn as in Figure 1 (imagine you are looking along the C–C bond).
- d** Which conformation do you think is the more stable? Explain your answer.

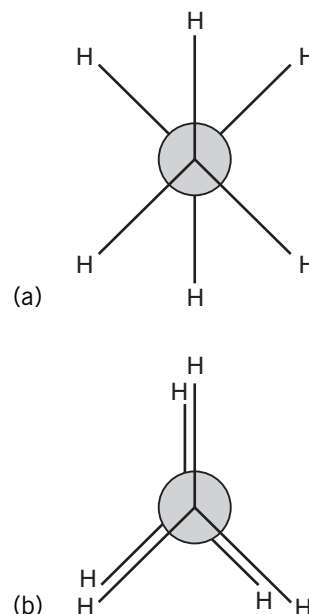
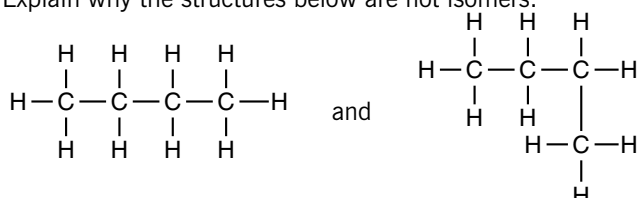


Figure 1 The two conformations of ethane

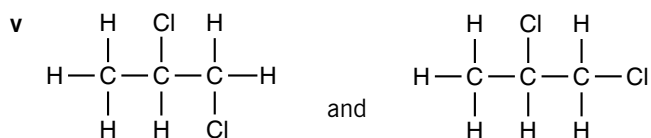
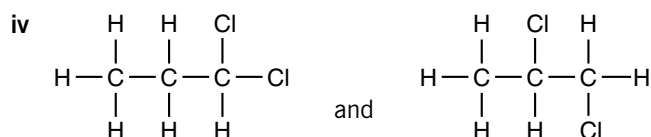
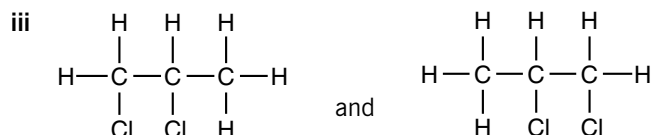
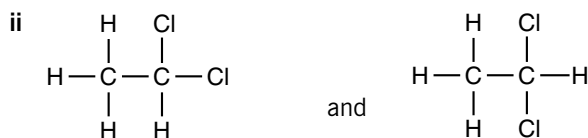
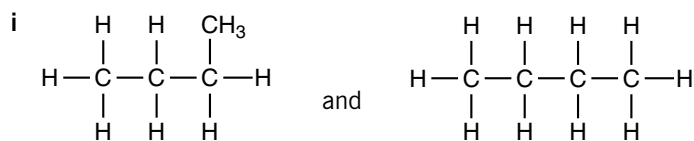
Branched alkanes and structural isomerism

It is possible to make models of two different molecules with the molecular formula C_4H_{10} , one with a 'straight' carbon chain and one with a branched carbon chain.

- 3 Examine the two models carefully. No amount of bond rotation will convert one structure into the other. To do this you would need to *break* and *reform* bonds. The two structures represent different compounds and are known as **isomers**.
- e** Write out the structural formulae of the two isomers of C_4H_{10} .
- f** Explain why the structures below are not isomers:



- g Look back at the two conformations of ethane in step 2. Explain why these two conformations are *not* isomers.
- h Which of the following pairs of structures are isomers? (If you are in doubt, making models may help.)



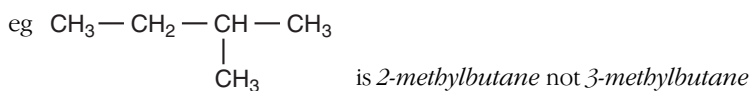
Rules for naming alkanes

Branched alkanes are named systematically according to the following rules.

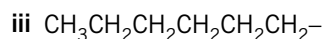
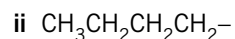
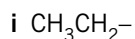
Rule 1 Find the longest continuous carbon chain and name this according to the parent alkane.

Rule 2 Name the substituent group, formed by removing a hydrogen atom from a straight-chain alkane. Replace *-ane* with *-yl*, e.g. CH_3- is methyl. Substituents derived from alkanes are called **alkyl** groups.

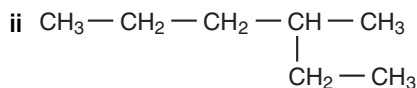
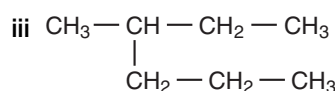
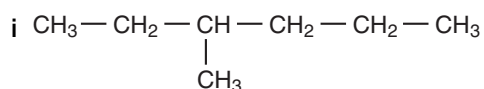
Rule 3 Number the carbon atoms in the longest chain to indicate the positions of any substituent groups. The end of the chain from which you *start* numbering is the one which produces the lower set of numbers.



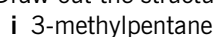
- i Name the following alkyl groups:



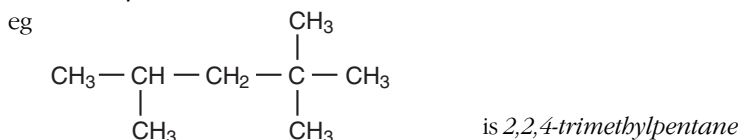
- j Name the following compounds:



- k Draw out the structures of:

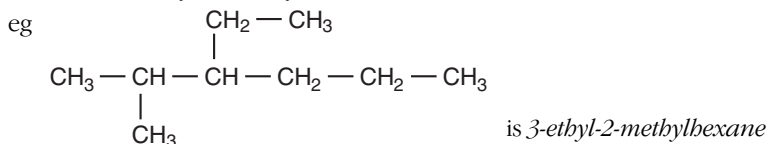


Rule 4 If the same alkyl group appears more than once as a substituent, indicate this by using *di-*, *tri-*, *tetra-* etc to show the number present. Separate the numbers by commas.

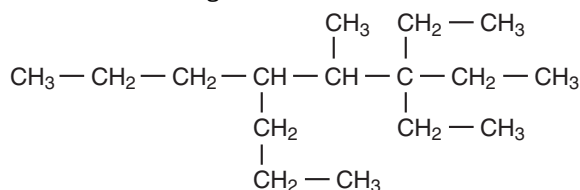


Rule 5 The names of the substituents are arranged alphabetically, regardless of the numbering. For example, *ethyl* comes before *methyl*.

Note that *dimethyl*, *trimethyl* and so on are all considered to start with 'm'.



l Name the following molecule:



m Draw out and name the isomers of C_7H_{16} . There are nine in all.

Cycloalkanes

As well as open-chain alkanes, it is possible for alkane molecules to form rings.

4 Try to make a model of the simplest cycloalkane, cyclopropane (C_3H_6). (Do not damage your molecular models by forcing the bonds into a three-membered ring. Your teacher may already have a model of this compound for you to look at.)

n Draw out the structural formula of cyclopropane.

o What must the bond angles be in the three-membered ring? How do you think this might affect the stability of the molecule?

5 Make models of cyclobutane (C_4H_8), cyclopentane (C_5H_{10}), and cyclohexane (C_6H_{12}).

Cyclohexane is the first member of the cycloalkane series to be strain-free. It is a non-planar molecule and the bond angles are the normal tetrahedral angles of 109° for saturated carbon atoms. Try moving the bonds in your cyclohexane model around, to get different conformations. The most stable conformation is called the **chair** conformation (Figure 2).

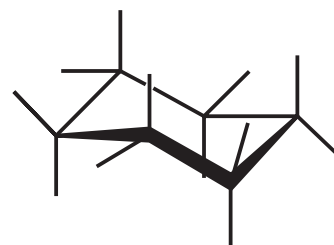
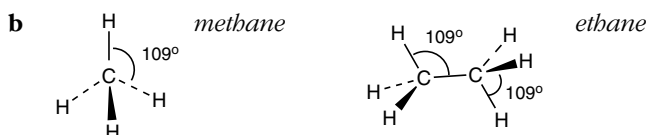
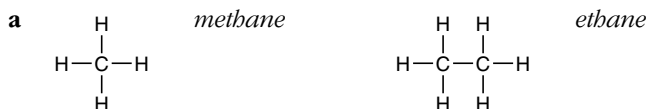


Figure 2 Chair conformation of cyclohexane (C and H atoms have been omitted for the sake of clarity)

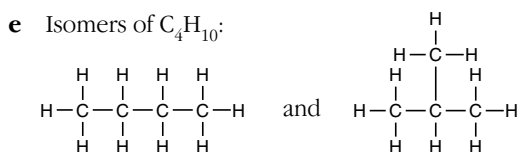
Answers to questions in Activity DF4.1

Straight-chain alkanes



- c** To minimise electron repulsion. Each bond is a pair of electrons.
- d** Conformation (a). In this form, the electron pair repulsion is minimised because the bonds and atoms are as far apart as possible. (However, the energy difference between the two conformations is quite small and, at room temperature, there is usually free rotation about C–C bonds, so the different conformations can easily change from one to the other.)

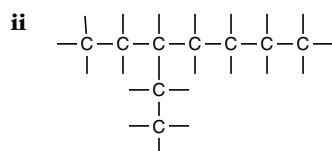
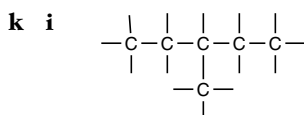
Branched alkanes and structural isomerism



- f** These represent the same molecule – the atoms are joined to each other in exactly the same way. (If you are not convinced, make a model. You can convert one structure into the other simply by rotating about the central C–C bond.)
- g** The two conformations can be easily interconverted by rotating about the C–C bond, so they are the same compound, not isomers.
- h** Pair (iv).

Rules for naming alkanes

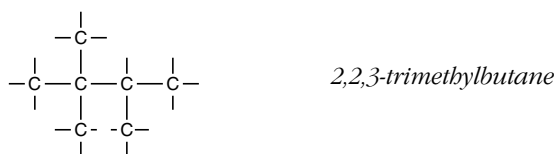
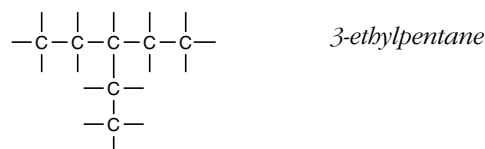
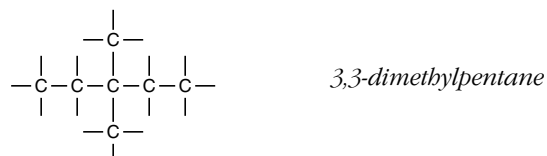
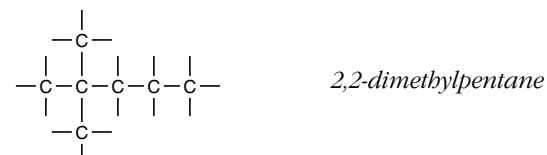
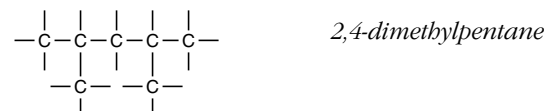
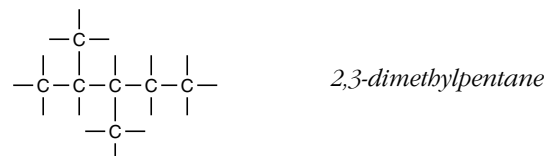
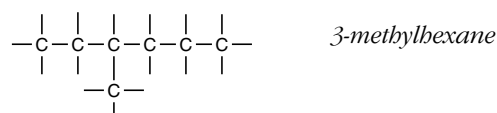
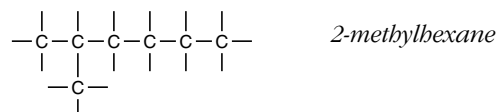
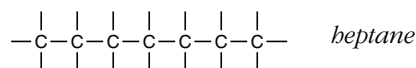
- i** i ethyl
ii butyl
iii hexyl.
- j** All are 3-methylhexane.



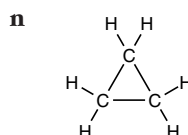
(Only the carbon framework is shown. Hydrogen atoms have been omitted.)

- l** 3,3-diethyl-4-methyl-5-propyloctane.

m Isomers of C_7H_{16} :



Cycloalkanes



- o** The bond angle in a three-membered ring is 60° , which is much less than the tetrahedral bond angle (109°) for saturated carbon atoms. Cyclopropane is a strained molecule and less stable than the corresponding open-chain alkane, C_3H_8 . It is reactive and tends to break open its ring to produce a strain-free open-chain molecule.

The octane numbers of different alkanes

In this activity you will use data on the octane number of different alkanes to see whether there is any relationship between the structure of an alkane and its octane number. The activity is also a useful opportunity to practise naming alkanes.

Table 1 shows the octane number of different alkanes.

| Name of alkane | Octane number |
|---------------------|---------------|
| heptane | 0 |
| hexane | 25 |
| pentane | 62 |
| 3-methylhexane | 65 |
| 2-methylpentane | 73 |
| 3-methylpentane | 75 |
| 2,3-dimethylpentane | 91 |
| 2-methylbutane | 93 |
| butane | 94 |
| 2-methylpropane | >100 |

Table 1 Octane numbers for some alkanes

QUESTIONS

- For each of the alkanes named in the table, write the full structural formula.
- Which of the alkanes are isomers of one another? Sort them into groups of isomeric alkanes.
- Classify each alkane as:
 - S straight-chain
 - B branched-chain
 - M multiple-branched chain.
- Plot a graph showing the octane number of the alkane against the number of carbon atoms in the molecule. Label each point on the graph with the type of alkane concerned (S, B or M).
- What do you conclude about:
 - the effect of chain length on octane number
 - the effect of chain branching on octane number?
- What is the significance of all this for petrol blending?

Zeolites are important in petrol production: they are used as molecular sieves during isomerisation and as catalysts in cracking. In the first part of this activity you will learn about the structure of zeolites, which will help you to understand their uses in petrol production. The activity concludes with an exercise to practise the skill of making a summary.

Requirements

- molecular model kits
- copies of the card model shapes (page 45) – the copies should be photocopied on thin card, or paper copies pasted onto card: each group of students will need at least twelve copies
- scissors, glue and sticky tape

What are zeolites?

Zeolites belong to a large family of minerals which occur naturally in igneous rocks and clay-like deposits. They are compounds mainly of aluminium, silicon and oxygen, with smaller amounts of other elements. As well as occurring naturally, they can be made synthetically.

Zeolites have the general formula $M[(AlO_2)_x(SiO_2)_y] \cdot nH_2O$, where M is a metal such as K, Na or Ca. There are many different zeolites because of the different ways in which the aluminium, silicon and oxygen atoms can be arranged in the crystal structure. To understand how these structures are built up, you can use molecular models.

What you do

Building up zeolites

- 1 You need four model silicon atoms from a molecular modelling kit. Use model atoms which have four tetrahedral 'bonds' (the sort usually used for carbon) to represent the silicon atoms. You also need sixteen model oxygen atoms (usually red); they should each have two 'bonds'.
- 2 Join four oxygens to each silicon.
- 3 Now form a ring containing the four silicon atoms by making them share oxygen atoms (Figure 1). Join one silicon to another by removing an oxygen and forming a Si–O–Si linkage. In the card model, we shall represent this structure with a square. The corners will represent the silicons with 'spare' oxygens; the edges will represent the non-linear Si–O–Si linkage.

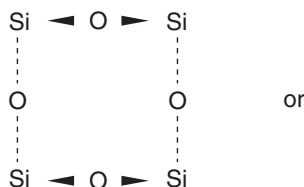


Figure 1 A 'square' ring containing 4 silicons

- 4 In zeolites, rings containing 5 or 6 silicons can also form. Try making a 6-silicon ring like the one in Figure 2. In the card model, we shall represent this structure with a hexagon.

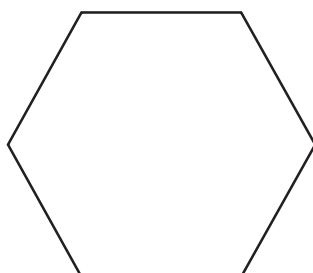
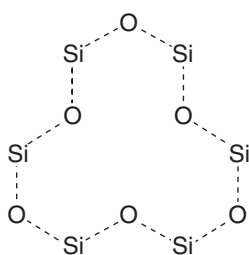


Figure 2 A 'hexagonal' ring containing 6 silicons

Card models of zeolites

You have seen how Si and O atoms can make rings that are square (Figure 1) or hexagonal (Figure 2).

- 5 These rings can be joined together by means of more Si–O–Si linkages. Make one of the resulting structures by cutting out Shape 1 on the sheet of card model shapes and sticking it together. This is called a *sodalite cage* (Figure 3).

You will find it instructive to compare your card sodalite cage with one made with a molecular model kit to show all the atoms present. On your card model, each edge represents a non-linear Si–O–Si linkage; each vertex represents a silicon atom with one remaining unshared oxygen. These unshared oxygens can link cages together through Si–O–Si linkages to form larger structures.

- 6 If the members of your group make eight sodalite cages, then you can join them to make a basic zeolite structure.
- Prepare twelve of the 4-square strips (Shape 2 on the sheet of card model shapes; *omit* the dotted parts of the shape) on thin card. Fold and stick these to form square-section tubes.
 - Take eight of your sodalite cages. Use the square tubes to join the cages through their square faces so that the eight cages are at the vertices of a cube. Joining the card shapes represents joining structures together by Si–O–Si bonds. You have made a model of Type A zeolite (Figure 4).
 - If you have time and patience, you can use more square tubes and sodalite cages to construct a larger model of the zeolite.

- 7 You could also try making a Type Y zeolite (Figure 5). You will need more sodalite cages and some hexagon section tubes (made from Shape 2, but this time *include* the dotted parts). Join the cages through their hexagonal faces. To make a basic unit of this second zeolite structure you need ten cages and twelve hexagonal-section tubes.

Up to now, you have been thinking of the structures as containing only silicon and oxygen. In zeolites, aluminium atoms take the place of some of the silicon atoms. Because aluminium has one less outer-shell electron than silicon, extra electrons are needed and the structure gains a negative charge for each aluminium it contains. As a result, it attracts positive ions, such as K^+ , Ca^{2+} , NH_4^+ or H^+ . The structure also attracts water molecules.

You can see from the models you have made that the zeolite structures will have a network of minute pores with connecting channels. The zeolite is rather like a sponge with a regular structure. There are many factors which can be changed, including:

- the number of tetrahedral centres (silicons or aluminiums) in the rings
- the way the rings join to form cages
- the way in which the cages are joined to form the overall structure
- the ratio of silicon to aluminium
- substituting phosphorus for some silicon
- the type of positive ions and amount of water attached to the framework.

Using zeolites

By controlling the factors above, the zeolite can be designed to have pores and channels of specific sizes and shapes. In the zeolites we shall be considering in this activity, the pore openings have much the same dimensions as the hydrocarbon molecules that are found in the refinery.

Chemists use zeolites as **molecular sieves** to sort out molecules by size and shape; the zeolite can be designed to trap certain molecules from a mixture, leaving other molecules free. It will trap those which can fit inside the structure, but will not trap those which are too large or have the wrong shape to fit inside the pores. For example, zeolites can be used in separating alkane isomers after the isomerisation process in an oil refinery.

The isomers are a mixture of straight and branched chains. The mixture is passed through a column packed with zeolite crystals (Figure 6).

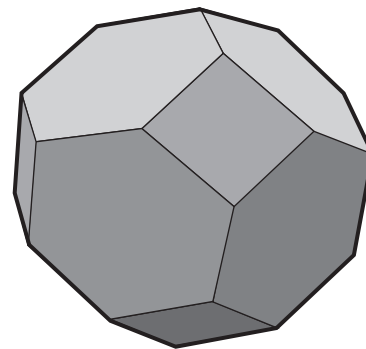


Figure 3 A sodalite cage

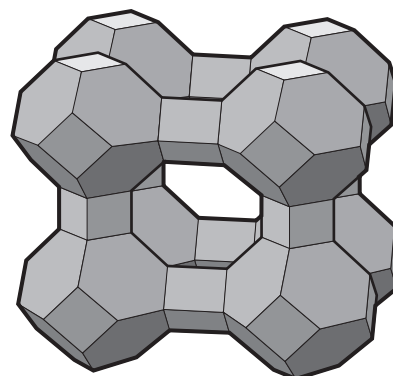


Figure 4 Type A zeolite

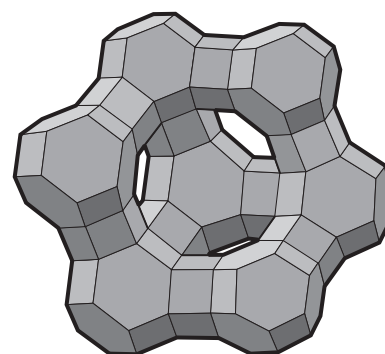


Figure 5 Type Y zeolite

You could use molecular models to demonstrate the action of your Type A zeolite model as a molecular sieve. Build models of a straight-chain alkane and its branched isomer. You need to have the isomers such that one will fit inside the zeolite structure and one will not.

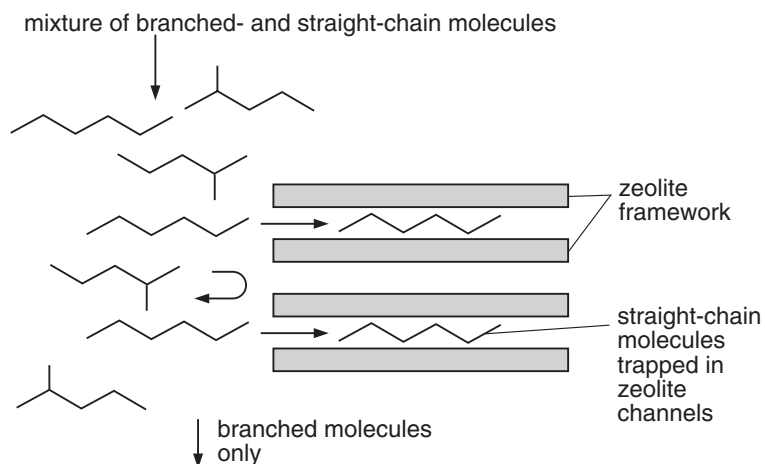


Figure 6 Using a zeolite as a molecular sieve

Catalysts by design

Zeolites are also very versatile catalysts. They are particularly suited to a systematic approach to designing catalysts using computers. Catalyst engineers can simulate the structure of catalyst surfaces on a computer screen and design the zeolite pores to fit specific molecules. Zeolites are important as catalysts in the catalytic cracking process used in the refinery.

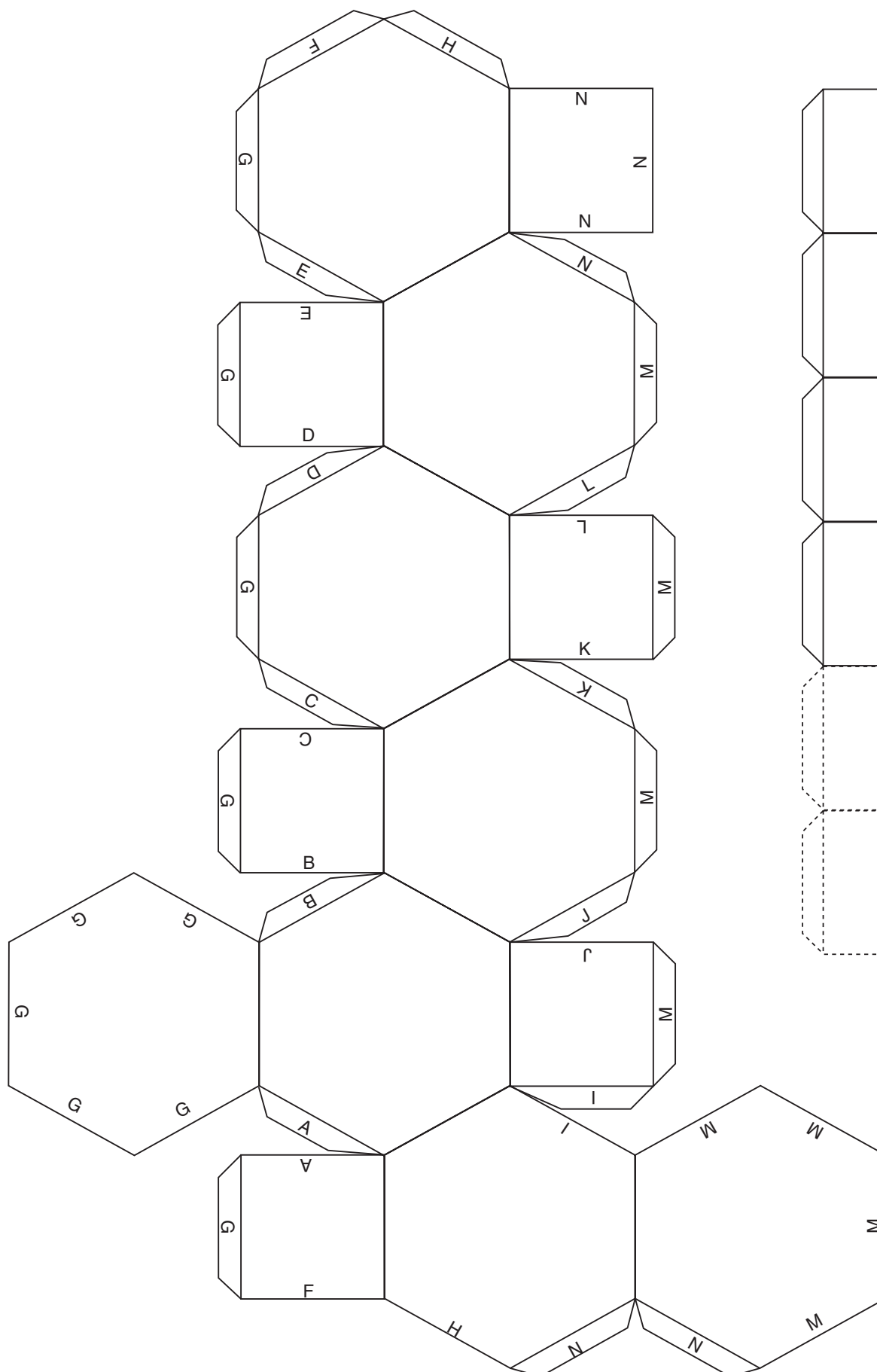
Making a summary

Write a brief summary of the key points about zeolites which are contained in this activity. You will gain most benefit from this if you try to write a first draft from memory and then look back at the activity to edit this to about 100 words.

Templates for making models of zeolites

Shape 1 A sodalite cage

Shape 2 A 'square' strip



This part of the activity will allow you to practise and develop your skills in experimental design. The experiment is a small-scale version of an industrial cracking process. The products are liquid and gaseous hydrocarbons.

Planning

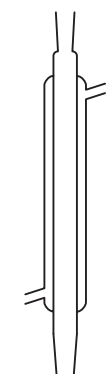
In this part of the activity, you are asked to use standard laboratory apparatus to design a small-scale version of the catalytic cracking process used in industry.

What you do

- Using a selection from the following pieces of apparatus, design an experiment to pass alkane vapour over a heated solid catalyst and then collect the liquid and gas produced. The starting material is a liquid or solid alkane.

Draw a diagram of the arrangement of the apparatus which you plan to use and write a set of instructions which could be followed by another student without any further help.

Apparatus



condenser



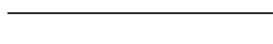
tap funnel



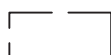
gas jar



funnel



wide hard-glass tube



beehive shelf



trough



syringe



porcelain boat



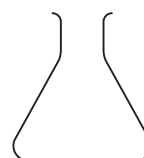
test-tube



boiling tube



beaker



conical flask



round flask

+ rubber tubing, bungs and glass tubing

- Prepare a **Risk Assessment** for your planned activity and a list of sources you have used in developing your plan and your Risk Assessment.

In this part of the activity you carry out the experiment to investigate the action of strong heat on alkane vapour in the absence of air but in the presence of a catalyst. It is a small-scale version of an industrial cracking process.

Requirements

- test-tubes with rubber bungs and delivery tubes to fit (2)
- corked test-tubes (4)
- Bunsen burner
- crystallising dish (or plastic plant pot saucer)
- inert absorbent, eg Vermiculite or mineral wool
- catalyst: broken unglazed porcelain, aluminium oxide granules, pumice or zeolite
- 250 cm³ beaker for water bath
- bromine water
- combustion spoon or glass rod
- solid alkane mixture, eg Vaseline, petroleum jelly or liquid alkane mixture, liquid paraffin
- access to a fume cupboard

bromine water



IRRITANT

CARE Eye protection must be worn.



WEAR EYE PROTECTION

CARE Work in a well-ventilated laboratory or preferably in a fume cupboard.

CARE Beware of 'suckback' (see below for explanation).

What you do

- 1 Set up the apparatus as shown in Figure 1. The reaction tube should be at about 10° to the horizontal. Make certain that the bungs fit tightly.
- 2 Remove the reaction tube and add about 1 cm³ of solid alkane mixture. Warm the tube in a warm water bath until the jelly melts, then add about 2 cm depth of the absorbent material. Rotate the tube to help the liquid soak into the solid absorbent. If you use liquid paraffin, add about 1 cm³ of the liquid to about 2 cm depth of absorbent material in the tube.
- 3 Pack some of the catalyst you are using into the reaction tube. Keep this separate from the alkane mixture and absorbent and make sure you have space above the catalyst so that gases can pass freely over it. Replace the reaction tube into the rest of the apparatus.

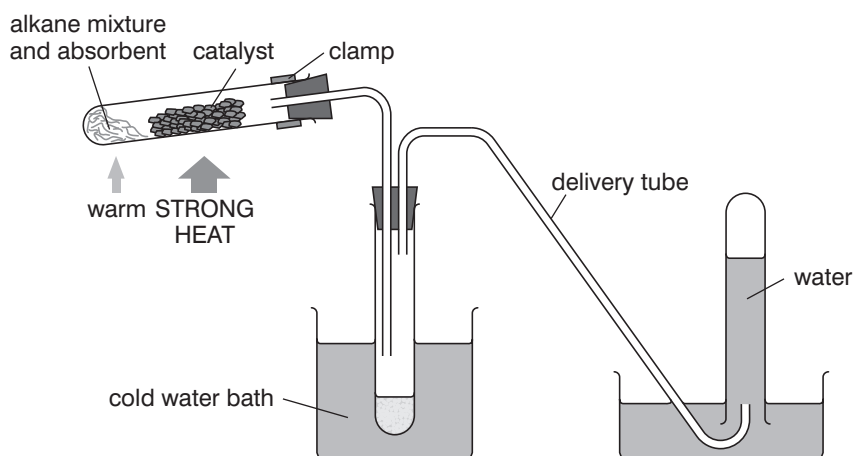


Figure 1 Apparatus for cracking a mixture of alkanes

- 4 Heat the catalyst strongly. Then gently warm the alkane mixture to drive off a little alkane vapour.
- 5 Move the burner backwards and forwards between the catalyst and the alkane mixture until you have collected several tubes of gas. Cork them for testing later. The first tube can be discarded because it will contain mainly displaced air from the apparatus. (**CARE** Do not allow water to suck back from the crystallising dish. Remove the delivery tube from the water if this starts to happen. Begin heating again when the risk of suck-back is over.)
- 6 Continue heating until some product is obtained in the middle test-tube. Note its appearance. Keep this product for testing as described below.

- 7 Lift the delivery tube out of the water and leave the apparatus to cool. Then dismantle it in a fume cupboard.
- 8 Carry out the following tests on the gaseous product in the corked tubes, on the alkane mixture and on the product from the middle tube.
 - i Burn them. (**CARE** Eye protection) Is the flame smoky or not? Compare their flammability. (The liquids can be burned by dipping a combustion spoon or a glass rod into them and placing it in a flame.)
 - ii Shake them with about a 1 cm depth of bromine water (**CARE** Irritant). Is the bromine water decolorised?

Testing for alkenes

Alkenes are **unsaturated** hydrocarbons with a double covalent bond between two of the carbon atoms. They are much more reactive than alkanes, which do not contain double bonds and are said to be **saturated**. One test for alkenes is that they decolorise bromine water. Another test is that they burn with a smokier flame than alkanes.

QUESTIONS

- a What do you deduce about the molecules of the gaseous product from the tests you have carried out? Are the molecules larger or smaller than the molecules in the alkane mixture? Do they contain carbon–carbon double bonds?
 - b The product in the middle tube contains a mixture of hydrocarbons. Do you think that there are any unsaturated hydrocarbons in the mixture? How do the sizes of their molecules compare with the molecules in the original alkane mixture or in the gaseous product?
 - c What do you notice about the appearance of the catalyst after the experiment? Explain what has happened and how this problem could be overcome in a large-scale process.
 - d Molecules of the straight-chain alkane $C_{20}H_{42}$ are present in a gas oil fraction. Write equations to show two ways in which these molecules could break down in an experiment like this.
-

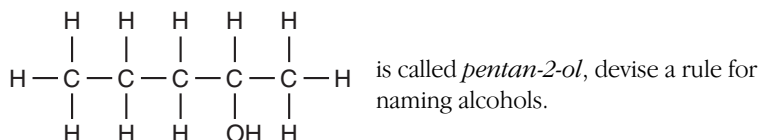
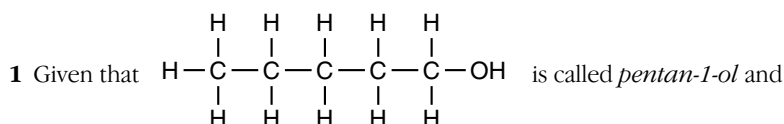
In this activity, you will have an opportunity to investigate the structure and physical properties of some alcohols. You will also practise naming alcohols in a systematic way.

Requirements

- set of molecular models (Molymod or similar)

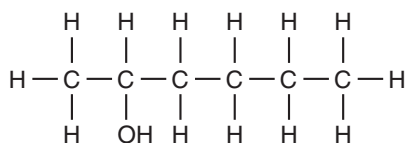
This activity is designed to be a self-study exercise, so the answers to the questions are provided at the end to enable you to check on your progress.

Naming alcohols

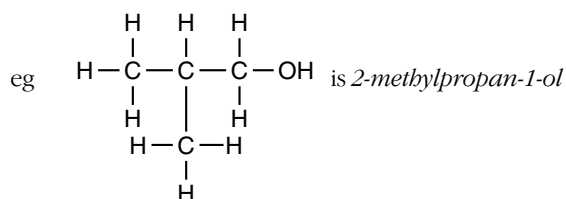


- a Use your rule to help you draw out the structures of:
- propan-2-ol
 - hexan-3-ol.

- b Name the following alcohol:



- 2 The functional group always takes precedence in the numbering system if there are also alkyl substituents. The stem is always named after the longest carbon chain in which there is an -OH substituent.



(though it is not strictly necessary to label the position of the methyl group in this molecule – it can only be in one position).

- c Draw out 2-methylpropan-2-ol.
- 3 Structural formulae are sometimes written in a shortened form.
- eg butan-2-ol can be written as $\text{CH}_3\text{CH}_2\text{CH}(\text{OH})\text{CH}_3$
 2-methylpropan-1-ol can be written as $(\text{CH}_3)_2\text{CHCH}_2\text{OH}$.
- d In the same way, write out shortened structural formulae for:
- propan-2-ol.
 - 2-methylpentan-1-ol.

Isomerism in alcohols

- 4 Make a model of butan-1-ol. How many other alcohols can you make which are isomeric with butan-1-ol?
- e Name the isomers you make.
- 5 Now make models of other isomers of butan-1-ol which are *not* alcohols.

Looking at the physical properties of alcohols

- f The boiling points of some alcohols are given below:

| Boiling point/K |
|-----------------|
| 351 |
| 370 |
| 381 |
| 386 |
| 411 |

The five alcohols are these: propan-1-ol, 2-methylpropan-1-ol, pentan-1-ol, 2,2-dimethylpropan-1-ol, ethanol.

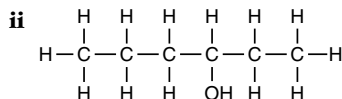
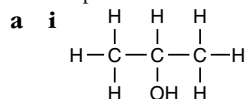
Using the trends identified in your work on alkanes, match the given boiling points to the appropriate alcohols.

- g Using the boiling-point values for ethanol, propan-1-ol and pentan-1-ol, predict the boiling-point value of heptan-1-ol. Explain the reasons for your choice of boiling-point value.
- h This question involves comparing the boiling points of alkanes and alcohols to investigate the effect of the –OH functional group on boiling point.
- What is the general molecular formula of:
- alkanes
 - alcohols?
- Choose two molecules (an alkane and an alcohol) which should allow you to make a fair comparison.
- iii Give the formulae of your two molecules and explain the reason for your choice.
- iv Use the **Data Sheets** to look up the values for the boiling points. What conclusions can you draw about the effect of the –OH group on boiling-point values?
- v Suggest possible reasons for the effect identified in iv.
- i Suggest explanations for the following observations. (You may wish to use molecular models for this question.)
- The boiling point of butan-1-ol is 391K, whereas that of butan-2-ol is 372 K.
 - The boiling point of ethanol is 351 K whereas that of ethane-1,2-diol is considerably higher.
- Make an 'educated guess' at the boiling-point value of ethane-1,2-diol in view of your explanation.

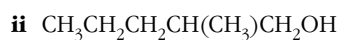
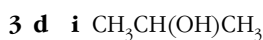
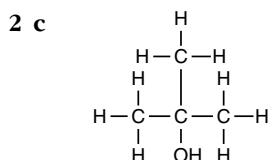
Answers to questions

Naming alcohols

- 1 Count up the number of carbon atoms in the alcohol and name its parent alkane, eg C–C–C is butane. Remove the 'e' from the parent alkane and replace by 'ol' indicating the position of the –OH group on the chain by the lowest possible number.

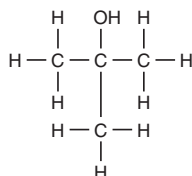
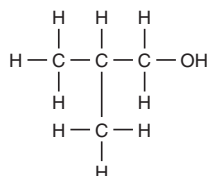
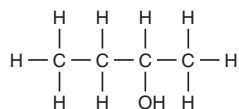


b hexan-2-ol



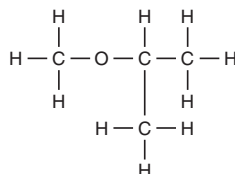
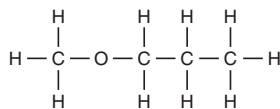
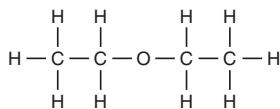
Isomerism in alcohols

- 4 There are three alcohols that are isomeric with butan-1-ol:



e butan-2-ol, methylpropan-1-ol, methylpropan-2-ol.

- 5 There are three ethers that are isomeric with butan-1-ol:



Looking at the physical properties of alcohols

f

| Boiling point/K | Alcohol |
|-----------------|-------------------------|
| 351 | ethanol |
| 370 | propan-1-ol |
| 381 | 2-methylpropan-1-ol |
| 386 | 2,2-dimethylpropan-1-ol |
| 411 | pentan-1-ol |

- g** The boiling point of heptan-1-ol is 449 K. (An increase of about 19 K–20 K for every CH_2 added.)



iii Choose an alkane and an alcohol with similar molecular masses and carbon skeletons.

iv The presence of an –OH group in the molecule causes the boiling point to rise.

v Alcohols have higher boiling points due to polar interactions and hydrogen bonding between molecules in the liquid. These attractive forces must be overcome when the liquid boils and turns into a gas.

- i** In butan-2-ol the –OH group is positioned in the centre of the chain, rather than on the end of the chain as in butan-1-ol. It is less easy for two –OH groups on adjacent molecules in butan-2-ol to approach each other to interact.

The boiling point of ethane-1,2-diol is 471 K. The boiling point of ethane-1,2-diol is higher than that of ethanol because it has an increased molar mass, and an extra –OH group.

In this activity you will be using the same methods that are employed by oil companies when they try to produce a blend of petrol with the right properties. The activity will help reinforce your understanding of octane numbers and the components used in petrol. You will need to interpret and use the available information to make decisions in the face of economic and other constraints. The activity is a good one to do on a computer.

The scenario

You are working in an oil refinery at the time it started producing unleaded petrol. You are responsible for blending petrol. Your refinery at present produces both Regular and Premium grade *leaded* petrol. You have to start producing *unleaded* petrol, but this will mean building a new processing plant. The new plant will not be ready until next year – but you have to start making the unleaded petrol as soon as possible. That means you'll have to buy in the extra blending components you need.

The quantity of unleaded petrol required is **20 000 000 litres per year**. Naturally, you have to make it at the lowest possible cost. You must decide which blending components you will use, and in what proportions. The petrol you make must have the right octane number, and the right volatility. (Volatility is measured as an **E70** value. This is the percentage of the petrol that evaporates when the petrol is heated to 70°C. The more volatile the petrol blend, the higher the E70 value.)

The specification for the blend is summarised below:

- *Octane number* 95.0 minimum
- *E70 (volatility)* between 20 and 40
- *Quantity* 20 000 000 litres per year
- *Price* as low as possible

What's available?

Table 1 shows the blending components that are available. The figures in brackets in the octane numbers column show the octane number when the component has lead added.

| Component | Octane number (values for leaded petrol in brackets) | E70 (volatility) | Quantity available/ million litres per year | Maximum % allowed in blend | Relative cost/pence per litre |
|---|---|---------------------|--|----------------------------------|----------------------------------|
| straight-run (see note 1) | 71 (79) | 95 | 5 | unlimited | 5 |
| butane (see note 2) | 98 (100) | 100 | 1.5 | 10 | 4 |
| reformate (see note 3) | 97 (100) | 10 | 12 | unlimited | 8 |
| crackate (see note 4) | 92 (94) | 50 | 8 | unlimited | 7 |
| MTBE (see note 5) | 113 | 0 | unlimited | 15 | 13 |
| unleaded petrol bought from competitors | 95 | 25 | unlimited | unlimited | 9 |

Table 1 Details of the components available for blending unleaded petrol

Notes

- 1 'Straight-run' is the gasoline fraction that comes straight from distillation of crude oil.
- 2 Butane comes from the refinery gases separated during distillation of crude oil. It is a gas, and simply dissolves in the gasoline. You can't use more than 10% of it because it evaporates so easily.

- 3 'Reformate' is made by reforming and isomerising the naphtha fraction from the distillation of crude oil. This increases the proportion of branched-chain alkanes and aromatic hydrocarbons.
- 4 'Crackate' is made by cracking heavier fractions. It contains a higher proportion of branched alkanes than straight-run gasoline.
- 5 MTBE is an ether with a very high octane number, used as an octane 'booster'.

You can assume that when you blend components together, the properties of the blend are a weighted average of the properties of the different components. For example, if you blend 75% reformat (octane number 97) with 25% straight run (octane number 71), you can assume you would get a blend with octane number $(0.75 \times 97) + (0.25 \times 71) = 90.5$.

To illustrate this, Table 2 shows how the refinery used to produce Premium *leaded* petrol. The octane number of this blend is an average of the octane numbers of the components, weighted according to their percentages. It comes to $(0.50 \times 100) + (0.40 \times 94) + (0.075 \times 100) + (0.025 \times 79) = 97$.

| Component | Percentage | Quantity/ million litres per year | Contribution to total cost/ pence per litre |
|--------------------------|------------|---|---|
| straight-run (leaded) | 2.5 | 0.5 | 0.125 |
| butane (leaded) | 7.5 | 1.5 | 0.300 |
| reformat (leaded) | 50 | 10.0 | 4.000 |
| crackate (leaded) | 40 | 8 | 2.800 |
| MTBE | 0 | 0 | 0 |
| Totals | 100 | 20 | 7.225 = total cost |

Table 2 Composition of Premium *leaded* petrol

What you do

Draw up a table similar to Table 2, to show the percentage and quantity of each component that will go into your blend for unleaded petrol. You may want to extend the table to include your calculations. Decide the percentages of each component that you will use to get the necessary quantity of unleaded petrol. Remember that it must meet the specifications given at the beginning of this activity. It must also be made at the lowest possible cost.

This problem can be solved by trial and error, but try to use the information given wisely to minimise the amount of calculation needed.

Using a computer

In a refinery, such problems are solved by computer, and you could try doing it this way yourself. You will need a spreadsheet application, like the one you used in **Activity DF2.1**.

Afterwards ...

Compare your price with those obtained by other members of the class, and with that of your competitors, shown in Table 1. Will you stay in business? Is the blend with the lowest price always the best, or are there other criteria?

QUESTIONS

- a Compare the price of unleaded blend with that of the leaded Premium blend given in Table 2. Explain any differences if you can.
- b The petrol blend required in this problem is for use in summer time. What changes would you have to make for a winter blend?
- c Why are straight-run petrol and butane so much cheaper than reformat and crackate?
- d Look at the blend for Premium *leaded* petrol in Table 2. Why is no MTBE used in the blend?

Why do hydrocarbons mix?

Blending a sample of petrol may involve mixing as many as a hundred different hydrocarbon compounds. The molecules in a liquid like petrol are constantly moving around in a random arrangement, colliding with one another all the time. Molecules of different hydrocarbon compounds mix spontaneously – and stay mixed – because of chance. This activity uses chance, in the form of dice-throwing, to illustrate this idea.

Requirements

- sheet of A4 paper divided in two halves by a line drawn parallel to the shorter edges
- circular counters numbered 1–6 (6)
- square counters numbered 1–6 (6)
- dice (2)

Note 1 You can use other counters if you wish, eg different colours, different sizes.

Note 2 If a computer is available, it can be quite simply programmed to run this activity for you.

What you do

A simulation of molecular mixing

- 1 Work in a pair and arrange the twelve counters on the sheet of paper as shown in Figure 1. The arrangement represents the molecules in two pure liquids which are unmixed.

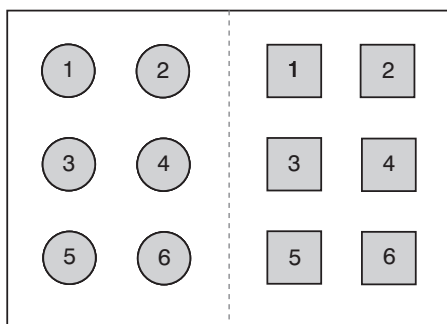


Figure 1 The initial arrangement

- 2 Each of you will need a die and you will be responsible for one sort of counter. For example: Student A, circular counters; Student B, square counters.

Both dice are thrown. The numbers which 'come up' tell you which counters swap places. For example, if Student A throws a 3 and Student B throws a 5, the board will look like Figure 2.

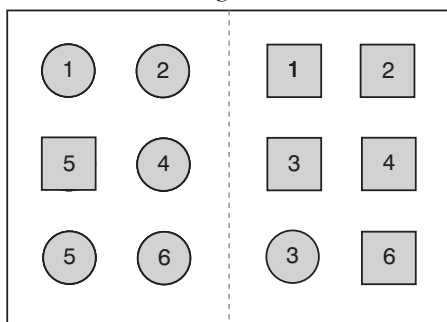


Figure 2 A possible arrangement after one throw

- 3 What you are doing is simulating the chance motion of two molecules. It has led to some mixing of the liquids. What happens if you provide many more chances for your 'molecules' to move?

You can find out by throwing more dice. Each time, you swap the counters whose numbers come up. But remember – one of you is always responsible for circular counters, the other for square counters. Sometimes your counters will swap 'across the board'; at other times they will swap within only one half of the board – that doesn't matter.

QUESTIONS

- a What happens to the arrangement of the counters after 10 throws?
- b What do you think the arrangement would have been like if you had continued for:
 - i 100 throws
 - ii 1000 throws?
- c What is the chance that the arrangement would ever return to the one at the start of the activity?
- d Real molecules move very rapidly. They could make a thousand 'swaps' in a tiny fraction of a second. What do you think is the most likely thing that would happen to two liquid hydrocarbons if you poured them into the same container? Explain your answer in terms of what you have observed in this activity.

Petrol – pulling it all together

This activity will help you to organise your work on petrol in Storyline DF3 and DF4.

In **Storyline DF3** and **DF4** you have followed the story of petrol; what it is, how it is made, and what chemists are doing about producing better fuels for motor vehicles in the future. Now make a summary of what you consider to be the important points. **Activity DF2.2** gives some hints on making notes.

It may help to use the following headings – or you may wish to use your own.

- What is petrol?
- What properties are important in a blend of petrol?
- How is petrol made?
- What is the octane number and why is it important?
- What are the important processes in a refinery?
- What is the role of oxygenates?

It is sometimes a good idea to work in pairs to do this. Each member of the pair first makes their own summary. Then, the two of you compare your notes. Have you both included the same points? Do you want to adjust your summary as a result?

Try to record the information as concisely as possible. For example, you could summarise the common refinery processes in the form of a table like this:

| Refinery process | Feedstock | Catalyst | Product | Comments |
|--------------------|-----------------------|-----------------|----------------------------|--|
| isomerisation | C_5H_{12}/C_6H_{14} | Pt on Al_2O_3 | branched isomers (alkanes) | conversion incomplete: product separated using molecular sieves; straight-chain alkanes recycled |
| reforming | | | | |
| catalytic cracking | | | | |

Review

Make sure you understand the meaning of the following terms:

- fractional distillation
- refinery gas
- gas oil
- knock
- auto-ignition
- reforming
- MTBE
- gasoline fraction
- kerosene
- naphtha
- diesel fuel
- octane number (or rating)
- isomerisation
- cracking

Developing revision skills

So far you have been encouraged to think about and develop skills associated with information gathering, note making and the creation of summaries in a variety of styles. Now is an appropriate time to begin to think about the development of revision skills.

You have to develop a range of revision strategies which suit you, but the most effective of them will require you to be as active as possible. Simply reading and re-reading material is far less effective.

Your starting point is likely to be the notes and summaries you have created. Set yourself tasks, each of which is manageable and not too daunting, for example:

- check that your notes cover the list of topics provided at the end of the unit
- highlight key words and/or headings in your notes
- check that you have created effective and interesting summaries of sections within each unit
- working from one of these summaries,
 - read the relevant sections from your notes and/or the **Chemical Ideas** book, the **Storylines** book or your records of **activities** you have done
 - try to expand a brief summary into a more detailed one by jotting down what you know about each of the headings
 - try problems in the **Chemical Ideas** book or questions from past examination papers which are relevant.

Once you have identified appropriate revision strategies you will find it easier to produce an action plan made up of a sequence of tasks and linked to the time available.

What happens to the sulphur?

This two-part activity will help you to learn more about the refining process. In the first part, you will consider the removal of sulphur from oil during the refining process. This will give you the opportunity to practise chemical calculations. In the second part, you will practise writing and using equations. The problem-solving exercises in each part will give you an idea of the role of a chemical engineer in the refinery.

Part 1: Getting the sulphur out of the oil

There are sulphur compounds present in crude oil. They are generally compounds with the formula R-SH. The alkyl group, R, is usually quite large and so the sulphur-containing compounds are more concentrated in the heavier fractions from the primary fractional distillation column.

Why is sulphur a problem?

If these sulphur compounds are not removed, they will poison the catalysts used in the refinery. The catalysts are essential to the effectiveness of the refinery processes and would be expensive to replace.

What's more, if sulphur compounds went into petrol and diesel fuel, they would cause atmospheric pollution as they would burn in the air to form sulphur dioxide. The European Union agreement is that by the year 2005, the concentration of sulphur in petrol should be no higher than 30 parts per million (ppm) and in diesel no higher than 50 ppm.

At what stage should the sulphur be removed?

Look at Figure 1, which represents key stages in the production of petrol and diesel fuel.

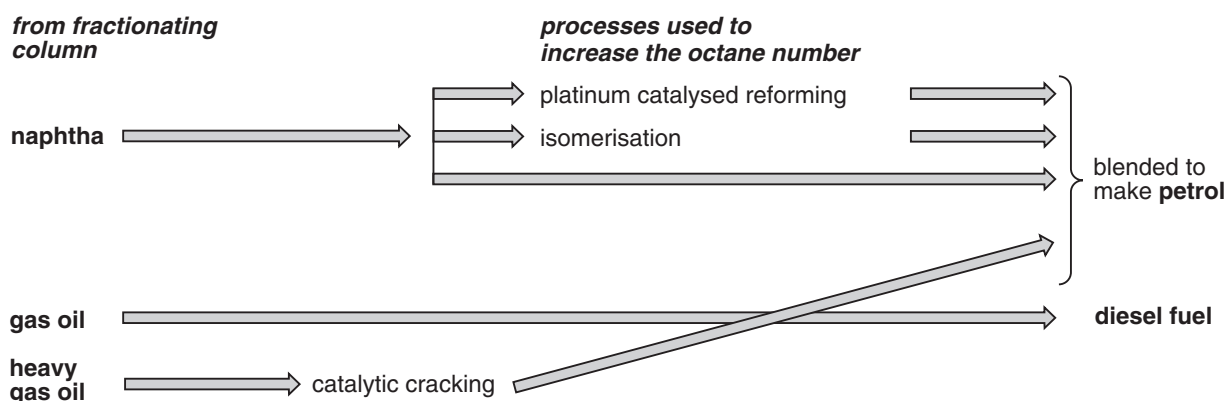


Figure 1 Key stages in the production of petrol and diesel fuel in a refinery

- a Where would it be necessary to position sulphur-removing steps in the flow diagram? Remember the problems which are caused by the presence of sulphur.

How is the sulphur removed?

The sulphur compounds are removed by reacting them with the hydrogen which is produced in processes such as reforming. The reaction produces hydrogen sulphide gas, H_2S .

The oil fraction which contains sulphur compounds enters the sulphur-removing stage at about 100°C . It is heated in a furnace up to 300°C and is mixed with the hydrogen from other refinery processes. The reaction mixture is passed down a tower in which the reaction takes place. The gas emerging from the base of this reactor is a mixture of oil (without sulphur compounds) and hydrogen sulphide at 300°C . This is then cooled to 93°C .

- b Present this information as a flow diagram. Sketch it in rough as you will need to modify it in parts c, g and h of this activity. So that you produce a flow diagram which could be understood by a chemical engineer, you should use the types of symbols which are on the **Information Sheet** (*The language of chemical engineering*).

- c How can the mixture of hydrogen sulphide gas and oil (liquid at 93°C) be separated in one simple step which can operate continuously? To your flow diagram, add such a separator, showing where the gas-oil mixture would enter and where the separated gas and oil would leave.

Where does the energy come from?

- d For the sulphur-removal reaction, the oil had to be heated up. What might be a suitable fuel to heat the incoming oil?
- e The quantity of energy required to heat the incoming oil
 $= \text{mass of oil} \times \text{temperature rise} \times \text{specific heating capacity of oil}$.
 How much energy is required per day by a sulphur-removal plant which treats 3000 tonnes of oil with a specific heating capacity of $3.0 \text{ kJ kg}^{-1} \text{ K}^{-1}$?
- f This energy can be supplied to the furnace by burning surplus ethane from the fractionation of the original crude oil. The enthalpy change of combustion of ethane is $-1560 \text{ kJ mol}^{-1}$. A typical furnace is 80% efficient at transferring energy from the flame to the oil.
- What amount of ethane would be required in moles per day?
 - What mass of ethane is this in tonnes per day?
 - If ethane costs £60 per tonne, what is the daily cost of heating the incoming oil?

Is energy being wasted?

- g Where in the process is energy being wasted? Add a heat exchanger at that point in your flow diagram so that the energy can be used. (Use the **Information Sheet** to find the correct symbol for a heat exchanger.)
- h Where would this energy be of use in the process? Divert the flow that needs to be heated so that it goes through the heat exchanger.

Is it worth using heat exchangers?

The energy extracted from the reaction products by your heat exchanger =
 (mass \times specific heating capacity \times temperature fall of reaction products).

The heat exchanger will transfer approximately

$$(3 \times 10^6 \text{ kg} \times 3.0 \text{ kJ kg}^{-1} \text{ K}^{-1} \times 207 \text{ K}) = 1.9 \times 10^9 \text{ kJ per day}$$

- i Compare this with the answer which you got in part e. You might think that no extra energy is needed after all. Being realistic about what happens to energy, suggest why the furnace will still be needed.

Part 2: Disposing of the hydrogen sulphide

What is the problem?

Desulphurising oil produces hydrogen sulphide. Hydrogen sulphide is very toxic (besides having an obnoxious smell). The sulphur in it can be extracted by a chemical reaction and sold to other chemical industries.

How is the hydrogen sulphide collected?

A suitable solvent is circulated to each of the places in the refinery where hydrogen sulphide is produced. The solvent is 20% di(ethanol)amine ("DEA") and 80% water; it dissolves hydrogen sulphide under pressure. The resulting solution contains about 2% hydrogen sulphide. When this solution returns to the sulphur recovery plant, it is heated to drive off the hydrogen sulphide. The DEA is then recirculated around the refinery to collect more hydrogen sulphide.

How can the hydrogen sulphide be converted to sulphur?

Converting hydrogen sulphide to sulphur involves an oxidation reaction. The hydrogen sulphide is burnt in a furnace with a controlled supply of air. Depending on the supply of air, the products of the oxidation of hydrogen sulphide are either sulphur or sulphur dioxide.

- j Write the two equations for the burning of hydrogen sulphide in air.

The aim is to produce sulphur from the hydrogen sulphide. The best way to do this conversion is to use two reactions. First, some of the hydrogen sulphide is burnt to sulphur dioxide. This sulphur dioxide and the remaining hydrogen sulphide can both be got rid of by reacting them together to form sulphur.

- k Write a balanced equation for the reaction between hydrogen sulphide and sulphur dioxide to form sulphur.
l What must be the ratio of hydrogen sulphide to sulphur dioxide if there is to be neither of these two gases left over?
m What must be controlled in order to achieve this ratio in the products of the combustion?

How can the sulphur be separated?

The products leaving the furnace include water, sulphur, sulphur dioxide and unburnt hydrogen sulphide. These are all gases on leaving the furnace. The melting point of sulphur is 119°C and its boiling point is 445°C. Sulphur dioxide and hydrogen sulphide are gases at room temperature.

- n How can sulphur be removed as a liquid from this mixture of gases?

Only some of the hydrogen sulphide and sulphur dioxide react, so the remaining mixture is reheated and passed over an alumina catalyst. More sulphur is removed. The process is repeated.

- o Draw a simple, clear flow diagram to show the whole process starting with hydrogen sulphide and ending with sulphur.

So what happens to the sulphur produced?

A refinery can extract about 50 tonnes of molten sulphur per day. This sulphur is taken away by road tankers and sold. A road tanker holds 26 tonnes of molten sulphur.

- p Suggest why road tankers are suitable for this purpose rather than other means of transport.
q Why is the sulphur transported in its molten state?
r What industries might want to buy this sulphur?

Information Sheet: The language of chemical engineering

Chemical engineers use symbols to represent the parts in a chemical plant, in much the same way as you will have drawn circuit diagrams with symbols to represent electrical components. Figure 1 shows some of the chemical engineering symbols which you might find useful in this activity.

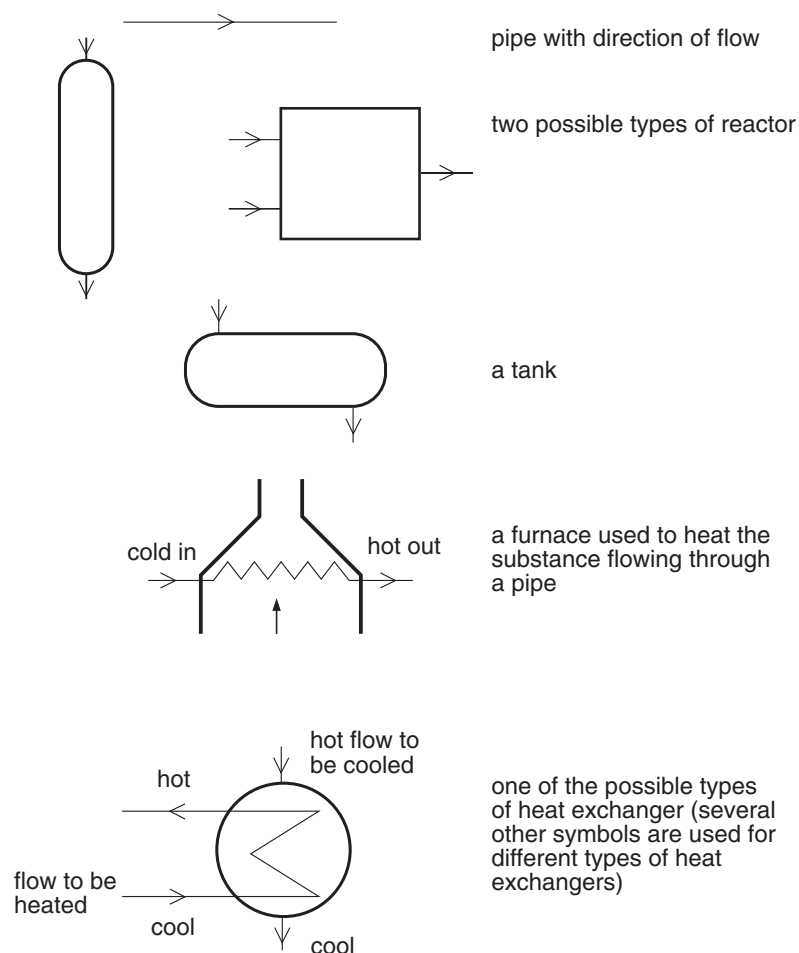


Figure 1

For example, a simple plant in which the reactants are heated in a furnace, passed down a reactor tower and then cooled in a heat exchanger could be drawn as in Figure 2.

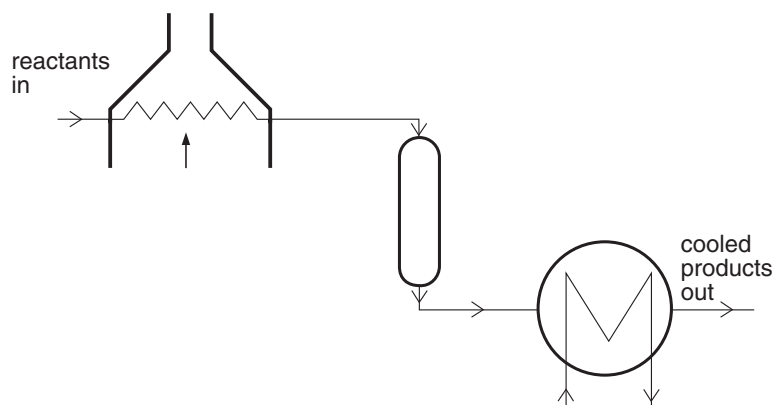


Figure 2

Check your notes on Developing Fuels

This activity helps you get your notes in order at the end of this unit

Use this list as the basis of a summary of the unit by collecting together the related points and arranging them in groups. This is a long list, so to get an overview of the unit, which is free from too much detail, break down the list into smaller groups of points. Check that the way you have summarised the information for each group of points suits the topic. **Activity DF2.2** gives some hints on making good notes. Remember that you will be coming back to many of the ideas in later units.

Most of the points are covered in the **Chemical Ideas**, with supporting information in the **Storyline** or **Activities**. However, if the *main* source of information is the Storyline or an Activity, this is indicated.

- The use of the concept of amount of substance to perform calculations involving: volumes of gases and balanced chemical equations.
- The meaning of the terms: *exothermic*, *endothermic*, *standard state*, *enthalpy change of combustion*, *enthalpy change of reaction* and *enthalpy change of formation*.
- The pattern of enthalpy changes of combustion for successive members of an homologous series (**Activity DF1.3**).
- How to calculate enthalpy changes from experimental results.
- The use of Hess's Law and enthalpy cycles to calculate enthalpy changes.
- Bond-breaking and bond-making as endothermic and exothermic processes.
- The relationship between *bond enthalpy*, bond length and bond strength.
- Recognise members of the following homologous series: alkanes, cycloalkanes, alkenes, arenes, alcohols and ethers.
- The meaning of the terms: *aliphatic* and *aromatic*.
- Systematic nomenclature for alkanes and alcohols.
- The meaning of the term *isomerism* and the nature of structural isomerism.
- The drawing and interpretation of structural formulae (full, shortened and skeletal) and the relationship to molecular shape.
- Balanced equations for the combustion (oxidation) of alkanes and alcohols.
- The effect of chain length and chain branching on the tendency of petrol towards auto-ignition (**Storyline DF4**; **Activity DF4.2**).
- The meaning of the octane rating of a petrol and how it may be increased (**Storyline DF4**; **Activity DF4.2**).
- The origin of pollutants from car exhausts: unburnt hydrocarbons, CO, CO₂, NO_x, SO_x, and the environmental implications (**Storyline DF5**).
- The formation of nitrogen monoxide (NO) in an internal combustion engine.
- The meaning of the terms: *catalysis*, *catalyst* and *catalyst poison* and an outline of how a heterogeneous catalyst works.
- The use of isomerisation, reforming and cracking reactions to improve the performance of hydrocarbon fuels (**Storyline DF4**).
- The use of catalysts in isomerisation, reforming and cracking processes and in the control of exhaust emissions (**Storyline DF4** and **DF5**).
- Entropy: a measure of the number of ways that molecules can be arranged.
- The differences in magnitude of the entropy of a solid, a liquid, a solution and a gas.
- The desirable properties of a fuel (**Activity DF1.1**).
- The work of chemists in improving fuels and in searching for and developing fuels for the future: use of oxygenates and the hydrogen economy (**Storyline** in general; **Activity DF1.1**).