

Mary Jones, Richard Harwood,
Ian Lodge and David Sang

Cambridge IGCSE®
**Combined and
Co-ordinated
Sciences**
Coursebook



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Mary Jones, Richard Harwood,
Ian Lodge and David Sang

Cambridge IGCSE®

Combined and Co-ordinated Sciences

Coursebook



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Introduction

This book has been written to help you obtain the knowledge and skills required for your Cambridge IGCSE® Combined Science 0653 or Cambridge IGCSE® Co-ordinated Sciences (Double Award) 0654 course. We hope that you enjoy using it.

All the Biology topics come first, then Chemistry and then Physics. However, you almost certainly won't follow this sequence in your lessons. You will probably find that you study Biology, Chemistry and Physics alongside each other, so you will use different parts of the book in different lessons.

Core and Supplement

Your teacher will tell you whether you are studying:

- Cambridge IGCSE Combined Science 0653 or Cambridge IGCSE Co-ordinated Sciences (Double Award) 0654
- only the Core part of the syllabus, or the Supplement as well.

Cambridge IGCSE Combined Science 0653 is a single award syllabus. This means that your final papers are the equivalent of one IGCSE subject. Cambridge IGCSE Co-ordinated Sciences 0654 is a double award syllabus. In this case, your final papers are the equivalent of two IGCSE subjects.

If you study the Core only, you will be entered for Papers 1 (Multiple Choice (Core)) and 3 (Theory (Core)) and either Paper 5 (Practical Test) or 6 (Alternative to Practical). If you also study the Supplement, you may be entered for Papers 2 (Multiple Choice (Extended)) and 4 (Theory (Extended)), and either Paper 5 (Practical Test) or 6 (Alternative to Practical).

There are sidebars in the margins of the coursebook to show which material relates to each syllabus and paper. If there is no sidebar, it means that everyone will study this material.

Use this table to ensure that you study the right material for your syllabus and paper:


Cambridge IGCSE Combined Science (0653)		Cambridge IGCSE Co-ordinated Sciences (0654)	
Core	Supplement	Core	Supplement
<i>You will study the material:</i>	<i>You will study the material:</i>	<i>You will study the material:</i>	<i>You will study everything.</i>
Without a sidebar	Without a sidebar	Without a sidebar	<i>This includes the material:</i>
	With a double blue sidebar	With a single blue sidebar	Without a sidebar
	With a double black sidebar	With a double blue sidebar	With a single blue sidebar
			With a double blue sidebar
			With a single black sidebar
			With a double black sidebar

Questions

Each chapter has several sets of questions within it. Most of these require quite short answers and simply test if you have understood what you have just read or what you have just been taught.

At the end of each chapter, there are some longer questions testing a range of material from the chapter. Some of these are past questions from Cambridge exam papers, or similar in style to Cambridge questions. We would like to thank Cambridge International Examinations for permission to reproduce exam questions.

Activities

Each chapter contains activities. These will help you to develop the practical skills you will need in your course. There are further activities on the CD-ROM. These are marked with this symbol: 

There are two possible papers aimed at testing your practical skills, called Paper 5 and Paper 6 (Practical Test and Alternative to Practical, respectively). Your teacher will tell you which of these you will be entered for. You should try to do the activities in this coursebook no matter which of these papers you are entered for.

Summary

At the end of each chapter, there is a short list of the main points covered in the chapter. Remember, though, that these are only very short summaries and you will need to know more detail than this for your course.

CD-ROM

There is a CD-ROM in the back of the book. You can use the revision checklists on the CD-ROM to check off how far you have got with learning and understanding each idea.

The CD-ROM also contains a set of interactive multiple-choice questions which test whether you know and understand the material from each chapter.

You will find some self-assessment checklists on the CD-ROM too, which you can print off and use to assess yourself each time you observe and draw a specimen, construct a results chart, draw a graph from a set of results or plan an experiment. These are all very important skills, and by using these checklists you should be able to improve your performance until you can do them almost perfectly every time.

There are some suggestions on the CD-ROM about how you can do well in your course by studying and revising carefully.

Workbooks

There are three workbooks to go with this coursebook – one for each science. If you have the workbooks, you will find them really helpful in developing your skills, such as handling information and solving problems, as well as some of the practical skills.

How to use this book

This chapter covers

sections set out the key topics within each unit, and help with navigation through the chapter.

B9

Coordination and homeostasis

This chapter covers:

- the human nervous system
- neurones and how they work
- the difference between voluntary and involuntary actions
- reflex actions
- the structure and function of the eye
- the hormone adrenaline
- the hormones insulin and glucagon
- how humans maintain a constant internal body temperature
- how plants respond to stimuli
- the role of auxin in shoot growth.

Key terms

boxes contain clear definitions of important scientific terms in each chapter.



KEY TERMS

A **solution** is made up of two parts:

- the **solute**: the solid that dissolves
- the **solvent**: the liquid in which it dissolves.

Tip boxes contain advice for students to avoid common misconceptions and provide support for answering questions.



TIP

Remember that ice is not always at 0°C – it may be colder than that. When you take ice from a freezer, it may be as cold as –20°C.

Worked examples

are featured throughout to provide step-by-step guidance for answering questions.

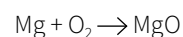
WORKED EXAMPLE C4.01

What is the balanced equation for the reaction between magnesium and oxygen?

Step 1: Make sure you know what the reactants and products are. For example, magnesium burns in air (oxygen) to form magnesium oxide.

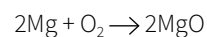
Step 2: From this you can write out the word equation:
magnesium + oxygen → magnesium oxide

Step 3: Write out the equation using the formulae of the elements and compounds:



Remember that oxygen exists as diatomic molecules. This equation is not balanced: there are two oxygen atoms on the left, but only one on the right.

Step 4: Balance the equation:



Activity

sections throughout each chapter provide guidance for conducting practical investigations.

ACTIVITY C7.05
 **The factors affecting reaction rate**
Skills:


AO3.1 Demonstrate knowledge of how to safely use techniques, apparatus and materials (including following a sequence of instructions where appropriate)

AO3.2 Plan experiments and investigations

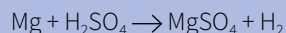
AO3.3 Make and record observations, measurements and estimates

AO3.4 Interpret and evaluate experimental observations and data

AO3.5 Evaluate methods and suggest possible improvements

 **Wear eye protection. Sulfuric acid is corrosive.**

You must plan an investigation to discover how one chosen factor affects the rate of a chemical reaction.



- 1 Measure 10 cm³ of 2 mol/dm³ sulfuric acid into a boiling tube.
- 2 Add a 5 cm strip of magnesium ribbon and start a stopclock.
- 3 When the reaction stops, record the time taken.
- 4 List the factors that could speed up or slow down this reaction.
- 5 Choose one of these factors and plan an investigation to discover how it affects the rate.
- 6 Your investigation should produce sufficient results to enable you to draw a graph.

A worksheet is included on the CD-ROM. The Notes on activities for teachers/technicians contain details of how this experiment can be used as an assessment of skills AO3.2 and AO3.5.

Questions

are featured throughout each chapter to assess students' knowledge and understanding of science.

QUESTIONS

- B2.01** Define diffusion.
- B2.02** List **three** examples of diffusion in living organisms.
- B2.03** You will need to think about your knowledge of particle theory to answer this question.
- a What effect does an increase in temperature have on the kinetic energy of molecules of a gas or a solute?
 - b Predict and explain how an increase in temperature will affect the rate of diffusion of a solute.

Check the introduction and the cover flap for information on how to use the sidebars in the margins.

At the end of each chapter, a **Summary** is included to recap the key topics.

Summary**You should know:**

- how diffusion results from the random movement of particles
- the factors that affect the rate of diffusion
- why diffusion is important to cells and living organisms
- the importance of water as a solvent
- about osmosis, which is a special kind of diffusion, involving water molecules
- how osmosis affects animal cells and plant cells.

Following the summary, there will be selection of exam-style **End of chapter questions** to help students to prepare for the type of questions on the IGCSE Combined or IGCSE Co-ordinated Sciences exams.

End-of-chapter questions

- 1 When a force moves, it does work. Copy and complete the following sentences, writing *more* or *less* in the spaces.
- a** When it moves, a bigger force does work than a smaller force. [1]
- b** The greater the distance moved by the force, the work it does. [1]
- 2 Power tells us about how quickly work is done. Copy and complete the following sentences, writing *work* or *energy* in the spaces.
- a** Power is the rate at which is transferred. [1]
- b** Power is the rate at which is done. [1]
- 3 We can calculate work done using this equation: $W = F \times d$.
- a** Write this equation in words. [2]
- b** Copy and complete the table to show the units of each quantity in the equation. [3]
- | Quantity | Unit |
|----------|------|
| W | |
| F | |
| d | |
- 4 Omar and Ahmed are lifting weights in the gym. Each lifts a weight of 200 N. Omar lifts the weight to a height of 2.0 m, whereas Ahmed lifts it to a height of 2.1 m. Who does more work in lifting the weight? Explain how you know. [2]
- 5 Millie and Lily are identical twins who enjoy swimming. Their arms and legs provide the force needed to move them through the water. Millie can swim 25 m in 50 s. Lily can swim 100 m in 250 s.
- a** Calculate the swimming speed of each twin. [2]
- b** Which twin has the greater power when swimming? Explain how you can tell. [2]
- 6 Write a word equation showing how *work done* and *energy transferred* are related. [2]



B4

Plant nutrition

36

This chapter covers:

- how plants make carbohydrates by photosynthesis
- the structure of a leaf
- the role of chlorophyll in transferring light energy to chemical energy
- how a leaf is adapted for photosynthesis
- how to test a leaf for starch
- investigating the need for chlorophyll, light and carbon dioxide for photosynthesis
- investigating the effect of light intensity on the rate of photosynthesis
- why plants need nitrate ions and magnesium ions.

B4.01 Types of nutrition

All living organisms need to take many different substances into their bodies. Some of these may be used to make new parts, or repair old parts. Others may be used to release energy. Taking in useful substances is called feeding, or nutrition.

Animals and fungi cannot make their own food. They feed on **organic** substances that have originally been made by plants. Some animals eat other animals, but all the

substances passing from one animal to another were first made by plants. Animal nutrition is described in Chapter B5.

Green plants make their own food. They use simple **inorganic** substances – carbon dioxide, water and minerals – from the air and soil. Plants build these substances into complex materials, making all the carbohydrates, lipids, proteins and vitamins that they need.

B4.02 Photosynthesis

Green plants make the carbohydrate glucose from carbon dioxide and water. At the same time, oxygen is produced.

If you just mix carbon dioxide and water together, they will not make glucose. They have to be given energy before they will combine. Green plants use the energy of sunlight for this. The reaction is therefore called **photosynthesis** ('photo' means light, and 'synthesis' means manufacture).



KEY TERM

photosynthesis: the process by which plants manufacture carbohydrates from raw materials using energy from light

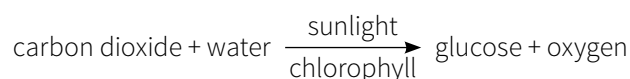
Chlorophyll

However, sunlight shining onto water and carbon dioxide still will not make them react together to make glucose. The sunlight energy has to be trapped, and then used in the reaction. Green plants have a substance which does this. It is called **chlorophyll**.

Chlorophyll is the pigment which makes plants look green. It is kept inside the chloroplasts of plant cells. When sunlight falls on a chlorophyll molecule, some of the energy in the light is absorbed. The chlorophyll molecule then releases the energy. The released energy makes carbon dioxide combine with water, with the help of enzymes inside the chloroplast. The glucose that is made contains energy that was originally in the sunlight. So, in this process, light energy is transferred to chemical energy.

The photosynthesis equation

The full equation for photosynthesis is written like this:



To show the number of molecules involved in the reaction, a balanced equation needs to be written. Carbon dioxide contains two atoms of oxygen and one of carbon, so its molecular formula is CO_2 . Water has the formula H_2O . Glucose has the formula $\text{C}_6\text{H}_{12}\text{O}_6$. Oxygen molecules contain two atoms of oxygen, and so they are written O_2 .

The balanced equation for photosynthesis is this:



QUESTIONS

- B4.01** Give **one** example of an organic substance.
- B4.02** Which inorganic substances does a plant use to make carbohydrates?
- B4.03** What is chlorophyll, and how does it help the plant?

B4.03 Leaves

Photosynthesis happens inside chloroplasts. This is where the enzymes and chlorophyll are that catalyse and supply energy for the reaction. In a typical plant, most chloroplasts are in the cells in the leaves. A leaf is a factory for making carbohydrates.

Leaves are therefore specially adapted to allow photosynthesis to take place as quickly and efficiently as possible.

Leaf structure

A leaf consists of a broad, flat part called the **lamina** (Figure B4.01), which is joined to the rest of the plant by a leaf stalk. Running through the leaf stalk are **vascular bundles**, which then form the veins in the leaf. These contain tubes that carry substances to and from the leaf.

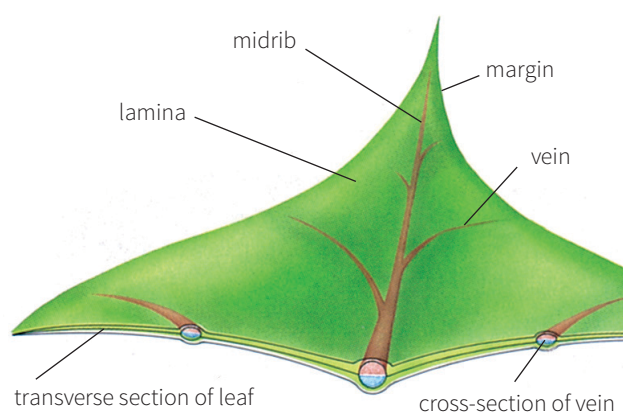


Figure B4.01 The structure of a leaf.

Although a leaf looks thin, it is in fact made up of several layers of cells. You can see these if you look at a transverse section (TS) of a leaf under a microscope (Figure B4.02, and Images B4.01 and B4.02).

The top and bottom of the leaf are covered with a layer of closely fitting cells called the **epidermis** (Figures B4.02 and B4.03, and Image B4.03). These cells do not contain chloroplasts. Their function is to protect the inner layers

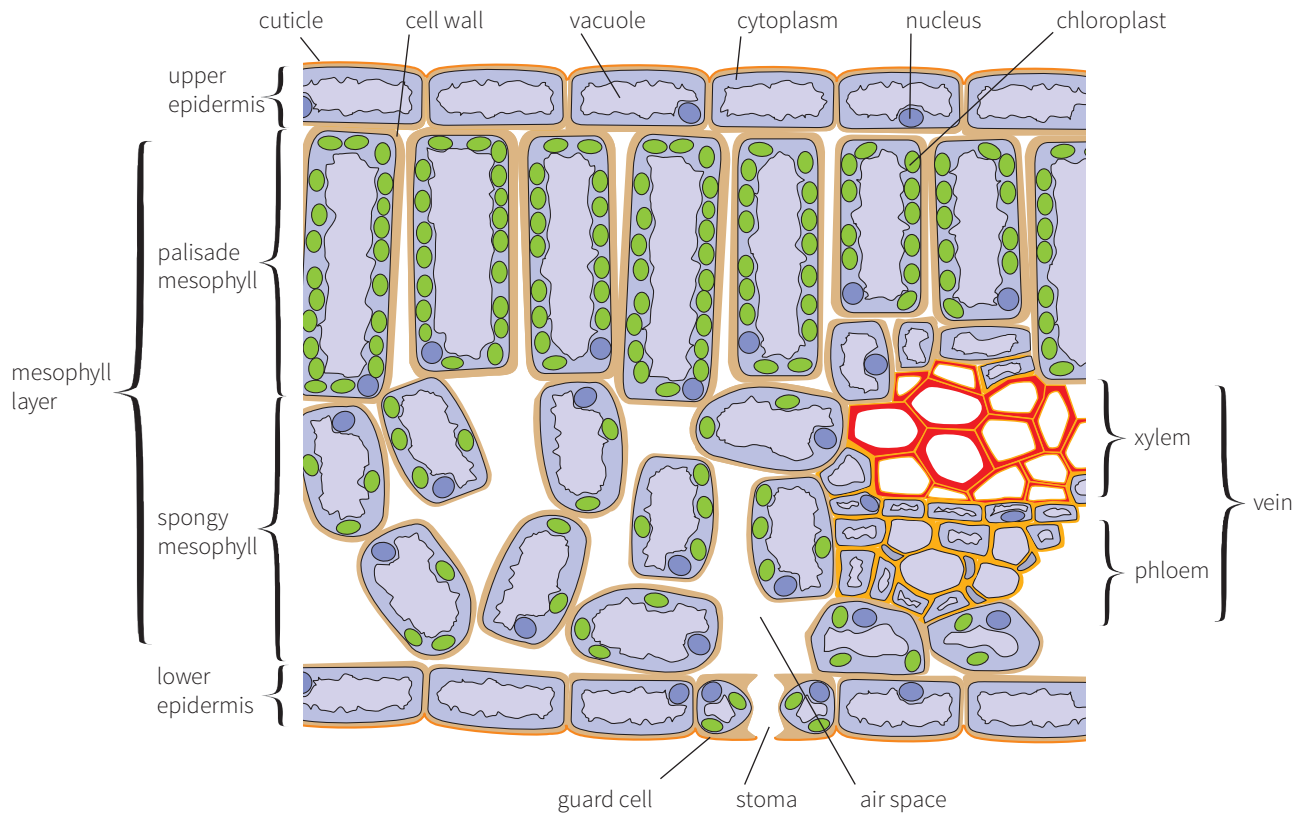


Figure B4.02 Transverse section through a small part of a leaf.

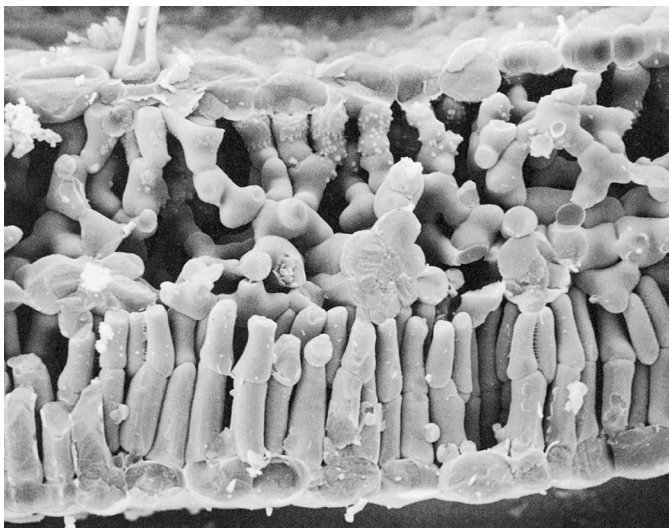


Image B4.01 A photograph taken with a scanning electron microscope, showing the cells inside a leaf. Scanning electron microscopes provide 3D images ($\times 400$).

of cells in the leaf. The cells of the upper epidermis often secrete a waxy substance that lies on top of them. It is called the **cuticle**, and it helps to stop water evaporating from the leaf. There is sometimes a cuticle on the underside of the leaf as well.

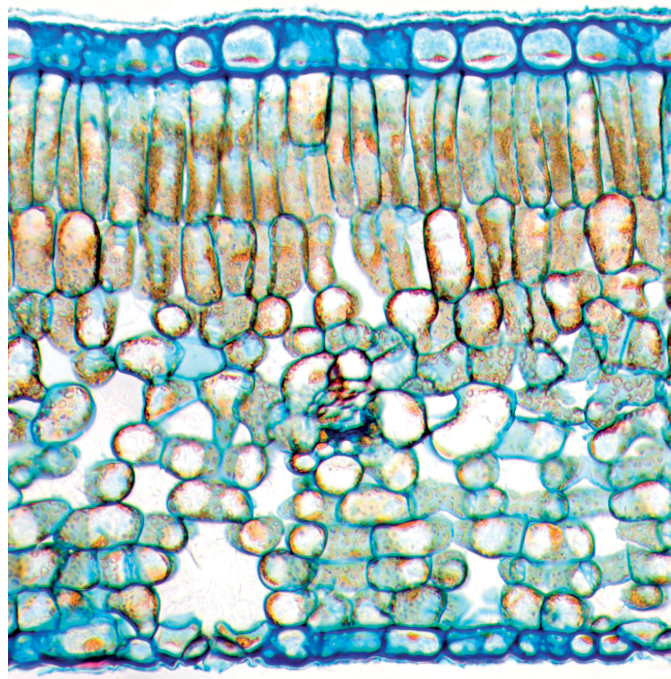


Image B4.02 This photograph was taken using a light microscope. It shows a transverse section of a leaf from a tea plant. Can you identify all the different layers of cells labelled in Figure B4.02?

In the lower epidermis, there are small openings called **stomata** (singular: **stoma**). Each stoma is surrounded by a pair of sausage-shaped **guard cells** which can open or close the hole. Guard cells, unlike other cells in the epidermis, do contain chloroplasts.

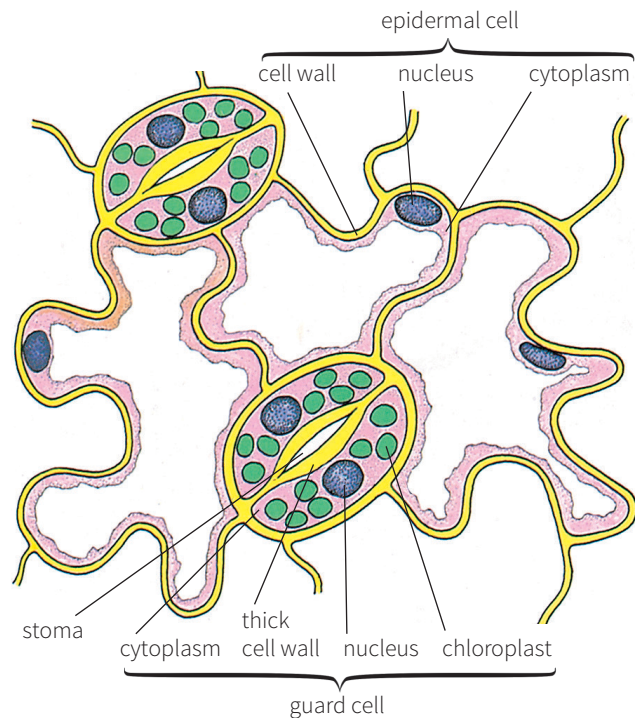


Figure B4.03 Surface view of the lower epidermis of a leaf.

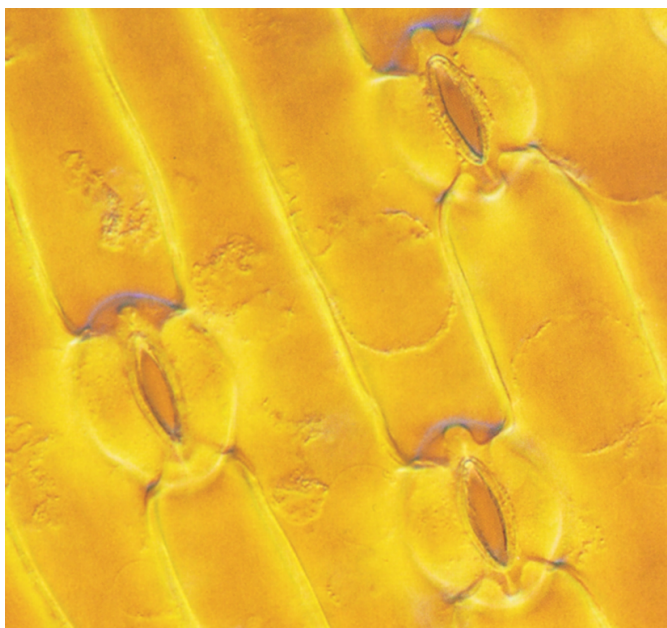


Image B4.03 The lower surface of a leaf, showing the closely fitting cells of the epidermis. The oval openings are stomata, and the two curved cells around each stoma are guard cells (× 450).

The middle layers of the leaf are called the **mesophyll** ('meso' means middle, and 'phyll' means leaf). These cells all contain chloroplasts. The cells nearer to the top of the leaf are arranged like a fence or palisade, and they form the **palisade mesophyll**. The cells beneath them are rounder, and arranged quite loosely, with large air spaces between them. They form the **spongy mesophyll** (Figure B4.02).

Running through the mesophyll are veins or vascular bundles. Each vein contains large, thick-walled **xylem vessels** (Figure B6.01) for carrying water. There are also smaller, thin-walled **phloem tubes** (Figure B6.03) for carrying away sucrose and other substances that the leaf has made.

QUESTIONS

- B4.04** Which kind of cell makes the cuticle on a leaf?
B4.05 What is the function of the cuticle?
B4.06 What are stomata?
B4.07 What are guard cells?
B4.08 List **three** kinds of cell in a leaf which contain chloroplasts, and **one** kind which does not.

Leaf adaptations

Leaves are adapted to obtain carbon dioxide, water and sunlight.

Carbon dioxide

Carbon dioxide is obtained from the air. There is not very much available, because only about 0.04% of the air is carbon dioxide. Therefore, the leaf must be very efficient at absorbing it. The leaf is held out into the air by the stem and the leaf stalk, and its large surface area helps to expose it to as much air as possible (Figure B4.04).

The cells which need the carbon dioxide are the mesophyll cells, inside the leaf. The carbon dioxide can get into the leaf through the stomata. It does this by diffusion, which is described in Chapter B2. Behind each stoma is an air space (Figure B4.02) which connects up with other air spaces between the spongy mesophyll cells. The carbon dioxide can therefore diffuse to all the cells in the leaf. It can then diffuse through the cell wall and cell membrane of each cell, and into the chloroplasts.

Water

Water is obtained from the soil. It is absorbed by the root hairs, and carried up to the leaf in the xylem vessels.

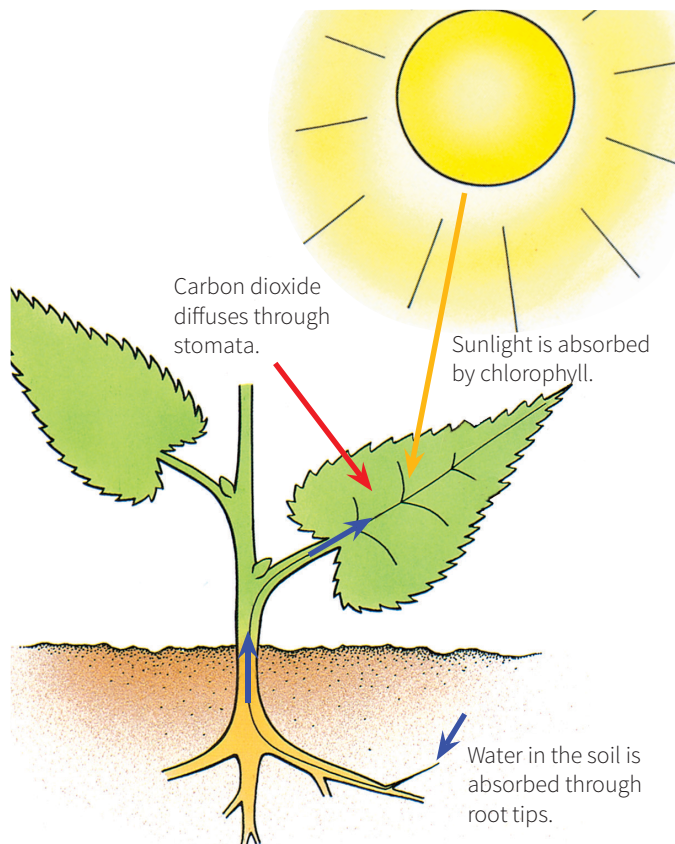


Figure B4.04 How the materials for photosynthesis get into a leaf.

It then travels from the xylem vessels to the mesophyll cells by osmosis, which was described in Chapter B2. The path it takes is shown in Figures B4.04 and B4.05.

Sunlight

The position of a leaf and its broad, flat surface help it to obtain as much sunlight as possible. If you look up through the branches of a tree, you will see that the leaves are arranged so that they do not cut off light from one another more than necessary. Plants that live in shady places often have particularly big leaves.

The cells that need the sunlight are the mesophyll cells. The thinness of the leaf allows the sunlight to penetrate right through it, and reach all the cells. To help this, the epidermal cells are transparent, with no chloroplasts.

In the mesophyll cells, the chloroplasts are arranged to get as much sunlight as possible, particularly those in the palisade cells. The chloroplasts can lie broadside on to do this, but in strong sunlight, they often arrange themselves end on. This reduces the amount of light absorbed.

Adaptations of leaves for photosynthesis are shown in Table B4.01.

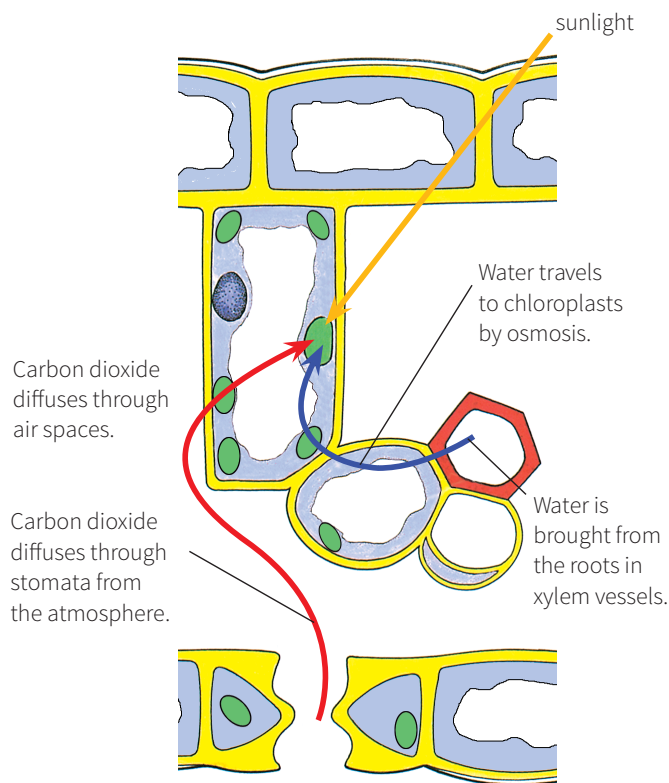



Figure B4.05 How the raw materials for photosynthesis get into a palisade cell.



TIP

Note that chlorophyll does not 'attract' light. It absorbs energy from light.

ACTIVITY B4.01

 **Use a microscope to observe the cells that cover a leaf**

QUESTIONS

- B4.09** What are the raw materials needed for photosynthesis?
- B4.10** What percentage of the air is carbon dioxide?
- B4.11** How does carbon dioxide get into a leaf?
- B4.12** How does a leaf obtain its water?
- B4.13** Give **two** reasons why the large surface area of leaves is advantageous to the plant.
- B4.14** Leaves are thin. What purpose does this serve?

Adaptation	Function
supported by stem and leaf stalk	to expose as much of the leaf as possible to the sunlight and air
large surface area	to expose as large an area as possible to the sunlight and air
thin	to allow sunlight to penetrate to all cells; to allow CO ₂ to diffuse in and O ₂ to diffuse out as quickly as possible
stomata in lower epidermis	to allow CO ₂ to diffuse in and O ₂ to diffuse out
air spaces in spongy mesophyll	to allow CO ₂ and O ₂ to diffuse to and from all cells
no chloroplasts in epidermal cells	to allow sunlight to penetrate to the mesophyll layer
chloroplasts containing chlorophyll present in the mesophyll layer	to absorb energy from sunlight, so that CO ₂ will combine with H ₂ O
palisade cells arranged end on	to keep as few cell walls as possible between sunlight and the chloroplasts
chloroplasts inside palisade cells often arranged broadside on	to expose as much chlorophyll as possible to sunlight
chlorophyll arranged on flat membranes inside the chloroplasts	to expose as much chlorophyll as possible to sunlight
xylem vessels within short distance of every mesophyll cell	to supply water to the cells in the leaf, some of which will be used in photosynthesis
phloem tubes within short distance of every mesophyll cell	to take away sucrose and other organic products of photosynthesis

Table B4.01 Adaptations of leaves for photosynthesis.

B4.04 Uses of glucose

One of the first carbohydrates to be made in photosynthesis is glucose. There are several things that may then happen to it (Figure B4.06).

Used for energy

Energy may be released from glucose in the leaf. All cells need energy, which they obtain by the process of respiration (Chapter B8). Some of the glucose which a leaf makes will be broken down by respiration, to release energy.

Stored as starch

Glucose may be turned into starch and stored in the leaf. Glucose is a simple sugar (Section B3.02). It is soluble in water, and quite a reactive substance. It is not, therefore, a very good storage molecule. First, being reactive, it might get involved in chemical reactions where it is not wanted. Secondly, it would dissolve in the water in and around

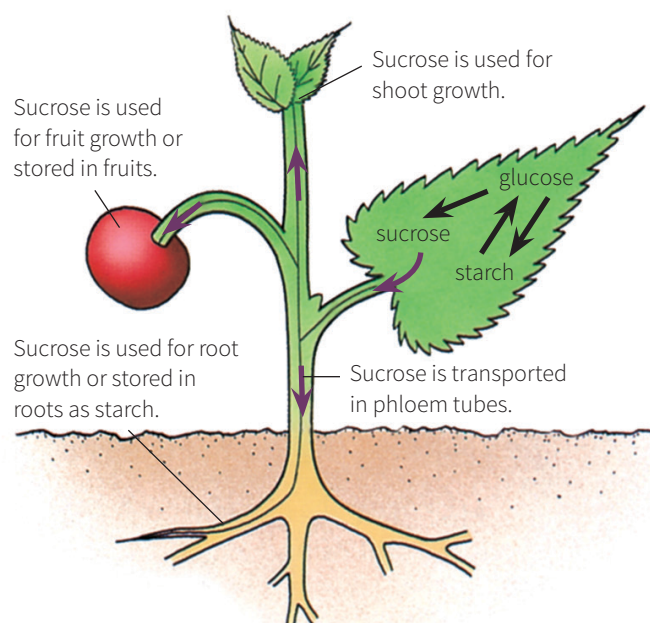


Figure B4.06 The products of photosynthesis.

the plant cells, and might be lost from the cell. Thirdly, when dissolved, it would increase the concentration of the solution in the cell, which could affect osmosis.

The glucose is therefore converted into starch to be stored. Starch is a polysaccharide, made of many glucose molecules joined together. Being such a large molecule, it is not very reactive, and not very soluble. It can be made into granules which can be easily stored inside the chloroplasts.

Used to make proteins and other organic substances

Glucose may be used to make other organic substances. The plant can use glucose as a starting point for making all the other organic substances it needs. These include the carbohydrates sucrose and cellulose. Plants also make fats and oils.

Plants can also use the sugars they have made in photosynthesis to make amino acids, which can be built up into proteins. To do this, they need nitrogen. Unfortunately, even though the air around us is 78% nitrogen, this is completely useless to plants because it is very unreactive. Plants have to be supplied with nitrogen in a more reactive form, usually as nitrate ions. They absorb nitrate ions from the soil, through their root hairs, by diffusion and active transport. The nitrate ions combine with glucose to make amino acids. The amino acids are then strung together to form protein molecules.

Another substance that plants make is chlorophyll. Once again, they need nitrogen to do this, and also another element – magnesium. The magnesium, like the nitrate ions, is obtained from the soil.

Table B4.02 shows what happens to a plant if it does not have enough of these ions. Image B4.04 shows what happens when a plant does not have enough nitrogen. Farmers often add extra mineral ions to the soil in which

Element	nitrogen	magnesium
Mineral salt	nitrate ions	magnesium ions
Why needed	to make amino acids, which can then be used for making proteins	to make chlorophyll
Deficiency	weak growth, yellow leaves	yellowing between the veins of leaves

Table B4.02 Mineral ions required by plants.

Original material © Cambridge University Press 2017



Image B4.04 This stunted, yellow maize seedling is suffering from nitrogen deficiency.

their crops are growing, to make sure that they do not run short of these essential substances.

Changed to sucrose for transport

A molecule has to be small and soluble to be transported easily. Glucose has both of these properties, but it is also rather reactive. It is therefore converted to the complex sugar sucrose to be transported to other parts of the plant. Sucrose molecules are also quite small and soluble, but less reactive than glucose. They dissolve in the sap in the phloem vessels and can be distributed to whichever parts of the plant need them (Figure B4.06).

The sucrose may later be turned back into glucose again, to be broken down to release energy, or turned into starch and stored, or used to make other substances which are needed for growth.

QUESTIONS

- B4.15** Why is glucose not very good for storage in a leaf?
- B4.16** What substances does a plant need to be able to convert glucose into proteins?
- B4.17** Explain why a plant that does not get enough nitrate ions has weak growth.
- B4.18** How do parts of the plant such as the roots, which cannot photosynthesise, obtain food?

B4.05 Testing leaves for starch

Iodine solution is used to test for starch. A blue-black colour shows that starch is present. However, if you put iodine solution onto a leaf which contains starch,

ACTIVITY B4.02

Testing a leaf for starch**Skill:****AO3.1 Using techniques, apparatus and materials**

Leaves turn some of the glucose that they make in photosynthesis into starch. If we find starch in a leaf, that tells us if it has been photosynthesising.

 Wear eye protection if available.

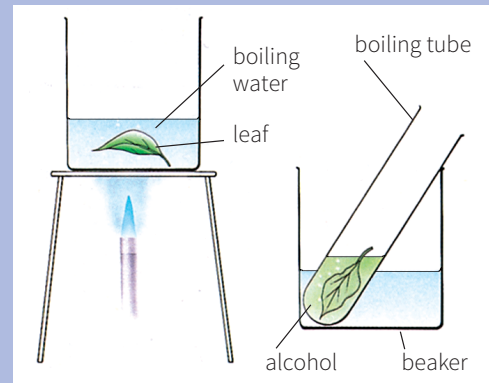
Take care with the boiling water.

Alcohol is *very flammable*. Turn out your Bunsen flame *before* putting the tube of alcohol into the hot water.

Use forceps to handle the leaf.

- 1 Take a leaf from a healthy plant, and drop it into boiling water in a water bath. Leave for about 30 s. Turn out the Bunsen flame.
- 2 Remove the leaf, which will be very soft, and drop it into a tube of alcohol in the water bath. Leave it until all the chlorophyll has come out of the leaf.
- 3 The leaf will now be brittle. Remove it from the alcohol, and dip it into hot water again to soften it.

- 4 Spread out the leaf on a white tile, and cover it with iodine solution. A blue-black colour shows that the leaf contains starch.

**Questions**

- A1** Why was the leaf put into boiling water?
A2 Why did the alcohol become green?
A3 Why was the leaf put into alcohol after being put into boiling water?

it will not immediately turn black. This is because the starch is inside the chloroplasts in the cells. The iodine solution cannot get through the cell membranes to reach the starch and react with it.

Another difficulty is that the green colour of the leaf and the brown iodine solution can look black together.

Therefore, before testing a leaf for starch, you must break down the cell membranes, and get rid of the green colour (chlorophyll). The way this is done is described in Activity B4.02. The cell membranes are first broken down by boiling water, and then the chlorophyll is removed by dissolving it out with alcohol.

Controls

If you do Activities B4.03, B4.04 and B4.05, you can find out for yourself which substances a plant needs for photosynthesis. In each investigation, the plant is given everything it needs, except for one substance. Another plant is used at the same time. This is a **control**. The control is given everything it needs, including the substance being tested for. Sometimes the control is a leaf, or even a part of a leaf, from the experimental plant. The important thing is that the control has all the substances it needs, while the experimental plant – or leaf – is lacking one substance.

Both plants (or leaves) are then treated in exactly the same way. Any differences between them at the end of the investigation, therefore, must be because of the substance being tested.

At the end of the investigation, test a leaf from your experimental plant and one from your control to see if they have made starch. By comparing them, you can find out which substances are necessary for photosynthesis.

Destarching plants

It is very important that the leaves you are testing should not have any starch in them at the beginning of the investigation. If they did, and you found that the leaves contained starch at the end of the investigation, you could not be sure that they had been photosynthesising. The starch might have been made before the investigation began.

So, before doing any of these investigations, you must destarch the plants. The easiest way to do this is to leave them in a dark cupboard for at least 24 hours. The plants cannot photosynthesise while they are in the cupboard because there is no light. So they use up their stores of starch. To be certain that they are thoroughly destarched, test a leaf for starch before you begin.

ACTIVITY B4.03

To see if light is needed for photosynthesis**Skills:**

AO3.1 Using techniques, apparatus and materials

AO3.3 Observing, measuring and recording

AO3.4 Interpreting and evaluating observations and data



Wear eye protection if available.

Take care with the boiling water.

Alcohol is *very flammable*. Turn out your Bunsen flame *before* putting the tube of alcohol into the hot water.

Use forceps to handle the leaf.

- 1 Take a healthy bean or *Pelargonium* plant, growing in a pot. Leave it in a cupboard for a few days, to destarch it.
- 2 Test one of its leaves for starch, to check that it does not contain any.
- 3 Using a folded piece of black paper or aluminium foil, a little larger than a leaf, cut out a shape (see diagram). Fasten the paper or foil over both sides of a leaf on your plant, making sure that the edges are held firmly together. Don't take the leaf off the plant!



- 4 Leave the plant near a warm, sunny window for a few days.
- 5 Remove the cover from your leaf, and test the leaf for starch.
- 6 Make a labelled drawing of the appearance of your leaf after testing for starch.

Questions

- A1** Why was the plant destarched before the beginning of the experiment?
- A2** Why was part of the leaf left uncovered?
- A3** What do your results tell you about light and photosynthesis?

ACTIVITY B4.04

To see if chlorophyll is needed for photosynthesis**Skills:**

AO3.1 Using techniques, apparatus and materials

AO3.3 Observing, measuring and recording

AO3.4 Interpreting and evaluating observations and data



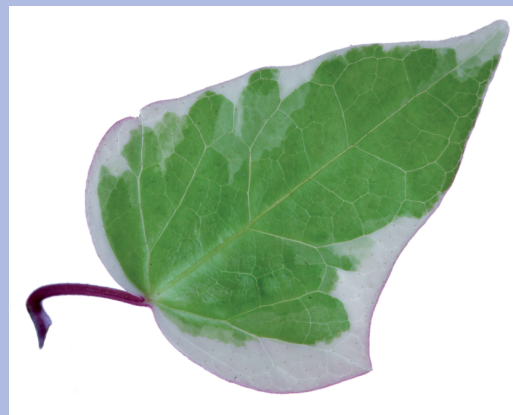
Wear eye protection if available.

Take care with the boiling water.

Alcohol is *very flammable*. Turn out your Bunsen flame *before* putting the tube of alcohol into the hot water.

Use forceps to handle the leaf.

- 1 Destarch a plant with variegated (green and white) leaves. Then leave your plant in a warm, sunny spot for a few days.
- 2 Test one of the leaves for starch (Activity B4.02).
- 3 Make a drawing of your leaf before and after testing.

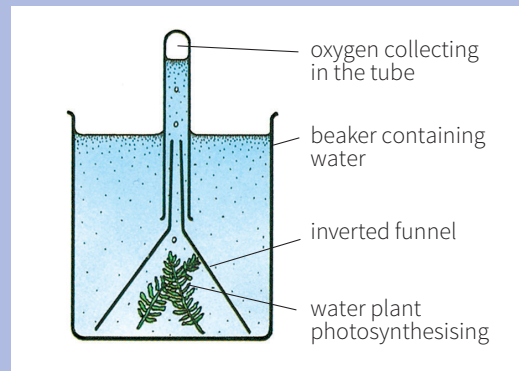
**Questions**

- A1** What was the control in this investigation?
- A2** What do your results tell you about chlorophyll and photosynthesis?

ACTIVITY B4.05


To show that oxygen is produced in photosynthesis**Skills:****AO3.1 Using techniques, apparatus and materials****AO3.3 Observing, measuring and recording**

- 1 Set up the apparatus shown in the diagram. Make sure that the test tube is completely full of water.
- 2 Leave the apparatus near a warm, sunny window for a few days.
- 3 Carefully remove the test tube from the top of the funnel, allowing the water to run out, but not allowing the gas to escape.
- 4 Light a wooden splint, and then blow it out so that it is just glowing. Carefully put it into the gas in the test tube. If it bursts into flame, then the gas is oxygen.

**Questions**

- A1** Why was this investigation done under water?
A2 This investigation has no control. Try to design one.

ACTIVITY B4.06

-  **To see if carbon dioxide is needed for photosynthesis**

ACTIVITY B4.07

-  **Photosynthesis in pond weed**

ACTIVITY B4.08

Investigating the effect of light intensity on photosynthesis**Skills:****AO3.1 Using techniques, apparatus and materials****AO3.2 Planning****AO3.3 Observing, measuring and recording****AO3.4 Interpreting and evaluating observations and data****AO3.5 Evaluating methods**

-  If you use an electric lamp, keep water well away from it.

If you did Activity B4.06, you may have noticed that the plant seemed to produce more bubbles in bright sunlight than when it was in the shade. This could mean that the rate of photosynthesis is affected by light intensity.

- 1 Write down a hypothesis that you will investigate. The hypothesis should be one sentence, and it should describe the relationship that you think exists between light intensity and the rate of photosynthesis. You can vary light intensity by moving a light source closer to the plant. The shorter the distance between the light and the plant, the greater the light intensity.
You can use a water plant in your investigation.
- 2 Once you have an idea about how you will do your experiment, write it down as a list of points. Then think through it again, and make improvements to your plan. Once you are fairly happy with it, show your teacher. You must not try to do your experiment until your teacher says that you may begin.
 - What apparatus and other materials will you need for your experiment?
 - What will you vary in your experiment? How will you vary it?
 - What will you keep the same in all the tubes or beakers in your experiment? How will you do this?
 - What will you measure in your experiment? How will you measure it? When will you measure it? Will you do repeat measurements and calculate a mean?
 - How will you record your results? (You can sketch out a results chart, ready to fill in.)
 - How will you display your results? (You can sketch the axes of the graph you plan to draw.)
 - What will your results be if your hypothesis is correct? (You can sketch the shape of the graph you think you will get.)

- 3** Once you have approval from your teacher, you should do your experiment. Most scientific researchers find that they want to make changes to their experiment once they actually begin doing it.
This is a good thing to do. Make careful notes about all the changes that you make.
- 4** Finally, write up your experiment in the usual way, including:
- a heading, and the hypothesis that you tested
 - a diagram of the apparatus that you used, and a full description of your method
 - a neat and carefully headed table of results, including means if you decided to do repeats
 - a neat and carefully headed line graph of your results
 - a conclusion, in which you say whether or not your results support your hypothesis
 - a discussion, in which you use what you know about photosynthesis to try to explain the pattern in your results
 - an evaluation of the reliability of your data
 - an evaluation of your method.

Summary

You should know:

- the equation for photosynthesis
- the role of chlorophyll in photosynthesis
- the structure of a leaf
- how a leaf is adapted to carry out photosynthesis efficiently
- how a plant uses and stores the carbohydrates made in photosynthesis
- why plants need nitrate ions and magnesium ions
- how to test a leaf for starch
- how to do experiments to investigate the need for chlorophyll, light and carbon dioxide for photosynthesis
- about the importance of a control in an experiment
- how to investigate the effect of light intensity on the rate of photosynthesis.

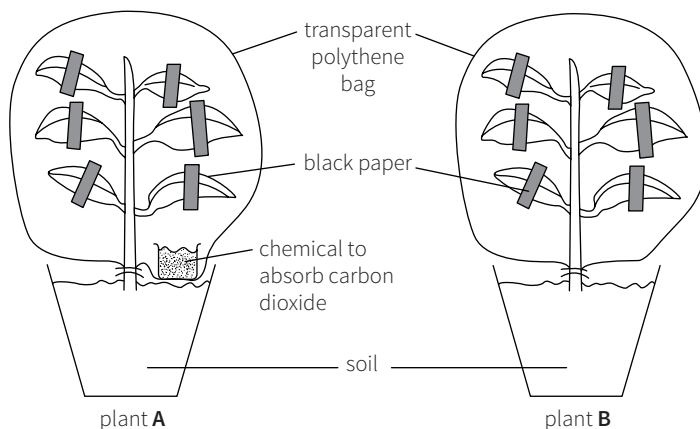
End-of-chapter questions

- 1** Copy and complete this table to show how, and for what purpose, plants obtain these substances.

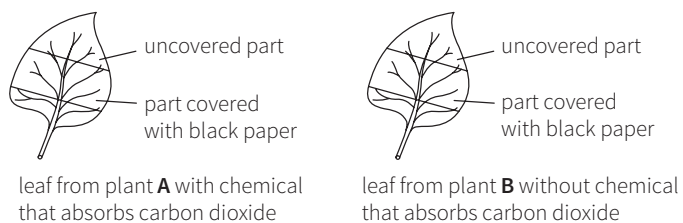
	Obtained from	Used for
Nitrates		
Water		
Magnesium		
Carbon dioxide		

- 2** Explain the difference between each of these pairs of terms.
- a chloroplast and chlorophyll
 - b palisade mesophyll and spongy mesophyll
 - c organic substances and inorganic substances
 - d guard cell and stoma
- 3**
- a Write the word equation for photosynthesis.
 - b Describe how a leaf obtains the two substances on the left hand side of your equation.
 - c Describe what happens to the two substances on the right hand side of your equation.

- 4 Explain how each of the following helps a leaf to photosynthesise.
- There is an air space behind each stoma.
 - The epidermal cells of a leaf do not have chloroplasts.
 - Leaves have a large surface area.
 - The veins in a leaf branch repeatedly.
- 5 Which carbohydrate does a plant use for each of these purposes? Explain why.
- transport
 - storage
- 6 A student did an experiment with two potted plants, each of which had been enclosed in a transparent polythene bag for a period of two days. During this time, the plants were exposed to bright light. In one of the polythene bags there was a chemical which absorbs carbon dioxide. Both plants had part of their leaves covered with black paper, as shown in the diagram below.



One leaf was removed from each plant, and labelled drawings of the two leaves were made as shown below.



Both leaves were then tested for starch.

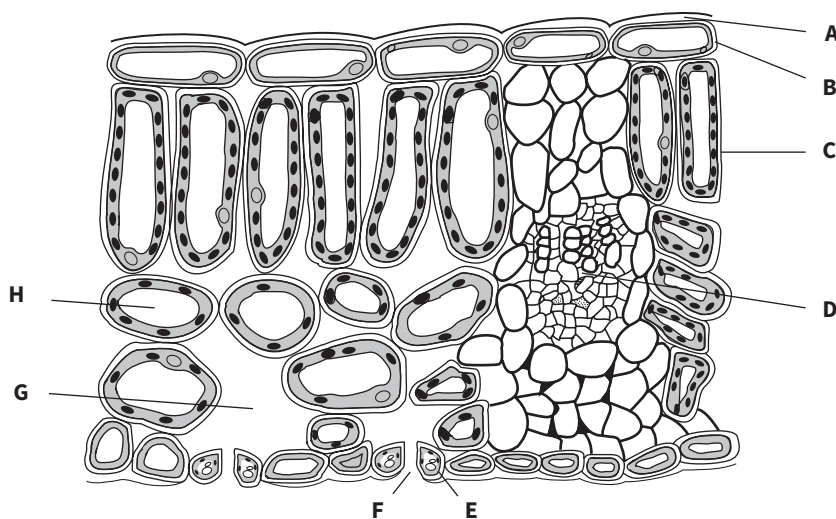
- The black paper was removed from each leaf.
 - The leaves were placed in hot water for two minutes.
 - The leaves were removed from the hot water, and placed in a test-tube of hot alcohol for five minutes.
 - The leaves were dipped briefly back into the hot water.
 - The leaves were spread out on a white tile, and covered with iodine solution.
- Make a copy of the diagrams of the two leaves. Label the different areas of each leaf to show the colours that you would expect to see after each leaf had been treated with iodine solution. [3]
 - In the starch test, explain the reasons for
 - placing the leaf in the hot water at the beginning, [1]
 - placing the leaf in hot alcohol [1]

(continued)

- c i** The purpose of the experiment with the black paper was to see if light is needed for photosynthesis. However, another student criticised this experiment, saying that the black paper might have prevented photosynthesis by preventing gas exchange. Suggest a modification of the experiment that would overcome this criticism. [1]
- ii** Another modification of the experiment would be to use just one plant, and enclose different part-covered leaves on this plant with and without the chemical that absorbs carbon dioxide. Explain why this might be considered to be a better experiment. [1]
- d** Describe an experiment that you could do to show that chlorophyll in a leaf is needed for photosynthesis. [3]

[Cambridge IGCSE Co-ordinated Sciences 0654 Paper 62 Q1 June 2013]

- 7** The diagram shows a section through a leaf.



- a** Give the letters that indicate **i** a stoma, **ii** the cuticle and **iii** a vascular bundle. [3]
- b i** The upper layers of a leaf are transparent. Suggest an advantage to a plant of this feature. [1]
- ii** The cuticle is made of a waxy material. Suggest an advantage to a plant of this feature. [1]
- iii** State **two** functions of vascular bundles in leaves. [2]
- c** Most photosynthesis in plants happens in leaves.
- i** Name the **two** raw materials needed for photosynthesis. [2]
- ii** Photosynthesis produces glucose. Describe how plants make use of this glucose. [4]

Adapted from [Cambridge IGCSE Biology 0610 Paper 21 Q4 November 2010]



C9

Industrial inorganic chemistry

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This chapter covers:

- the production of iron in the blast furnace
- steel making
- rusting of iron and barrier methods for its prevention
- sacrificial protection and galvanization as rust prevention methods
- the extraction of aluminium
- the Haber–Bosch process for the manufacture of ammonia
- the manufacture and use of fertilisers
- the manufacture of sulfuric acid
- the commercial electrolysis of brine
- limestone and its uses
- the production of lime and its uses
- recycling.

C9.01 The extraction of metals by carbon reduction

Iron and steel

In our modern world, we have invented and shaped many machines and clever devices. These are often made of steel. It is the most widely used of all metals. The durability, tensile strength and low cost of steel make it the basis of countless industries, from ship-building to watch-making. Iron and steel making are at the centre of our heavy industries.

Steel is mainly iron with between 0.2 and 1.5% carbon. The carbon makes the iron harder and stronger. Small quantities of other **transition metals** can also be added to make special steels. Steels are **alloys** in which the main metal is iron. The magnetic properties of iron make it easy to separate steel products from other waste, so the metal can be easily recycled.

The production of iron in the blast furnace

The main ore of iron is hematite (Fe_2O_3). The iron is obtained by reduction with carbon in a **blast furnace** (Image C9.01 and Figure C9.01). The furnace is a steel tower about 30 metres high. It is lined with refractory (heat-resistant) bricks of magnesium oxide which are cooled by water. The furnace is loaded with the 'charge', which consists of iron ore, coke (a form of carbon made from coal) and limestone (calcium carbonate). The charge is **sintered** (the ore is heated with coke and limestone) to make sure the solids mix well, and it is mixed with more coke. Blasts of hot air are sent in through holes near the bottom of the furnace. The carbon burns in the air blast and the furnace gets very hot.



Image C9.01 A worker in protective clothing takes a sample from a blast furnace in a steel works.

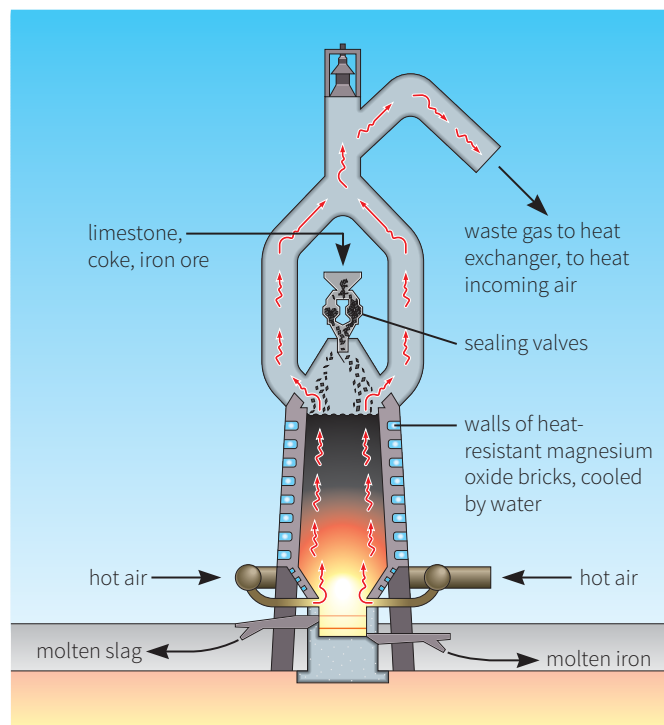
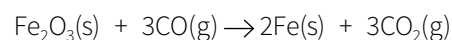


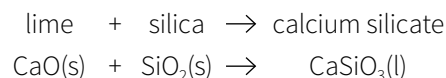
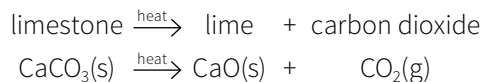
Figure C9.01 The blast furnace reduction of iron ore to iron.

A series of chemical reactions takes place to produce molten iron (Figure C9.02). The most important reaction that occurs is the reduction of the ore by carbon monoxide:



The iron produced flows to the bottom of the furnace where it can be 'tapped off' because the temperature at the bottom of the furnace is higher than the melting point of iron.

One of the major impurities in iron ore is sand (silica, SiO_2). The limestone added to the furnace helps to remove this impurity. The limestone decomposes to lime in the furnace. This then reacts with the silica:



The calcium silicate formed is also molten. It flows down the furnace and forms a molten layer of slag on top of the iron. It does not mix with the iron, as it is less dense. The molten slag is 'tapped off' separately.

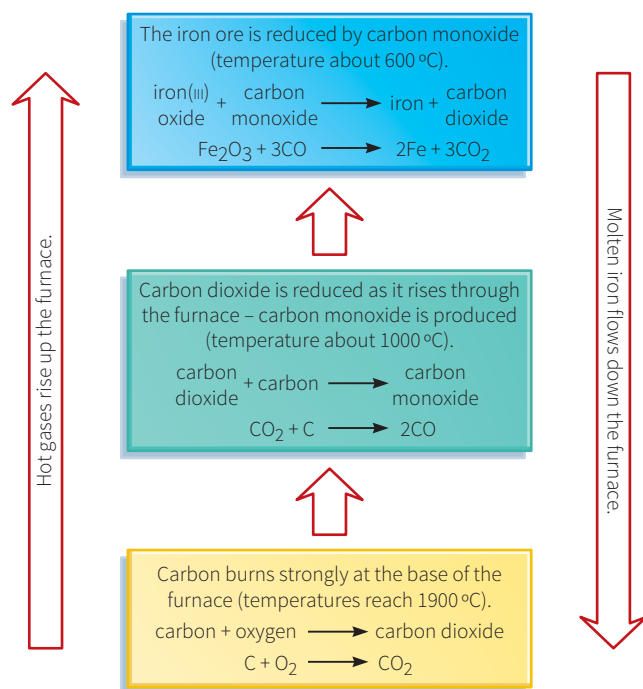


Figure C9.02 Iron is produced in the blast furnace by a series of reactions. Carbon monoxide is thought to be the main reducing agent.

The hot waste gases escape from the top of the furnace. They are used in heat exchangers to heat the incoming air. This helps to reduce the energy costs of the process. The extraction of iron is a continuous process.

The **blast furnace** extraction of iron:

- uses iron ore, coke, limestone and hot air
- involves the reduction of iron(III) oxide by carbon monoxide
- uses limestone to remove the main impurity (sand) as slag (calcium silicate).



TIP

For the blast furnace it is important that you are aware of the different aspects of how it works. You should be able to label a diagram of it and know what is fed into it.

Importantly, you should also know the key reactions of the furnace, including the formation of slag.

Steel-making

The iron produced by the blast furnace is known as 'pig iron' or 'cast iron' and is not pure. It contains about 4% carbon, and other impurities. This amount of carbon makes the iron brittle.

Most of the pig iron produced is taken to make steel. The carbon content is reduced by burning it off as carbon dioxide. This **basic oxygen process** is carried out in a tilting furnace (Figure C9.03). Scrap steel is added to the molten pig iron for recycling. A high-speed jet of oxygen is blown into the vessel through a water-cooled lance. Some impurities, for example silicon and phosphorus, do not produce gaseous oxides, so lime (CaO) is added to the furnace. The impurities form a 'slag', which floats on top of the molten iron. The molten iron is poured off by tilting the furnace. Controlled amounts of other elements such as chromium, manganese, tungsten or other transition metals are added to make different types of steel (see Tables C9.01 and C9.02).

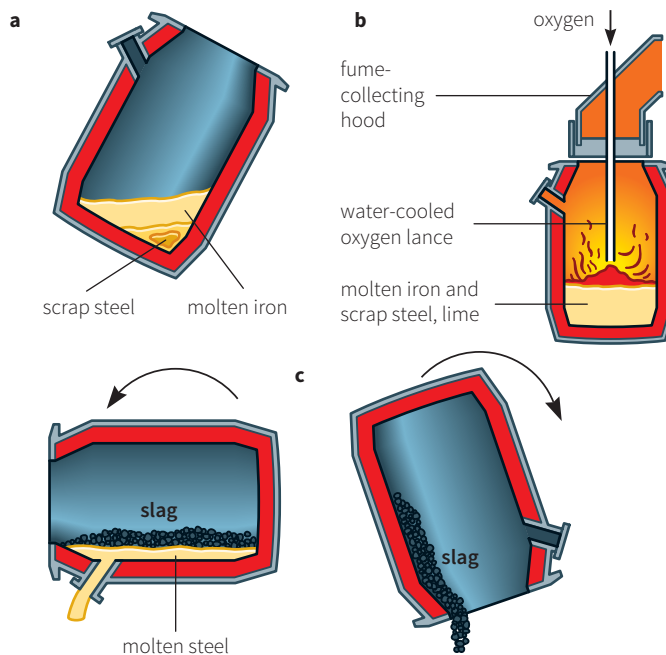


Figure C9.03 The different stages of the steel-making process (the basic oxygen process). **a** The furnace is charged with scrap steel and molten iron. **b** Oxygen is blown in through an 'oxygen lance'. **c** The molten steel, and then the slag, are poured from the furnace by tilting it in different directions.

Metal	Carbon content / %	Properties	Uses
cast iron	2.5–4.5	cheaper than steel; easily moulded	gear boxes, engine blocks, brake discs
mild steel	< 0.25	easily worked; not brittle	car bodies, chains, pylons
medium steel	0.25–0.45	tougher than mild steel	car springs, axles, bridges
high-carbon steel	0.45–1.5	hard and brittle	chisels, cutting tools, razor blades

Table C9.01 Cast iron and carbon steels.

Steel ^(a)	Typical composition		Properties	Uses
stainless steel	iron	74%	tough; does not corrode	cutlery, surgical instruments, kitchen sinks, chemical plant
	chromium	18%		
	nickel	8%		
tungsten steel	iron	95%	tough; hard, even at high temperatures	edges of high-speed cutting tools
	tungsten	5%		
manganese steel	iron	87%	tough; springy	drill bits, springs
	manganese	13%		

^(a)All these alloys have a low content of carbon (< 0.45%).

Table C9.02 Some typical alloy steels.

Carbon steels and alloy steels

There is a wide variety of steels to suit particular applications. Some steels are alloys of iron and carbon only. The amount of carbon in steels can vary between 0.2% and 1.5%. These **carbon steels**, which include the mild steel used for car bodies, are listed in Table C9.01.

But carbon steels tend to rust unless protected. So other metals, for example chromium, are added to prevent corrosion and to make the steel harder. Some of these **alloy steels** are listed in Table C9.02.



TIP

The syllabus very clearly states some examples of the major uses of mild and stainless steel. Make sure that you are aware of these.

The uses of other substances are also explicitly stated in the syllabus – so go through and make a list of these and specifically learn them.

The rusting of iron and its prevention

When a metal is attacked by air, water or other surrounding substances, it is said to **corrode**. In the case of iron and steel, the corrosion process is also known as **rusting**. Rusting is a serious economic problem. Large sums of money are spent each year replacing damaged iron and steel structures, or protecting structures from such damage.

Rust is a red-brown powder consisting mainly of hydrated iron(III) oxide ($\text{Fe}_2\text{O}_3 \cdot x\text{H}_2\text{O}$). Water and oxygen are essential for iron to rust (Figure C9.04).

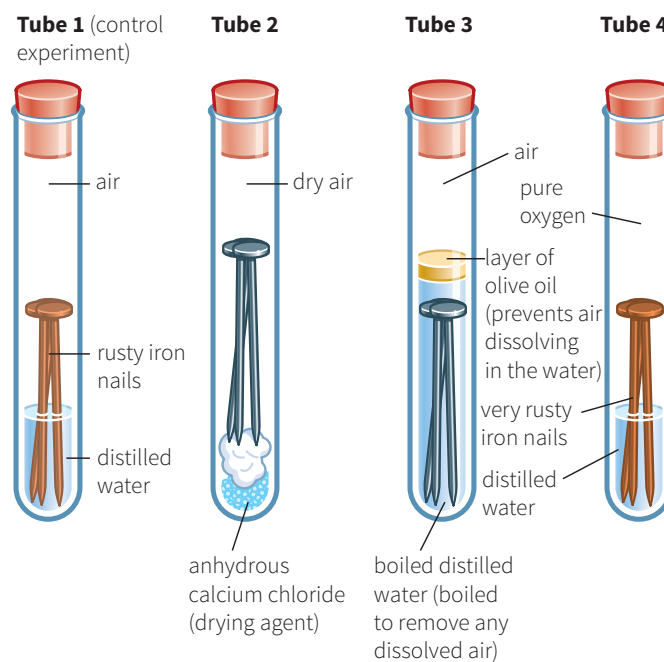


Figure C9.04 The results of an experiment to investigate the factors that are involved in rusting. In tube 2, the air is dry, so the nails do not rust. In tube 3, there is no oxygen in the water, so the nails do not rust. In tube 4, pure oxygen and water are present, so the nails are very rusty.

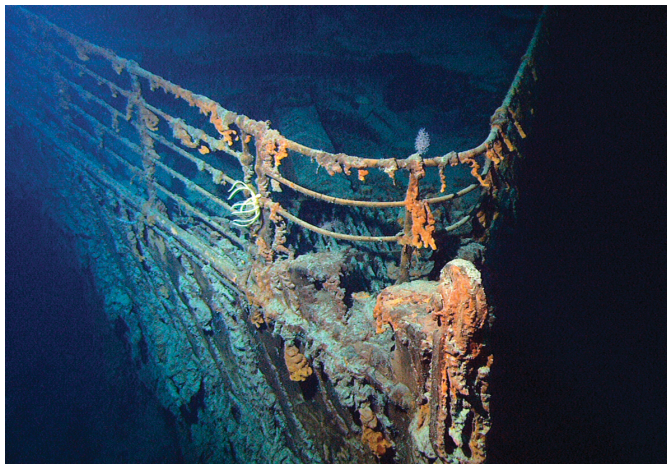


Image C9.02 Photograph of the highly rusted bow of the *Titanic* taken from a submersible.

The problem is made worse by the presence of salt; seawater increases the rate of corrosion. Pictures from the seabed of the wreck of the *Titanic* show that it has a huge amount of rust (see Image C9.02). Acid rain also increases the rate at which iron objects rust.

Aluminium is more reactive than iron, but it does not corrode in the damaging way that iron does. Both metals react with air. In the case of aluminium, a very thin single layer of aluminium oxide forms, which sticks strongly to the surface of the metal. This micro-layer seals the metal surface and protects it from further attack.

In contrast, when iron corrodes, the rust forms in flakes. It does not form a single layer. The attack on the metal can continue over time as the rust flakes come off. Indeed, a sheet of iron can be eaten right through by the rusting process.

Rust prevention

The need to protect iron and steel from rusting has led to many methods being devised. Some of these are outlined here.

- **Painting:** This method is widespread, and is used for objects ranging in size from ships and bridges to garden gates. Painting only protects the metal as long as the paint layer is unscratched. Regular re-painting is often necessary to keep this protection intact.
- **Oiling and greasing:** The oiling and/or greasing of the moving parts of machinery forms a protective

film, preventing rusting. Again, the treatment must be repeated to continue the protection.

- **Plastic coatings:** These are used to form a protective layer on items such as refrigerators and garden chairs. The plastic poly(vinyl chloride), PVC, is often used for this purpose.
- **Electroplating:** An iron or steel object can be electroplated with a layer of chromium or tin to protect against rusting. A 'tin can' is made of steel coated on both sides with a fine layer of tin. Tin is used because it is unreactive and non-toxic. However, this does raise a problem. With both these metals, if the protective layer is broken, then the steel beneath will begin to rust.
- **Galvanising:** An object may be coated with a layer of the more reactive metal, zinc. This is called **galvanising**. It has the advantage over other plating methods in that the protection still works even if the zinc layer is badly scratched.
- **Sacrificial protection:** This is a method of rust prevention in which blocks of a reactive metal are attached to the iron surface. Zinc or magnesium blocks are attached to oil rigs and to the hulls of ships (Figure C9.05). These metals are more reactive than iron and will be corroded in preference to it. Underground gas and water pipes are connected by wire to blocks of magnesium to obtain the same protection. In all cases, an electrochemical cell is set up. The metal blocks lose electrons in preference to the iron and so prevent the iron forming iron(III) oxide.

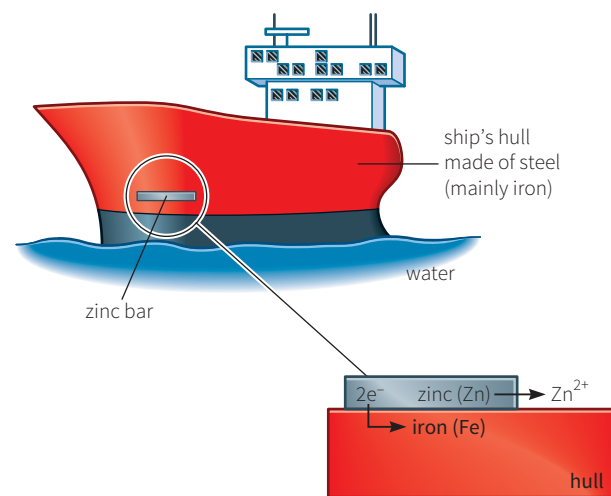


Figure C9.05 Blocks of zinc (or magnesium) are used for the sacrificial protection of the hulls of ships.

ACTIVITY C9.01

 Preventing rusting**Skills:**

AO3.1 Demonstrate knowledge of how to safely use techniques, apparatus and materials (including following a sequence of instructions where appropriate)

AO3.2 Plan experiments and investigations

AO3.3 Make and record observations, measurements and estimates

AO3.4 Interpret and evaluate experimental observations and data

In this activity, iron nails are protected from rusting using a variety of methods, including painting, greasing and sacrificial protection. By using corrosion indicator solution, the effectiveness of the different types of protection can be assessed.

A worksheet, with a self-assessment checklist, is included on the CD-ROM.

The extraction of copper

Copper is less reactive than the other metals we have considered so far. It can be found native in the USA, but most copper is extracted from copper pyrites, CuFeS_2 .

The copper produced from this ore is suitable for piping, boilers and cooking utensils. When it is to be used for

ACTIVITY C9.02

 The extraction of copper and the reactivity series**Skills:**

AO3.1 Demonstrate knowledge of how to safely use techniques, apparatus and materials (including following a sequence of instructions where appropriate)

AO3.3 Make and record observations, measurements and estimates

AO3.4 Interpret and evaluate experimental observations and data

This activity explores the reactivities of copper, hydrogen and carbon using microscale apparatus. The aim is to see whether copper(II) oxide can be reduced to copper by either hydrogen or carbon.

A worksheet is included on the CD-ROM. Details of a scaled-up version of this experiment are given in the Notes on activities for teachers/ technicians.

electrical wiring, it must be refined (purified) by electrolysis (see Section C4.05).

QUESTIONS

- C9.01** Why is limestone added to the blast furnace?
- C9.02** Write an equation for the reduction of iron(III) oxide.
- C9.03** Which element is used to remove the carbon from cast iron?
- C9.04** Why is chromium sometimes added to steel?
- C9.05** Which **two** substances are essential for the rusting of iron?
- C9.06** Give **two** ways in which zinc can be used to stop the rusting of iron.

C9.02 The extraction of metals by electrolysis

Reduction with carbon does not work for more reactive metals. The metals are held in their compounds (oxides or chlorides) by stronger bonds which need a lot of energy to break them. This energy is best supplied by electricity. Extracting metals in this way is a three-stage process:

- mining the ore
- purification of the ore
- electrolysis of the molten ore.

The extraction of a metal by electrolysis is expensive. Energy costs to keep the ore molten and to separate the ions can be very high. Because of this, many of these metals are extracted in regions where hydroelectric power is available. Aluminium plants are the most important examples. They produce sufficient aluminium to make it the second most widely used metal after iron.

The extraction of aluminium

Bauxite, the major ore of aluminium, takes its name from the mediaeval village of Les Baux in France, where it was first mined. Napoleon III saw its possibilities for military purposes and ordered studies on its commercial production. A method of extraction using sodium to displace aluminium from aluminium chloride existed at that time. However, in 1886, the Hall–Héroult electrolytic method for extracting aluminium was invented by Hall (an American) and Héroult (a Frenchman).



Image C9.03 The major ore of aluminium is bauxite. It is usually mixed with iron(III) oxide, which gives the ore its brown colour.

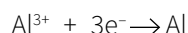
The Hall–Héroult process

Bauxite (Image C9.03) is an impure form of aluminium oxide. Up to 25% of bauxite consists of the impurities iron(III) oxide and sand. The iron(III) oxide gives it a red-brown colour.

The Hall–Héroult process involves the following stages.

- 1 The bauxite is treated with sodium hydroxide to obtain pure aluminium oxide (alumina). The alumina produced is shipped to the electrolysis plant.
- 2 The purified aluminium oxide (Al_2O_3) is dissolved in molten cryolite (sodium aluminium fluoride, Na_3AlF_6). Cryolite is a mineral found naturally in Greenland. It is no longer mined commercially there, and all the cryolite now used is made synthetically. Cryolite is used to lower the working temperature of the electrolytic cell. The melting point of aluminium oxide is 2030°C . This is reduced to $900\text{--}1000^\circ\text{C}$ by dissolving it in cryolite. The cryolite thus provides a considerable saving in energy costs.
- 3 The molten mixture of aluminium oxide and cryolite is electrolysed in a cell fitted with graphite electrodes (Figure C9.06).

Aluminium ions are attracted to the cathode where they are discharged to form liquid aluminium metal:



Oxide ions are attracted to the anode where they are discharged to form oxygen gas. At the high temperature of

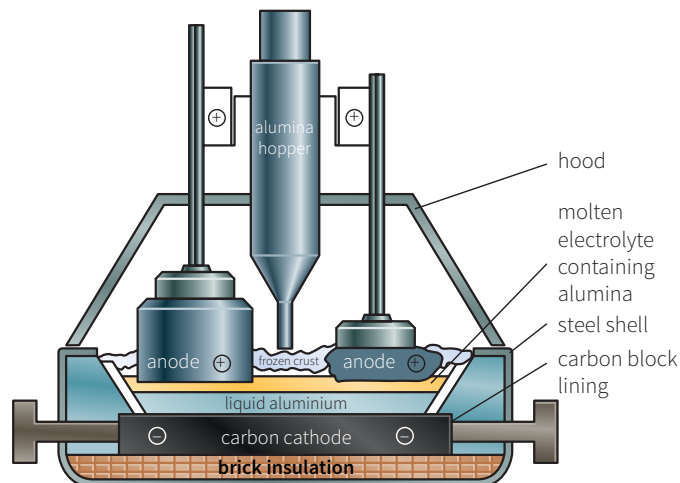


Figure C9.06 A cross-section of the electrolytic cell for extracting aluminium. At the cathode: $\text{Al}^{3+} + 3\text{e}^- \rightarrow \text{Al}$. At the anode: $2\text{O}^{2-} \rightarrow \text{O}_2 + 4\text{e}^-$.

the cell this reacts with the carbon of the anode to form carbon dioxide:



The anodes burn away and have to be replaced regularly.

The Hall–Héroult process uses a great deal of energy. It is also costly to replace the anodes, which are burnt away during the process. It is much cheaper to recycle the metal than to manufacture it. The energy requirement for recycling is about 5% of that needed to manufacture the same amount of 'new' metal.

Electroplating and copper refining

When electrolytic cells are set up with appropriate metal electrodes, metal can be effectively transferred from the anode to the cathode. Such methods can be used to plate objects with metals such as chromium or tin, or to refine copper to a very high degree of purity.

QUESTIONS

- C9.07** Why is aluminium expensive to extract?
- C9.08** Why is cryolite added to the cell as well as alumina?
- C9.09** Why do the anodes need replacing regularly?
- C9.10** Write an equation for the reaction at the cathode.
- C9.11** Aluminium is a reactive metal. Why, then, is it useful for window frames and aircraft?

C9.03 Ammonia and fertilisers

Ammonia has the following general properties as a gas:

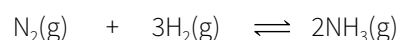
- colourless
- distinctive smell
- less dense than air
- very soluble in water to give an alkaline solution.

As a raw material for both fertilisers and explosives, ammonia played a large part in human history. It helped to feed a growing population in peacetime, and it was used to manufacture explosives in wartime.

Nitrogen is an unreactive gas, and changing it into compounds useful for plant growth (**nitrogen fixation**)

is important for agriculture. Most plants cannot directly use (or **fix**) nitrogen from the air. The main purpose of industrial manufacture of ammonia is to make agricultural fertilisers.

In the Haber process (Figure C9.07), nitrogen and hydrogen are directly combined to form ammonia:



Nitrogen is obtained from air, and hydrogen from natural gas by reaction with steam. The two gases are mixed in a 1 : 3 ratio and compressed to 200 atmospheres. They are then passed over a series of catalyst beds containing finely divided iron. The temperature of the converter is about 450 °C. The reaction is reversible and does not go to completion. A mixture of nitrogen, hydrogen and ammonia leaves the converter. The proportion of

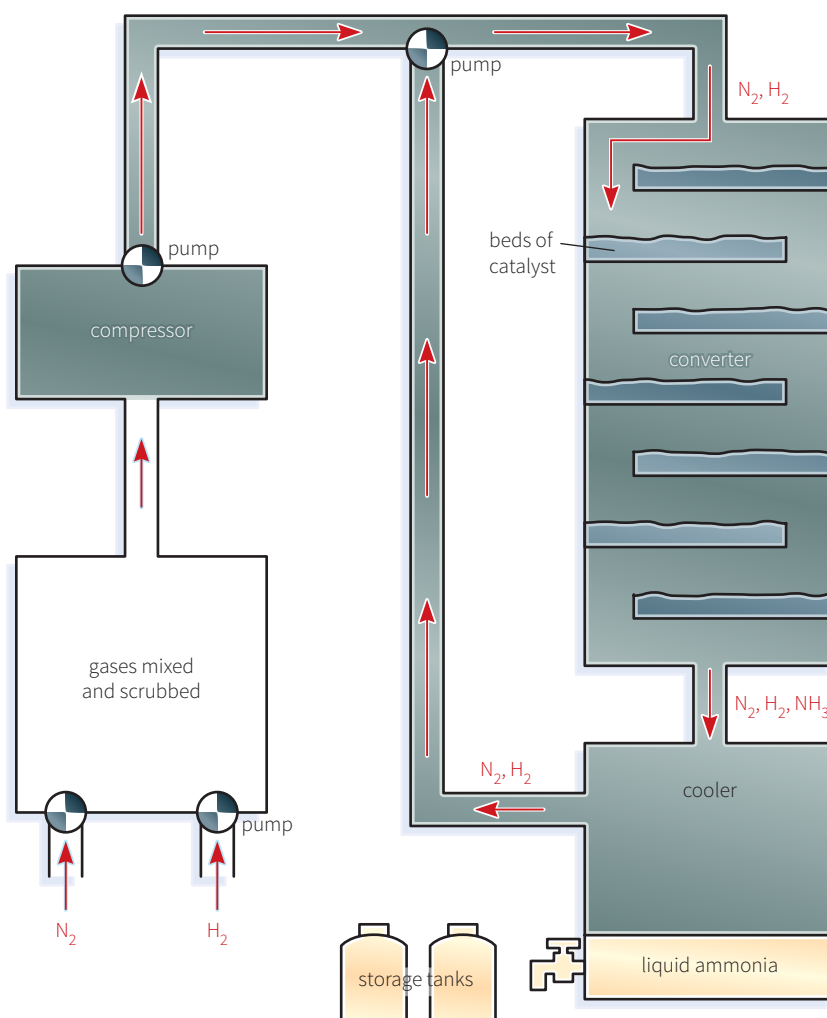


Figure C9.07 A schematic drawing of the different stages of the Haber process. Nitrogen and hydrogen are mixed in a ratio of 1 : 3 at the start of the process.

ammonia in the mixture is about 15%. This is separated from the other gases by cooling the mixture. Ammonia has a much higher boiling point than nitrogen or hydrogen, so it condenses easily. The unchanged nitrogen and hydrogen gases are re-circulated over the catalyst. By re-circulating in this way, an eventual yield of 98% can be achieved. The ammonia produced is stored as a liquid under pressure.

**TIP**

For the Haber process, and the Contact process for making sulfuric acid, it is important that you know the conditions used and how these are chosen. Remember these are both reversible reactions that reach an equilibrium under the conditions used (see Section C7.05).

Most of the ammonia produced is used to manufacture **fertilisers**. Liquid ammonia itself can in fact be used directly as a fertiliser, but it is an unpleasant liquid to handle and to transport. The majority is converted into a variety of solid fertilisers. A substantial amount of ammonia is converted into nitric acid by oxidation (Figure C9.08).

Ammonium nitrate and other fertilisers

Ammonium nitrate ('Nitram') is the most important of the nitrogenous fertilisers. It contains 35% by mass of nitrogen. It is produced when ammonia solution reacts with nitric acid:

ammonia + nitric acid → ammonium nitrate

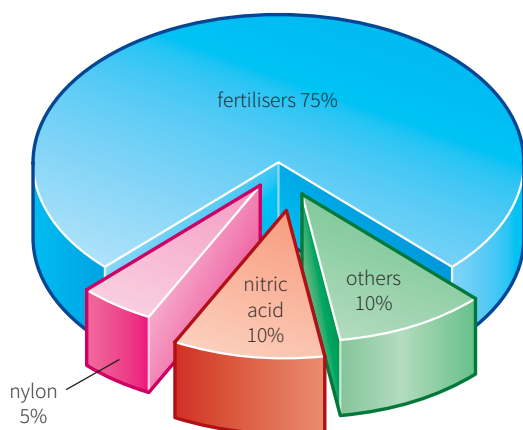
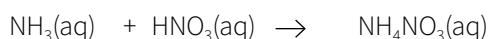


Figure C9.08 The uses of ammonia produced by the Haber process.

The ammonium nitrate can be crystallised into pellet form suitable for spreading on the land.

Ammonium nitrate is soluble in water, as are all other ammonium salts, for example ammonium sulfate, $(\text{NH}_4)_2\text{SO}_4$. This solubility is important because plants need soluble nitrogen compounds that they can take up through their roots. There are two types of nitrogen compounds that plants can use – ammonium compounds (which contain the NH_4^+ ion) and nitrates (which contain the NO_3^- ion). Ammonium nitrate provides these ions.

Ammonium salts tend to make the soil slightly acidic. To overcome this, they can be mixed with chalk (calcium carbonate), which will neutralise this effect. 'Nitro-chalk' is an example of a **compound fertiliser**.

A modern fertiliser factory will produce two main types of product:


- **straight N fertilisers** are solid nitrogen-containing fertilisers sold in pellet form, for example ammonium nitrate (NH_4NO_3), ammonium sulfate ($(\text{NH}_4)_2\text{SO}_4$) and urea ($\text{CO}(\text{NH}_2)_2$)
- **NPK compound fertilisers** (Image C9.04) are mixtures that supply the three most essential elements lost from the soil by extensive use, namely nitrogen (N), phosphorus (P) and potassium (K). They are usually a mixture of ammonium nitrate, ammonium phosphate and potassium chloride, in different proportions to suit different conditions.

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Image C9.04 Some fertiliser products; note the three key numbers (N : P : K) on the fertiliser bags.

ACTIVITY C9.03

 Making a fertiliser

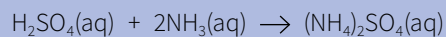
Skills:

AO3.1 Demonstrate knowledge of how to safely use techniques, apparatus and materials (including following a sequence of instructions where appropriate)

AO3.3 Make and record observations, measurements and estimates

AO3.4 Interpret and evaluate experimental observations and data

The introduction of the Haber process revolutionised agriculture by making it possible to manufacture artificial fertilisers. An example is ammonium sulfate and it is made in this activity by neutralising sulfuric acid with ammonia solution:



The ammonium sulfate solution can be concentrated by heating. It is then cooled to allow crystals to form.

A worksheet is included on the accompanying CD-ROM.

QUESTIONS

- C9.12** How is hydrogen obtained for use in the Haber process?
- C9.13** What conditions are needed to ensure the Haber process works efficiently?
- C9.14** Why are the unreacted gases re-circulated?
- C9.15** Why do many fertilisers contain N, P and K?
- C9.16** How can fertilisers cause pollution?

C9.04 Sulfur and sulfuric acid

Sulfuric acid is a major product of the chemical industry. It is made from sulfur by the Contact process.

Sulfur is burnt in air to form sulfur dioxide. The main reaction in the Contact process (Figure C9.09a) is the one in which sulfur dioxide and oxygen combine to form sulfur trioxide. This reaction is reversible. The conditions needed to give the best equilibrium position are carefully considered. A temperature of 450 °C and 1–2 atmospheres pressure are used. The gases are passed over a catalyst of vanadium(V) oxide. A yield of 98% sulfur trioxide is achieved.

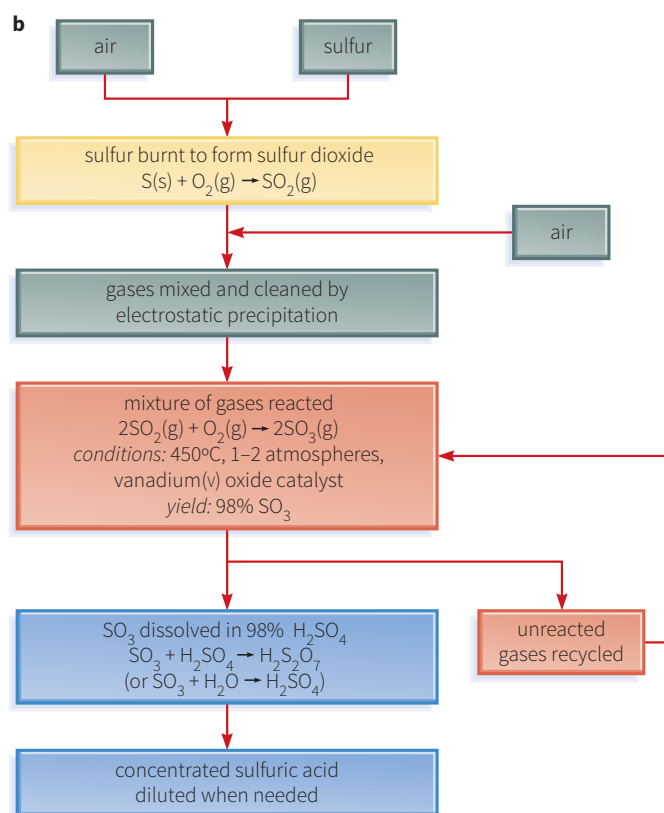


Figure C9.09 **a** The Contact process plant at Billingham, Teesside, in the UK. **b** A flow chart for making sulfuric acid by this process.

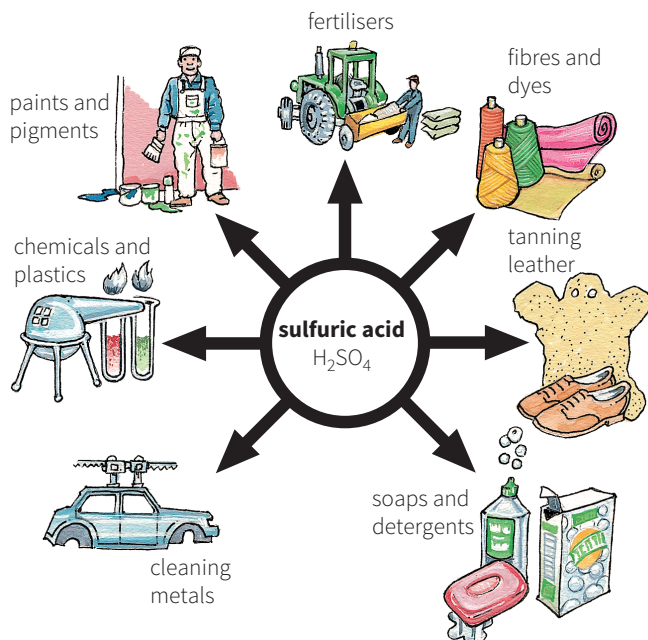


Figure C9.10 The uses of sulfuric acid.

The overall process is summarised in the flow chart shown in Figure C9.09b.

The sulfur trioxide produced is dissolved in 98% sulfuric acid, and not water, in order to prevent environmental problems of an acid mist which is formed if sulfur trioxide is reacted directly with water. The reaction between sulfur trioxide and water is extremely exothermic. The solution formed means that the acid can be transported in concentrated form (98.5% acid, sometimes known as **oleum**) and then diluted on-site.

Sulfuric acid is important for the fertiliser industry because it is needed to make ammonium sulfate and phosphoric acid. Figure C9.10 summarises the various uses of sulfuric acid.

QUESTIONS

- C9.17** Write an equation for the burning of sulfur.
- C9.18** What conditions are needed to convert sulfur dioxide into sulfur trioxide?
- C9.19** Why is sulfur trioxide not reacted with water to make sulfuric acid?

C9.05 The chlor-alkali industry

The chlor-alkali industry is a major branch of the chemical industry that has been built up around a single electrolysis reaction. The industry is centred around the electrolysis of concentrated sodium chloride solution (**brine**).

In this process, chlorine is produced at the anode (positive electrode) and hydrogen is produced at the cathode (negative electrode). Sodium ions from the sodium chloride and hydroxide ions from the water are left behind as sodium hydroxide. All three products are useful; their uses are summarised in Figure C9.11.

In Britain, the industry has developed around the Cheshire salt deposits. In this region, salt is brought to the surface by both underground mining and solution mining. One factory in Cheshire uses 1% of the entire UK electricity output just to electrolyse brine.

We have seen earlier in Chapter C1 that chlorine is used on a large scale in producing a clean domestic water supply. You will probably also be familiar with its similar use in killing microbial organisms in swimming pools. Chlorine has a wide range of other uses in industry.

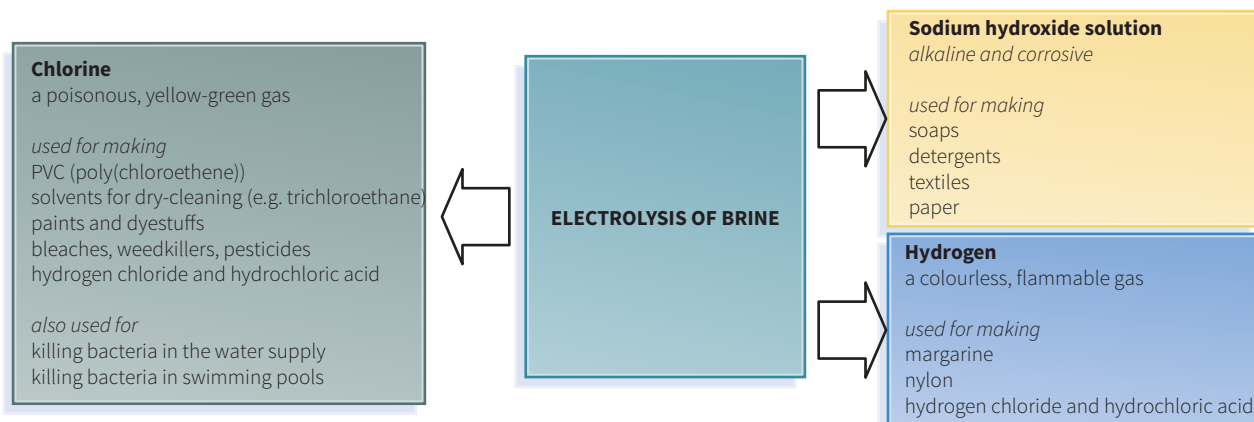


Figure C9.11 The chlor-alkali industry.

QUESTIONS

- C9.20** What is brine?
- C9.21** Why is the electrolysis of brine such an important process?

C9.06 Limestone

Limestone is quarried (Image C9.05) in large amounts world-wide. It has a wide range of uses. In some of these, the limestone is used directly; in others, it acts as a raw material for making other compounds.

Direct uses of limestone

Powdered limestone is often used to neutralise acid soils and lakes acidified by acid rain. It is cheaper than using lime (calcium oxide), which has to be produced by heating limestone. In the blast furnace for the extraction of iron, limestone is used to remove impurities found in the iron ore as slag (calcium silicate).

Cement is made by heating powdered limestone with clay in a rotary kiln (Figure C9.12).

Concrete is a mixture of cement and aggregate (stone chippings and gravel), which give it body. The mixture is mixed with water and can be poured into wooden moulds. It is then allowed to harden. Reinforced concrete is made by allowing the concrete to set around steel rods or mesh (Image C9.06).



Image C9.05 A limestone quarry in Maizeret, Belgium.

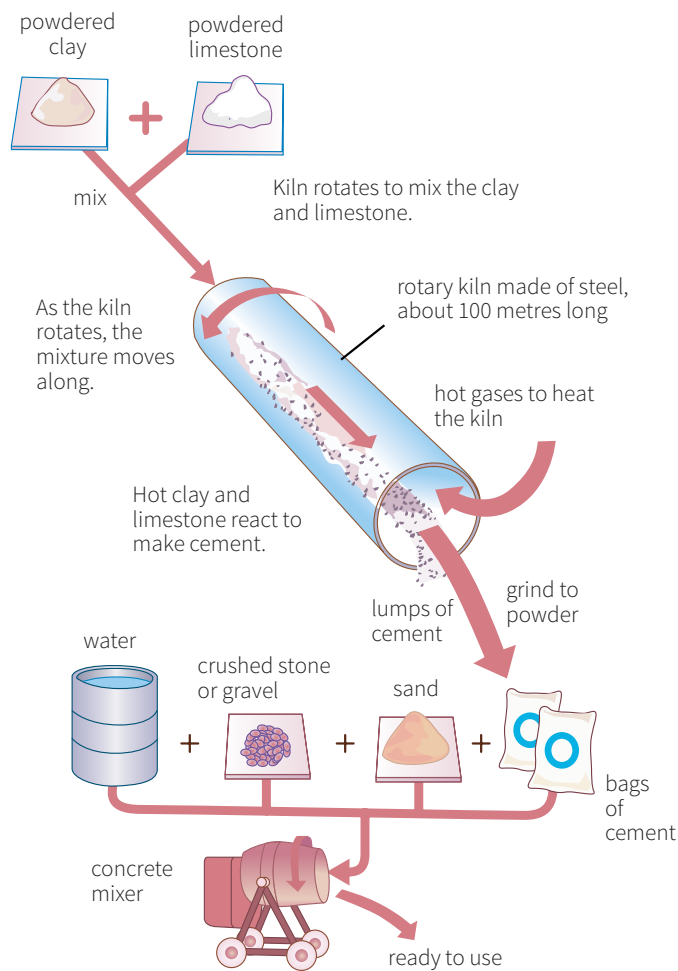


Figure C9.12 Limestone is used to make cement.



Image C9.06 Construction workers using a pump to lay concrete around a mesh of metal rods. The rods will strengthen this reinforced concrete.

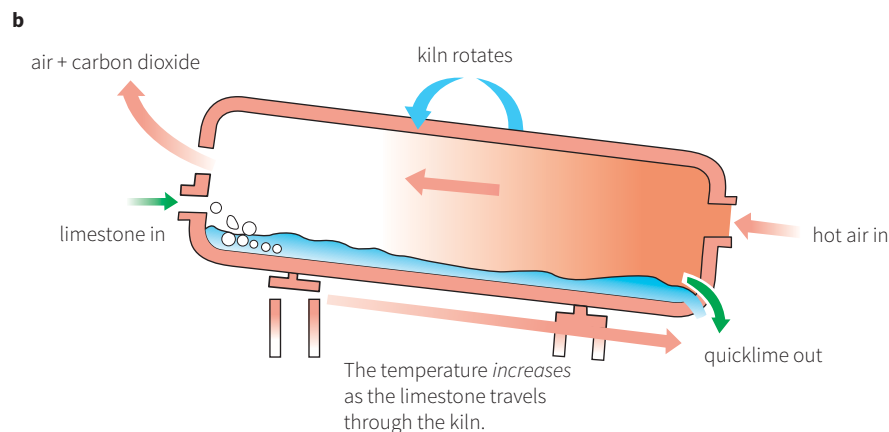
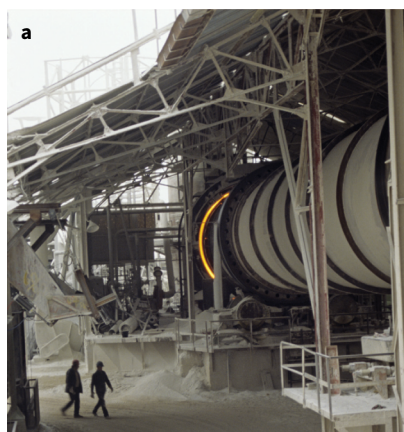
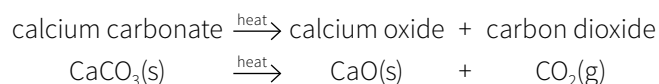


Figure C9.13 a A functioning rotary lime kiln in Belgium. Note the heated glow at the far end of the kiln.

b A diagram of a rotary kiln.

The manufacture of lime (calcium oxide)

Lime (quicklime) is calcium oxide and is produced by roasting limestone in a lime kiln (Figure C9.13). The limestone is decomposed by heat:



Lime is used in agriculture to neutralise acid soils. It is used with sodium carbonate and sand in making glass. Large amounts of lime are converted into slaked lime (hydrated lime), which is calcium hydroxide ($\text{Ca}(\text{OH})_2$). Equal amounts of lime and water are mixed to produce this material.



TIP

Remember that the reaction involved in the production of lime is an example of **thermal decomposition**. The calcium carbonate is not reacting with anything else. It is breaking up into simpler substances because of the high temperature. When you write the equation, do not try to include anything else on the left-hand side of the equation.

QUESTIONS

- C9.22** Why is limestone sometimes added to lakes?
C9.23 How is limestone used in iron production?
C9.24 Write an equation for the thermal decomposition of limestone.
C9.25 Write the chemical formula of slaked lime.
C9.26 Give **two** important uses of lime.

C9.07 Recycling metals

Recycling used substances is good for three reasons:

- it conserves the raw materials which the substances were made from
- it often uses less energy to recycle something than would be needed to make it from raw materials
- it avoids the need to bury the substances in landfill sites, possibly causing pollution.

Many metals can be recycled. Those most commonly recycled are aluminium and steel.

Aluminium

This metal is the ideal candidate for recycling because it costs so much to extract it from its ore. Using recycled aluminium saves 95% of the energy needed to make new aluminium. Recycling one aluminium can saves enough energy to run a television for 3 hours. Around 60% of the aluminium used in the UK and 50% worldwide is recycled.



(aluminium)

Steel

Steel, too, is cheaper to recycle than to make from scratch but the difference in cost is not as great as for aluminium. However, steel is easy to recycle because it is magnetic and so can easily be separated from other rubbish. For this reason, quite a lot of steel is recycled.



(steel)

QUESTIONS

C9.27 Why is the recycling of aluminium the most profitable type of recycling?

C9.28 Saving energy is one reason for recycling. What other reasons are there?

Summary

You should know:

- the chemistry involved in the production of iron and steel
 - the reduction of iron ore (hematite) in the blast furnace
 - the production of mild steel by the basic oxygen process
 - the uses of different types of steel alloys
 - the problem of the rusting of iron and steel structures
 - barrier methods of preventing the rusting of iron and steel
 - the use of sacrificial protection to prevent rusting
- how the extraction of other metals is linked to their reactivity
 - the extraction of aluminium from its ore (bauxite) by electrolysis
 - the protective oxide layer which prevents the corrosion of aluminium
- chemistry involved in the production of ammonia by the Haber process
 - the use of ammonia in the manufacture of fertilisers
 - the importance of NPK (nitrogen, phosphorus and potassium) fertilisers
- the chemistry involved in the production of sulfuric acid
- how the electrolysis of brine forms useful products
- about the importance of limestone as a raw material
 - the production of lime in a lime kiln
 - the uses of lime and slaked lime
 - the use of limestone in iron production and to make cement
- the advantages of recycling.

End-of-chapter questions

- 1 Apart from saving money, why is it important to recycle as many substances as possible?
- 2 A farmer uses slaked lime ($\text{Ca}(\text{OH})_2$) and ammonium sulfate to increase the fertility of his fields.
 - a What type of soil might the farmer use lime on? [1]
 - b Which essential element will ammonium sulfate add to the soil? [1]
 - c What reaction could take place between slaked lime and ammonium sulfate? [2]

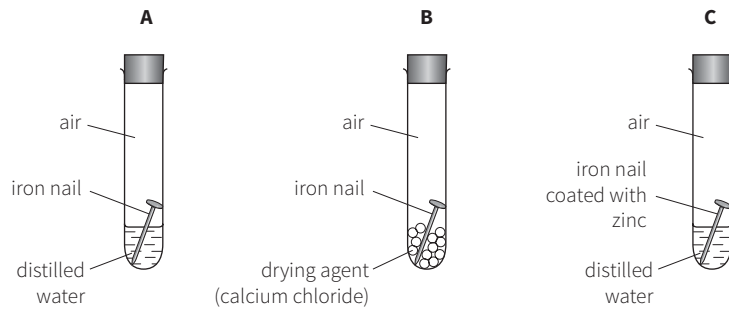
Lime (CaO) is manufactured from limestone by heating it strongly.

 - d What is the chemical formula of limestone? [1]
 - e Write a symbol equation for the reaction which occurs when limestone is changed to lime. [2]
 - f How is lime changed into slaked lime? [1]

Ammonium sulfate is manufactured by reacting ammonia with sulfuric acid. Ammonia is manufactured by the Haber process and sulfuric acid by the Contact process.

 - g Write an equation for the main reaction in the Haber process and give the conditions used. [4]
 - h Write an equation for the main reaction in the Contact process and give the conditions used. [4]

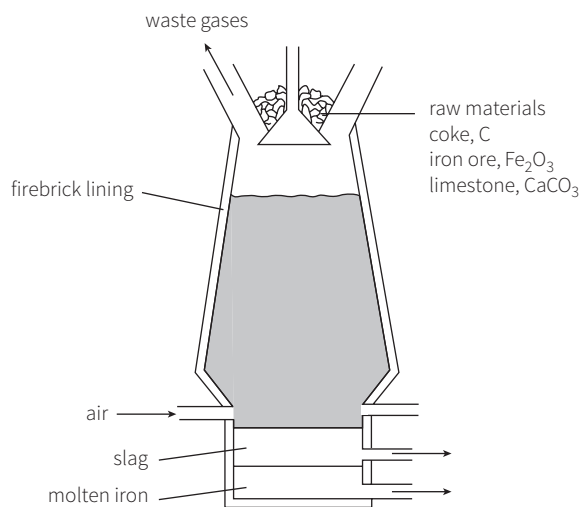
3 The diagram shows an experiment to investigate the rusting of some iron nails.



- a** For each tube, A, B and C, predict whether the nails will rust. In each case give a reason. [3]
b Iron from the blast furnace contains impurities such as carbon, phosphorus, silicon and sulfur. Describe how the level of these impurities is decreased when steel is made from impure iron. [3]
c State a use for stainless steel. [1]

[Cambridge IGCSE Chemistry 0620 Paper 2 Q7 a, b & c November 2009]

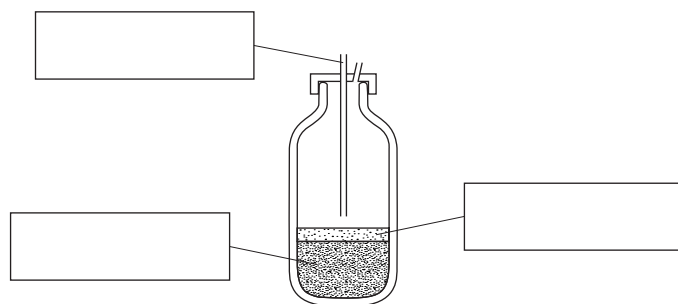
4 Iron is extracted from its ore, hematite, in the blast furnace.



Describe the reactions involved in this extraction. Include in your description an equation for a redox reaction and one for an acid/base reaction. [5]

[Cambridge IGCSE Chemistry 0620 Paper 32 Q4 June 2011]

- 5 The diagram shows a basic oxygen converter. This is used to convert impure iron from the blast furnace into steel. During this process, some of the impurities in the iron are converted into a slag.



- a Label a copy of the diagram to show each of the following:

- i where the oxygen enters
- ii the slag
- iii the molten steel.

[3]

- b In the converter, the oxygen oxidises sulfur, carbon and phosphorus to their oxides.

- i Explain why sulfur dioxide and carbon dioxide are easily removed from the converter.
- ii Explain how calcium oxide is used to remove phosphorus(v) oxide from the converter.

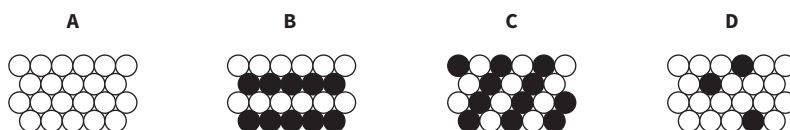
[1]

[3]

- c Stainless steel is an alloy.

- i Which one of the diagrams, A, B, C or D, best represents an alloy?

[1]

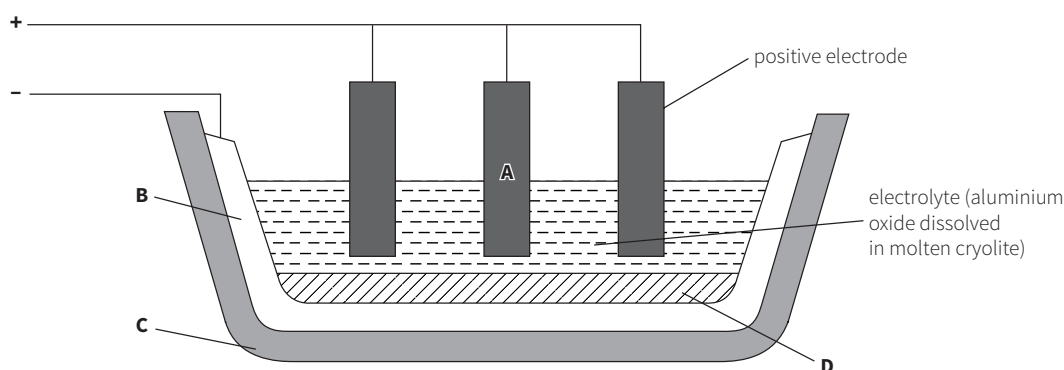


- ii State **one** use of stainless steel.

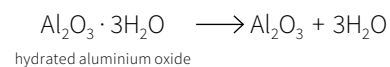
[1]

[Cambridge IGCSE Chemistry 0620 Paper 21 Q7 June 2011]

- 6 Aluminium is extracted by the electrolysis of aluminium oxide.



- a Hydrated aluminium oxide is heated to produce pure aluminium oxide.



What type of reaction is this? Choose from these possibilities:

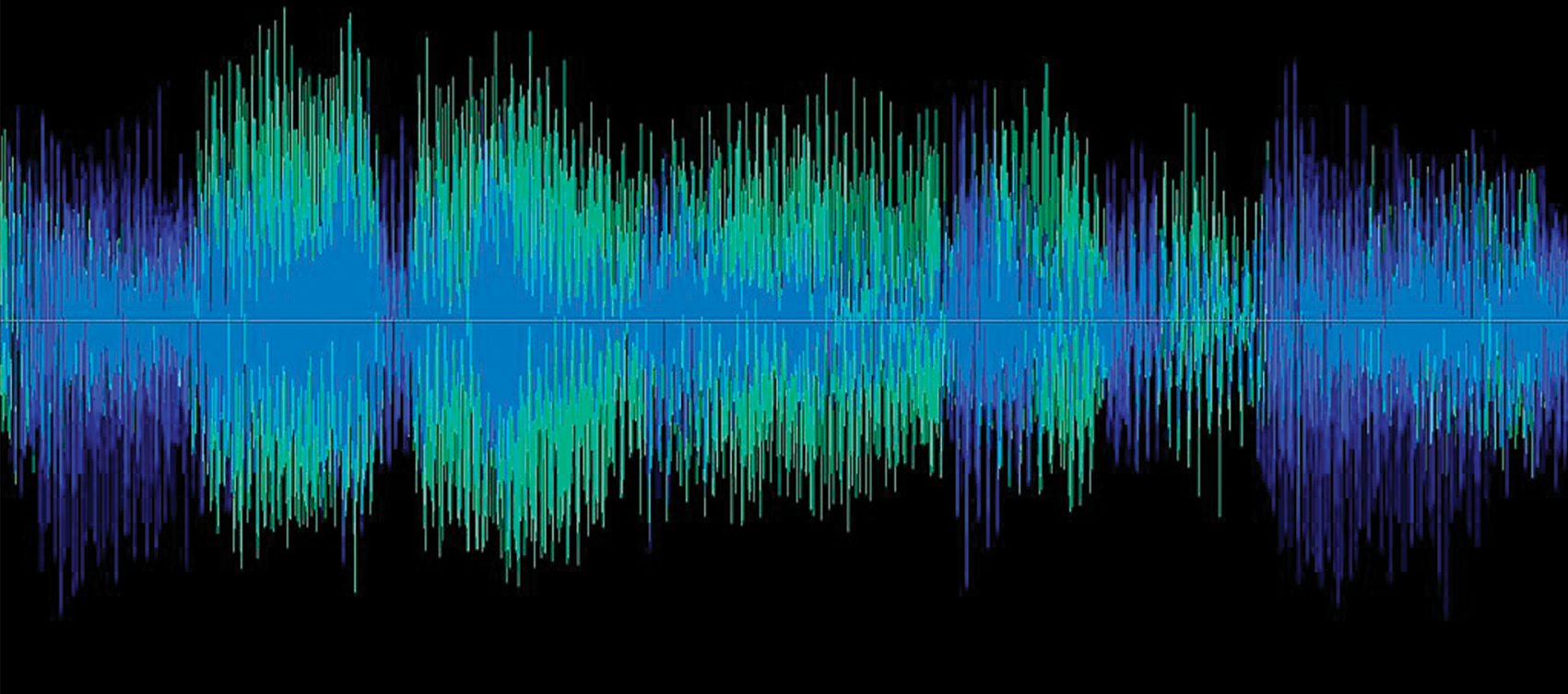
decomposition neutralisation oxidation reduction

[1]

- b** Explain why the electrolyte must be molten for electrolysis to occur. [1]
- c** What is the purpose of the cryolite? [1]
- d** Which letter in the diagram, A, B, C or D, represents the cathode? [1]
- e** State the name of the products formed at the anode and cathode during this electrolysis. [2]
- f** Why do the anodes have to be renewed periodically? [2]
- g** Complete the equation for the formation of aluminium from aluminium ions.
 $\text{Al}^{3+} + \dots\dots\dots \text{e}^{-} \longrightarrow \text{Al}$ [1]
- h** State one use of aluminium. [1]

[Cambridge IGCSE Chemistry 0620 Paper 2 Q6 November 2009]

- 7** The blast furnace is the industrial method for extracting iron from ores containing iron oxide.
- a** In this extraction, oxygen is removed from the iron oxide to produce the metal.
- i** State the name given to this type of reaction that removes oxygen. [1]
- ii** Which gaseous substance converts the iron oxide to iron in the furnace? [1]
- iii** What are the raw material(s) used by the furnace to supply this gaseous substance? [1]
- b** The temperature at the centre of a blast furnace can reach 1300 °C.
Copper can be extracted from copper oxide in the laboratory at a lower temperature than this.
Explain why the extraction of copper from copper oxide needs less energy than is needed in the extraction of iron from iron oxide. [2]
- c** The molten iron that collects at the base of the furnace contains silicon dioxide as an impurity.
Explain how this silicon dioxide is removed from the molten iron in the blast furnace. [3]



P12

Sound

530

This chapter covers:

- how sounds are produced and detected
- how to measure the speed of sound
- how pitch and loudness are related to frequency and amplitude
- the longitudinal nature of sound waves
- how sound travels
- the speed of sound in different materials.

P12.01 Making sounds

Different musical instruments produce sounds in different ways.

- *Stringed instruments.* The strings are plucked or bowed to make them vibrate. In most stringed instruments, the vibrations are transmitted to the body of the instrument, which also vibrates, along with the air inside it. The vibrations may be too small or too fast to see, but they can be shown up using laser techniques (see Image P12.01).
- *Wind instruments.* The ‘air column’ inside the instrument is made to vibrate, by blowing across the end of or into the tube (Image P12.02). The smallest instruments have a straight air column. Bigger instruments capable of playing deeper notes (such as a horn or tuba) have an

air column that is bent around so that the instrument is not inconveniently long. Some instruments have a reed in the mouthpiece. This vibrates as the player blows across it, causing the air to vibrate.

- *Percussion instruments.* These instruments are played by striking them (Image P12.03). This produces vibrations – of the keys of a xylophone, the skin of a drum, or the metal body of a gong, for example.

In each case, part (or all) of the instrument is made to vibrate. This causes the air nearby to vibrate, and the *vibrations* travel through the air to the audience’s ears. Some vibrations also reach us through the ground, so that they make our whole body vibrate (see Image P12.03). If you sit close to a loud band or orchestra, you may feel your whole body vibrating in response to the music.



Image P12.01 Although the player only touches the strings of a guitar, the instrument's whole body vibrates to produce the notes we hear. This is shown up in this image, produced by shining laser light onto the guitar. Different notes produce different patterns of vibration, and this helps to give each note its particular quality.



Image P12.02 Two recorders can look very similar, but the lower one is made of wood and the other of plastic. A flute may be made of wood or metal. This tells us that it is not the material that the instrument is made of that matters. It is the air inside that vibrates to produce the desired note. Blowing into the instrument causes the air column inside it to vibrate, and the vibrations are transferred to the air outside.



Image P12.03 Evelyn Glennie is one of the world's top solo percussionists, despite the fact that she is deaf. She has trained herself to be sensitive to vibrations that reach her body through the ground. This allows her to follow the rhythm of a piece of music, as well as to detect the subtle differences in tone between different percussion instruments.

Sounds travel through the air as vibrations. These vibrations can travel through any material – through the solid ground, through the glass panes of a window, through water. If you put a battery-powered radio on the side of the bath and submerge your ears, you will hear the sounds from the radio travelling through the solid bath and the liquid water to your ears.

When the vibrations reach your ear, they cause the eardrum to vibrate. The vibrations are transmitted inwards to the inner ear where they are converted into electrical signals which pass to the brain. A microphone works in a similar way. Sound vibrations cause part of the microphone to vibrate, and these vibrations are converted to a varying electrical current which has the same pattern as the vibrations of the sound.

QUESTIONS

- P12.01** Which of the following materials can sound travel through: wood, air, water?
- P12.02** When a woodwind instrument such as a flute produces a note, what part of it vibrates?

P12.02 At the speed of sound

The speed of sound in air is about 330 m/s, or 1200 km/h. That is about ten times the speed of cars on a major highway. When someone speaks, it seems to us that we hear the sound they make as soon as they make it. However, it takes a small amount of time to reach our ears. For example, if we are speaking to someone who is just 1 m away, the time for sounds to travel between us is:

$$\frac{1 \text{ m}}{330 \text{ m/s}} = 0.003 \text{ s} = 3 \text{ ms (3 milliseconds)}$$

This is far too short a time for us to notice.

However, there are occasions when we may notice the time it takes for sounds to travel. For example, imagine that you shout at a distance from a long high wall or cliff.

After you shout, you may hear an *echo*. The sound has reflected from the hard surface and back to your ears (see Figure P12.01). Worked example P12.01 shows how to calculate the time it takes for the sound to travel to a wall and back again.

If you watch people playing a game such as cricket or baseball, you may notice a related effect. You see someone hitting a ball. A split second later you hear the sound of the ball being struck. The time interval between seeing the hit and hearing it occurs because the sound travels relatively slowly to your ears, while the light travels very quickly to your eyes. So the light reaches you first, and you see before you hear. When cricket matches are televised, they may use a microphone buried in the pitch to pick up the sounds of the game, so that there is no noticeable gap between what you see and what you hear.

For the same reason, we usually see a flash of lightning before we hear the accompanying roll of thunder. Count the seconds between the flash and the bang. Then divide this by three to find how far away the lightning is, in kilometres. This works because the sound takes roughly 3 s to travel 1 km, whereas the light travels the same distance in a few microseconds.



TIP

It is useful to remember that sound travels 1 km in about 3 s.

WORKED EXAMPLE P12.01

A man shouts loudly close to a high wall (see Figure P12.01). He hears one echo. If the man is 40 m from the wall, how long after the shout will the echo be heard? (Speed of sound in air = 330 m/s.)

Step 1: Calculate the distance travelled by the sound.
This is twice the distance from the man to the wall (since the sound travels there and back).

$$\text{distance travelled by sound} = 2 \times 40 \text{ m} = 80 \text{ m}$$

Step 2: Calculate the time taken for the sound to travel this distance.

$$\begin{aligned} \text{time taken} &= \frac{\text{distance}}{\text{speed}} \\ &= \frac{80 \text{ m}}{330 \text{ m/s}} = 0.24 \text{ s} \end{aligned}$$

So the man hears the echo 0.24 s (about a quarter of a second) after his shout.

Measuring the speed of sound

One way to measure the speed of sound in the lab is to find out how long a sound takes to travel a measured distance, just as you might measure the speed of a moving car or cyclist. Since sound travels at a high speed, you need to be able to measure short time intervals. Figure P12.02 shows one method.

When the student bangs the two blocks of wood together, it creates a sudden, loud sound. The sound reaches one microphone, and a pulse of electric current travels to the timer. The timer starts running. A fraction of a second later, the sound reaches the second microphone.

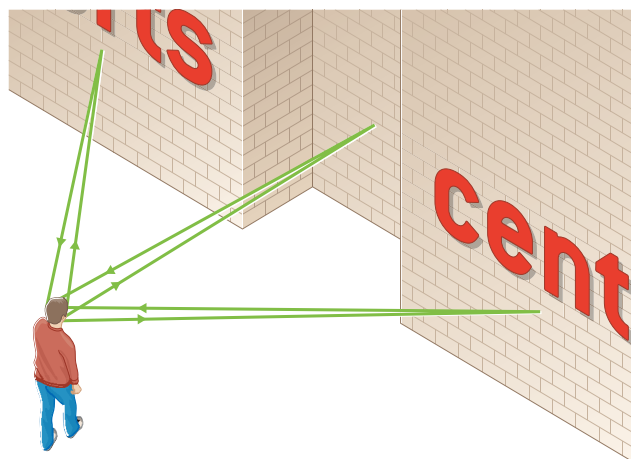


Figure P12.01 An echo is heard when a sound reflects off a hard surface such as a large wall. Sound travels outwards from the source, and bounces off the wall. Some of it will return to the source. If there are several reflecting surfaces, several echoes may be heard.

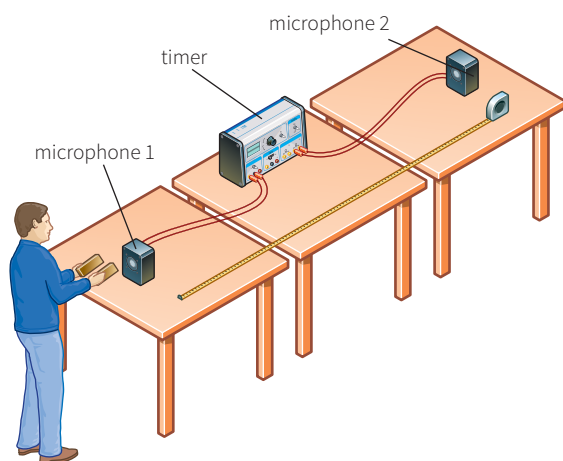


Figure P12.02 A 'time-of-flight' method for measuring the speed of sound. The wooden blocks and the two microphones are arranged in a straight line. The bang from the blocks is picked up first by microphone 1 and then by microphone 2. The first activates the timer, and the second stops it. The speed of sound is calculated from the distance between the two microphones and the time taken by the sound to travel between them.

A second pulse of current stops the timer. Now the timer indicates the time taken for the sound to travel from one microphone to the other.

It is important that the two microphones should be a reasonable distance apart – say, three or four metres. The further apart the better, since this will give a longer 'time of flight' for the sound to travel from one microphone to the other.

ACTIVITY P12.01

Measuring the speed of sound in air

Skills:

- A03.1** Demonstrate knowledge of how to safely use techniques, apparatus and materials (including following a sequence of instructions where appropriate)
- A03.3** Make and record observations, measurements and estimates
- A03.4** Interpret and evaluate experimental observations and data
- A03.5** Evaluate methods and suggest possible improvements

Use echoes to help you to measure the speed of sound in air.

This experiment must be performed out of doors. You need a large reflecting surface such as the wall of a building. You also need a partner.

Method

- 1** Stand at a distance from the wall. The first student bangs two wooden blocks together once. Listen to the echo.
- 2** Now bang the blocks together at a regular rate, so that each bang coincides with the previous echo. (This will need some practice.)
- 3** The second student uses the stopwatch to time ten bangs (count zero, one, two, three, ..., ten). Calculate the time for one bang. This is the time taken for the sound to travel to the wall and back again.
- 4** Measure the distance from where you are standing to the wall.
- 5** Use your measurements to calculate the speed of sound.

Questions

- A1** Were you standing in the best place to hear the echoes?
- A2** Could you stand further from the wall to increase the time between bang and echo?
- A3** Why would this give a more accurate result?

QUESTION

P12.03 Sound takes about 3 ms (3 milliseconds) to travel 1 m.

- a** How long will it take to travel from the centre of a cricket pitch to spectators who are 200 m away?
- b** What fraction of a second is this?

Different materials, different speeds

We talk about ‘the speed of sound’ as 330 m/s. In fact, it is more correct to say that this is the speed of sound in air at 0°C. The speed of sound changes if the temperature of the air changes, if it is more humid, and so on. (Note also that some people talk about ‘the velocity of sound’, but there is no need to use the word ‘velocity’ here, since we are *not* talking about the direction in which the sound is travelling – see Chapter P2.)

Table P12.01 shows the speed of sound in some different materials. You can see that sound travels faster through solids than through gases. Its speed in water (a liquid) is in between its speed in solids and gases.

	Material	Speed of sound / m/s
Gases	air	330
	hydrogen	1280
	oxygen	16
	carbon dioxide	68
Liquids	water	1500
	sea water	1530
	mercury	1450
Solids	glass	5000
	iron, steel	5100
	lead	1200
	copper	3800
	wood (oak)	3800

Table P12.01 The speed of sound in different materials (measured at standard temperature and pressure).

QUESTIONS

P12.04 Look at the experiment to measure the speed of sound shown in Figure P12.02. Explain why the wooden blocks and the two microphones must be in a straight line.

P12.05 Which travels faster, light or sound? Describe **one** observation that supports your answer.

P12.03 Seeing sounds

When a flautist plays her flute, she sets the air inside it vibrating. A trumpeter does the same thing. Why do the two instruments sound so different? The flute and the



Image P12.04 To display the vibrations of a musical note, it is converted to an electrical signal by a microphone and displayed on the screen of an oscilloscope. The trace on the screen shows the regular pattern of vibration of the sounds.

trumpet each contain an ‘air column’, which vibrates to produce a musical note. Because the instruments are shaped differently, the notes produced sound different to our ears.

An image of the notes can be produced by playing the instrument next to a microphone connected to an oscilloscope (Image P12.04). The microphone receives the vibrations from the instrument and converts them to an electrical signal, which is displayed on the oscilloscope screen. The trace on the screen shows the regular up-and-down pattern of the vibrations that make up the sound.

Pure notes

A signal generator can produce pure notes that have a very simple shape when displayed on an oscilloscope screen, as shown in Figure P12.03. As shown in the diagram, we can make an important measurement from this graph. This is the time for one complete vibration, known as the

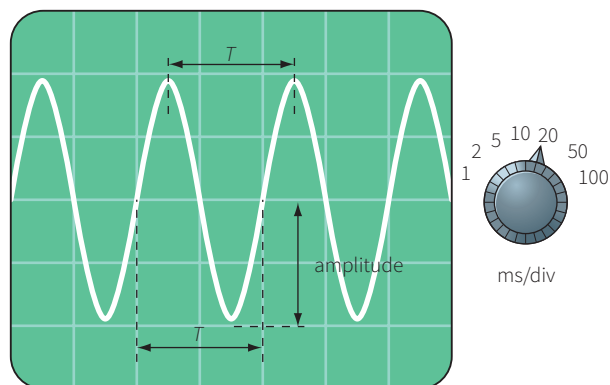


Figure P12.03 A pure note has the shape shown in this oscilloscope trace. The setting of the oscilloscope timebase is indicated on the right. This tells you how much time is represented by the divisions on the horizontal scale.

period T of the vibration. This is related to the **frequency** f of the sound:

period T = number of seconds for one vibration

frequency f = number of vibrations per second

Hence we can write the following equation:

$$f = \frac{1}{T}$$

Frequency is measured in hertz (Hz). A frequency of 1 Hz is one vibration per second.

High and low, loud and soft

You can understand how an oscilloscope works by connecting it up to a signal generator. With a low-frequency note (say, 0.1 Hz), you will see that there is a single dot, which moves steadily across the oscilloscope screen. The electrical signal from the signal generator makes it move up and down in a regular way. Increasing the frequency makes the dot go up and down faster, until it blurs into a continuous line.

Changing the settings on the signal generator allows you to see the traces for notes of different frequencies and loudnesses. A loudspeaker will let you hear them as well. As shown in Figure P12.04, increasing the frequency of the note squashes the vibrations together on the screen. The note that you hear has a higher **pitch**. Increasing the *loudness* produces traces that go up and down further – their **amplitude** increases. Take care: the amplitude is measured from the centre line to a **crest** (peak), not from a **trough** to a crest.

To summarise:

- higher pitch means higher frequency
- louder note means greater amplitude.

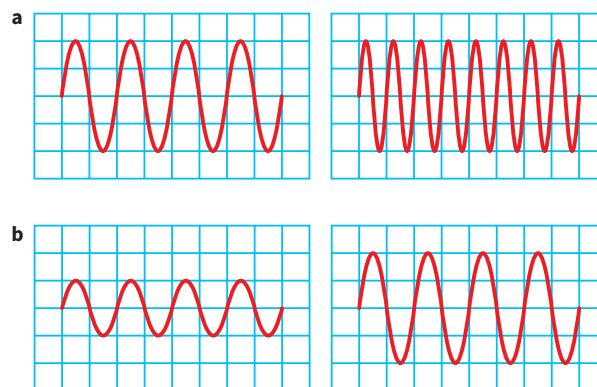


Figure P12.04 **a** Two notes with the same amplitude, and hence the same loudness. The second has more waves squashed into the same space, so its frequency is higher. Its pitch is higher too (it sounds higher). **b** Two notes with the same frequency. The second has a greater amplitude, so that it sounds louder.

Range of hearing

A piano keyboard covers a wide range of notes, with frequencies ranging from about 30 Hz at the bottom end to about 3500 Hz at the top end. Most other instruments cover a narrower range than this. For example, a violin ranges from about 200 Hz to 2500 Hz. The range of human hearing is greater than this. Typically, we can hear notes ranging from about 20 Hz up to about 20 000 Hz (20 kHz, 20 kilohertz). However, older people gradually lose the ability to hear high-pitched sounds. Their **upper limit of hearing** decreases by about 2 kHz every decade of their age.

ACTIVITY P12.02

Seeing sounds

Skills:

AO3.1 Demonstrate knowledge of how to safely use techniques, apparatus and materials (including following a sequence of instructions where appropriate)

AO3.2 Plan experiments and investigations

AO3.3 Make and record observations, measurements and estimates

AO3.4 Interpret and evaluate experimental observations and data

Use a signal generator and an oscilloscope to show traces for different sounds, and test your range of hearing.

- 1 Use two connecting wires to connect a loudspeaker to the low-impedance output of the signal generator.