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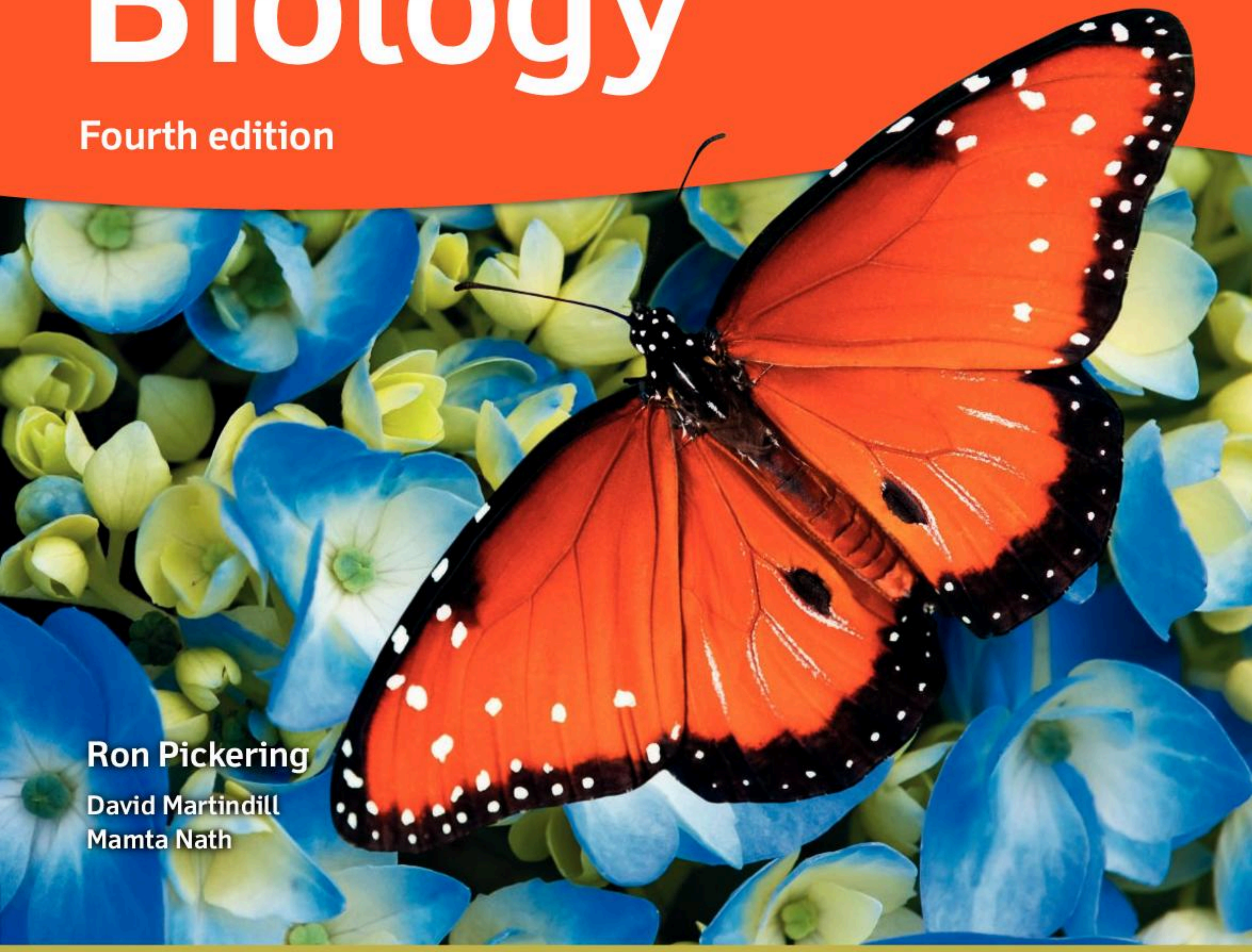
Cambridge IGCSE® & O Level Complete Biology

Fourth edition



Ron Pickering
David Martindill
Mamta Nath

Oxford excellence for Cambridge IGCSE® & O Level

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Dedication

For Nola, our darling granddaughter, who has already provided a great deal of evidence that she has a scientist's inquisitive mind.

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Development of organisms and the continuity of life

Organisms and their environment

Introduction

Biology is the study of life and living organisms. During the past few hundred years, biology has changed from concentrating on the structure of living organisms (often by examining dead specimens!) to looking more at how they work or function. Over the past thirty years or so biologists have begun to understand how the molecules which make up the bodies of living organisms are responsible for this function. We have discovered much about health and disease, about the interactions of different organisms forming communities, about the genes which control the activities of our bodies, and how humans can affect the lives of other organisms. These advances in biological knowledge raise many issues. We need to understand how our activities affect the environment, how humans can take responsibility for their own health and welfare, and how we must make rules for the appropriate use of our genetic information.

In this book you will study a range of living organisms, the life processes they carry out, the effects that these life processes might have on our health, and the responsibilities which we have towards other organisms.

This book has been organised to help you find information quickly and easily. It is written in double-page units – each is a topic which forms part of the IGCSE syllabus – and there is also a practical assessment section that will alert you to the mathematical skills required.

Core syllabus content

If you are following the Core syllabus content, you can ignore any material with a red line beside it.

Supplement syllabus content

S For this, you need all the material on the white pages, including the supplement material marked with a red line.

The Enhanced Online Book supports this student book by offering high-quality digital resources that help to build scientific and examination skills in preparation for the high-stakes IGCSE assessment. If you purchase access to the digital course, you will find a wealth of additional resources to help you with your studies and revision:

- A worksheet and interactive quiz for every unit
- On Your Marks activities to help you achieve your best
- Glossary quizzes to consolidate your understanding of scientific terminology
- Full practice papers with mark schemes

Each person has their own way of working, but the following tips might help you to get the most from this book:

- Use the contents page — this will provide information on large topics, such as reflexes or water pollution.
- Use the index — this will allow you to use a single word such as 'neurone' or 'eutrophication' to direct you to pages where you can find out more about that word.
- Use the questions — this is the best way of checking whether you have learned and understood the material on each spread. Questions are to be found on most units and within or at the end of each section. Harder questions are identified by the icon Q

There are more exam-style questions, and revision 'tips', in the IGCSE Biology Exam Success Guide.

Syllabus matching grid

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4	The variety of life	1.2/1.3
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12	Vertebrate animals: five classes	1.3/1.4
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16	Viruses / questions / Questions on keys	1.3/1.4
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20	Organisms are made of cells	2.1
22	Structures within the cytoplasm / Cell structure	2.1/2.3
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38	Enzymes control biochemical reactions	5.1
40	Questions on enzymes/molecules	5.1
42	Photosynthesis and plant nutrition	6.1
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46	Leaf structure and photosynthesis	6.2
48	The control of photosynthesis	6.1
50	Control by humans: greenhouses	6.1
52	Photosynthesis and the environment	6.1
54	Plants and minerals	6.3

Assessment for IGCSE

The IGCSE examination will include questions that test you in three different ways. These are called Assessment Objectives (AO for short). How these different AOs are tested in the examination is explained in the table below:

Assessment Objective	What the syllabus calls these objectives	What this means in the examination
AO1	Knowledge with understanding	Questions which mainly test your recall (and understanding) of what you have learned. About 50% of the marks in the examination are for AO1.
AO2	Handling information and problem solving	Using what you have learned in unfamiliar situations. These questions often ask you to examine data in graphs or tables, or to carry out calculations. About 30% of the marks are for AO2.
AO3	Experimental skills and investigations	These are tested on the Practical Paper or the Alternative to Practical (20% of the total marks). However, the skills you develop in practising for these papers may be valuable in handling questions on the theory papers.

The end-of-section questions in this book include examples of those testing AO1, AO2 and AO3. Your teacher will help you to attempt questions of all types. You can see from the above table that it will not be enough to try only 'recall' questions.

All candidates take three papers.

The make-up of each assessment programme is shown below:

Core assessment

Questions are based on Core content.

Paper 1: Multiple Choice (Core), 45 mins There are a total of 40 marks available, worth 25% of your IGCSE. The paper consists of multiple-choice questions.	Paper 3: Theory (Core), 1 hour 15 mins There are a total of 80 marks available, worth 50% of your IGCSE. The paper consists of compulsory short-answer and structured questions.
You will be tested in AO1 and AO2 and can achieve a grade C to G.	You will be tested in AO1 and AO2 and can achieve a grade C to G.

Extended assessment

Questions are based on the Core and Supplement subject content.

Paper 2: Multiple Choice (Extended), 45 mins There are a total of 40 marks available, worth 25% of your IGCSE. The paper consists of multiple-choice questions.	Paper 4: Theory (Extended), 1 hour 15 mins There are a total of 80 marks available, worth 50% of your IGCSE. The paper consists of compulsory short-answer and structured questions.
You will be tested in AO1 and AO2 and can achieve a grade A* to G	You will be tested in AO1 and AO2 and can achieve a grade A* to G.

Practical assessment

Students take either Paper 5 or Paper 6.

Paper 5: Practical Test, 1 hour 15 mins There are a total of 40 marks available, worth 25% of your IGCSE. You will be required to do experiments in a lab as part of the assessment.	Paper 6: Alternative to Practical, 1 hour 15 mins There are a total of 40 marks available, worth 25% of your IGCSE. You will NOT be required to do experiments in a lab as part of the assessment.
You will be tested in AO3 and can achieve a grade A* to G.	You will be tested in AO3 and can achieve a grade A* to G.

I hope that you enjoy using this book, and that it helps you to understand the world of biology. You, like every other living organism, are a part of this world – perhaps one day you will find yourself working to help others to understand more about it.

1.1 Biology is the study of life and living organisms

OBJECTIVES

- To understand that living things differ from non-living things
- To be able to list the characteristics of living things
- To understand that energy must be expended to maintain life

The dawn of life

Scientists believe that the Earth was formed from an enormous cloud of gases about 5 billion years ago. Atmospheric conditions were harsh (there was no molecular oxygen, for example), the environment was very unstable and conditions were unsuitable for life as we know it.

Many scientists believe that the first and simplest living organisms appeared on Earth about 2.8 billion years ago. These organisms probably fed on molecules in a sort of 'soup' (called the **primordial soup**) which made up some of the shallow seas on the Earth at that time. A question that has always intrigued scientists, philosophers and religious leaders is:

> What distinguishes these first living organisms from the molecules in the primordial soup?

In other words, what is life?

Characteristics of living organisms

You know that a horse is alive, but a steel girder is not. However, it is not always so obvious whether something is alive or not – is a dried-out seed or a virus particle living or non-living? To try to answer questions like this, biologists use a list of characteristics that living organisms show.

Living organisms:

- **Respire**
- Show **irritability** (sensitivity to their environment) and **movement**
- **Nourish** themselves
- **Grow** and **develop**
- **Excrete**
- **Reproduce**

The opposite page gives more details of the characteristics of life.

You may see other similar lists of these characteristics using slightly different words. You can remember this particular list using the word RINGER. It gives **Ringer's solution** its name. This is a solution of ions and molecules that physiologists use to keep living tissues in – it keeps the cells alive.

As well as the characteristics in the 'ringer' list, living things have a **complex organisation** that is not found in the non-living world. A snowflake or a crystal of quartz is an organised collection of identical molecules, but even the simplest living cell contains many different complex substances arranged in very specific structures.

Living things also show **variation** – the offspring are often different from one another and from their parents. This is important in adaptation to the environment and in the process of evolution.

How the characteristics of life depend on each other

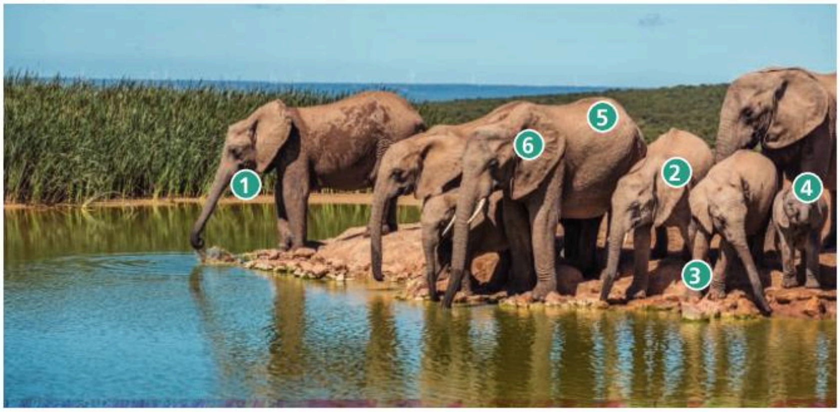
Each of the characteristics of life is linked to the others – for example, organisms can only grow if they are nourished. As they take nourishment from their environment, they may also produce waste materials which they must then excrete. To respond to the environment, they must organise their cells and tissues to carry out actions. Because of the random nature of reproduction, they are likely to show variation from generation to generation.

Depending on energy

The organisation in living things and their ability to carry out their life processes depends on a supply of **energy**. Many biologists today define life as a set of processes that result from the organisation of matter and which depend on the expenditure of energy.

In this book we shall see:

- how energy is released from food molecules and trapped in a usable form
- how molecules are organised into the structures of living organisms
- how living organisms use energy to drive their life processes.



1. Nutrition: the taking in of materials for energy, growth and development. Plants require light, carbon dioxide, water and ions and make their foods using the process of photosynthesis. Animals require organic compounds and ions (and usually water) and obtain their foods 'ready made' by eating them.

2. Growth and development: the processes by which an organism changes in size and in form. For example, as a young animal increases in size (as it grows), the relative sizes of its body parts change (it develops). Growth is a **permanent** increase in size and dry mass, and results from an increase in cell number or cell size or both.

3. Excretion: removal from organisms of toxic materials, the waste products of metabolism (chemical reactions in cells including respiration) and substances in excess of requirements.

4. Reproduction: the processes that make more of the same kind of organism – new individuals. An organism may simply split into two, or reproduction may be a more complex process involving fertilisation. Reproduction makes new organisms of the same species as the parents. This depends on a set of chemical plans (the genetic information) contained within each living organism.

5. Respiration: the chemical reactions that break down nutrient molecules in living cells to release energy for metabolism. The form of respiration that releases the most energy uses oxygen. Many organisms have **gaseous exchange** systems that supply their cells with oxygen from their environment.

6. Irritability (or sensitivity): the ability to detect or sense changes in the internal or external environment and to make appropriate responses. The changes are called stimuli and the responses often involve **movement** (an action by an organism or part of an organism causing a change of position or place).

Q

1. Approximately how many years passed between the formation of the Earth and the appearance of the first living organisms?
2. What sort of molecules do you think might have been present in the primordial soup?
3. **RINGER** is a word that helps people remember the characteristics of living organisms. Think of your own word to help you remember these characteristics.
4. Suggest **two** ways in which reproduction is essential to living organisms.

1.2 The variety of life

OBJECTIVES

- To know that organisms can be classified into groups by the features that they share
- To appreciate why classification is necessary
- To understand the use of a key
- To be able to name the five kingdoms, and describe their distinguishing characteristics
- To understand the hierarchy of classification
- To know why a binomial system of nomenclature is valuable

The need to classify living things

Variation and natural selection lead to evolution. Evolution, and the isolation of populations, leads to the development of new species (see page 235). Each species has different characteristics, and some of these characteristics can be inherited by successive generations of this species. Observing these inherited characteristics allows scientists to put all living organisms into categories. The science of placing organisms into categories on the basis of their observable characteristics is called **classification**. There are so many different types of living organism (i.e. an enormous variety of life) that the study of these organisms would be impossible without an ordered way of classifying them.

For example, classification is important in:

S

- **Conservation**: scientists need to be able to identify different organisms in habitats which are being managed, and they need to control which organisms are used in breeding programmes
- **Understanding evolutionary relationships**: organisms which have many of the same features are normally descended from common ancestors. The more features shared by different organisms, the more recently they separated from one another during evolution.

Classification keys

Taxonomists (people who study classification) place organisms into groups by asking questions about their characteristics, such as 'Does the organism photosynthesise?' or 'Does the organism contain many cells?'. A series of questions like this is called a **classification key**. Examples of such keys are shown below and on the opposite page.

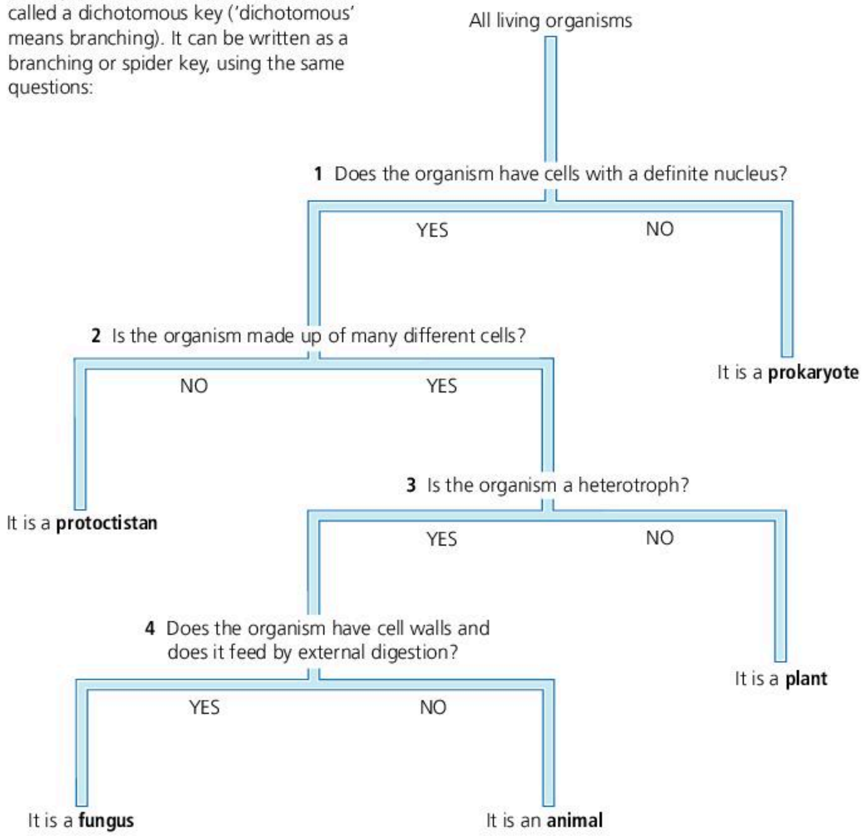
S

The characteristics of living organisms used to make classification keys have traditionally been based on **morphology** and **anatomy** (the shape and structure of organisms) because this was what the scientists could easily observe and measure.

1 Does the organism have cells with a definite nucleus?	YES NO	Go to question 2 It is a prokaryote
2 Is the organism made up of many different cells?	YES NO	Go to question 3 It is a protoctistan
3 Is the organism a heterotroph?	YES NO	Go to question 4 It is a plant
4 Does the organism have cell walls and does it feed by external digestion?	YES NO	It is a fungus It is an animal

▲ A key may be used to place an organism in one of the five kingdoms

▶ This kind of key, with only two answers to each question (in this case, YES or NO), is called a dichotomous key ('dichotomous' means branching). It can be written as a branching or spider key, using the same questions:



The five kingdoms
Prokaryotes
Protoctistans
Plants
Fungi
Animals

Branching keys are easy to use, but take up a lot of space when fully drawn out. For this reason the listed form of a dichotomous key like the one shown opposite is usually used for identification of organisms outside the laboratory.

Five kingdoms

Using the key above, it is possible to place any living organism into one of five very large groups. These groups, distinguished from one another by obvious characteristics of morphology and anatomy, are called the **five kingdoms**. Each of these kingdoms contains an enormous number of different species, and keys can be used within a kingdom to place any individual species into further groups. The diagram on the next page shows the names of these groups, and how the lion is classified within the Animal Kingdom.

Hierarchy of classification*

The sequence of kingdom, **phylum, class, order, family, genus** and **species** is called a **hierarchy of classification**.

Notice that each classification group is given a name. Lions belong to the class Mammalia and the order Carnivora, for example. The final two group names are written in *italics* – this is a worldwide convention amongst scientists. The lion is called simba in Swahili, león in Spanish and leu in Romanian but is known as *Panthera leo* to scientists in each of these countries. This convention of giving organisms a two-part name made up of their genus and species was introduced by the Swedish biologist Carolus Linnaeus. He gave every organism known to science a two-part name based entirely on the body structure of the organism. This binomial system of nomenclature is still in use today (binomial = 'two name').

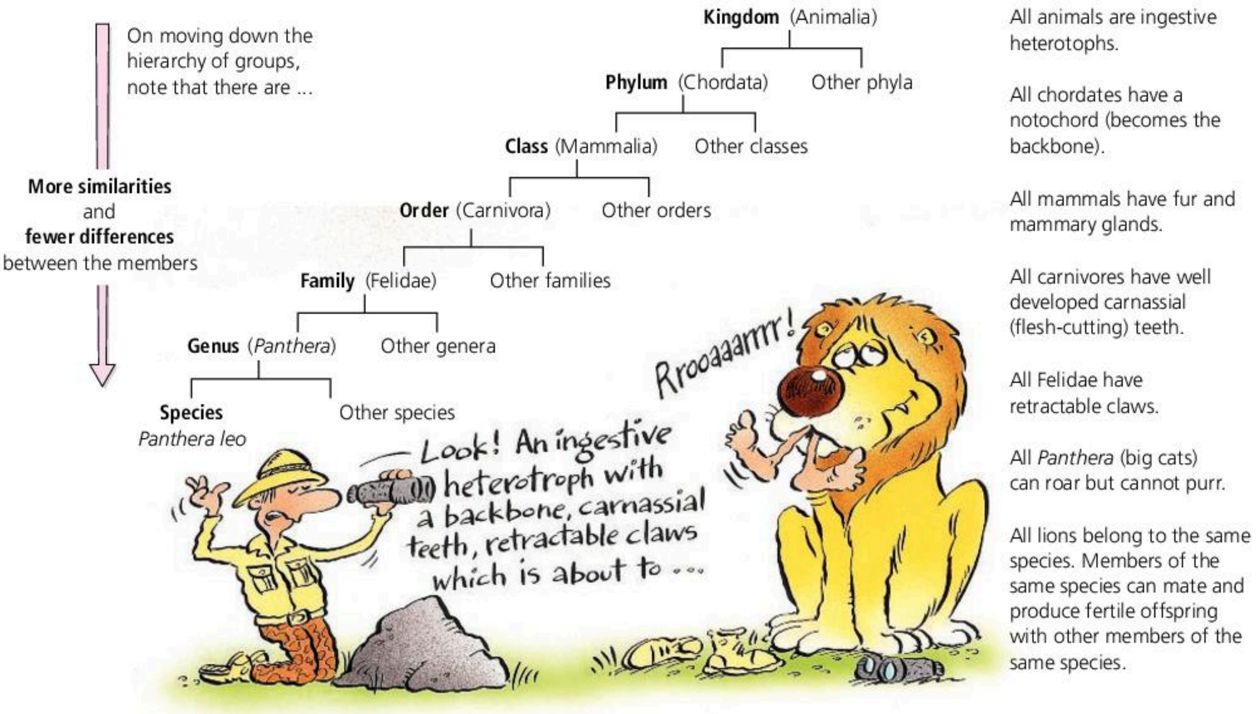
New species today may be classified based on characteristics such as protein structure, chromosome number or gene (DNA or RNA) sequence, which Linnaeus knew nothing about. Each organism, even each individual, has its own DNA profile. Scientists can compare the DNA profiles of different species.

How this helps in classification

- **Protein structure:** organisms which are closely related (share a more recent ancestor) have very similar amino acid sequences in proteins such as haemoglobin.

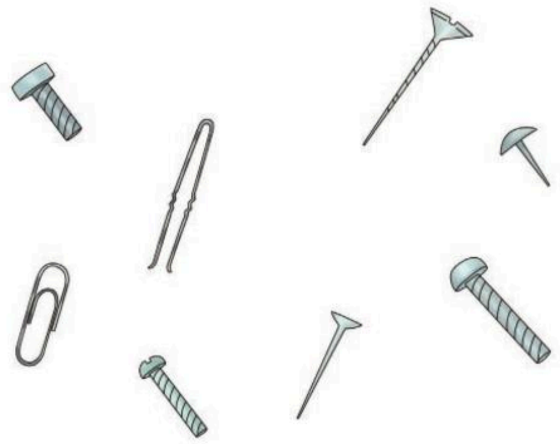
> Organisms that are closely related have very similar DNA profiles – humans and chimpanzees, for example, share 98.6% of their genes!

- **DNA structure:** closely related organisms have very similar base sequences in DNA (see page 210) because there has been less 'evolutionary time' for mutation to change these base sequences.



▲ The hierarchical classification of the lion

MAKING A KEY – INVESTIGATION

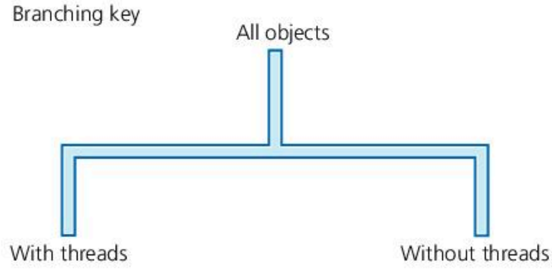


Examine the collection of objects.

- Choose a feature that allows you to divide the group into two approximately equal-sized subgroups.
- Draw a 'branch/fork' and use the feature that you have chosen to place each object into one of the two groups.

For example:

Branching key



- Repeat this branching process until you have separated all the objects on the basis of some observable external characteristic.
- Ask one of your classmates to use the key to identify one of the objects (you choose which one they should try to identify).

Q

1 State which of the following is the best definition of classification.

a Giving every organism a name
b Arranging organisms into groups
c Describing the external features of organisms
d Identifying all living organisms

2 State which of the following is the correct binomial name for the English oak (a species of oak tree).

a *Quercus robur*
b *Quercus Robur*
c *quercus robur*
d *QUERCUS ROBUR*

3 Arrange these classification groups in order of size (from the largest to the smallest):
class, family, genus, kingdom, order, phylum, species.

4 The scientific names for the weasel and mink are *Mustela nivalis* and *Mustela vison*, respectively. Both of these animals belong to the order Carnivora, as do the fox (*Vulpes vulpes*) and otter (*Lutra lutra*). The otter, mink and weasel all belong to the family Mustelidae.

a Which feature must they have in common to belong to the order Carnivora?
b Which two animals are most closely related?
c Which animal is the most different from the other three?
d Suggest one feature that places all of these organisms in the Animal Kingdom.

5 The scientific name for the human is *Homo sapiens*. State the meaning of this name.

6 The table below lists some of the characteristics of living organisms.

a Match each characteristic with its definition. Write the letter and number to show your answer, for example, **a–4**.

Characteristic	Definition
a excretion	**1** the ability to detect changes in the environment
b nutrition	**2** processes that make more of the same organism
c sensitivity	**3** removal of the waste products of metabolism
d reproduction	**4** taking into the body of materials for energy, growth and development

b Suggest why many biologists believe that respiration is the most significant characteristic of a living organism.

1.3 Fungi*

OBJECTIVES

- To know the structure of a fungus
- To understand the methods of nutrition used by fungi
- To understand the use of spores in fungal reproduction
- To appreciate the impact of fungi on the lives of humans

Fungal cells have a common structure

The fungi are a very large group of organisms. They range in size from single-celled yeasts to enormous fungi whose underground parts may occupy an area greater than a football or hockey field.

Fungal cells have a cell wall made of a mixture of substances including **chitin**. The cytoplasm contains many organelles including nuclei, ribosomes and mitochondria (see page 24), because the fungus manufactures digestive enzymes. It feeds by **saprotrophic** ('dead-feeding') **nutrition**, as illustrated opposite.

Reproduction in fungi

Single-celled yeasts reproduce asexually by binary fission, but all other fungi reproduce by the production of **spores**.

Requirements of fungi

Fungi have very similar requirements to those of bacteria, that is:

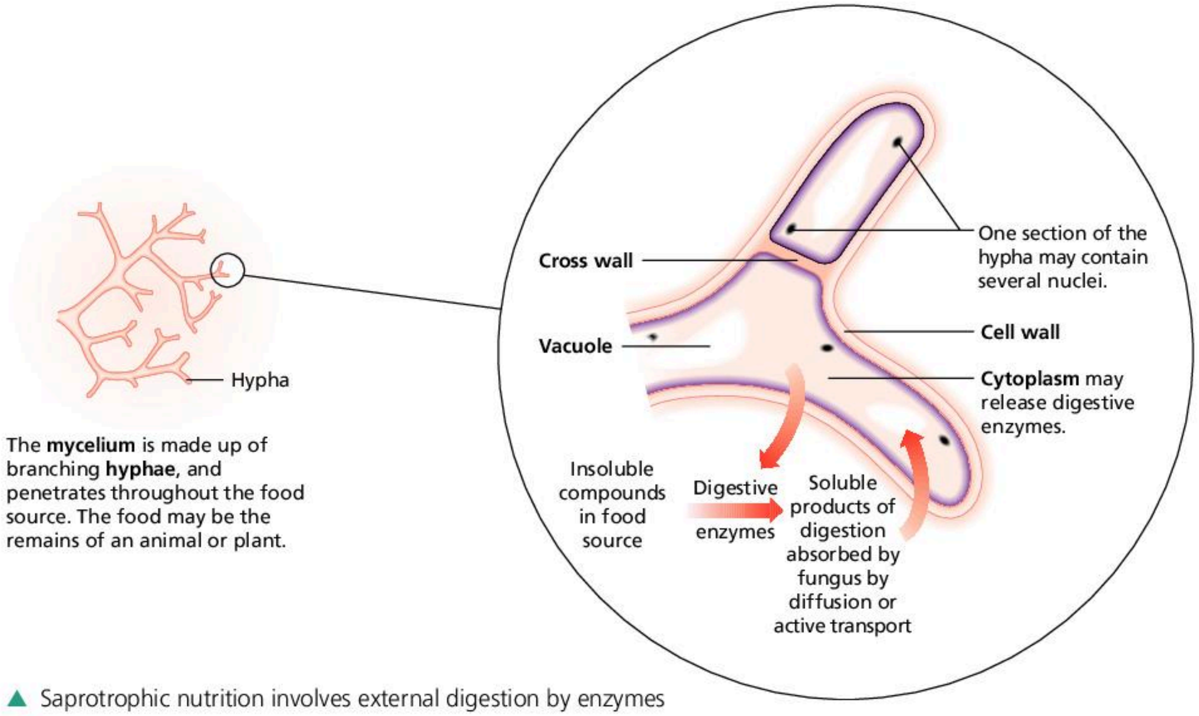
- a moist environment, so that they can absorb the soluble products of digestion of their food source in solution
- a warm environment, so that enzymes can work at their optimum temperature
- a nutrient source to provide the raw materials and energy required for growth.

Fungi do not require light because they do not rely on photosynthesis for the production of food compounds. This means that fungi are rarely found in light environments, because such environments are usually too warm and dry for fungal growth.

The importance of fungi

Fungi have a number of effects on the lives of humans. For example:

- they are **decomposers**, and play a vital role in **nutrient cycles** (see page 250)
- mould fungi consume food which might otherwise be eaten by humans (see page 250)
- fungi may be agents of disease, as in athlete's foot, for example (see page 112)
- they may themselves be a source of food, for example, mushrooms
- fungi are used in biotechnology – the brewing and baking industries (see page 298) are entirely dependent on the activities of yeast, for example.



▲ Saprotrophic nutrition involves external digestion by enzymes

Q

1 Pin mould is a kind of fungus. It grows on damp materials, such as bread or some fruits.
Explain why:
a pin mould is not green
b pin mould will not grow on dry food
c pin mould produces very large numbers of spores
d the spores produced by pin mould are very light.

2 This list contains a number of statements about fungi. Complete the statements by matching a letter with a number.

a the body of a fungus is made up of threads called	**1** starch
b A fungus can secrete the enzyme amylase which digests	**2** saprotrophism
c The wall of a fungal cell is made of	**3** diffusion and active transport
d The method of nutrition used by fungi is called	**4** sporulation
e Fungi reproduce by a process called	**5** photosynthesis
f Fungi absorb nutrients by	**6** hyphae
g Fungi have no chlorophyll and so cannot carry out	**7** chitin

1.4 Plants: the Plant Kingdom

OBJECTIVES

- To recall that all plants are autotrophs, and are able to absorb light energy to drive photosynthesis
- To understand some of the steps in the adaptation of plants to life on dry land
- To recall the characteristics of two main plant groups

Plants are autotrophs

As **autotrophs**, plants manufacture food molecules from simple, inorganic sources by the process of photosynthesis using light as a source of energy. Plants all **contain the light-absorbing pigment chlorophyll** (or similar molecules which perform the same function) inside cells which **have a definite cellulose cell wall**.

Adaptations to life on land

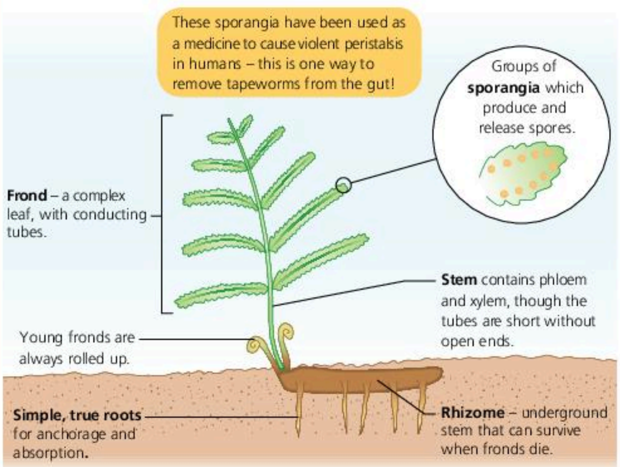
The first plants lived in water, but as living organisms evolved, plant forms developed that could live on land. The classification of plants into groups follows this sequence of evolution.

The Plant Kingdom may be divided into three main groups (phyla): **mosses**, **ferns** and **seed plants**.

Mosses cannot grow far away from water, but ferns and flowering plants (angiosperms) are much better adapted to life on land.

Ferns

Ferns are much better adapted to life on land than mosses. They have roots, stems, complex leaves and vascular tissues. They are able to produce spores for wide dispersal. However, they do not have very thick cuticles and can only survive in shady, humid areas. The gametes of ferns, like those of mosses, must swim through a film of moisture to reach the site of fertilisation. An example of a fern is described below.



◀ Ferns have complex leaves, vascular tissues and true roots. They reproduce by producing spores.

Angiosperms

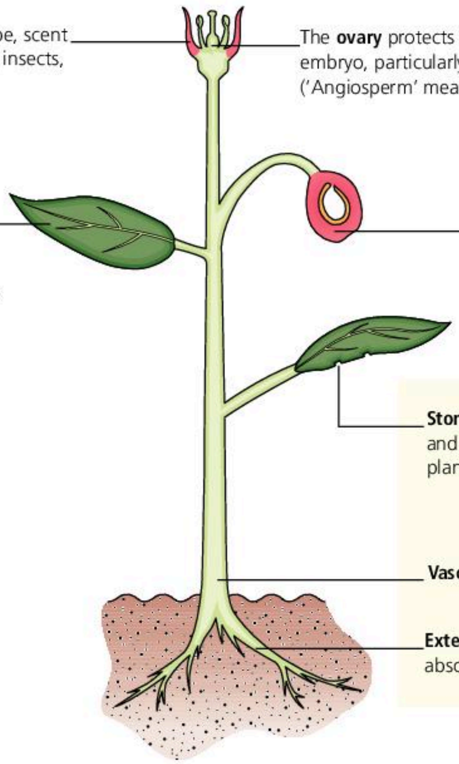
The angiosperms or flowering plants are the most successful of plants – they have evolved into many species and have colonised almost every available habitat. More than 80% of all plants are angiosperms (plants with enclosed seeds). Many features of the lives of flowering plants are covered elsewhere in this book (see pages 46–59, 86–93, 170–173 and 178–185, for example). The diagram at the top of the opposite page summarises these features, and emphasises the adaptations of flowering plants to a successful life on land, including warmer habitats.

Two groups of angiosperms

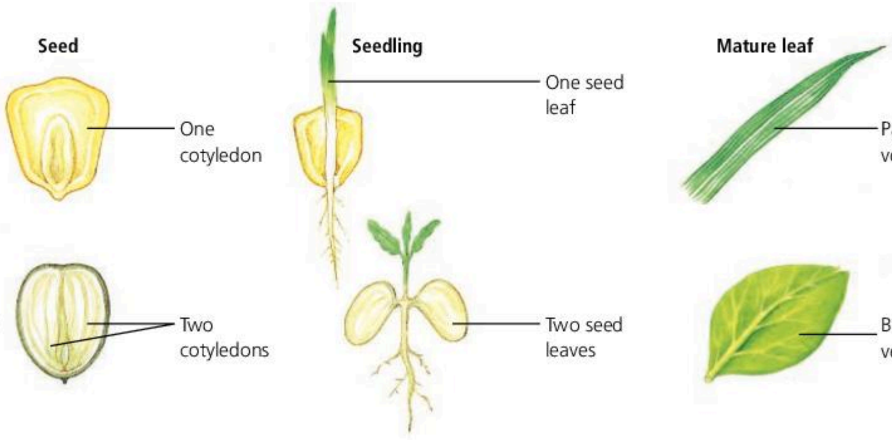
There are two major subgroups within the angiosperms. In one group, there is a single cotyledon in the seed (see page 183) – these are the **monocotyledons**. In the other group, there are two cotyledons – these are the **dicotyledons** (eudicotyledons). There are other differences between monocotyledons and dicotyledons, as shown in the diagram on the next page.

▲ Each brown patch on the underside of the leaf is made up of many sporangia, which produce and release spores

Angiosperm features adapt them for life on dry land



Monocotyledons and dicotyledons (eudicotyledons) – two groups of angiosperms (flowering plants)



Q

1. In what ways are ferns well adapted to life on land?
2. Seed plants are well adapted to live and to reproduce in dry environments. What major adaptation allows reproduction on dry land?

1.5 Invertebrate animals

OBJECTIVES

- To know the difference between a vertebrate animal and an invertebrate animal
- To be able to distinguish between different classes of arthropods
- To understand the importance of metamorphosis in insects

Vertebrates and invertebrates

All animals share one characteristic – **they feed on organic molecules** (see page 36). Members of the Animal Kingdom can be divided into two large groups based on whether they have a backbone as part of a bony skeleton. Animals with a backbone are called **vertebrates** and those without a backbone are called **invertebrates**.

Arthropods

The arthropods are the most numerous of all animals, both in terms of the number of different species and the number of individuals in any one species. The insects are arthropods that show an interesting adaptation in their life cycle called **metamorphosis** that allows them to use the resources of their habitat to the maximum.

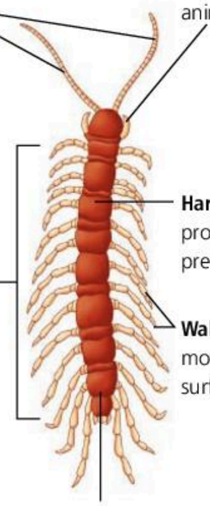
Apart from insects, the arthropod phylum includes three other classes – arachnids (spiders, for example), crustaceans (crabs, for example) and myriapods (millipedes and centipedes). The diagrams on the opposite page compare insects and spiders. Amongst the arthropods, insects and spiders are sometimes confused with one another. The table below highlights the differences.

	Insects	Spiders
Body sections	3	2
Legs	3 pairs	4 pairs
Wings	Usually 2 pairs	None
Eyes	Compound	Simple

Crustacea

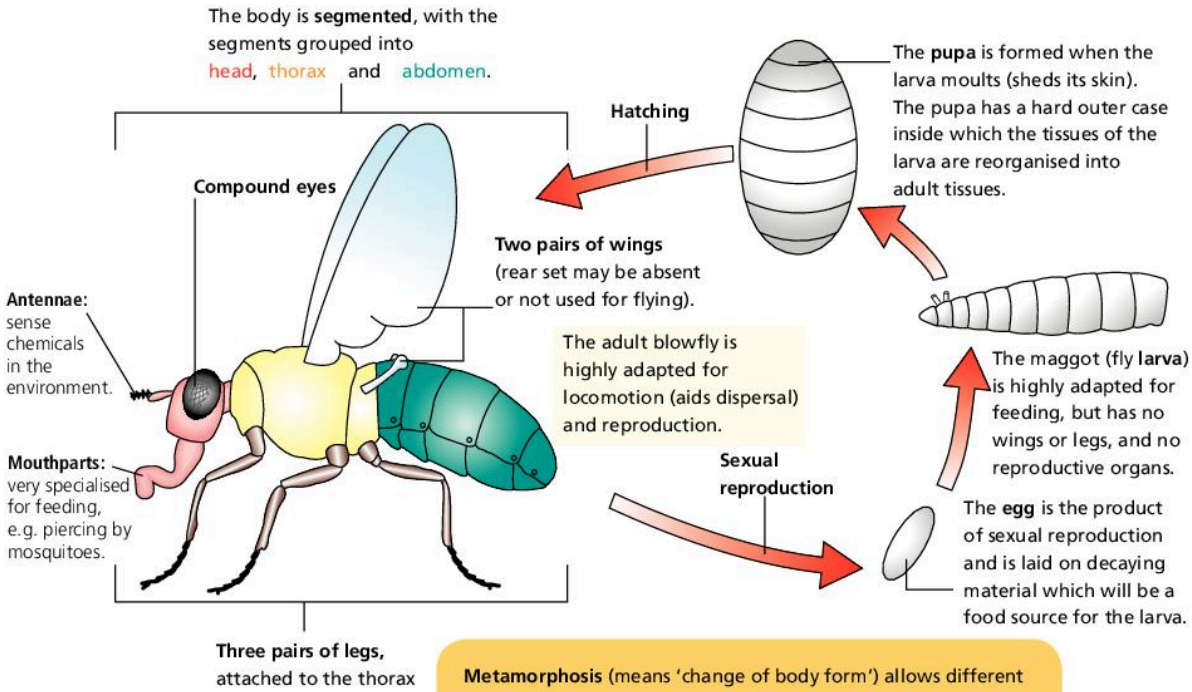
Crabs are slightly unusual because many of their segments are tucked under their body.

Myriapods



Insects

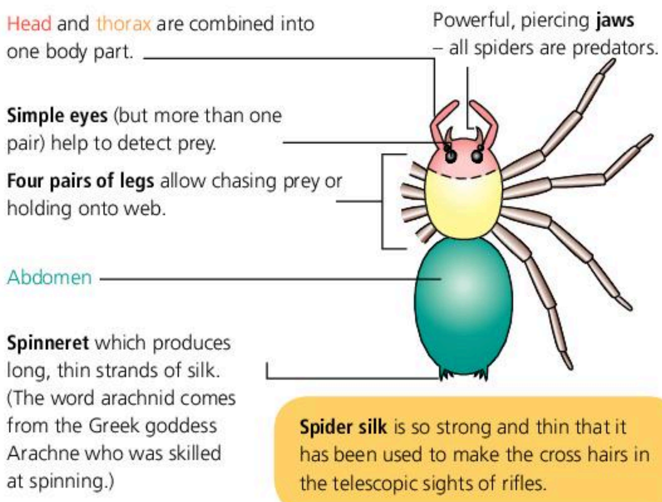
e.g. blowfly, mosquito



Metamorphosis (means 'change of body form') allows different stages which:

- do not compete for the same food sources
- can be highly specialised for different functions. The **larva** is adapted for **feeding** and **growth**, and the **adult** for **locomotion** and **reproduction**.

Arachnids



Spider silk is so strong and thin that it has been used to make the cross hairs in the telescopic sights of rifles.

Q

1 Copy and complete the following paragraph.
All animals have one common characteristic – ______. The invertebrates are animals that do not have ______. ______ are the most numerous of all animals.

2 The arthropods include four classes – insects, arachnids, crustaceans and myriapods.
- **a** List three features that all of these classes possess.
- **b** List three features that only insects possess.
- **c** Compare insects and spiders under the headings 'Number of legs', 'Number of body sections', 'Number of wings' and 'Type of eyes'.

3 Insects are the most abundant of all animals on land. Many of them show an adaptation called complete metamorphosis. What does this term mean, and how does it help to explain why there are so many insect species?

1.6 Vertebrate animals: five classes

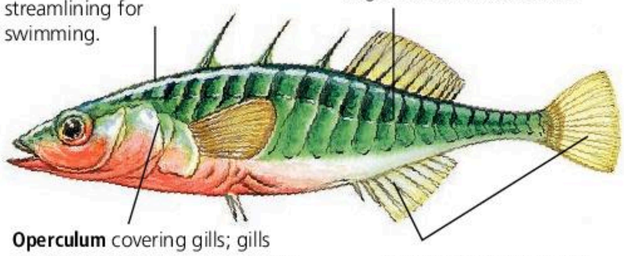
OBJECTIVES

- To know the characteristics of the vertebrates
- To understand how different classes of vertebrates show increasing adaptation to dry land
- To know the five classes of vertebrate, and to provide examples of each

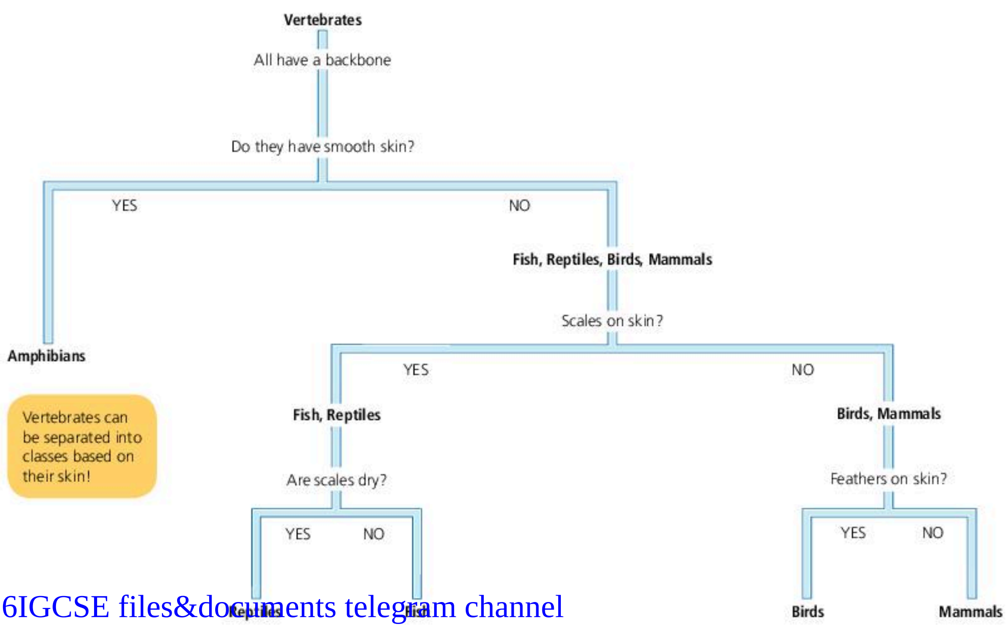
If asked to name an animal, most people would probably name a mammal because these are the most familiar animals to us. Mammals are just one class of the phylum **Chordata**. The chordates are often called the **vertebrates**, although strictly speaking there are a few chordates that are not vertebrates. Vertebrates have a hard, usually bony, internal skeleton with a backbone. The backbone is made up of separate bones called **vertebrae**, which allow these animals to move with great ease.

There are five classes of vertebrates, which, like the members of the Plant Kingdom, show gradual adaptations to life on land. The classes are **fish**, **amphibians**, **reptiles**, **birds** and **mammals**.

Fish

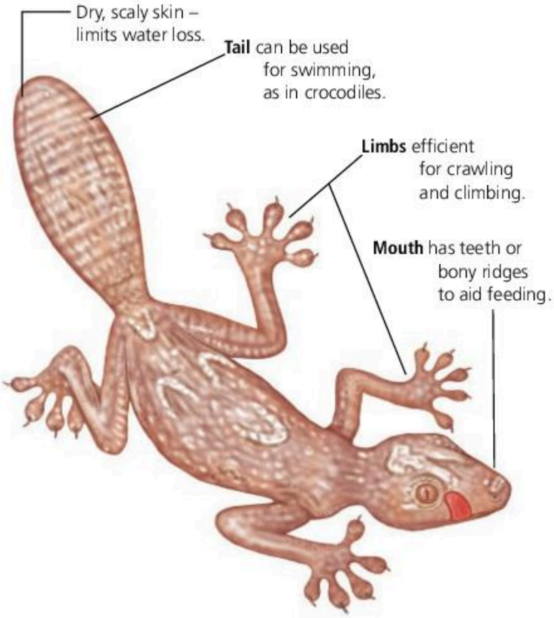


Amphibians



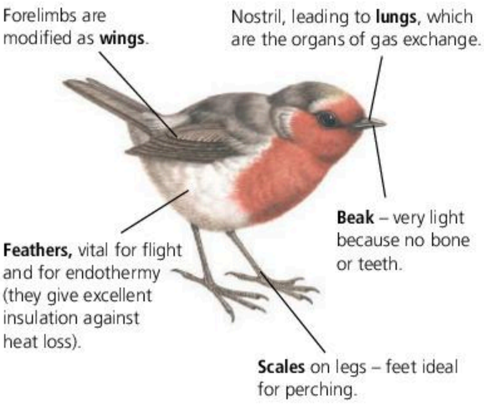
Vertebrates can be separated into classes based on their skin!

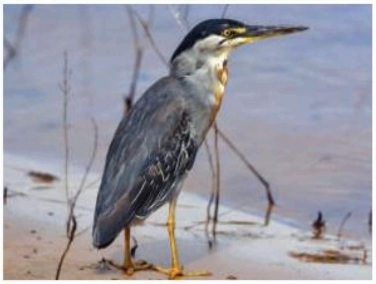
Reptiles



▲ The crocodile has the typical dry scaly skin of reptiles. The eyes on the top of its head and its sharp, pointed teeth adapt it for catching prey in water.

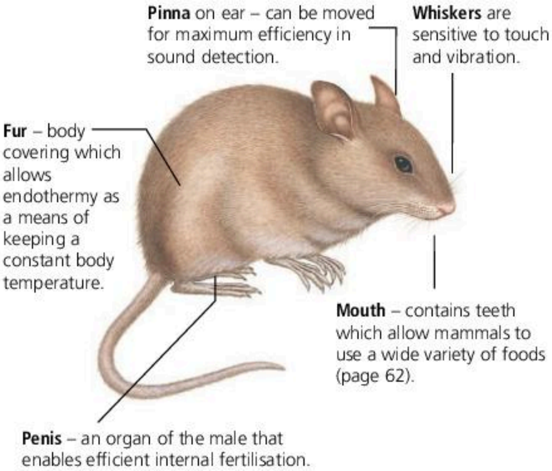
Birds





▲ The heron has typical bird features of feathers and a beak. It is well adapted to capture fish and frogs as it has large eyes to spot its prey, a long pointed beak to grab its prey and large feet for walking over soft, muddy ground.

Mammals



Mammals are endothermic vertebrates that have the characteristics shown in the diagram below.

A wide range of adaptations has allowed mammals to colonise habitats as diverse as the polar wastes and the Arabian desert.

Humans are mammals

Humans show the typical mammalian characteristics of hair, mammary glands and a diaphragm, for example. Humans, though, are unique amongst all animals in that the adaptations they show allow them to modify their environment so that it is suitable for human occupation.

As a result, humans have been able to live and work in many habitats – no animal has a wider range. Human adaptation has allowed advanced development of the brain, and of all the complex activities that the brain can coordinate. The human brain is extremely sensitive to changes in temperature. Human adaptations include many that are concerned with the fine regulation of blood temperature (see page 146). Another feature that makes humans very special mammals is an upright posture, freeing the hands for complex movements including the use of tools.

1.7 Protoctists and prokaryotes: often single celled

OBJECTIVES

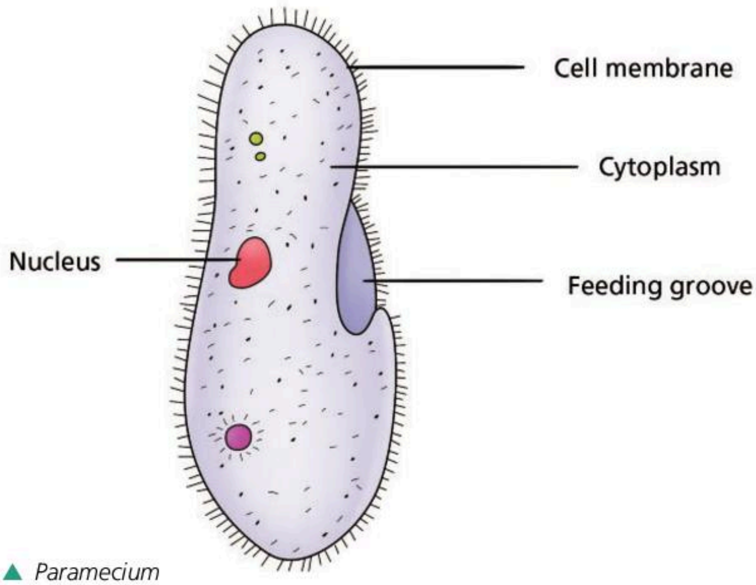
- To know the structure of a protoctist
- To know the structure of a bacterial cell, an example of a prokaryote
- To know the difference between a protoctist and a prokaryote

Tips!

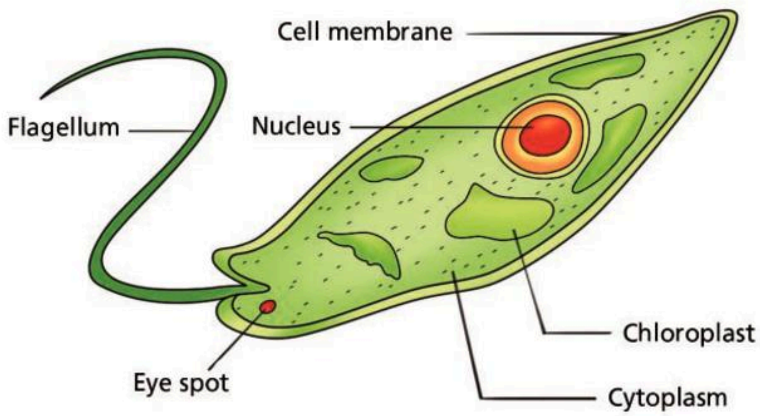
Remember: if a unicellular organism has a nucleus, then it is a protoctist and *not* a prokaryote.

Protoctists

This is a kingdom with many members of different types. They are placed in the Protoctistans Kingdom because they do not fit anywhere else! All protoctists have cells with nuclei and may have other organelles such as chloroplasts. Many are unicellular and some are multicellular. Some feed like animals, others can photosynthesise and there are even some, like *Euglena*, which can do both. Unicellular protoctists include *Plasmodium*, which is the parasitic organism that causes malaria. Algae are classified as protoctists; they vary in size from tiny unicellular organisms to giant seaweeds.



▲ *Paramecium*



▲ *Euglena*

Bacterial way of life

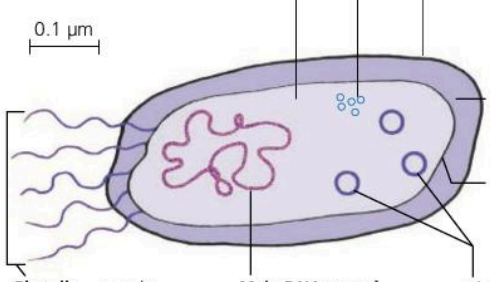
Bacteria are examples of prokaryotes.

Bacteria (singular: bacterium) are single-celled organisms that **have no true nucleus**. Bacterial cells do not contain organelles like those found in typical animal and plant cells (see page 23), but are able to carry out all of their life processes without them. A few can photosynthesise, but most feed off other organisms. They may be **parasites**, feeding off living organisms, or **saprotrophs**, feeding off dead organisms.

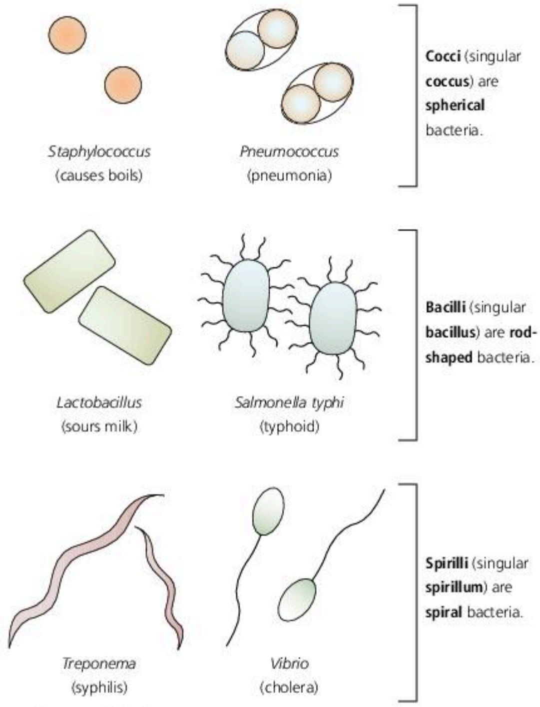
Bacteria are very small, usually about 1–2 μm in length, and so are only visible using a high-powered microscope. The structure of a typical bacterium is shown in the diagram below.

Bacteria exist in a number of different shapes, some of which are shown opposite. Shape can be used to classify bacteria.

An understanding of bacterial structure and metabolism is very important in genetic engineering and biotechnology (see page 292).



▲ Bacteria have a cell wall but do not have a nucleus or organelles



▲ Bacterial shapes

1 True or false?

a Bacteria contain a nucleus, although it is smaller than an animal cell nucleus.

b All bacteria are parasites.

1.8 Viruses

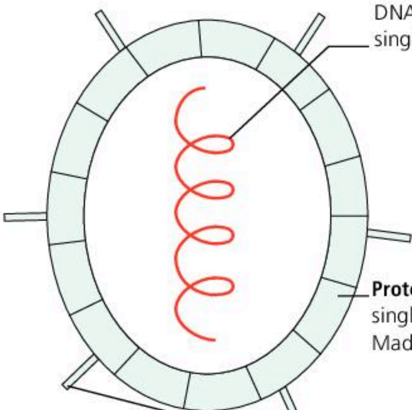
OBJECTIVES

- To know the structure of a virus
- To know that viruses can only live and reproduce inside the cells of another living organism
- To know the differences between bacteria and viruses

Viruses

When the five-kingdom system of classification was devised, no one was able to find a place for the group of organisms called the **viruses**. This is because viruses do not show the typical features of living things – respiration, nutrition and reproduction, for example – unless they are inside the cells of another living organism. In other words, all viruses are parasites and therefore cause harm to their host. Some taxonomists have suggested that viruses belong in a sixth kingdom. There is great variation in the structure of viruses, but they all have certain common features. The structure of a typical virus is shown below.

Most viruses cause disease – they may infect humans, domestic animals or plants. The virus COVID-19 is responsible for a severe respiratory illness. The virus is called a **coronavirus** because when viewed under the electron microscope the spikes which stick out from the protein coat look like a crown (corona = crown in Latin).



▲ A typical virus has genetic material and a protein coat, but cannot carry out its life processes. It has no cytoplasm.

It is important not to confuse viruses with **bacteria**. The structure of bacteria and their importance to humans are described on page 292.

1 True or false?

a All viruses cause disease.
b Viruses can only reproduce inside living cells.
c All viruses are the same shape.
d Viruses are made up of a protein coat surrounding double-stranded DNA or RNA.

Questions on characteristics and classification

1 Butterflies are insects for which of the following reasons?

A Because they lay eggs
B Because they can fly
C Because they have three main body parts
D Because they feed on nectar [1]

2 An eagle is a bird for which of the following reasons?

A Because it has scales
B Because it has a beak
C Because it can fly
D Because it feeds on other birds [1]

3 Fungi are not included in the Plant Kingdom for which of the following reasons?

A Because they do not reproduce
B Because they do not respire
C Because they do not photosynthesise
D Because they do not excrete [1]

4 The table below lists some of the characteristics of groups of living organisms.

a Match each description with its classification group. Write the letter and number to show your answer, for example, **a–4**.

Group	Description of characteristics
a spider	**1** cells with a definite cell wall but no chlorophyll
b insect	**2** produces spores and cells contain chlorophyll
c fungus	**3** two body parts and eight jointed legs
d fern	**4** body is made of a single cell, with a clear nucleus and cytoplasm
e protoctist	**5** three body parts and six jointed legs

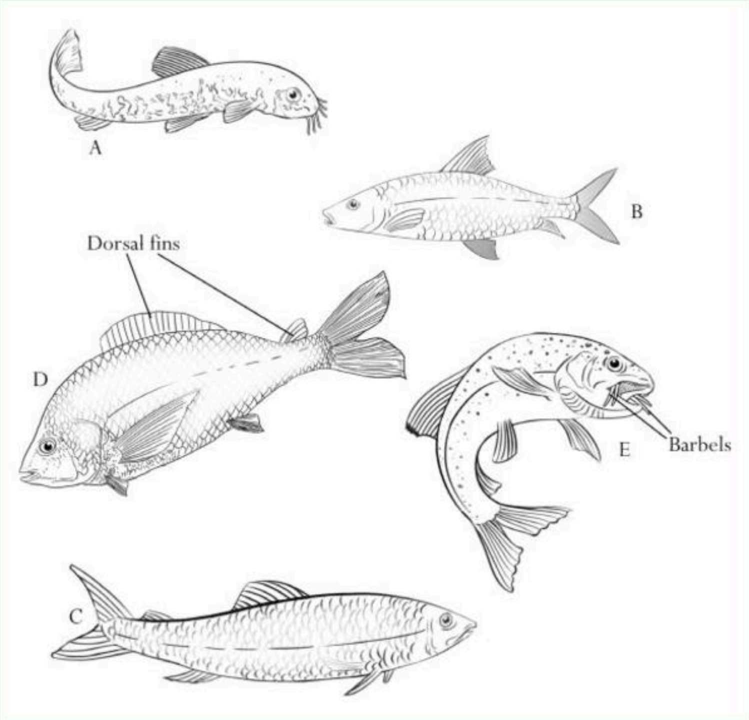
[4]

a i State **one** way in which a bacterium differs from all of the above organisms. [1]

ii State **one** way in which a virus differs from a bacterium. [1]

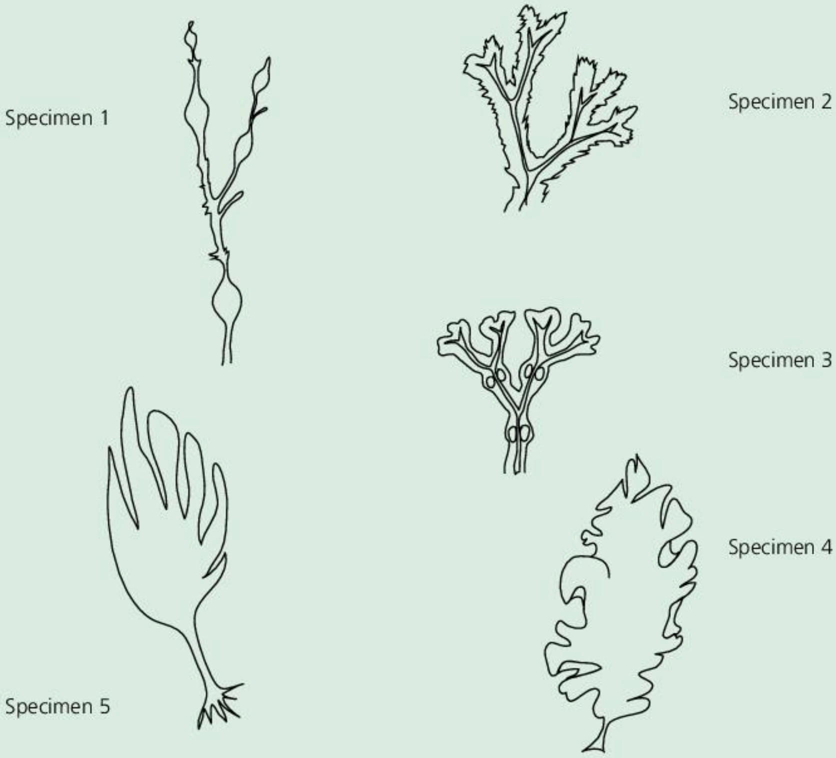
5 Use the key to identify the five fish shown in the drawings. Write down the letter of each fish and its name.

[4]



Key		
1. One dorsal fin Two dorsal fins	2 4	
2. Barbels (fleshy extensions at corners of mouth)	3	
No barbels at corners of mouth	*Phoxinus phoxinus*	☐
3. Four barbels	*Barbus barbus*	☐
Six barbels	*Barbatula barbatula*	☐
4 More than 10 bony rays in first dorsal fin	*Thymallus thymallus*	☐
10 or fewer bony rays in first dorsal fin	*Osmerus eperlanus*	☐

6 The figure shows five different seaweeds. [4]



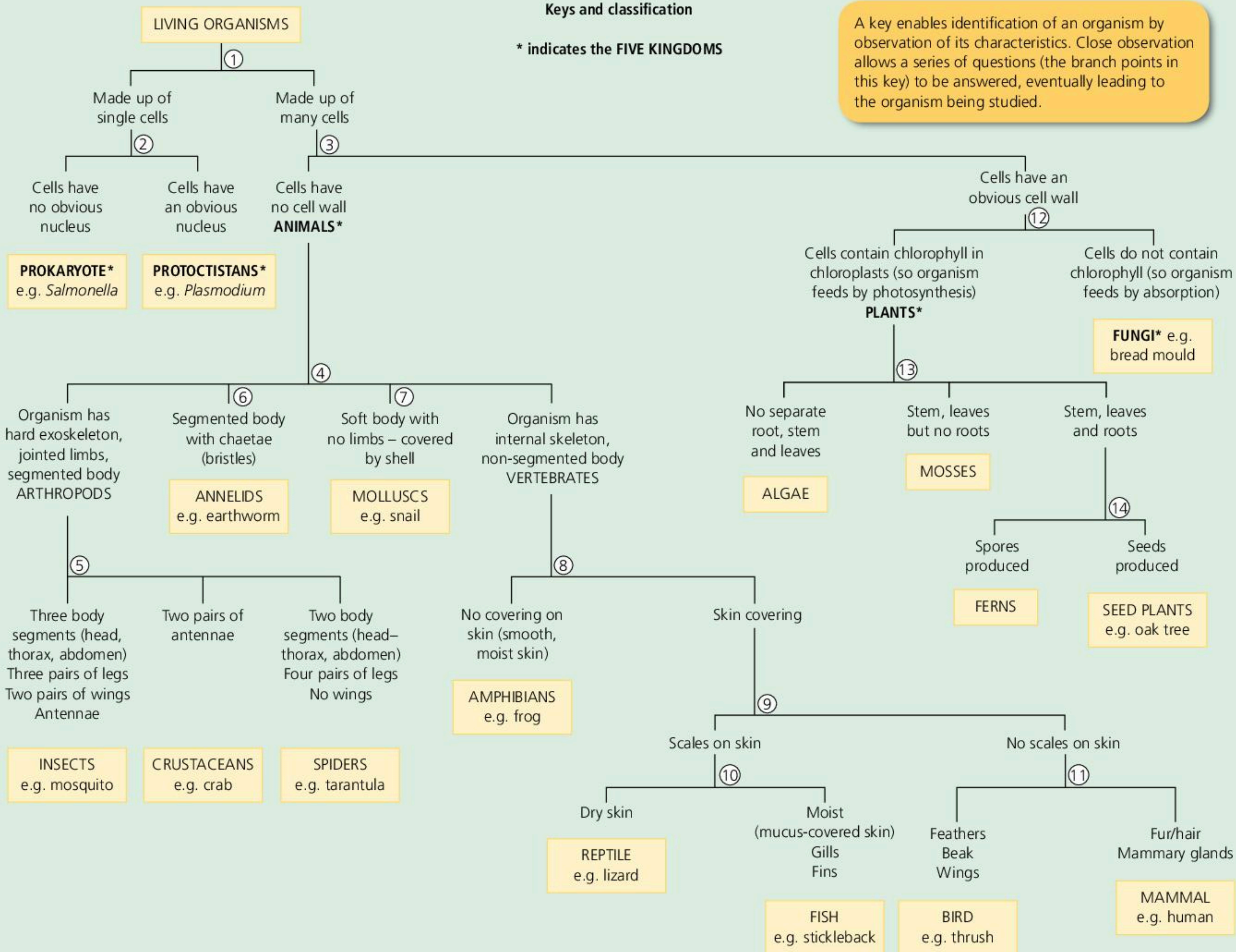
a Describe **ONE** feature of EACH seaweed which is NOT present in any of the others. [5]

b Use your answers to part **a** to construct a dichotomous key which can be used to distinguish between the five seaweeds. [4]

Keys and classification

*** indicates the FIVE KINGDOMS**

A key enables identification of an organism by observation of its characteristics. Close observation allows a series of questions (the branch points in this key) to be answered, eventually leading to the organism being studied.

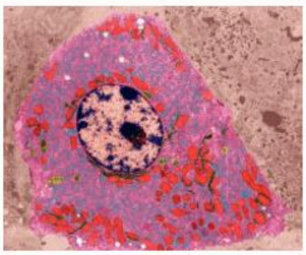


2.1 Organisms are made up of cells

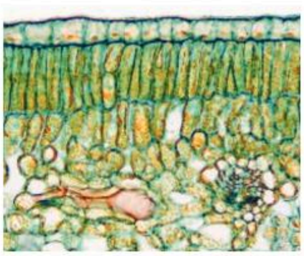
OBJECTIVES

- To know that the basic unit of living organisms is the cell
- To know that all cells have certain features in common, but that there are differences between plant and animal cells
- To understand that the study of cells requires the use of a microscope

All living organisms are made up of units called **cells**. Although cells may take on very specialised functions, they have certain common features. These are shown on the opposite page. Both animal and plant cells have a **cell surface membrane**, **cytoplasm** and a **nucleus**. These three features can be seen on the photograph of a liver cell below. In addition, plant cells have a **cellulose cell wall**, a **vacuole** and may have **chloroplasts**. These features can be seen on the photograph of the palisade cell below.



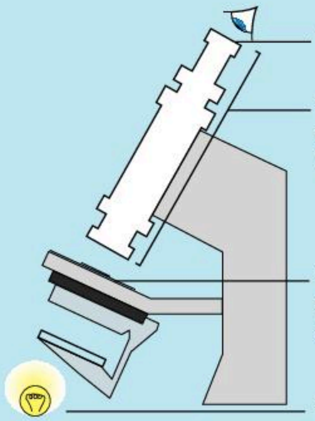
▲ A cell from the inside of the liver, viewed using a light microscope (magnified × 1500 times)



▲ A palisade cell from a leaf, viewed using a light microscope (magnified × 500 times)

The light microscope

Cells are too small to see with the naked eye so a **microscope** is used to study them. Visible light passes through a suitable specimen, and a series of lenses magnify the image that is formed. A light microscope can give a useful magnification of about 400 times, which means the image seen is actually 400 times larger than the specimen. The contrast between different structures in the image can be improved by using dyes or stains. The nucleus of an animal cell, for example, shows up particularly well when stained with a dye called **methylene blue**, and plant cells often show up better when stained with **iodine solution**.



A typical animal cell is about one-fortieth of a millimetre in diameter. This is rather a clumsy term, so scientists use smaller units: one metre (m) contains 1000 millimetres (mm), and one millimetre contains 1000 micrometres (μm). So a typical animal cell is about 25 μm in diameter.

The **size** of a structure or an organism is measured in **units of length** (such as mm or m). When a diagram is made, or a photograph taken, it may not be easy to directly show the correct size – for example, when a structure is extremely small or very large. The correct (or true) size of an organism can be calculated using a combination of actual measurement and a known magnification.

$$\textbf{Magnification} = \frac{\textbf{Measured length}}{\textbf{Actual length}}$$

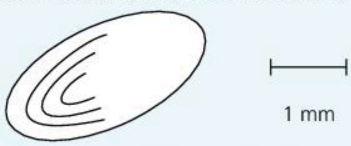
$$\text{or } \textbf{Actual (true) length} = \frac{\textbf{Measured length}}{\textbf{Magnification}}$$

For example, look at this poppy seed.

Mag × 50

$$\text{Actual length} = \frac{5}{50} = \frac{1}{10} = 0.1 \text{ mm}$$

We can also use a **scale line** to work out magnification



$$\textbf{Magnification} = \frac{\textbf{Measured}}{\textbf{Actual}} = \frac{10}{1} \times 10$$

▲ Calculating magnification and size

Tips!

1. Make sure that measured and actual lengths are given in the same units.
2. To help remember the formula:
   $\textbf{Magnification} = \frac{\textbf{Measured}}{\textbf{Actual}}$
3. Core students can use millimetres as a unit. Extension students may need to use millimetres and micrometres.

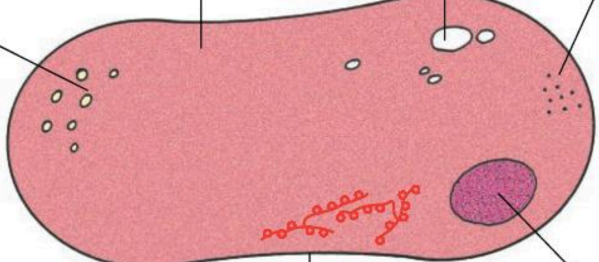
Secretory vesicles containing cell products such as hormones or enzymes are much more common in animal cells.

Cytoplasm of animal cells is often denser, with many more organelles and dissolved substances.

Vacuoles are small and temporary. They can be involved with digestion (e.g. in phagocytes) or with excretion (contractile vacuoles may remove excess water).

Glycogen is the storage form of carbohydrates.

Animal cell features often relate to **heterotrophic nutrition** and high rates of **metabolic activity** (e.g. liver cell).



The absence of the cellulose wall means that animal cells may be **very irregular in shape**. The amount of cytoplasm that can be controlled by the nucleus is limited, so that animal cells may be **quite small** – about 25 μm in diameter.

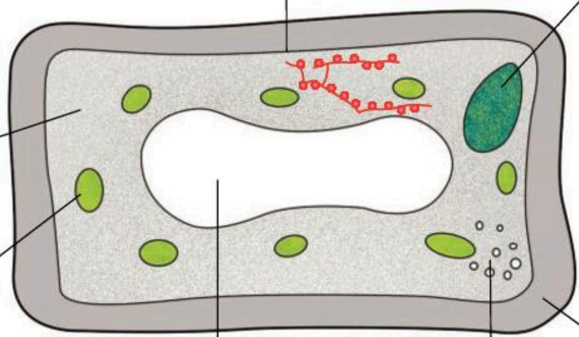
Plant and animal cells have common features which relate to maintaining the characteristics of life.

Do not confuse the cell wall with the cell surface membrane.

Cell surface membrane surrounds the cytoplasm. It controls the **entry and exit** of dissolved substances and separates the cell's contents from its surroundings.

Nucleus contains the genetic material (**DNA** which makes up **genes** on the **chromosomes**). This carries the coded instructions for controlling the activities and characteristics of the cell. The chromosomes only become visible during cell division.

Plant cell features often relate to **autotrophic** nutrition. (e.g. palisade cell of leaf).



The presence of the cellulose cell wall means that plant cells tend to be **regular in shape**. The presence of the vacuole means that plant cells may be **quite large** – often 60 μm (or 0.06 mm) in diameter.

Cytoplasm contains water and dissolved substances such as sugars and salts.

Chloroplasts contain the pigment **chlorophyll** (for light absorption) and the **enzymes** necessary for the production of glucose by photosynthesis.

Large permanent vacuole contains water necessary to provide turgor pressure and may store ions and molecules.

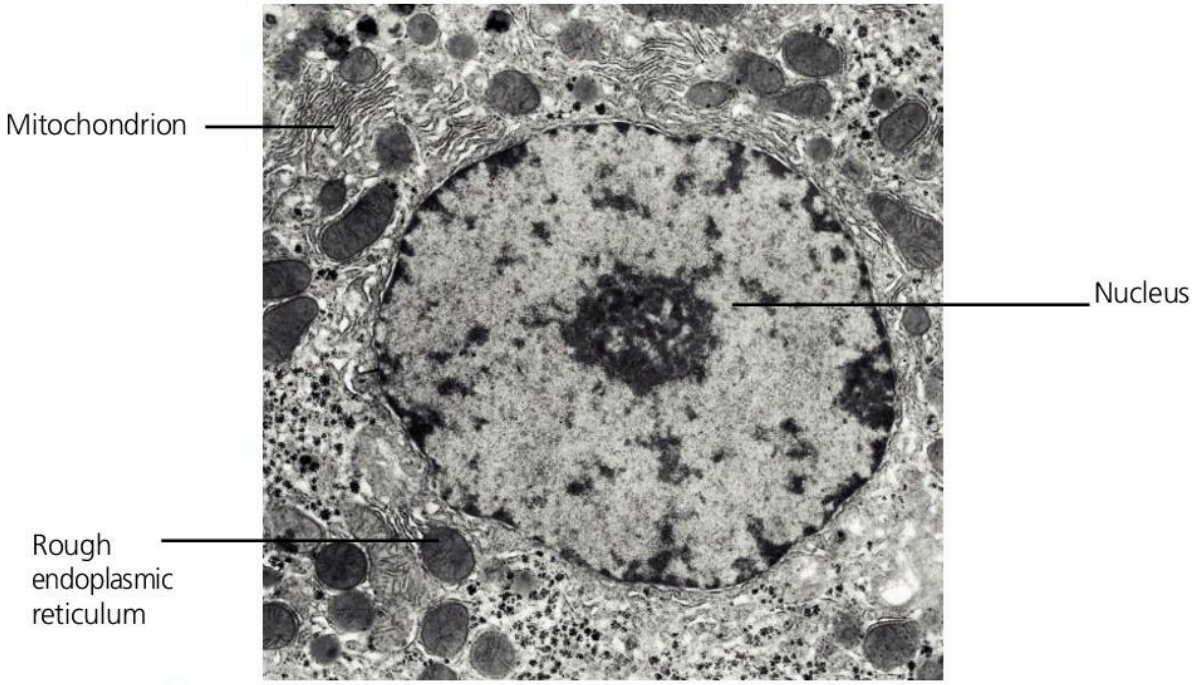
Starch (in the cytoplasm or the chloroplasts) is the storage form of carbohydrates.

Cellulose cell wall provides structural support (pressure of cell contents leads to **turgidity**) and protects against damage caused by osmotic intake of water. The cell wall is **freely permeable to water and dissolved substances.**

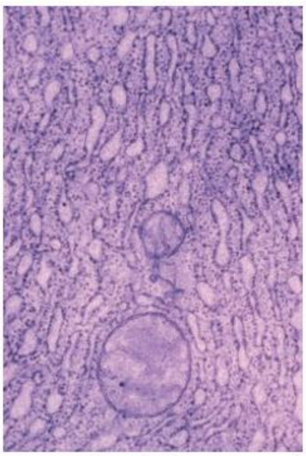
▲ The features of plant and animal cells allow these cells to carry out the basic processes of life. The differences between plant and animal cells are due to the differences in lifestyles of animals and plants, especially to their different methods of nutrition.

Structures within the cytoplasm

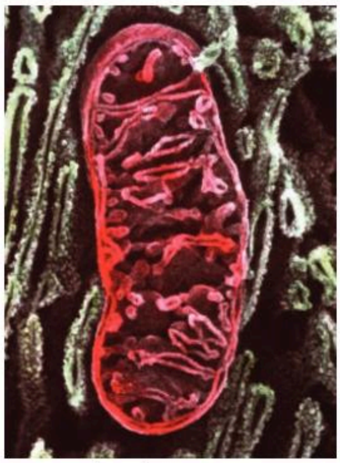
Some organelles are so small that they cannot be seen clearly using a light microscope. However, an electron microscope is capable of showing these minute structures, including **mitochondria** and **rough endoplasmic reticulum**.



▲ Animal cell viewed through an electron micrograph



▲ Rough endoplasmic reticulum



▲ Mitochondrion

Rough endoplasmic reticulum is made up of flattened membranes with ribosomes on their surface. These are the sites of protein synthesis (see page 210) and so are common in cells which make many proteins (liver cells, for example).

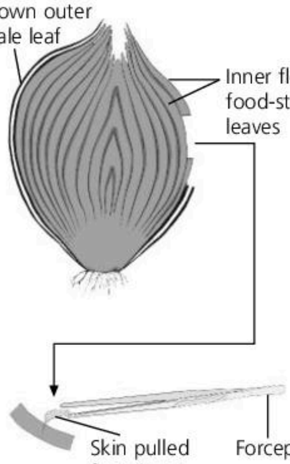
Mitochondrion (plural: mitochondria) is made up of membranes which provide a large surface area for some of the reactions of aerobic respiration. This process releases energy needed to perform work in the cell (see page 123). The mitochondria are like powerhouses, and there are many of them in cells that require a lot of energy. Muscle cells, nerve cells and cells in the liver have many mitochondria.

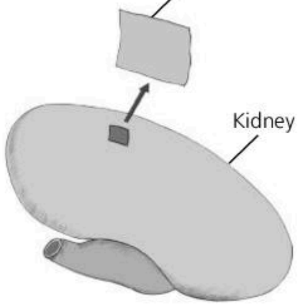
Cell investigations

1 LOOKING AT CELLS

Plant cells

1. Use a razor to cut a small piece out of an onion leaf. Use forceps to peel skin off the inner surface of the leaf. Put the skin into a Petri dish of water.
2. Put a drop of iodine solution onto a slide. Put a small piece of the onion skin (less than 5 mm) into the solution and smooth it out so there are no folds. Lower a coverslip over it, taking care not to trap any bubbles. Prepare another slide in the same way but using water instead of the iodine solution.
3. Study the stained onion cells under the low, medium and high power of a microscope, then look at unstained cells. What parts of the cell have become stained?





Animal cells

4. Use a razor and forceps to peel pieces of transparent skin off the outside of a kidney. Make a slide of the skin in water, and another in iodine.
5. Study stained and unstained cells. How are they different?
6. Draw plant and animal cells and list their *similarities* and *differences*.

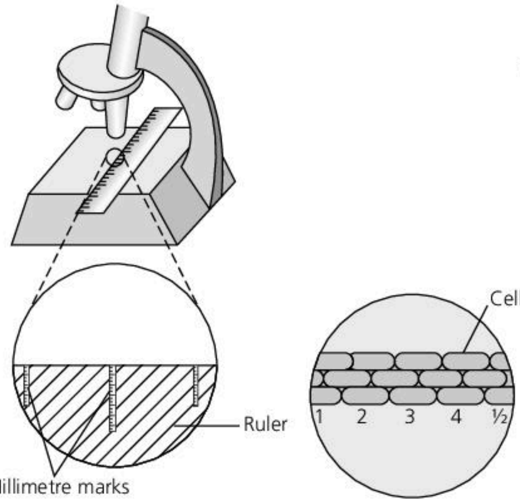
2 MEASURING CELLS

Measuring a field of view

1. Place a clear plastic ruler under a microscope and focus on it with low power magnification. How many millimetres wide is the field of view?
2. Remember: 1 mm = 1000 µm. Convert your field of view to micrometres (µm).

Measuring onion cells

3. Prepare a slide of onion cells. Look at the slide under low power magnification. How many cells fit across the field of view? In the drawing, four and a half cells fill a field of view 2200 µm wide. What is the average length of each cell?
4. What is the average length (in µm) of onion cells in your slide? Turn the slide around and calculate the average width of the cells.
5. You now know the length in µm of one onion cell. Use this information, and your onion slide, to calculate the field of vision in µm under medium and high power magnification.



Hazard warning

Razors (and scalpels) are sharp, handle with care.

Q

1. An onion is a bulb, rather like a daffodil. The bulb sends up a shoot with a flower at the tip. Assume that the shoot is 25 cm tall. Calculate the smallest number of onion cells which would reach along this length. (First convert 25 cm to mm).
2. Onion cells stay still when you are examining them under a microscope. Think of trying to examine a small moving single-celled animal. Suggest how you could slow down the movement of the animal and so make measurement easier.

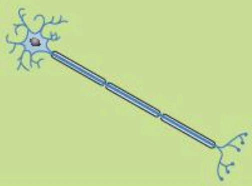
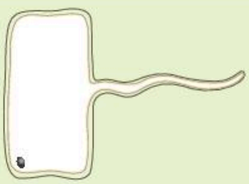
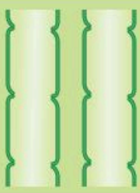
2.2 The organisation of living organisms

OBJECTIVES

- To understand that the body of a living organism is a highly organised structure
- To understand that cells, tissues, organs and systems represent increasing degrees of organisation in living organisms

Specialised cells

Large organisms are **multicellular** – they are made up of many cells. Different types of cell have particular structures designed to help them carry out different tasks and functions – they have become **specialised**. Some examples of specialised cells, and their functions, are shown in the table.

Cell type	Appearance	Functions and adaptations
Animal cells		
Red blood cell (page 96)		**Transports** oxygen from the lungs to the tissues where aerobic respiration occurs. The cytoplasm is filled with the pigment haemoglobin, which carries oxygen. The cells have no nucleus, leaving more space for haemoglobin, and they are very flexible (they can be forced through even the narrowest of blood vessels).
Ciliated cell (page 129)		Has a layer of tiny hairs (cilia) which can **move and push mucus** from one place to another. The mucus can transport trapped dust and microbes when it is pushed by the cilia.
Motor nerve cell (page 157)		**Conducts nerve impulses.** The cell has a long fibre called an axon along which impulses travel, a fatty sheath which gives electrical insulation, and a many-branched ending which can connect with many other cells.
Other important specialised animal cells are the gametes, sperm and egg (page 190). These are specialised for **fusion to form a zygote**. The sperm (male) is able to swim and the ovum (female) has a large food store. Each of them has the haploid number of chromosomes.		
Plant cells		
Root hair cell		**Absorbs minerals and water** from the soil water. The cell has a long extension (a root hair) which increases the surface area for the absorption of materials.
Xylem vessel		**Transports water and supports the plant.** The cell has no cytoplasm (so water can pass freely), no end wall (so that many cells can form a continuous tube) and walls strengthened with a waterproof substance called lignin.
Another important specialised plant cell is the palisade mesophyll cell (page 50). This cell has many chloroplasts and a shape that allows many of them to pack together in the regions of highest light intensity for the **maximum absorption of light energy**.		

Specialised cells combine to form tissues ...

Cells with similar structures and functions are massed together in **tissues**. Some plant and animal tissues are shown in the tables below.

Animal tissue	Main functions
Epithelium	Lines tubes such as the gut and covers surfaces such as the skin
Connective tissue	Binds and strengthens other tissues, such as tendons
Blood	Transports substances around the body, and defends against disease
Skeletal tissue	Supports and protects softer tissues, and allows movement
Nervous tissue	Sets up nerve impulses and transmits them around the body
Muscle tissue	Contracts to support and move the body

Plant tissue	Main functions
Epidermis	Protects against water loss, and may be involved in absorption of water and ions
Mesophyll	Photosynthesis
Parenchyma	Fills spaces between other plant tissues and may be involved in storage, as in the potato tuber
Vascular tissue	Transports materials through the plant body
Strengthening tissue	Supports the plant

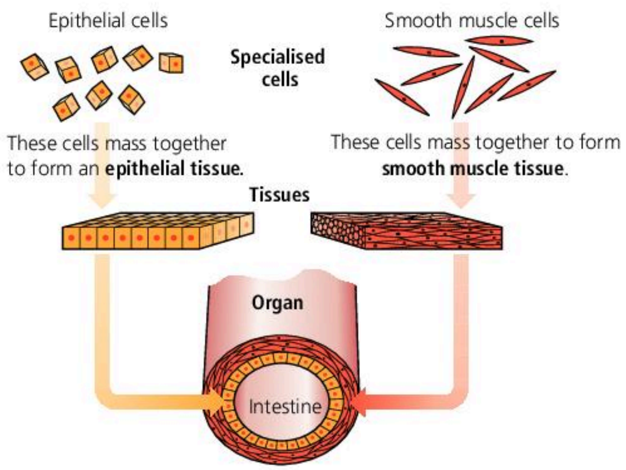
... tissues combine to form organs ...

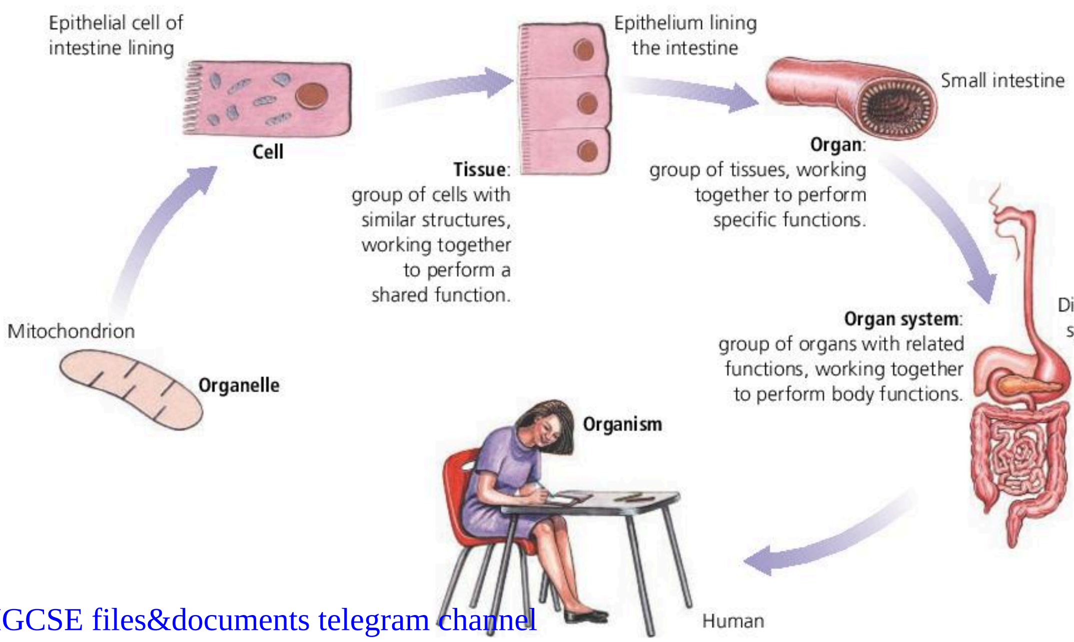
Several tissues may be combined to form an **organ**, a complex structure with a particular function, such as the small intestine shown right.

... organs combine to form organ systems

In complex organisms, several organs work together to perform a particular task. These organs form an **organ system**.

Each cell, tissue and organ in an organism has a specialised part to play (there is **division of labour**) but their activities must be coordinated.





Questions on cells and organisation

1 Arrange these biological terms in order of size (from the smallest to the largest): [3]

organ, cell, organism, organelle, tissue, system.

2 Arrange these units of length in order, starting with the largest and ending with the smallest:

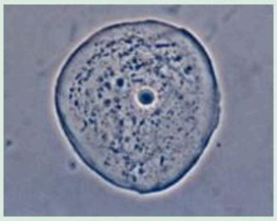
kilometre, micrometre, metre, millimetre. [2]

An average plant cell is 50 micrometres long. How many plant cells could fit into one millimetre? Show your working. [2]

3 Look at these photomicrographs (photographs taken through a microscope).

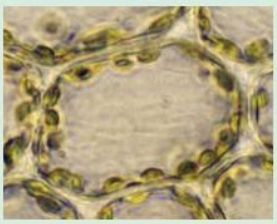
12 µm

Epithelial cell



35µm

Palisade cell



a List **three** differences between the epithelial and palisade cells, and **three** common features which they share. Why are there differences between these cells? [7]

b Use the scales to calculate the following in µm:

i the height of the palisade cell

ii the width of the palisade cell

iii the width of the epithelial cell at its widest point

iv the length of a single chloroplast

v the length of an animal cell nucleus. [5]

4 Copy and complete this table by placing a tick if the structure is present and a cross if it is not.

Structure	Liver cell	Palisade cell
Cell surface membrane		
Chloroplasts		
Cytoplasm		
Cellulose cell wall		
Nucleus		
Starch granule		
Glycogen granule		
Large, permanent vacuole		
Mitochondrion		
Ribosome on endoplasmic reticulum		

[10]

5 The table below describes some cell structures. Match each structure with its description. Write the letter and number to show your answer, for example, **a–4**.

Structure	Description
a Cell membrane	**1** Structures which contain chlorophyll
b Cell wall	**2** Cavity found only in plant cells
c Chloroplasts	**3** Surrounds a plant cell and contains cellulose
d Cytoplasm	**4** Main site of protein synthesis
e Mitochondria	**5** Sites of aerobic respiration
f Endoplasmic reticulum	**6** Controls entry and exit of substances
g Nucleus	**7** Carries genetic information and controls cell activities
h Vacuole	**8** Site of anaerobic respiration

[7]

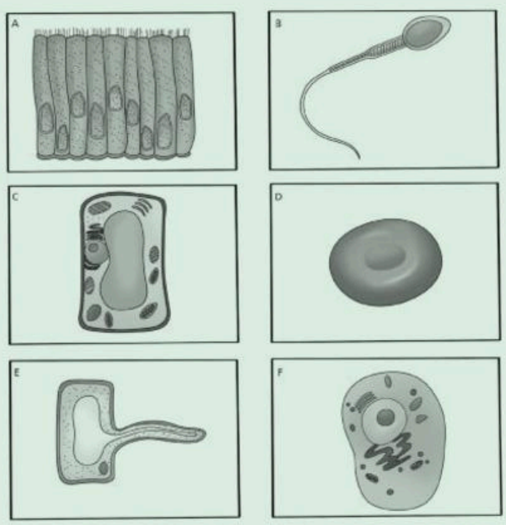
6 The following diagrams show six cells. One of the cells transports oxygen in the blood. This cell does not contain a nucleus.

a **i** Give the letter of the cell that transports oxygen in the blood. [1]

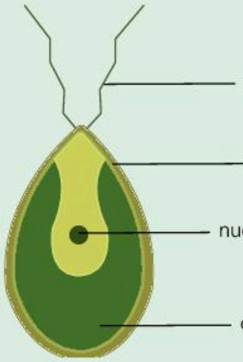
ii State the function of the nucleus in most cells. [1]

b **i** State the letters of two plant cells. [2]

ii State the letter of the cell with a surface adapted for the uptake of minerals. [1]



7 The diagram shows a single-celled organism called *Chlamydomonas*. This organism is able to swim about in the small pools of water where it lives.



a In the table below, which set of numbers (A, B, C or D) correctly relates functions of cell parts to the structures labelled in the diagram?

	Function			
	Protection against bursting	Photosynthesis	Movement	Control of cell activities
A	2	4	1	3
B	1	3	2	4
C	4	2	1	3
D	2	4	3	1

[1]

b State **three** structures in the *Chlamydomonas* cell that would **not** be found in a sperm cell. [3]

8 On the following diagram of a liver cell, identify:

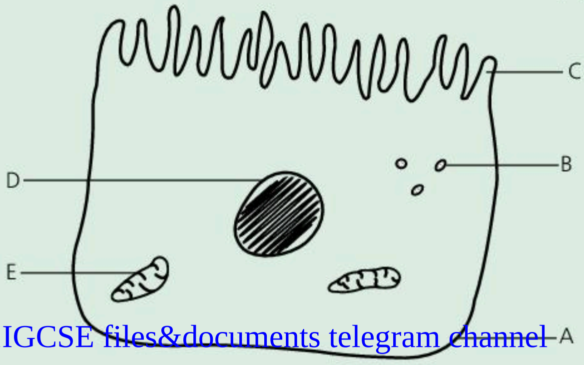
a which structure carries out aerobic respiration

b which structure controls the movement of salts into the cell

c which structure would carry the genes

d which feature increases the surface area of the cell

e which structure is a food store. [4]



9 Use words from this list to complete the following paragraphs. The words may be used once, more than once or not at all.

palisade cell, epidermis, tissues, excretory system, specialised, cells, blood, kidney, chloroplasts, leaf, red blood cell, division of labour, xylem, phloem, nervous, systems, endocrine, organ.

a Large numbers of ____ that have the same structure and function are grouped together to form ____, for example ____. Several separate tissues may be joined together to form an ____ which is a complex structure capable of performing a particular task with great efficiency. In the most highly developed organisms, these complex structures may work together in ____, for example the ____ in humans is responsible for the removal of the waste products of metabolism. [6]

b The structure of cells may be highly adapted to perform one function, i.e. the cells may become ____. One excellent example is the ____ which is highly adapted to carry oxygen in mammalian blood. If the different cells, tissues and organs of a multicellular organism perform different functions they are said to show ____. One consequence of this is the need for close co-ordination between different organs – this function is performed by the ____ and ____ systems in mammals. [5]

c In plants, an example of a cell highly specialised for photosynthesis is the ____ which contains many ____. These cells are located in the organ called the ____ which also contains other tissues such as ____ which limits water loss and ____ which transports water and mineral ions to the leaf. [5]

3.1 Movement in and out of cells: diffusion

OBJECTIVES

- To understand that the contents of a living cell must be kept separate from its surroundings
- To know that the cell surface membrane can act as a barrier to some substances which might pass between a cell and its surroundings
- To understand the principles of diffusion, osmosis, active transport and phagocytosis

On page 22, we saw that the cell cytoplasm is surrounded by a **cell surface membrane**. This acts as a boundary between the cell contents and its surroundings – it has very little strength, but it plays a vital role in regulating the materials that pass in and out of the cell. Materials may pass in and out of cells by:

- **diffusion**
- **osmosis**
- **active transport**
- in special cases, **phagocytosis**.

Diffusion – 'mixing molecules'

Molecules and ions in a liquid or a gas move continuously. The movement is quite random, and the particles change direction as they bump into one another. The particles collide more often when they are close together (when they are **concentrated**) and so they tend to **diffuse**, or spread out, until they are spaced evenly throughout the gas or liquid.

E The random movement of the particles is due to their own **kinetic energy**. When diffusion happens in living cells, the cells themselves do not have to expend any energy for it to take place.

If there is a region of high concentration and a region of low concentration, we can say that there is a **concentration gradient** between the regions. We can therefore define **diffusion** as:

- **the net movement of molecules within a gas or liquid**
- **from a region of high concentration to a region of lower concentration (down a concentration gradient)**
- **as a result of their random movement**
- **until an equilibrium is reached.**

Partially permeable membranes

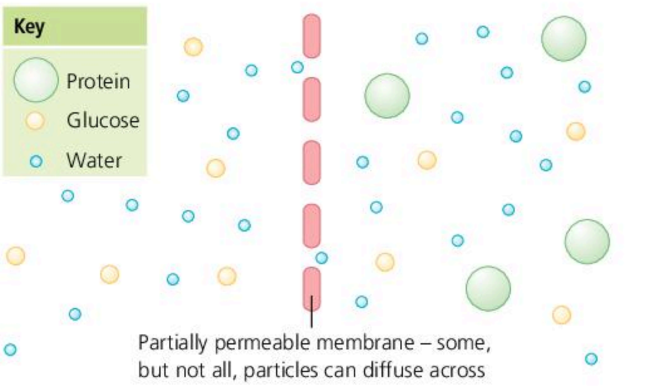
Not all particles can diffuse through cell surface membranes. Sometimes the particles are too big, or they have the wrong electrical charge on them, or the chemical composition of the membrane prevents them passing across. The diagram below shows a **partially permeable membrane** – it is **permeable** to glucose and water but **impermeable** to protein.

Diffusion and life processes

Diffusion is the main process by which substances move over short distances in living organisms. Some of the life processes that involve diffusion are shown in the diagram above right.

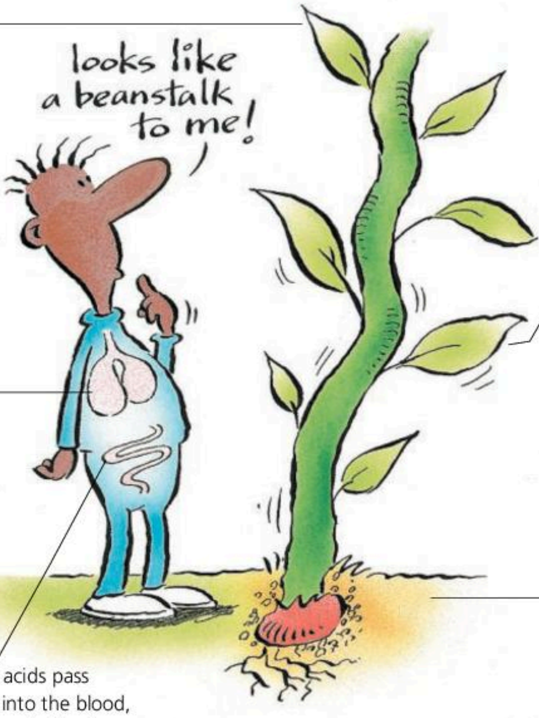
S Living organisms have certain adaptations to speed up diffusion:

- **Diffusion distances are short** – the membranes in the lungs, for example, are very thin so that oxygen and carbon dioxide can diffuse between the blood and the lung air spaces.
- **Concentration gradients are maintained** – glucose molecules that cross from the gut into the blood, for example, are quickly removed by the circulating blood so that their concentration does not build up and equilibrium is not reached.
- **Diffusion surfaces are large** – the surface of the placenta, for example, is highly folded to increase the surface area for the diffusion of molecules between a pregnant female and the developing fetus in her uterus.



▲ The overall (net) movement of glucose and water molecules depends on their concentration gradient. Protein molecules cannot diffuse across this membrane, even though the concentration gradient suggests that they should move from right to left.

Life depends on the exchange of materials between different cells, and between cells and their surroundings. For example, a plant absorbs carbon dioxide from its surroundings by diffusion, and the carbon dioxide passes through the leaf to the photosynthesising cells by the same process.



Oxygen produced by photosynthesis diffuses out of the plant into the air. It enters the boy's lungs as he breathes in. The lungs are adapted to speed up the diffusion of oxygen into the blood, because they have thin surfaces with a very large surface area.

From the lungs, oxygen enters the blood by diffusion. The continual movement of the blood keeps up a high concentration gradient between the air and the blood.

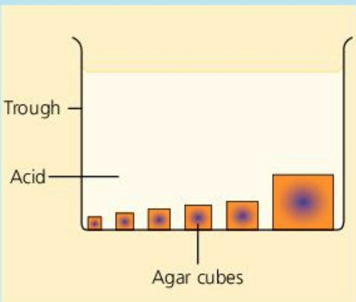
Mineral ions from the soil solution are absorbed by plant roots. This process depends upon diffusion, as well as on active transport.

Glucose and amino acids pass from inside the gut into the blood, partly by the process of diffusion.

▲ Many life processes depend on diffusion to move substances around. Diffusion has no 'energy cost' to a living organism.

How surface area affects rate of diffusion

In an investigation to measure the speed of diffusion, cubes of agar which had been stained purple with an indicator solution were placed in dilute acid as shown in the diagram. The time taken for each cube to turn completely orange is shown in the table.



Length of side of cube / mm	Time taken to turn orange / s	Surface area of cube (total of 6 sides) / mm^2	Volume of cube / mm^3	Surface area to volume ratio (surface area ÷ volume)
1	20			
2	41			
3	76			
4	104			
5	188			
10	600			

a Copy and complete the table. Plot a graph of surface area to volume ratio against time taken to turn orange. Plot time taken on the vertical axis.

b What do the results suggest about the efficiency of diffusion in supplying materials to the centre of an organism's body?

c Suggest methods which organisms might use to improve the supply of materials by diffusion. Try to provide examples of these methods.

Q

1 Using an example, explain what is meant by a partially permeable membrane.

2 What is a concentration gradient?

3 List the processes in living organisms that are dependent on diffusion.

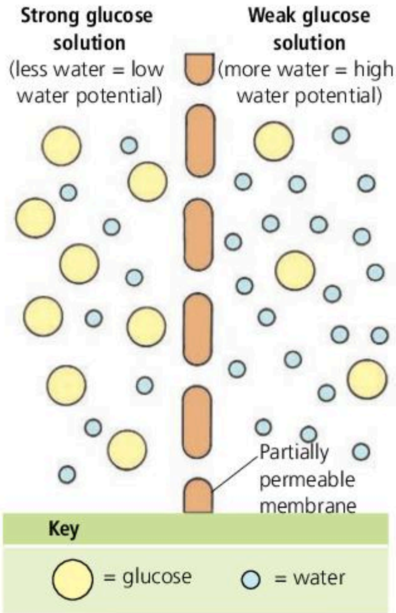
4 Explain how living organisms are adapted to increase the possibility of diffusion.

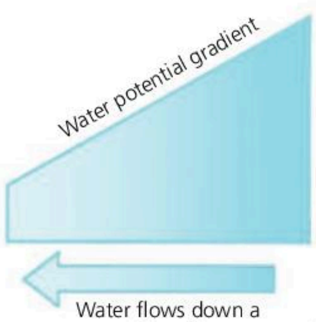
3.2 Movement in and out of cells: osmosis

Osmosis is a special case of diffusion

The biochemical processes in living cells always take place in a **solution**. A solution is made up of a **solvent** (the dissolving fluid) and a **solute** (the particles dissolved in the solvent). In living organisms, the solvent is water and the solution is called an aqueous solution.

Living cells are separated from their surroundings by the **partially permeable cell surface membrane**. The contents of the cell,
the cytoplasm, is one aqueous solution and the surroundings of the cell, for example pond water, is another aqueous solution. If the two solutions do not have the same concentrations of various substances, molecules can move from one to the other by diffusion, if the membrane is permeable to these substances.





Water flows down a water potential gradient – osmosis

The diagram on the left shows two glucose solutions separated by a partially permeable membrane – this membrane will allow the diffusion of water molecules but not glucose (the solute) molecules. As a result, water can move from the right, where there is a high concentration of water molecules, to the left, where there is a lower concentration of water molecules, by the process of diffusion. This diffusion of water is called **osmosis**, and will continue until a water equilibrium has been reached.

S Because it is sometimes confusing to talk about water 'concentration', biologists use the term **water potential** instead. A solution with many water molecules has a **high water potential**, and a solution with few water molecules has a **low water potential**. In the diagram, a **water potential gradient** exists between the two solutions, and water molecules can flow down this gradient from right to left.

Osmosis can be defined as:

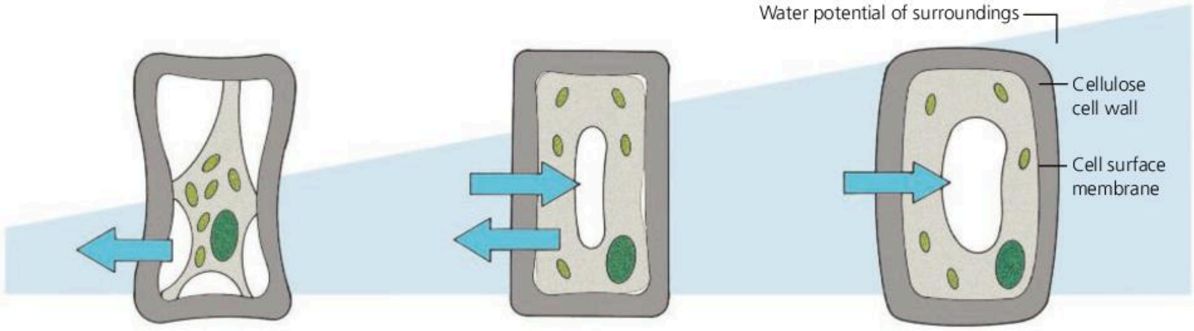
- **the diffusion of water molecules**
- **from a region of higher concentration of water molecules to a region of lower concentration of water molecules**
- S **down a water potential gradient**
- **through a partially permeable membrane.**

Cells and osmosis

A cell is surrounded by a partially permeable membrane, and water may cross this membrane easily. If a cell is placed in a solution of lower water potential, water leaves the cell by osmosis. If the cell is placed in a solution of higher water potential, water enters by osmosis.

Plant cells and osmosis

If water enters a plant cell by osmosis, the cytoplasm will swell but only until it pushes against the cellulose cell wall, as shown below. A plant cell will not be permanently damaged by the entry of water. If water leaves a plant cell by osmosis, the cytoplasm will shrink but the cellulose cell wall will continue to give some support. Plant cells rarely suffer permanent damage through the loss of water.



Cell in solution of lower water potential than cell contents – water leaves by osmosis. The cytoplasm pulls away from the cell wall and the cell becomes **flaccid** ('floppy').

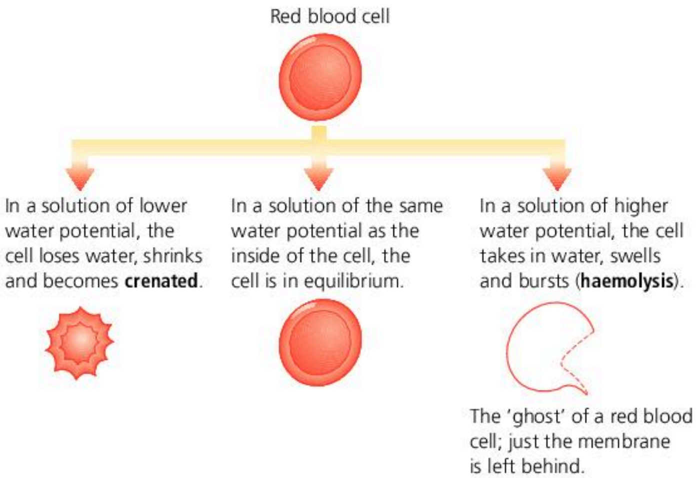
Cell in solution of equal water potential – no *net* movement of water; cytoplasm just presses against cell wall.

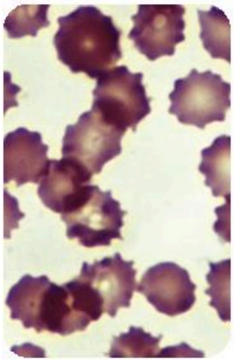
Cell in solution of higher water potential – water enters by osmosis. The cytoplasm pushes hard against the cell wall and the cell becomes **turgid** (firm).

Animal cells and osmosis

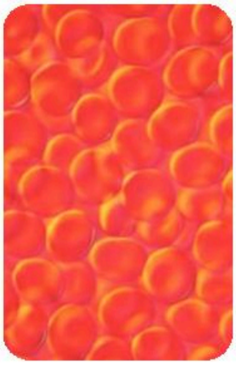
Animal cells have no cell wall, just a membrane. They are likely to suffer damage as a result of osmosis, as shown in the diagram below.

Osmosis is potentially damaging to animal cells, and animals have mechanisms to keep the blood plasma and the body fluids at the same water potential as the cytoplasm of cells. In mammals, the kidney plays a vital part in this process of **osmoregulation** (see page 140).





▲ Crenated red blood cells



▲ Red blood cells in equilibrium

3.3 Movement in and out of cells: active transport

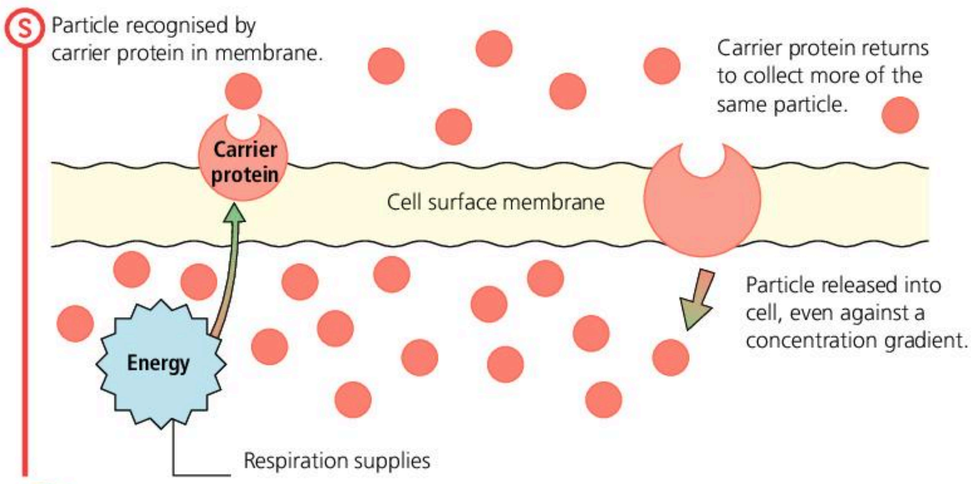
Active transport requires energy to move materials

Molecules and ions can move from one place to another by diffusion, but only until an equilibrium has been reached. If no concentration gradient exists between the two places, no diffusion can occur – this means that if an equilibrium has been reached, useful particles cannot be absorbed by diffusion. **Active transport** is a method by which particles can cross membranes even against a concentration gradient. In active transport, protein molecules in the cell surface membrane pick up and carry particles across the membrane. These protein molecules are called **carriers**, and when they work they use energy supplied by the cell. Active transport is explained in the diagram below, and important examples of its use are the uptake of ions by plant root hairs (page 88) and the uptake of glucose by epithelial cells of the villi. To summarise – active transport:

- **can move molecules against a concentration gradient** but
- **requires energy** and
- **involves protein carriers in membranes.**

Some cells use phagocytosis*

Some particles are too large to cross a membrane by diffusion or by active transport. A few very specialised cells have developed a method for taking up these particles – the particles are literally engulfed by the cell surface membrane flowing around them. This process of **phagocytosis** is used by white blood cells, and is described on page 117.



◀ Active transport uses energy to move substances against a concentration gradient. The protein carriers involved in active transport are rather like enzymes. They are able to recognise particular molecules and select them from a mixture. As a result active transport is specific, and the cell can 'choose' which molecules it absorbs from its surroundings.

Q

1 Copy and complete the following paragraphs.
Animal cells contain ____, a semi-fluid solution of salts and other molecules, and are surrounded by a ____. When in distilled water, the animal cells ____ because the cell has a ____ water potential than the surrounding water. Plant cells do not have this problem because they are surrounded by a ____.
In the gut, soluble food substances such as ____ cross the gut lining into the capillaries by the process of ____, which is the movement of molecules down a ____. When an equilibrium is reached between the gut contents and the blood, glucose may continue to be moved using the process called ____, which consumes ____ and can move molecules ____ a concentration gradient.
The leaves of green plants obtain the gas ____, which they require for the process of photosynthesis, by the process of ____. They also lose the gas oxygen, produced during ____, by the same process.

2 Make a table that compares diffusion with active transport. Include one example of each process in your table. Under what circumstances would an organism use phagocytosis rather than diffusion or active transport?

Questions on diffusion and osmosis

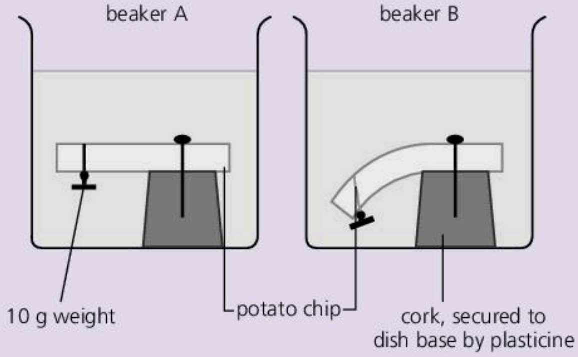
1 Using **only** the information in the following passage and the figure below, answer questions **i** to **v**.

> **When a plant's cells are fully inflated by water the plant is said to be turgid. Each cell pushes against nearby cells and together they help to support the plant. If water is lost and not replaced each cell loses turgor. Cells in this state are said to be flaccid.**

i What does the term turgid mean? [1]

ii How does turgor play a part in the support of plant tissues? [1]

The figure below shows the results of an experiment.



iii Which beaker is likely to contain pure water? [1]

iv Which potato chip is flaccid? [1]

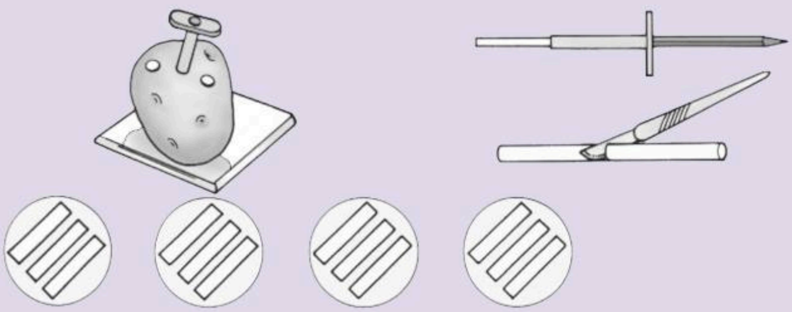
v What would happen if the potato chip from beaker B was placed in beaker A for 24 hours? Explain your answer. [2]

2 A student carried out an investigation based on the one in the diagram using a range of sugar solutions. He obtained the results below.

a Copy and complete the table, and present the results in a suitable graph. [5]

b Use the graph to calculate the sugar concentration inside the potato cells. Explain your answer. [2]

c Why is it useful to present the results in terms of 'percentage change' in length? [2]



Concentration of sugar solution / mol per dm^3	Length of cylinder at start / mm	Mean length / mm	Length of cylinder after 24 hours / mm	Mean length / mm	Percentage change
0.0	50, 50, 50		54, 52, 55		
0.1	50, 49, 50		53, 52, 53		
0.2	50, 50, 50		51, 52, 51		
0.3	50, 51, 49		49, 49, 49		
0.4	50, 50, 50		47, 47, 48		
0.5	50, 51, 51		45, 47, 46		

4.1 Biological molecules

OBJECTIVES

- To understand that the structures of living things depend on the molecules that make them up
- To list the types of molecule found in living organisms

Organic molecules

Biological molecules are often called **organic** molecules, because many of them were discovered in living organisms. Chemists have found that organic molecules all contain carbon and hydrogen atoms (often along with other elements). Carbon atoms bond strongly to other carbon atoms, so organic molecules can be large and show a wide variety of chain and ring structures, with many carbon atoms bonded together. Organisms need organic molecules to:

- provide **energy** to drive life processes
- provide **raw materials** for the growth and repair of tissues.

Nutrition supplies living organisms with the molecules that they need. There are four main groups of organic chemicals used by living things:

- **carbohydrates**
- **lipids**
- **proteins**
- **nucleic acids**.

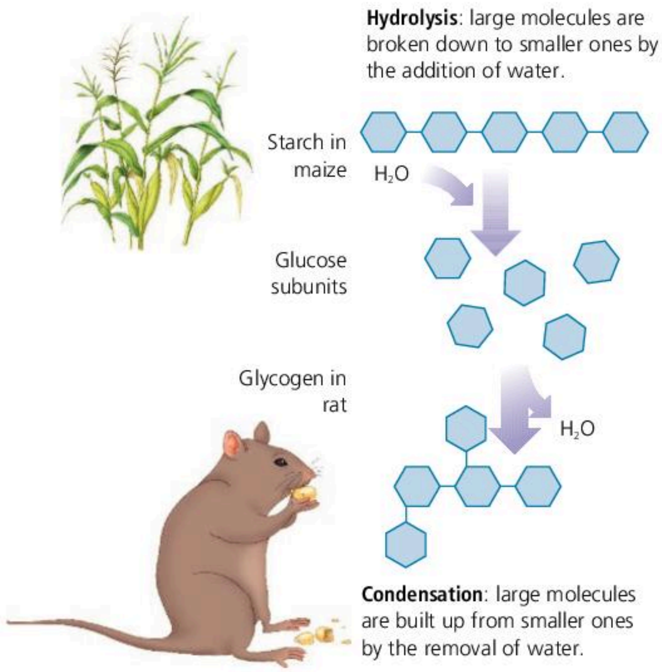
The diagram on the next page shows the structures of these different groups of organic molecules: note which elements they contain.

Basic biochemistry*

Living organisms also contain inorganic molecules (such as water) and a number of ions. The study of the organic and inorganic molecules that make up living organisms is called **biochemistry**. The sum of all the chemical reactions in living organisms is sometimes called **metabolism**.

Large organic molecules are usually made up of lots of similar smaller molecules called **subunits**. The subunits can be split apart by a reaction called **hydrolysis**, which uses water. They can be joined together again, perhaps in new combinations, by a reaction called **condensation**, which produces water (see opposite page).

In this way living organisms can take molecules from their environment and rearrange them into shapes that suit their own particular requirements, as illustrated below.



▲ The carbohydrate starch in the maize is hydrolysed in the rat's cells into subunits called glucose. These are then built up into the carbohydrate glycogen by condensation reactions.

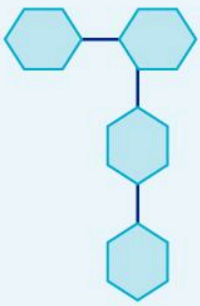
Q

1. List the main groups of organic compounds found in living organisms. Suggest one important function for each group.
2. Some molecules such as glucose and amino acids are **soluble**, whereas others such as starch and fats are **insoluble**. Why is this physical property important in living organisms?
3. Some scientists would say that nucleic acids are the most important molecules in living cells; others might suggest that proteins are more important; and some might say that life could not continue without a supply of carbohydrates. Write a sentence in support of each of these points of view.

Carbohydrates (page 62)

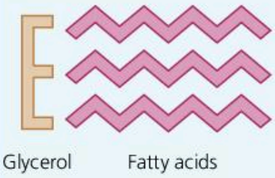
Monosaccharides are the simplest carbohydrates, for example, glucose. Glucose is soluble so it is easily transported in blood and dissolves in the cytoplasm of cells. Monosaccharides are the main source of energy for many cells.

Hydrolysis ⇅ Condensation



Polysaccharides are formed from many monosaccharide molecules – for example, **starch** and **glycogen** are two polysaccharides both made of many thousands of glucose molecules. Polysaccharides are insoluble, so they are good stores of energy and can form important structures such as **cellulose** cell walls.

Lipids (page 62)

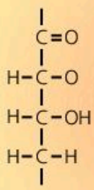


Lipids are formed by the condensation of three molecules of **fatty acid** with one molecule of **glycerol**.

Hydrolysis ⇅ Condensation

Fats (which are solid at room temperature) and **oils** (which are liquid at room temperature) are insoluble in water. As a result, they are excellent stores of energy, and form barriers between watery environments, such as between a cell and its surroundings.

Some contain only carbon (C), hydrogen (H) and oxygen (O)

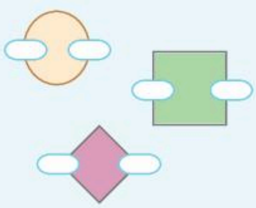


All organic molecules contain the elements **carbon** and **hydrogen**. The simplest organic molecule is methane, CH_4. More complex organic molecules also contain **oxygen**. The biological function of a molecule depends on its shape and structure.

Some also contain nitrogen (N) and sometimes sulfur (S)

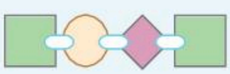
Some also contain nitrogen (N) and phosphorus (P)

S **Proteins** (page 62)



Proteins are made up of long chains of subunits called **amino acids**, joined together in particular sequences which are coded for by genes. The 20 different amino acids can be joined together in a vast number of different orders, and some proteins are thousands of amino acids long. The sequence of amino acids determines the shape of the protein molecule – some are long and thin (such as **keratin**, the protein in hair and nails), whilst others are more egg shaped or spherical. The function of proteins depends on their shape. For example, the **active site** of **enzymes** and the **binding site** of **antibodies** are the areas of these two egg-shaped proteins that bind to their substrates.

Hydrolysis ⇅ Condensation



Amino acids are soluble so they are easily transported in living organisms, and can take part in reactions in the watery cytoplasm of the cell.

S **Nucleic acids** (page 208)

In DNA, these chains are coiled around one another to form a double helix. The sequence of bases forms a code which carries the genetic information. This code is passed from one generation to the next and instructs a cell or an organism to carry out a particular task.

Water as a solvent

As well as taking part in these hydrolysis reactions, water is the most important **biological solvent** (it is able to dissolve other substances).

Water acts as a solvent in:

- digestion (see page 76)
- excretion (see page 140)
- transport (see page 86).

Other important functions of water are described on page 256.

4.2 Testing for biochemicals

OBJECTIVE

- To describe simple chemical tests for the molecules of living organisms

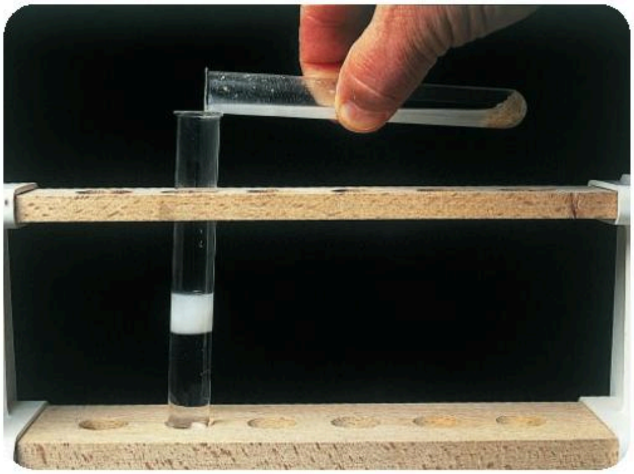
Scientists often need to know whether or not a particular type of molecule is present in a solution. For example, a doctor might try to detect glucose in a urine sample (which suggests the patient has diabetes), or an environmental scientist might test for starch in the outflow from a food factory. There are a number of simple chemical tests that can be carried out on biological solutions. Some of these tests are described on the opposite page.

A special test for lipids

An important feature of fats and oils is that they are insoluble in water. This means that you cannot make an aqueous solution of a fat or oil on which to carry out a biochemical test. However, the fact that lipids are insoluble forms the basis of a **physical test**.

This is known as the **emulsion test**:

- 2 cm^3 of ethanol are added to the unknown solution, and the mixture is gently shaken.
- The mixture is poured into a test tube containing an equal volume of distilled water.
- If a lipid is present, a milky-white emulsion is formed.



▲ A milky emulsion shows that a lipid is present

Q

1 **a** What is the difference between a fat and an oil?
b Both lipids and carbohydrates contain carbon, hydrogen and oxygen. How do they differ from one another?
c Draw a diagram to show a molecule of fat. Suggest why it is possible to have many kinds of fat.

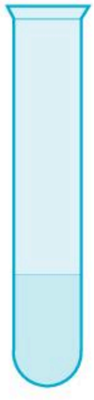
2 Here are the results of a series of tests on biological solutions. Acidification and neutralisation splits sucrose into reducing sugars.

Solution	Colour after testing with reagent:			
	Iodine solution	Benedict's reagent	Biuret reagent	Benedict's reagent after acidification and neutralisation
A	Blue-black	Clear blue	Clear blue	Clear blue
B	Straw yellow	Orange	Purple	Orange
C	Straw yellow	Clear blue	Clear blue	Orange
D	Blue-black	Clear blue	Faint purple	Clear blue
E	Straw yellow	Orange	Clear blue	Orange

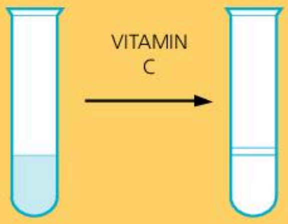
Suggest, giving your reasons, which of these solutions might be:

a the washings from a laundry
b milk
c crushed potato solution
d urine from somebody who has sugar diabetes
e sweetened tea.

3 Describe the two types of control which are used in food tests and explain why they are needed.



Testing for **vitamin C:** using DCPIP
Vitamin C takes the colour out of a blue dye called DCPIP.

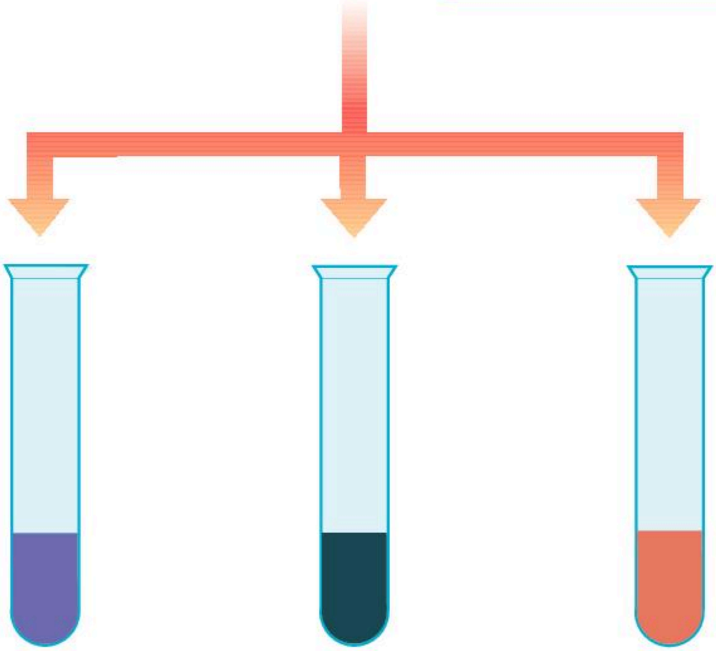


The number of drops of vitamin C solution needed to make this happen depends on how concentrated the vitamin C solution is.

So

few drops: strong vitamin C solution

many drops: weak vitamin C solution



A **control** is needed to make sure that results are valid.

- To show that the test is working properly, a solution that is known to contain the substance is tested (for example, the Biuret reagent is used with a solution known to contain protein). This should give a positive result.
- To show that the test solutions are not contaminated, each test should be carried out on a sample of water. This should give a negative result.

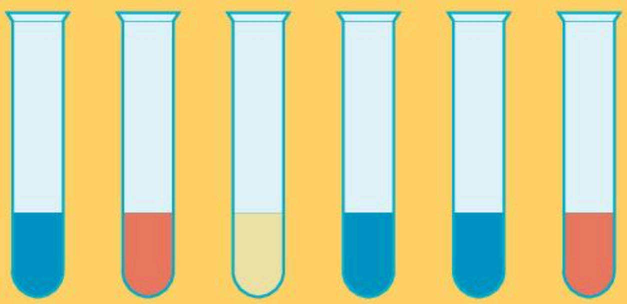
To test for **protein,** a few drops of **Biuret reagent** are added to 2 cm^3 of the unknown solution, and the mixture is gently shaken. A **mauve/purple** colour is a positive result (protein is present).

To test for **starch**, a few drops of **iodine solution** are added to 2 cm^3 of the unknown solution, and the mixture is gently shaken. A **deep blue-black** colour is a positive result (starch is present).

To test for **glucose** (a **reducing sugar**), 2 cm^3 of **Benedict's reagent** are added to 2 cm^3 of the unknown solution, and the mixture is heated in a boiling water bath for 2–3 minutes. An **orange/brick-red** colour is a positive result (glucose is present).

When **making comparisons** between different solutions – for example, to compare the glucose content of different urine samples – it is important to carry out all tests under the same conditions. For example, a series of Benedict's tests should be performed:

- on equal volumes of unknown solutions
- using equal volumes of Benedict's solution
- with all mixtures heated to the same temperature
- for the same length of time.



5.1 Enzymes control biochemical reactions in living organisms

OBJECTIVES

- To appreciate that biochemical reactions in living organisms must be controlled
- To understand how enzymes can act as biological catalysts
- To list and explain the factors that affect enzyme activity
- To list some examples of human exploitation of enzymes

Enzymes are biological catalysts

The sum of all the chemical reactions going on within a living organism is known as **metabolism**. **Anabolic** reactions build up large molecules from smaller ones, and usually require an input of energy. **Catabolic** reactions break down large molecules into smaller ones, and often release energy. The condensation of glucose molecules into the polysaccharide glycogen is an example of anabolism, and this happens in cells of the liver and skeletal muscle. The breakdown of glucose into carbon dioxide and water by respiration is an example of catabolism, and this also occurs in cells of the liver and skeletal muscle. What determines whether glucose molecules are built up into glycogen or broken down into carbon dioxide and water? The answer is **enzymes**. Enzymes are proteins that function as biological **catalysts** (catalysts speed up reactions without themselves being changed by the reaction). The molecules that react in the enzyme-catalysed reaction are called **substrates**, and the molecules produced in the reaction are **products**. Different enzymes are involved in anabolic and catabolic reactions, and so the presence or absence of a particular enzyme controls what will happen to a particular molecule.

Enzymes and cells

Enzymes are synthesised in living cells. Most enzymes work inside the cell – an example of these **intracellular enzymes** is **catalase** (which breaks down harmful hydrogen peroxide in liver cells). Other enzymes are made inside cells and then released from the cell to perform their function – examples of these **extracellular enzymes** include the digestive enzyme **lipase** (which breaks down fats to fatty acids and glycerol) and **amylase**, which converts starch to maltose during germination (see page 184). Enzymes are **specific** – most enzymes work on one kind of substrate only. For example, proteases break down proteins but have no effect on carbohydrates or lipids. This **specificity** results from the complementary shape and fit of the active site and the substrate.

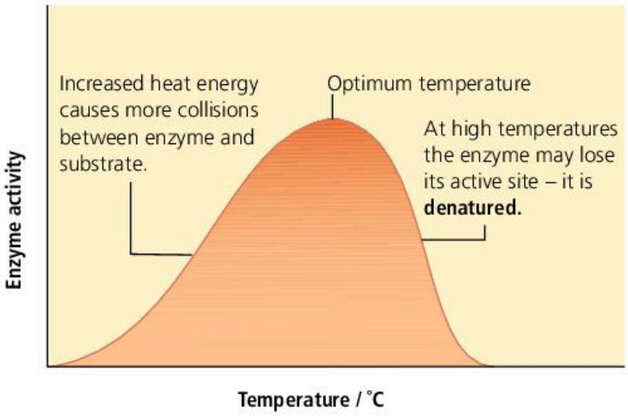
Factors affecting enzyme activity

Temperature

Temperature affects the activity of enzymes. The enzyme activity increases with a rise in temperature, up to a point. This is because:

S
- A higher temperature speeds up the movement of substrate molecules, so that when they collide with the enzyme they have more kinetic energy and are more likely to bind to the active site.
- The enzyme molecules themselves also gain in kinetic energy as the temperature rises so that they begin to vibrate. Eventually

the enzyme molecules vibrate so much that they become **denatured** – they lose their three-dimensional shape and can no longer bind to their substrate. Because of this, high temperatures reduce enzyme activity. Each enzyme has an **optimum temperature**, which is a balance between these two effects, as shown in the graph below. Most human enzymes have an optimum temperature around 37°C, whilst for most plants the optimum is rather lower at around 25°C. Denaturation is usually irreversible, and living cells make great efforts to keep the conditions suitable for their enzymes to work.



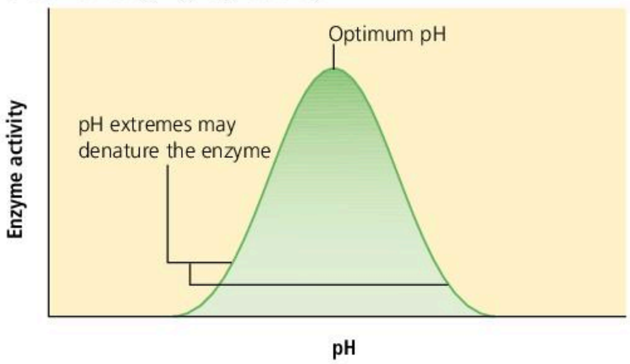
▲ An enzyme-catalysed reaction gets faster, reaches a maximum rate and then slows down again the temperature increases

pH

pH also affects enzyme activity.

Changing the acid or base conditions around an enzyme molecule affects its three-dimensional shape and can denature the enzyme.

Each enzyme has its own **optimum pH**, as shown in the graph below, which depends on the environment in which the enzyme is working – **pepsin** is an enzyme that works in the stomach, and has an optimum pH around pH 2.0 (very acidic), whereas **amylase** works in the mouth and small intestine and has an optimum pH around 7.5 (slightly basic).



Activators and inhibitors

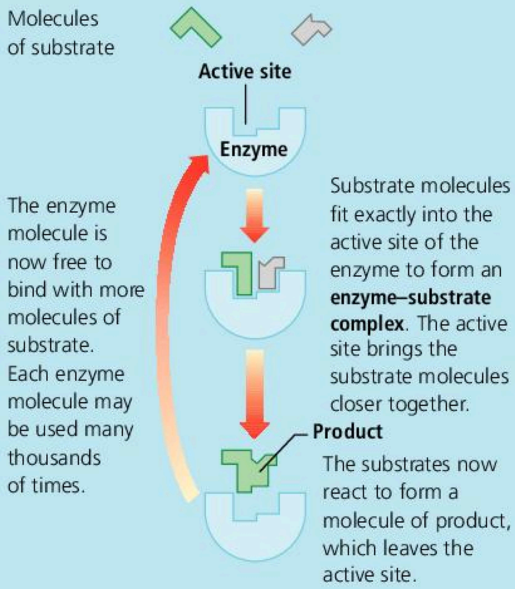
Some molecules change the likelihood of an enzyme being able to bind to its substrate. **Activators** make this binding more likely – for example, chloride ions are essential for the activity of salivary amylase. **Inhibitors** make it more difficult for the enzyme to bind to the substrate – for example, cyanide ions block the active sites of enzymes involved in respiration.

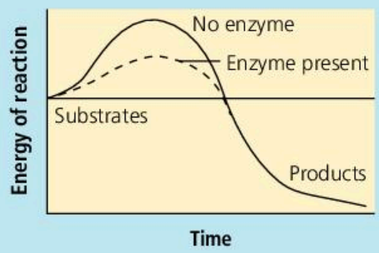
Humans exploit enzymes

Because enzymes are specific, and can be used over and over again, they are very useful in the fields of industry, food preparation and medicine – an enzyme from snake venom can break down blood clots, for example. Other uses are described on page 294.

The mechanism of enzyme action (the lock and key hypothesis)

An **enzyme** is a protein, folded into a complex three-dimensional shape. The **active site** is the part of the enzyme that allows it to act as a catalyst, as shown below.





▲ The enzyme lowers the energy needed for the reaction, and the reaction is then much more likely to take place.

1 Copy and complete the following paragraph about enzymes.

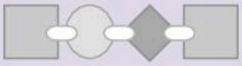
Enzymes are ____ which speed up the biochemical ____ in living organisms. The enzymes themselves are not changed in these reactions, that is they are biological ____.

Enzymes are ____ – each one controls only one type of reaction. They are ____ by high temperatures and by extremes of pH.

2 Enzyme action is explained by the lock and key hypothesis (see box above). The example shows an enzyme that catalyses a condensation reaction – two small molecules are joined together to make a larger one. Redraw the diagram to show the action of an enzyme catalysing a hydrolysis reaction, and give an example of such an enzyme.

Questions on enzymes and biological molecules

1 The diagram below shows a protein molecule.



a Name the subunit molecules that are assembled into the protein. [1]

b Name **two** proteins found in the human body. [2]

c State **two** places in the human body where many proteins are made. [2]

d Some seeds are rich in proteins. Describe the chemical test that you would use to determine whether different types of seed are rich in proteins. Include the practical details of the test in your answer. [4]

2 A student used the DCPIP test to find out how much vitamin C is present in different fruit juices. The concentration of the DCPIP solution was 10 g per dm^3. The student followed these instructions:

1 Put 2 cm^3 of DCPIP solution into a test tube.

2 Use a graduated pipette or burette to add a 10 g per dm^3 vitamin C solution drop by drop to the DCPIP solution. Shake the tube gently after adding each drop. Continue to add the vitamin C solution until the colour of the DCPIP solution disappears.

3 Record the volume of vitamin C solution that was added.

4 Repeat the procedure two more times and calculate a mean volume.

5 Repeat steps 1 to 4 with the juices to be tested.

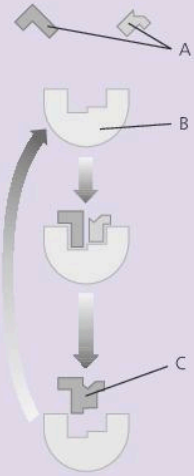
The results are shown in the table below.

Test substance	Volume added to DCPIP solution / cm^3			
	1	2	3	mean
10 g per dm^3 vitamin C solution	1.8	1.9	2.1	1.9
orange juice	2.4	2.6	2.3	2.4
grapefruit juice	3.2	3.1	2.9	3.1
apple juice	9.6	9.1	9.4	9.4

a Explain why the student took three readings for each test substance. [3]

b Use the results to calculate the concentration of vitamin C in the three fruit juices. Show your working. [3]

3 a The diagram below shows an enzyme-catalysed reaction.



i State the names of A, B and C. [3]

ii Use the diagram to describe what happens when an enzyme catalyses a reaction. [3]

iii Explain why the model is known as 'lock and key'. [2]

b Explain the following statements:

i Amylase digests starch, but proteases do not. [1]

ii Human enzymes catalyse reactions at 37°C, but not at 73°C. [2]

c The table shows the relative activity of a human enzyme in solutions of different pH kept at 35°C.

pH	Relative activity
3	4
5	12
7	31
9	9
11	4

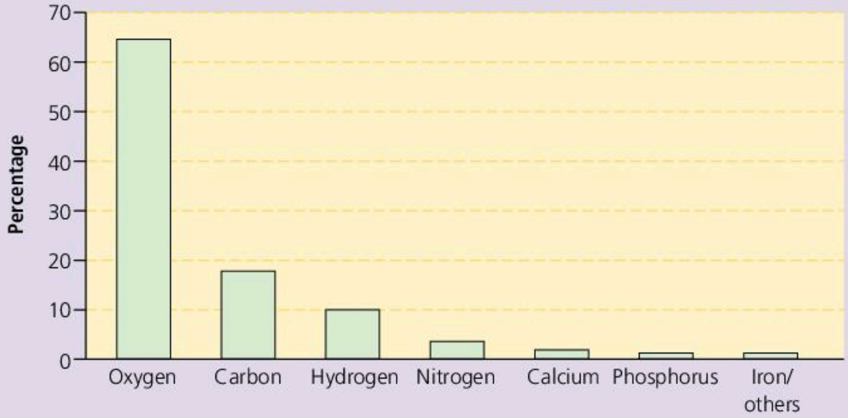
i Explain why all the reaction mixtures were kept at 35°C. [2]

ii Draw a graph of the results in the table. [4]

iii Describe and explain the results shown in the graph. [4]

4 a The bar chart below shows the percentage of each of the main elements in the human body.
Convert this data into:
i a table
ii a pie chart.
Which do you think is the better way of showing the data? Explain why.

b These elements are mostly present in the body as part of compounds.
The proportions of the main groups of compounds in a human body are shown in the table.
i Which is the most abundant compound?
ii Which compound contains most of the nitrogen in the body?
iii Which compound contains most of the oxygen?
iv Which compound contains most of the carbon?
v The total of these compounds does not add up to 100%. Suggest another organic compound that forms a proportion of the remainder.
vi Try to find out which structure(s) in the body contain most of the calcium.



Compound	Approximate percentage in the body
Fats	14%
Proteins	12%
Carbohydrates	1%
Water	70%

5 a The properties of enzymes were investigated using the simple experiment shown below. Which of the following conclusions are valid from these results?

i The enzyme reaction occurs more quickly at 30°C than at 20°C.

ii The enzyme in saliva is inactivated by boiling.

iii Saliva contains an enzyme which digests starch.

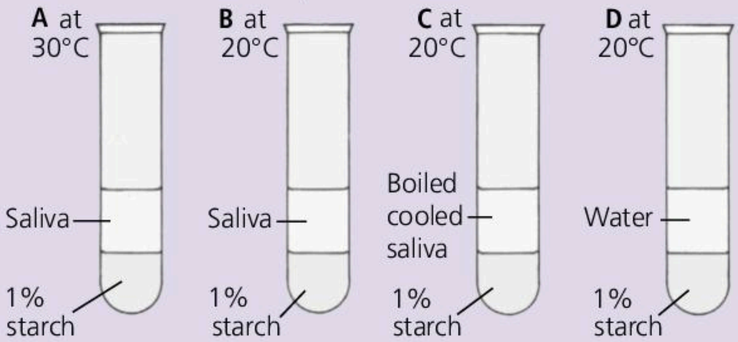
iv Boiled saliva contains an enzyme which digests starch.

b What is the purpose of tube D?

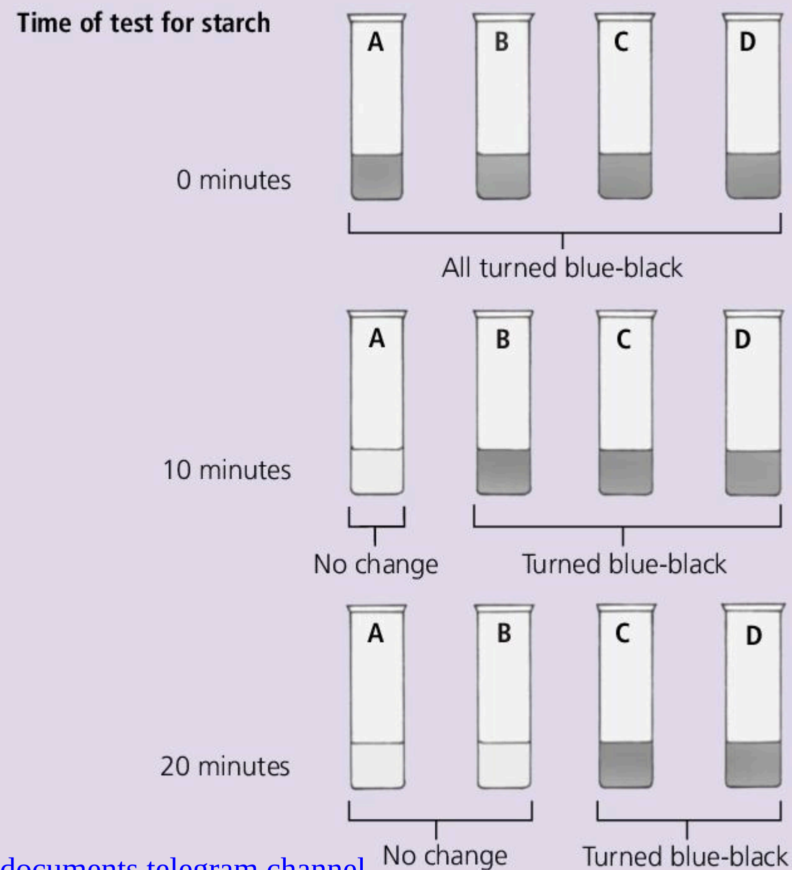
c How could you increase the validity of these results?

d What is the product of starch digestion present in tubes A and B after 20 minutes? Describe a simple biochemical test for this substance.

Four test tubes were set up:



The tubes were shaken. They were immediately tested for starch by adding one drop of iodine solution to one drop of the mixture in a specimen tube. The test was repeated at intervals.



6.1 Photosynthesis and plant nutrition

OBJECTIVES

- To understand that plants, like all living organisms, must receive nourishment
- To know the basic definition for photosynthesis
- To know word and symbol equations for photosynthesis
- To remember that a plant body has organs that are well suited to carry out particular functions

Plants need food

Plants, like animals, require raw materials for building tissues and as a source of energy. They manufacture everything they need out of simple ions and compounds available in the environment. The building up of complex molecules from simpler substances (**synthesis**) requires energy and enzymes. The enzymes are in the plant's cells, and the energy comes from sunlight. The process is therefore called **photosynthesis**: this could be defined as the basic process by which plants manufacture carbohydrates from raw materials using energy from light. An outline of plant nutrition is shown in the diagram below.

Chloroplasts are energy transducers

Plants can absorb and use light energy because they have a green pigment, **chlorophyll**, contained in **chloroplasts** in some of their cells. Chlorophyll allows the energy in sunlight to drive chemical reactions. Chloroplasts act as **energy transducers**, converting light energy into chemical energy.

Defining photosynthesis

Photosynthesis is the process in which light energy, trapped by chlorophyll, is used to convert carbon dioxide and water into glucose and oxygen.

These equations summarise photosynthesis:

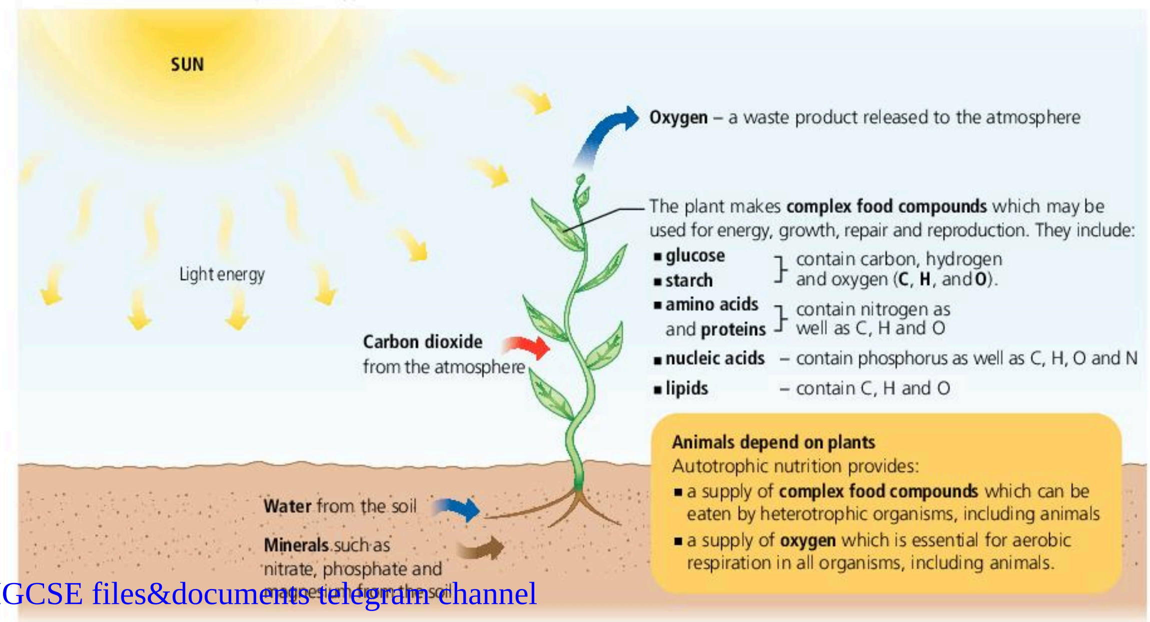
$$\text{carbon dioxide} + \text{water} \xrightarrow[\text{chlorophyll}]{\text{light energy}} \text{glucose} + \text{oxygen}$$

S

$$6CO_2 + 6H_2O \xrightarrow[\text{chlorophyll}]{\text{light energy}} C_6H_{12}O_6 + 6O_2$$

These equations are simplified, and show only glucose as a food product of photosynthesis. In fact, plants can make all of their food compounds by photosynthesis and other chemical processes.

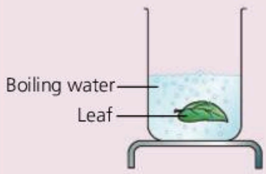
▼ Plants are **autotrophic** (self-feeding) – they take simple substances from their environment and use light energy to build them up into complex food compounds



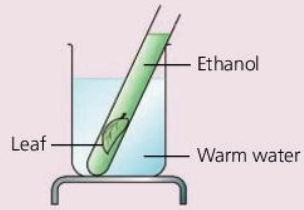
Some of the glucose produced is stored in the plant cells as **starch**. The experiment below shows how a starch test can be used to demonstrate the conditions needed for photosynthesis.

TESTING LEAVES FOR STARCH

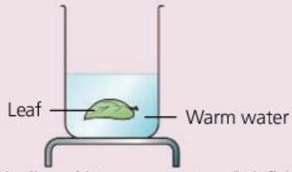
To demonstrate that some factor is necessary for the production of starch, the plant must have no starch to begin with. The plant is placed in a dark cupboard or box for 48 hours. It uses any starch that is already in its leaves and is now **destarched**.



(a) Leaf is boiled in water for about 2 minutes. Purpose: to break down cell walls and to stop the action of enzymes within the leaf. Also allows easier penetration by ethanol.

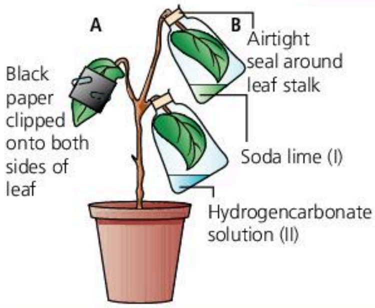


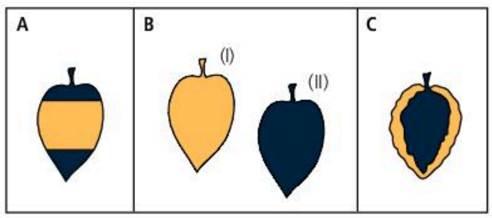
(b) Leaf is warmed in ethanol until leaf is colourless. Purpose: to extract the chlorophyll, which would mask observations later. (Chlorophyll dissolves in ethanol but not in water.)



(c) Leaf is dipped into warm water (briefly). Purpose: to soften the now brittle leaf, and allow penetration by iodine solution.

(d) Leaf is placed on white tile and iodine solution added. Purpose: iodine shows the presence (blue-black) or absence (orange-brown) of starch; colours are shown against the white tile.





These questions are about the diagram above.

1 Before testing for starch, the leaf is warmed in ethanol. The ethanol turns green. Why is this?

2 A group of students wanted to investigate the conditions needed for photosynthesis. They set up the three experiments shown as A, B and C. Each of the plants was given the same light conditions.

- **a** What does the result of experiment A suggest?
- **b** Soda lime removes carbon dioxide from the atmosphere, and hydrogencarbonate slowly releases it. What do the results of experiment B suggest about carbon dioxide and starch formation?
- **c** What is the purpose of experiment C?
- **d** From experiments A, B and C, list the factors necessary for starch formation by photosynthesis.

3 The students' teacher asked for some further tests to be completed before accepting their results as valid.

- **a** How could the students show that there was no starch in the leaves at the start of the experiment?
- **b** The teacher suggested that the black paper attached to the leaf in experiment A prevented the leaf from absorbing gases, and that was why no starch had been produced in the covered area.
  How could the students disprove this theory?

4 What additional experiment could be set up to show that the formation of starch by photosynthesis depends on the activity of enzymes? (There is a clue given in one part of the diagram above.)

6.2 The rate of photosynthesis

OBJECTIVES

- To understand a quantitative method of investigating photosynthesis
- To perform an exercise in experimental design

Measuring photosynthesis

The most straightforward way of showing whether or not photosynthesis has occurred is to test for the presence of starch. Starch is a product of photosynthesis and the blue-black colour of the iodine test is a simple method for detecting it. Unfortunately, this is an 'all-or-nothing' test, that is, the colour is just as dark with a small amount of starch as it is with a large amount. The iodine test is said to be **qualitative** – it only shows whether or not starch is present. To find out *how quickly* photosynthesis is going on, we need to use a **quantitative** test.

The basic equation for photosynthesis is:

$$\text{carbon dioxide} + \text{water} \xrightarrow[\text{chlorophyll}]{\text{light energy}} \text{glucose (starch)} + \text{oxygen}$$

This shows that, as well as starch, there is another product of photosynthesis – oxygen. It is quite easy to measure amounts (volumes) of oxygen, and so the production of oxygen can be used as a quantitative test for photosynthesis.

Tracing photosynthesis

The rate of photosynthesis can be estimated by measuring how much carbon dioxide a plant absorbs. This is done using a radioactively labelled form of carbon dioxide, $^{14}CO_2$. Labelled carbon dioxide is absorbed by the leaf cells and converted into labelled carbohydrates in exactly the same way as 'normal' carbon dioxide. A Geiger counter is used to detect how much radioactive material has been incorporated by the plant in a fixed length of time – the rate of photosynthesis. This method is useful for studying the rate of photosynthesis in a 'real-life' situation – in the middle of a crop field, for example – where it is not possible to collect and measure volumes of oxygen.

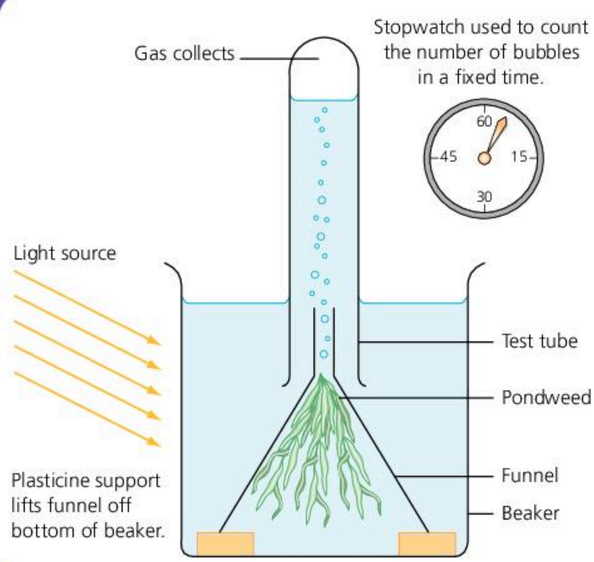
Using radioactive tracers can also provide information about other compounds that plants make following photosynthesis, and about how plants transport food substances from one place to another in the plant.

ANALYSING THE DESIGN OF AN EXPERIMENT

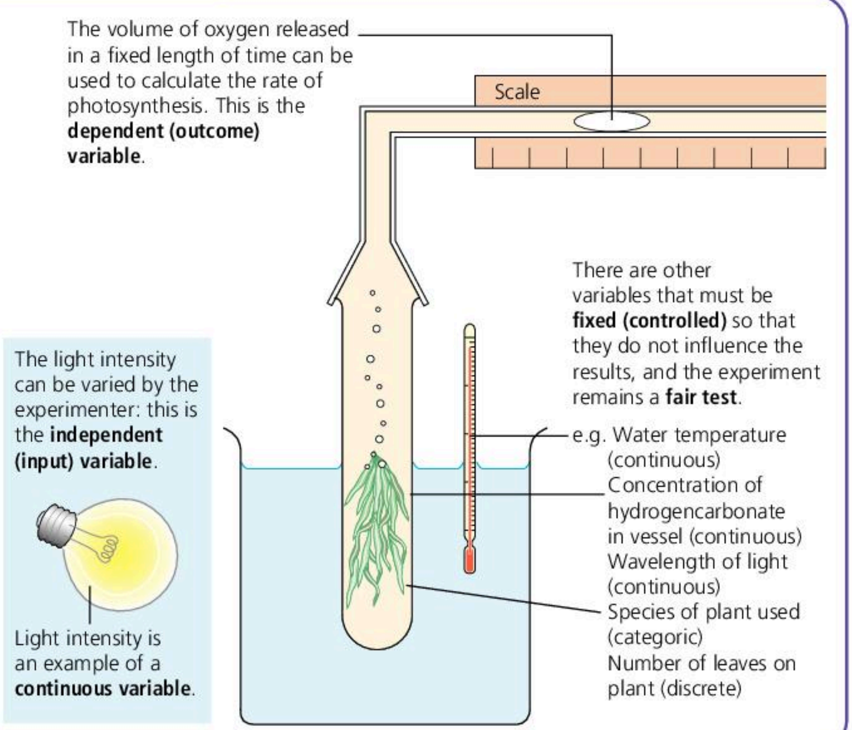
The simplest apparatus for measuring oxygen release is shown in the next box. This method depends on counting the number of oxygen bubbles given off in a fixed length of time.

Apparatus that can be used to measure the *volume* of oxygen released in a fixed length of time is shown on the opposite page. When looking at this, remind yourself of the principles of experimental technique.

SIMPLE ESTIMATION OF PHOTOSYNTHESIS



MEASURING THE RATE OF PHOTOSYNTHESIS



▶ A more accurate method for measuring the rate of photosynthesis. This apparatus can be used to investigate the effect of light intensity on the rate of photosynthesis.

Q

1 What important assumption about the bubbles is being made, when using the method shown on the page opposite, to measure the rate of photosynthesis?

2 Using the apparatus above, Samantha and Jane obtained the results shown in the table.

a Plot this information in the form of a graph.

Light intensity / arbitrary units	Volume of oxygen released / mm^3 per minute
1	7
2	14
3	21
4	28
5	34
6	39
7	42
8	44
9	45
10	45

b At what light intensity did the plant produce 25 mm^3 of oxygen per minute?

c What levels of light intensity had the greatest effect on the rate of photosynthesis? How could this information be useful to a grower of greenhouse tomatoes?

Samantha and Jane wanted to investigate whether the wavelength of the light would affect photosynthesis, and decided that they could use the same apparatus.

d What is the input variable in this investigation? How could the two students change this variable?

e What are the fixed variables in this investigation?

f The students decided to repeat their experiment, and then to pool their results with the results of other students in the same class. Why was this pooling of results important?

g The teacher said that if the students were going to pool their results then they must remove the plants from the apparatus and weigh them. Why should they do this?

h State the input, outcome and fixed variables in an investigation into the effect of temperature on the rate of photosynthesis.

3 This question is about the box 'Tracing photosynthesis' on the opposite page.

a What important assumption is being made when using the rate of uptake of $^{14}CO_2$ as a measure of the rate of photosynthesis?

b Why is it important that radioactively labelled carbon dioxide, $^{14}CO_2$, is treated by leaf cells in exactly the same way as 'normal' carbon dioxide?

c Which process might release $^{14}CO_2$ from the plant?

6.3 Leaf structure and photosynthesis

OBJECTIVES

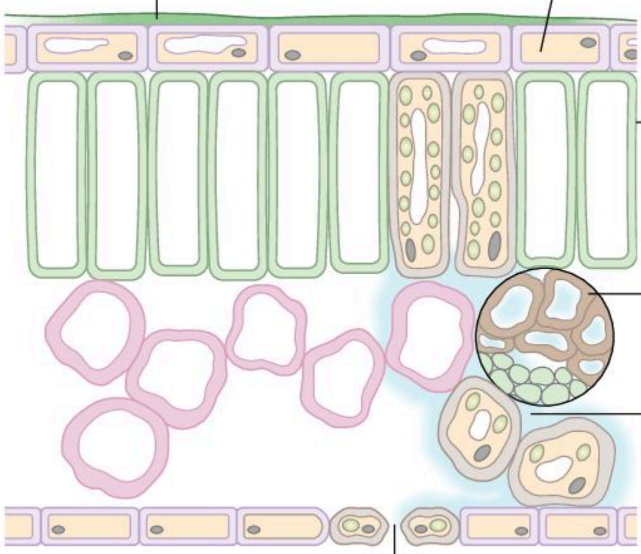
- To understand how the structure of the leaf is adapted for photosynthesis
- To recall the structure of a palisade cell
- To understand how whole plants can be adapted to make the most of light energy

Features of the leaf

In order to photosynthesise efficiently, a leaf needs:

- a method for **exchange of gases** between the leaf and its surroundings
- a way of **delivering water** to the leaf
- a system for the **removal of glucose** so that it can be transported to other parts of the plant
- an efficient means of **absorbing light energy**.

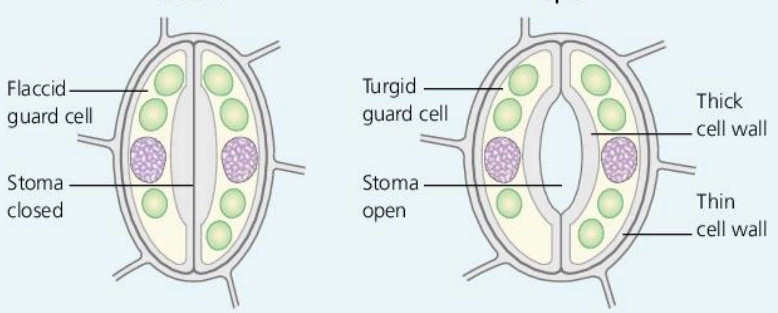
The diagram below shows how the structure of the leaf meets these requirements.



Stomata – (singular: **stoma**) these minute pores **allow the entry of carbon dioxide and the exit of oxygen.** They are mainly present in the **lower epidermis.** This surface is less exposed to the Sun's radiation so that evaporation of water is kept to a minimum. The stomata can be closed when no carbon dioxide intake is needed (in the dark, for example).

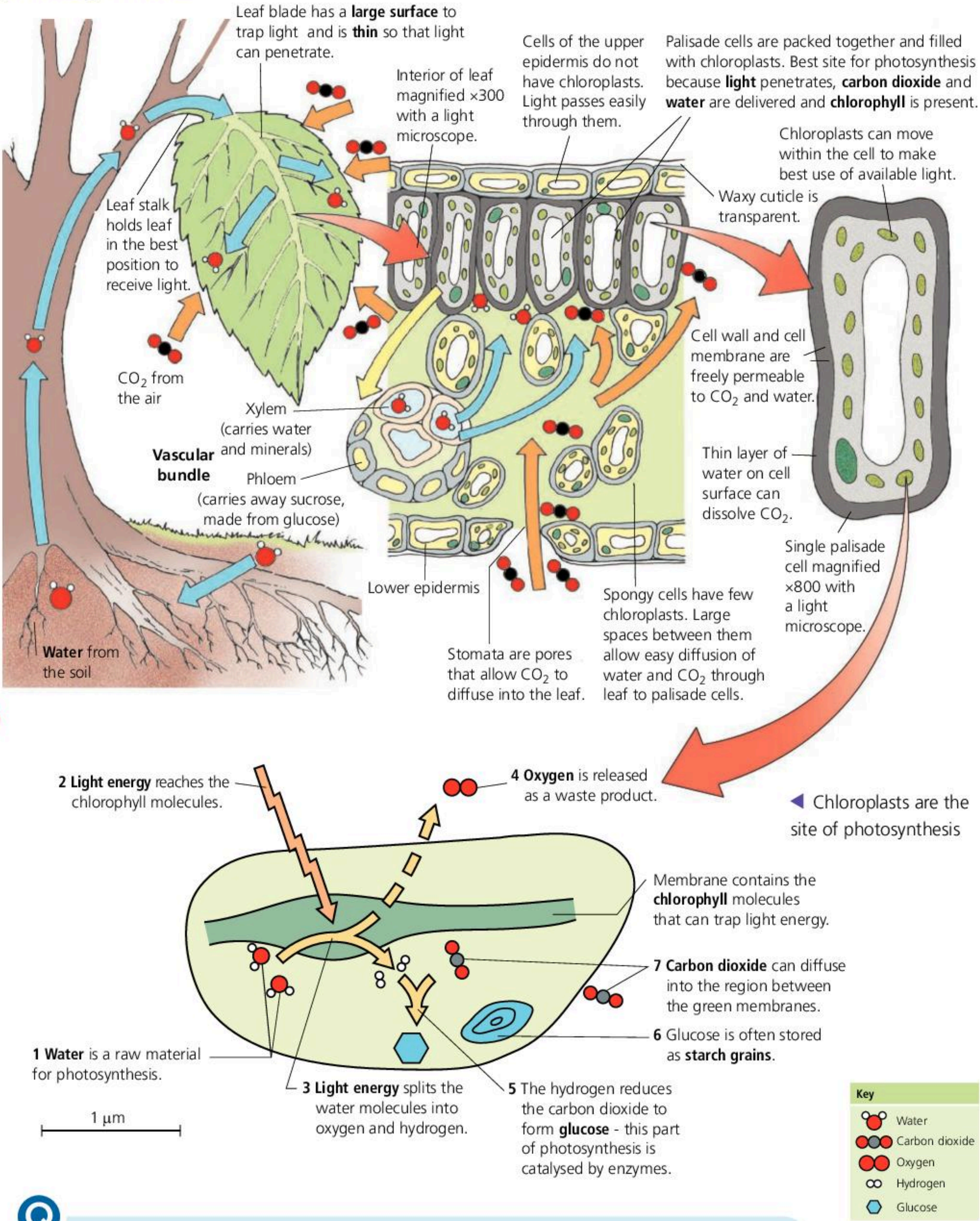
When a plant is short of water, the guard cells become flaccid, closing the stoma.

When a plant has plenty of water, the guard cells become turgid. The cell wall on the inner surface is very thick, so it cannot stretch as much as the outer surface. So as the guard cells swell up, they curve away from each other, opening the stoma.



▲ Leaf structure is a compromise between maximising photosynthesis and minimising water loss

This diagram shows how leaf, palisade cell and chloroplast are adapted for photosynthesis



◀ Chloroplasts are the site of photosynthesis

1 Work out the magnification of the single chloroplast. Show how you reached your answer.

6.4 The control of photosynthesis

OBJECTIVES

- To understand that photosynthesis is affected by a number of different factors
- To appreciate that photosynthesis is affected most by the factor that is in shortest supply – the limiting factor
- To know that an understanding of limiting factors can be used in the efficient growth of greenhouse crops

Requirements for photosynthesis

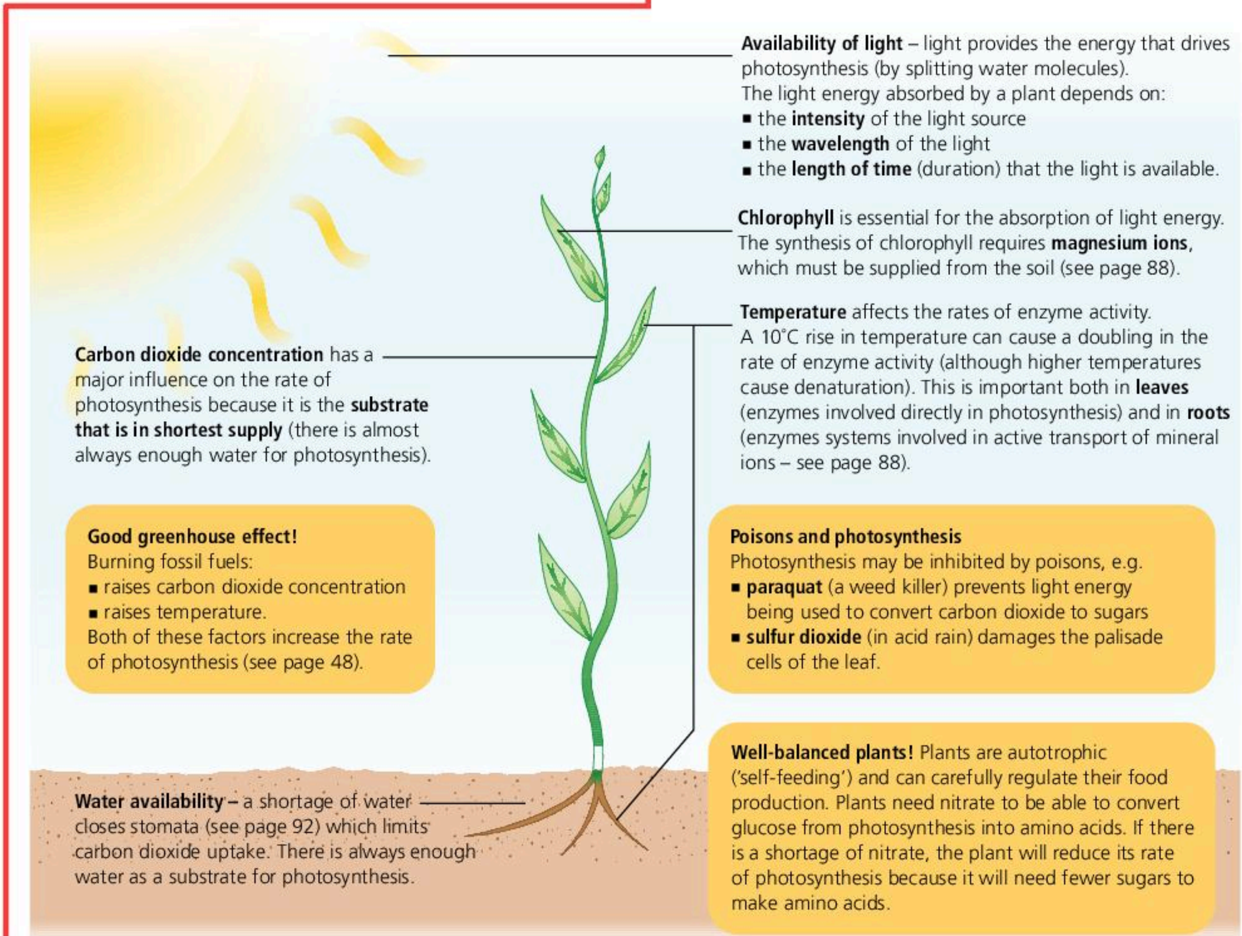
The process of photosynthesis depends upon:

- the availability of light
- the presence of a pigment to absorb the light
- a supply of carbon dioxide and water
- a temperature suitable for enzyme activity.

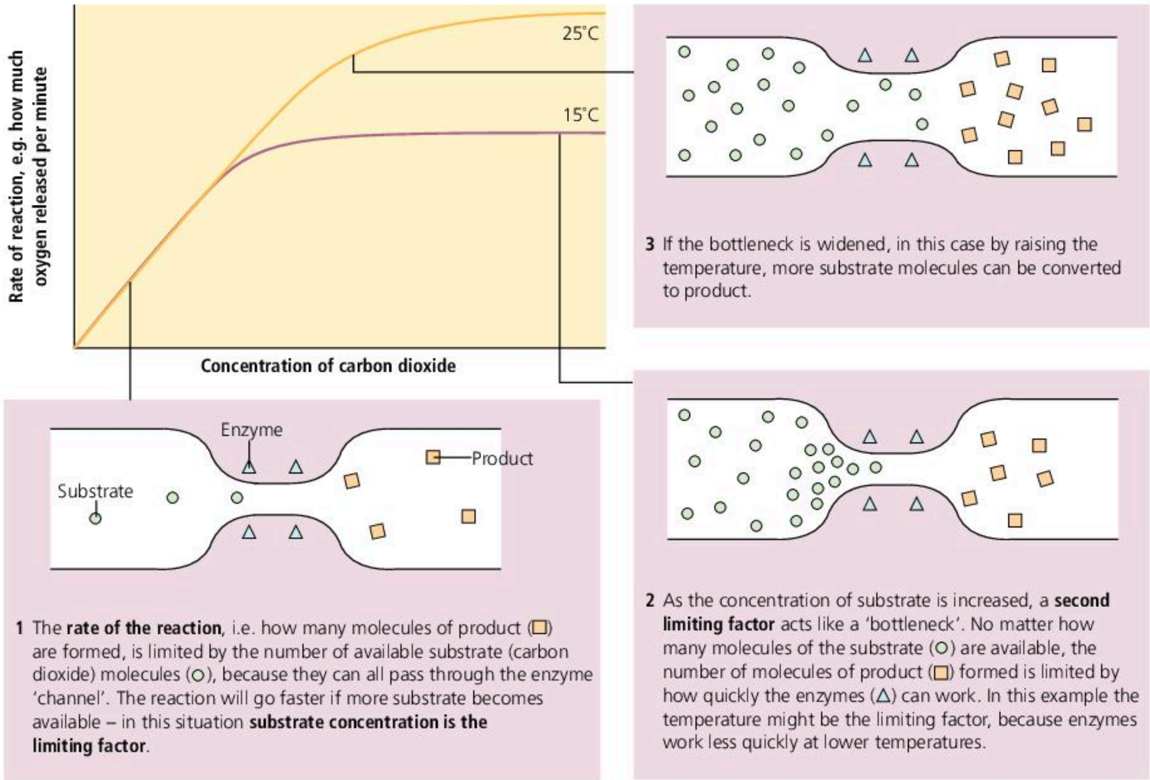
The need for each of these requirements or **factors** is outlined in the diagram below.

If any of these factors is in short supply, the rate of photosynthesis will be less than its maximum possible rate. One factor can cause a 'bottleneck' in the overall process as shown at the top of the page opposite. (This factor is called the **limiting factor**.) The limiting factor is the one which restricts the rate of the overall process because it is the factor nearest to its minimum value. The limiting factor varies at different times and under different conditions.

- In the UK, during the summer, light and temperature may be ideal for photosynthesis but the carbon dioxide concentration may be the limiting factor.



▲ Factors affecting photosynthesis



▲ Limiting factors control the rate of reactions in living organisms

- During any 24-hour period, light will be the limiting factor from dusk to dawn.
- During a British winter, plants may not photosynthesise on a bright, sunny day because temperature is the limiting factor.

The availability of water is rarely a limiting factor for photosynthesis, because there are so many other physiological processes in plants that depend on water that these processes will usually halt in a water shortage before photosynthesis does.

Controlling the limiting factors

In an open field, there is very little that farmers can do to speed up photosynthesis – they cannot change the degree of cloud cover or warm up the air, for example. However, in an enclosed environment, such as a greenhouse, it is possible to control the factors affecting photosynthesis and so get the maximum yield from crops. This requires an understanding of the principle of limiting factors – it is no good simply increasing the light availability by having lights on in dull weather without making sure that carbon dioxide concentration and temperature are adequate, for example. A greenhouse grower will also try to use strains of plants selected for their high yield (see page 54), control any potential pests and will probably use automatic systems to control the factors that might limit the crop yield.

Q

1 List the three most important factors that control the rate of photosynthesis.
2 The burning of fossil fuels can both help and hinder photosynthesis. Explain this statement.
3 Which ion deficiency is most likely to affect photosynthesis? Explain why.
4 What is a limiting factor? Which limiting factor is most likely to affect photosynthesis:
   a on a cloudy, spring day
   b on a bright, sunny day in winter
   c in the middle of a crop field on a sunny, warm July day?

6.5 Control of photosynthesis by humans: use of greenhouses

OBJECTIVES

- To understand how humans can control environmental resistance
- To describe examples of maximising yields in the commercial management ecosystems

Humans exploit many other organisms, often as sources of food. Our understanding of population growth and the effect of environmental resistance allows us to maximise yields of 'food' populations by minimising environmental resistance. Two examples of the use of biological principles in the management of food-producing ecosystems are greenhouses (described here) and fish farming (see page 278).

Carbon dioxide concentration is a major limiting factor in photosynthesis. In a greenhouse, plants may photosynthesise very quickly and CO_2 is rapidly used up. The CO_2 level is usually raised to about 0.1% of the atmosphere (about three times higher than in normal air). This gives an increase in yield of about 50%. The extra CO_2 can be provided by burning paraffin (which also raises the temperature) or by releasing it from a cylinder.

High-yielding strains of crop are used. Selective breeding and/or genetic engineering can develop crop strains which:

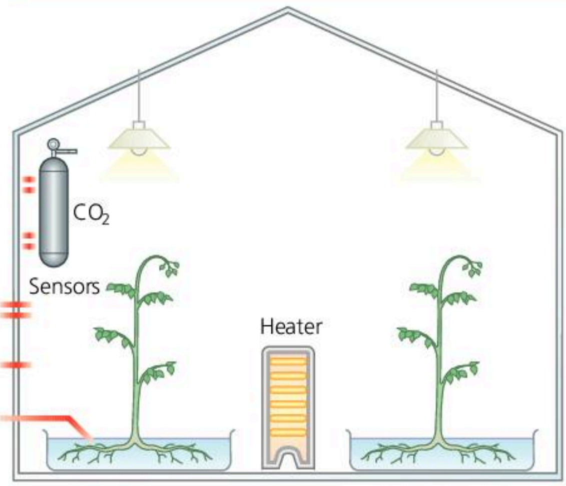
- give a high yield
- produce fruit of a desirable colour/texture/size
- produce fruit at the same time
- may have genetic pest resistance.

Temperature affects plant growth because of its effect on the enzymes of photosynthesis. High temperatures may also speed up the life cycle of pests. Sunlight provides some heat (shading may be necessary in summer) but thermostatically regulated heaters provide greater control.

Illumination – it is important to control:

- **intensity – higher light intensity** leads to more photosynthesis until some other limiting factor intervenes
- **quality** – photosynthesis is most efficient at red and blue wavelengths; white light contains some wavelengths (green) which are not useful
- **duration** – if fruit is the desired product, the plant must flower; flowering is controlled by day length (the duration of light in a 24-hour period).

Sunlight provides some illumination but artificial lighting systems are more controllable (though more expensive).



▲ Greenhouse management involves an understanding of the limiting factors that control photosynthesis (see page 52). Maximum photosynthesis means maximum plant growth.

When looking at photosynthesis, consider these key points:

- What is a **limiting factor**?
- In the equation for photosynthesis, why are carbon dioxide and water required?
- Why is light essential for photosynthesis?
- Why does temperature affect the rate of photosynthesis? (Think: enzymes and temperature.)

1 The table below shows the rate of photosynthesis of geranium plants under eight different sets of conditions, A to H.

	Light intensity / arbitrary units	Carbon dioxide concentration / %	Temperature / °C	Rate of photosynthesis / arbitrary units
A	4	0.03	20	60
B	8	0.03	20	60
C	4	0.15	20	120
D	8	0.15	20	180
E	4	0.03	30	60
F	8	0.03	30	60
G	4	0.15	30	170
H	8	0.15	30	250

a State which set of conditions gives the highest rate of photosynthesis.
b State the effect of increasing the temperature when there is a high light intensity and carbon dioxide concentration.
c The usual concentration of carbon dioxide in the atmosphere is 0.03%. State what these results indicate about the effect of adding carbon dioxide to the air.
d Explain why the rate of photosynthesis is identical in conditions A, B, E and F.

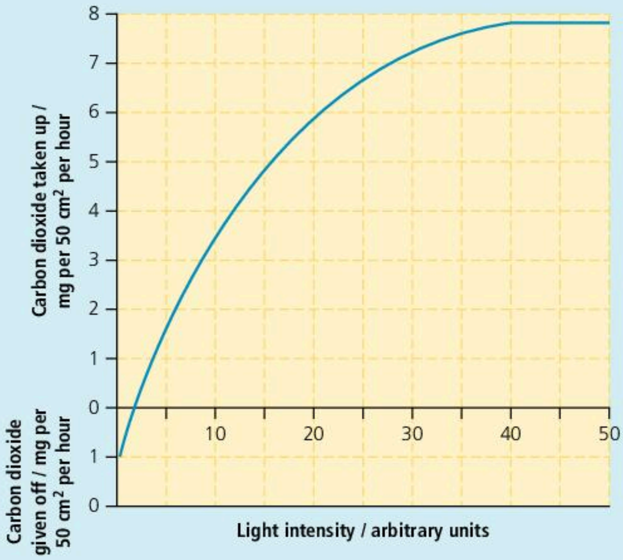
2 The table below shows the effect on yields of adding extra carbon dioxide to the atmosphere in a greenhouse.

Crop	Normal atmosphere	Atmosphere enriched with CO_2
Lettuce	0.8 kg	1.0 kg (mass of 10 lettuces)
Tomatoes	3.8 kg	6.2 kg (mass of each whole plant)

a Calculate the percentage increase in the crop yield of lettuce in the enriched atmosphere. Show your working.
b Three possible ways of increasing the carbon dioxide concentration in the greenhouse atmosphere are:
- using paraffin heaters in the greenhouse (combustion releases carbon dioxide and water)
- keeping small animals, such as rabbits, in the greenhouse
- releasing carbon dioxide from gas cylinders.

Suggest and explain the best method for increasing the crop yield.

3 The graph below shows the rate of photosynthesis.



Use this graph to explain the term **limiting factor**.

6.6 Photosynthesis and the environment

OBJECTIVES

- To understand that plants both photosynthesise and respire
- To understand that these processes affect the composition of the atmosphere
- To appreciate that photosynthesis plays an important part in the carbon cycle

Photosynthesis and respiration

From the equation for photosynthesis (see page 46) we know that this process removes carbon dioxide from the atmosphere and at the same time releases oxygen. This is the opposite of the exchange of gases in respiration:

glucose + oxygen ⟶ carbon dioxide + water

Green plants both photosynthesise and respire:

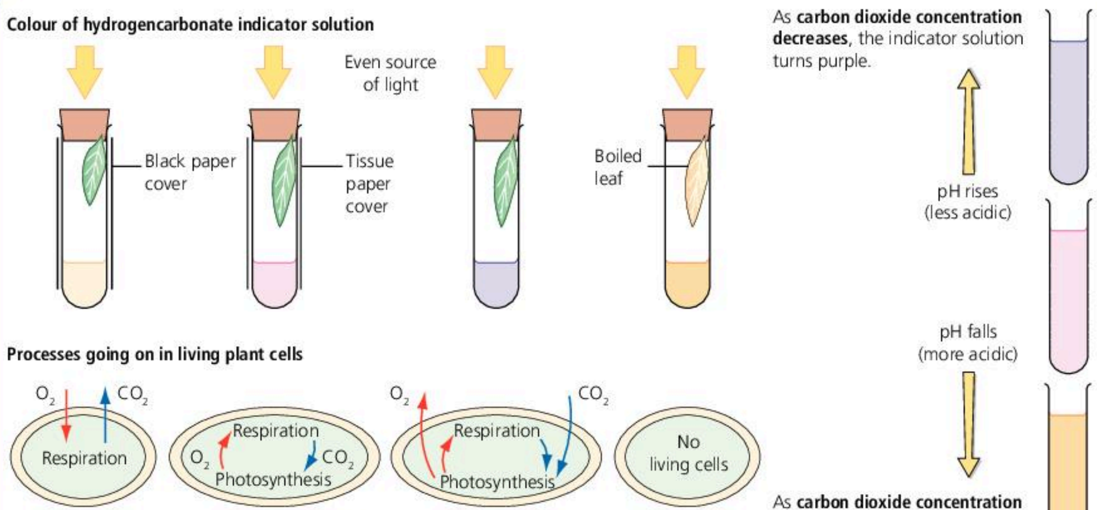
- if photosynthesis exceeds respiration (in the light) plants will, overall, remove carbon dioxide and add oxygen
- if photosynthesis is less than respiration (in the dark) plants will, overall, remove oxygen and add carbon dioxide.

Demonstrating gas exchange

The overall change in carbon dioxide levels in the atmosphere can be demonstrated using **hydrogencarbonate indicator**, as shown in the diagram below. Carbon dioxide produces a weak acid, **carbonic acid**, in water and this indicator is sensitive to the changes in pH caused by the acid.

In the dark, the rate of respiration greatly exceeds the rate of photosynthesis – the plant cells are living on the sugars they manufactured during previous periods of photosynthesis. As the light intensity increases after dawn, there comes a point where the rates of respiration and photosynthesis exactly balance one another and there is no net uptake or loss of carbon dioxide or oxygen. This is called the **compensation point** and, at this point, the glucose consumed by respiration is exactly balanced by the glucose produced during photosynthesis. Beyond the compensation point the plant begins to gain glucose, as photosynthesis exceeds respiration.

EXPERIMENT TO DEMONSTRATE THE EFFECT OF LIGHT INTENSITY ON THE BALANCE BETWEEN PHOTOSYNTHESIS AND RESPIRATION

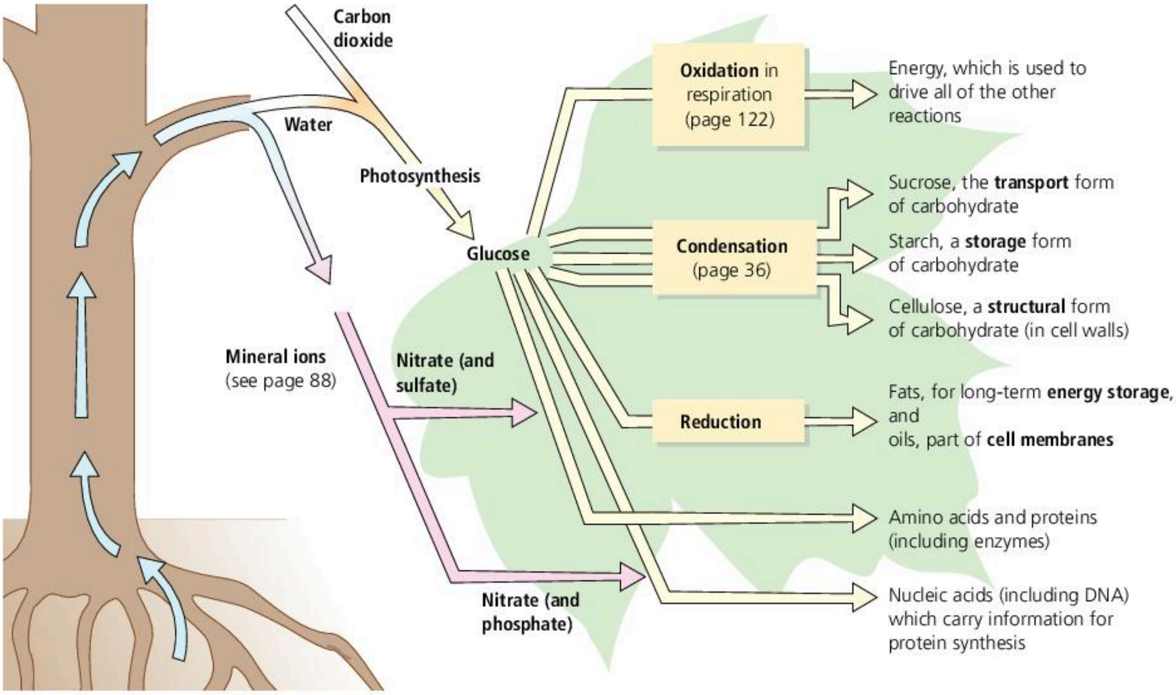


▶ Hydrogencarbonate indicator reacts to changes in carbon dioxide in the air

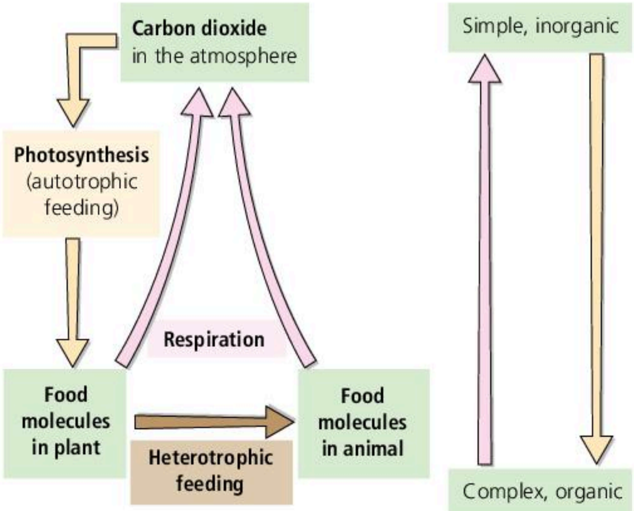
The products of photosynthesis

Plants manufacture all of their food requirements, starting from the glucose molecule. The diagram shows some of the products that the plant makes.

These products are available to the plant, and to any organism that eats the plant. An animal that eats plant material will use most of it to obtain energy by respiration. The carbon dioxide released as a waste product is then available for plants as a substrate for photosynthesis. An atom of carbon in carbon dioxide could be taken in by a plant, built up to a complex food molecule, and then eaten by an animal which breaks it down to carbon dioxide again. Thus atoms are **recycled** between simple and complex molecules, through the bodies of plants, animals and other living organisms. The **carbon cycle** is described simply in the diagram at the bottom of the page, and more fully on page 252.



▲ Plants produce all their food molecules from the products of photosynthesis by metabolic reactions



▲ Photosynthesis and the carbon cycle – carbon is recycled between simple inorganic and complex organic compounds

Q

1. Name an indicator that can be used to measure carbon dioxide concentrations in solution. What colour change would you predict for this indicator in the presence of an actively photosynthesising plant? Explain your answer.
2. What is meant by the term compensation point? Why is it important that a grower of greenhouse crops should understand this term?
3. 'Photosynthesis provides plants with sugars' – is this true, and is it the whole story?
4. Plants take up carbon dioxide, which they convert to carbohydrate. Explain how it is possible for the plant to take in the same molecule of carbon dioxide more than once.

6.7 Plants and minerals

OBJECTIVES

- To know that plants require minerals such as nitrate and magnesium
- To know the functions of minerals in plants
- To appreciate how information about plants' mineral requirements can be obtained

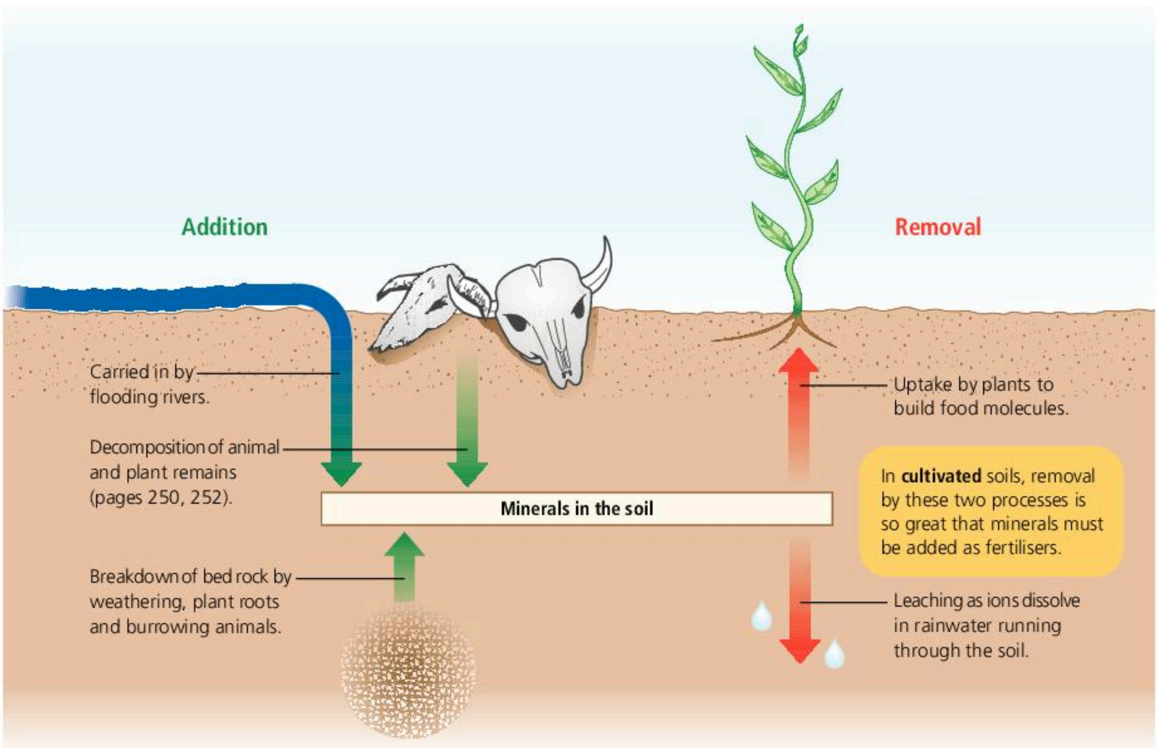
Plants need a number of minerals. The plant uses minerals to make food molecules such as amino acids, proteins and nucleic acids out of the carbohydrates made by photosynthesis (see page 46). Plants absorb minerals from the soil in the form of **ions**. The mechanism of ion uptake is described on page 88. Here we shall consider *why* the ions are required, and how scientists might work out the function of each different mineral nutrient.

Minerals in soil

The minerals present in soil depend on the type of rock beneath the soil and on the decomposition of animal and plant remains lying on the soil.

Minerals are taken out of the soil by plants, and are also washed out by rain. In natural, uncultivated soils there is a balance between the formation and the loss of mineral ions, as shown below.

In *cultivated* soils the ground is prepared and then the crop is harvested. There are few plant remains left to decompose and replace the minerals taken up into the plant body. Levels of minerals such as nitrate and phosphate fall, so farmers add these back in the form of **fertilisers**. These may be **natural fertilisers**, such as sewage sludge, animal manure or compost, or they may be **artificial fertilisers**. The most common artificial fertiliser is **NPK** fertiliser which contains three main nutrients – nitrogen (**N**), phosphorus (**P**) and potassium (**K**). The role of some of these minerals, and the effect on the plant of mineral deficiencies, is shown in the diagram on the opposite page. Providing these minerals is one of the most important aspects of preparing soil for agriculture.

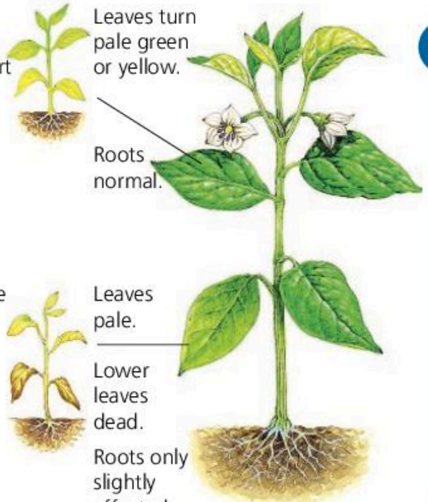


▲ Minerals are added to the soil and also removed by natural processes

Problems with fertilisers

Excessive use of fertilisers can cause problems of eutrophication (see page 274). The fertiliser runs off into nearby streams, rivers and lakes and boosts the growth of algae. As algae die, they are decomposed by bacteria, which use all of the oxygen dissolved in the water for aerobic respiration. As a result, the water becomes oxygen deficient, and larger animals such as fish and insects die.

Nitrogen probably has the greatest effect on plant growth. Farmers use expensive NPK fertilisers to replace nitrogen removed from the soil when crops are harvested.



▲ Plant growth and mineral deficiencies

Q

1 Copy and complete the following paragraph.

Plants require minerals such as ____ for protein synthesis and ____ for the production of chlorophyll. The minerals are absorbed in the form of ____ by the process of ____, which is passive, and ____, which requires energy.

Absorption is made easier because the ____ have an enormous surface area.

INVESTIGATION OF PLANTS AND MINERALS

The apparatus shown on the right can be used to investigate the effects of mineral deficiencies on plant growth. Cereal plants of equal age and size are grown in a series of culture solutions. One of the solutions contains all known mineral nutrients in the correct proportions; each of the others is missing a single mineral. All the vessels are placed in identical conditions of temperature and light intensity, and the plants are allowed to grow for equal lengths of time.

1 Why is the vessel surrounded by black paper?

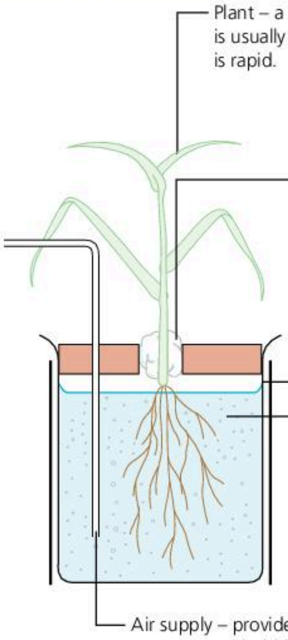
2 The bubbled air supply provides oxygen to the roots. Why might this be important in mineral uptake?

3 What is the independent variable in this investigation, and what is the dependent variable?

4 Suggest some fixed variables, and state how you would attempt to control them.

5 Cereal plants such as grasses are useful in this sort of investigation, because many identical plants can be obtained from a single clump. Why is this important in providing valid data?

6 The plant nutrients used in this investigation are supplied as salts. How could you make up a culture solution that is only lacking a single element?



Questions on photosynthesis and plant nutrition

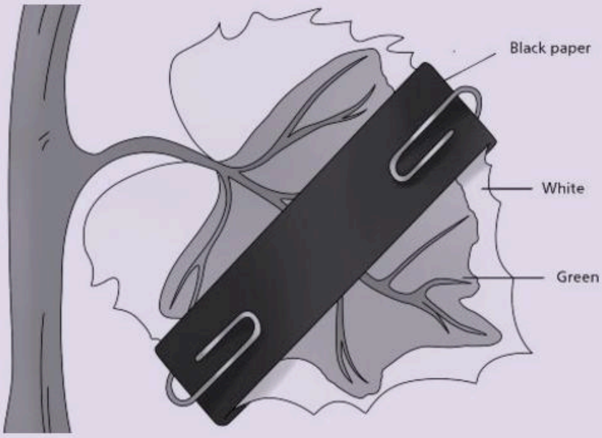
1 What is the green pigment which absorbs light energy for photosynthesis called?

A Haemoglobin
B Chlorophyll
C Keratin
D Chloroplast [1]

2 Starch produced during photosynthesis can be detected by which solution?

A Biuret solution
B Benedict's solution
C Iodine solution
D DCPIP [1]

3 A plant with variegated (green and white) leaves was destarched. Part of one leaf was covered on both sides with black paper as shown in the diagram below. The plant was left in bright light for 8 hours. The leaf was then detached and tested for the presence of starch.

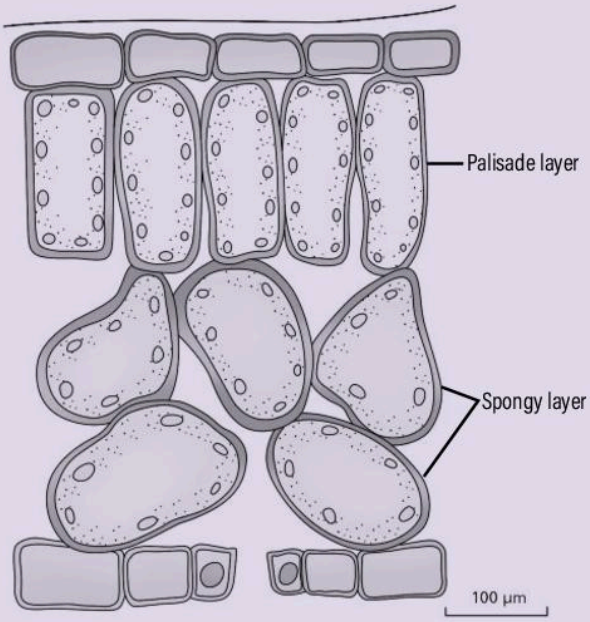


a Explain
  i how you would destarch the plant [1]
  ii why destarching is necessary. [1]

b Describe how the green pigment can be removed from the leaf before testing for starch. [1]

c Redraw the leaf to show how it would appear after testing for starch. State the colours you would see in different parts of the leaf. [2]

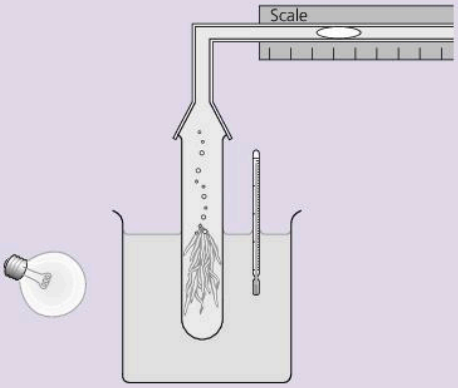
4 The diagram below shows a simplified diagram of a section through the green part of a leaf.



a Count the number of chloroplasts that you can see in each of the cells of the palisade and spongy layers.
  i Calculate the mean number of chloroplasts per cell in each layer. Show your working. [4]
  ii Suggest an explanation for your results. [2]

b **i** Use the scale on the diagram to calculate the thickness of the leaf. Show your working. [2]
  ii Explain how this leaf shape is important for photosynthesis. [2]

5 A student investigated the effect of varying the light intensity on the rate of photosynthesis using the apparatus shown below.



a State how the student would:

i vary the light intensity [2]

ii determine the rate of photosynthesis [2]

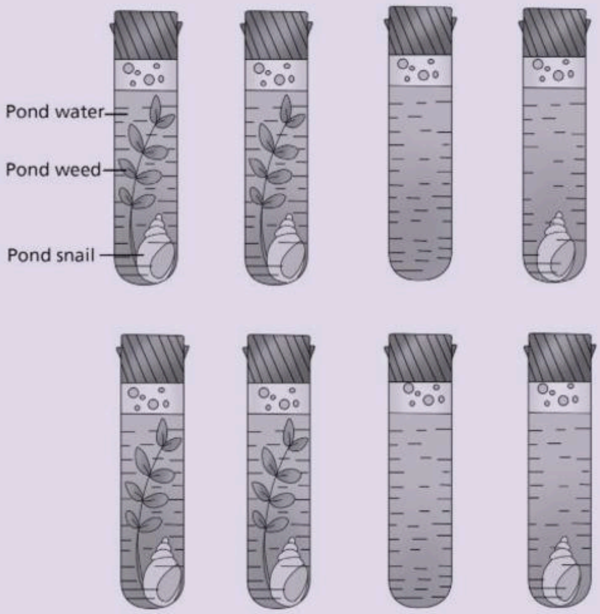
iii maintain a constant temperature and constant carbon dioxide concentration throughout the investigation. [4]

b The results for the experiment are shown in the table below.

Light intensity / arbitrary units	Distance moved by bubble in the 4 min period / mm
0.5	0
1.0	6
2.0	18
3.0	30
4.0	42
5.0	54

Using the term **limiting factors**, describe and explain the results shown in this table. [4]

6 A group of students carried out an investigation on the effects of photosynthesis and respiration on the environment. They set up eight boiling tubes as shown below.



Tubes A–D were kept in bright light and tubes E–H in the dark for 3 hours. After this time, red hydrogencarbonate indicator was added to each of the tubes.

Hydrogencarbonate indicator is affected by the concentration of carbon dioxide.

Purple ← CO_2 levels decrease — Red — CO_2 levels increase → Yellow

Bicarbonate indicator

a Suggest the likely colour of the indicator in tubes A and B. [2]

b Explain any differences in colour between tubes A and E. [2]

c Explain any differences between the colour of the solution in tubes B and D. [2]

d Explain why tubes C and G were included in the investigation. [1]

7 Two groups of seedlings were grown in solutions that were deficient in two ions that plants need. Group M was grown without nitrate ions; group N was grown without magnesium ions. Group O received all the ions that plants require. The results are shown in the table below.

Seedling group	Colour of leaves	Growth
M	yellow (especially the lower leaves)	reduced growth but not as much as seedlings in group N
N	lower leaves – yellow upper leaves – pale green	severely reduced growth
O	green	normal growth

a Explain the effects of the deficiencies of nitrate ions and magnesium ions as shown in the table. [2]

b Suggest why it was necessary to include the seedlings in group O. [2]

7.1 Food and the ideal diet: carbohydrates, lipids and proteins

OBJECTIVES

- To understand why organisms require food
- To list the constituents of an ideal diet
- To know the functions of each component of an ideal diet

Food

All living organisms are made up of molecules, organised so that they can carry out the characteristics of life. Food supplies them with:

- molecules that are the **raw materials** for repair, growth and development of the body tissues
- molecules that can be oxidised in respiration, and act as a **source of energy**
- elements and compounds that enable the raw materials and energy to be used efficiently.

All living organisms need food, but some, green plants in particular, can make their own organic molecules. These organisms are said to be **autotrophic** (or 'self-feeding'). Green plants use a form of autotrophic nutrition called **photosynthesis** to supply them with all the organic molecules they need (see page 46). Other organisms cannot make their own food, and must take in food molecules from their surroundings. These molecules have been made by another organism, so living things that feed in this way are said to be **heterotrophic** (or 'other feeding'). Humans, like all animals, are totally dependent on other organisms for their food.

A balanced diet

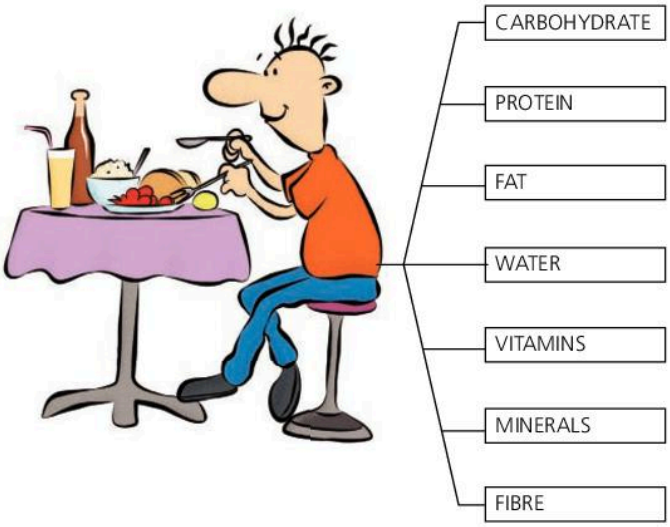
The total of the molecules or **nutrients** that we need is called the **diet**. A **balanced diet** provides all the nutrients, in the correct amounts, needed to carry out the life processes. If the diet does not provide all the nutrients in the correct proportions, a person may suffer from **malnutrition** (see page 68, for example).

Food can be analysed to find out what chemicals it contains using quite simple chemical techniques (see page 38). A balanced diet should contain the correct proportions of **carbohydrates**, **lipids**, **proteins**, **vitamins** and **minerals**, **water** and **dietary fibre**. We shall look at each in turn.

An adequate diet provides sufficient **energy** for the performance of metabolic work, although the 'energy' could be in any form.

A balanced diet provides all dietary requirements **in the correct proportions**. Ideally this would be 1/7 **fat**, 1/7 **protein** and 5/7 **carbohydrate**.

In conditions of **under**nutrition the first concern is usually provision of an adequate diet, but to avoid symptoms of **mal**nutrition a **balanced diet** must be provided.



Q

1. Give three reasons why living organisms need food.
2. Write one sentence to explain the difference between autotrophic and heterotrophic nutrition.
3. What is a balanced diet?
4. List the main energy foods for humans.
5. State four functions of proteins, using particular examples to illustrate your answer.

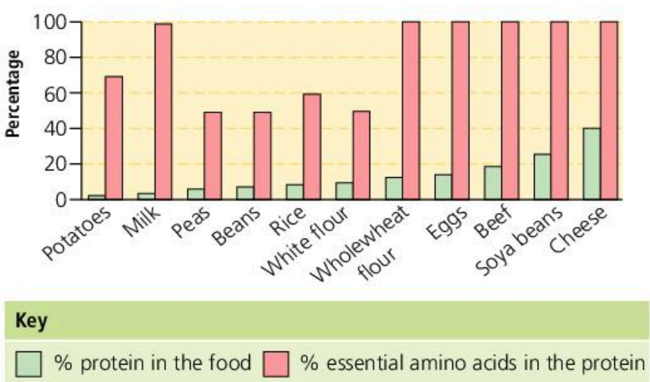
Carbohydrates, lipids and proteins: three food types

Good source	Functions in humans	Comments
Carbohydrates		
Rice, potatoes, wheat (e.g. pasta) and other cereals provide **starch**. Food sweetenings, such as those in desserts, sweets and soft drinks, and preservatives provide **refined sugars**, such as **sucrose (cane sugar)** and **glucose**.	A **source of energy**. Glucose is oxidised in **respiration** (see page 122) to release **energy** for active transport, cell division, muscle contraction and the manufacture of large biological molecules. Excess carbohydrate can be stored as **glycogen** (see page 148) and as **fat**.	Carbohydrates are digested in the mouth and small intestine and absorbed as **glucose.** Refined sugars are absorbed very rapidly, giving a sudden boost of 'energy source'. Starch is digested and absorbed more slowly, giving a steady supply of energy: starches are called **slow-release carbohydrates**.
Lipids		
Meat and animal foods (eggs, milk, cheese) are rich in **saturated fats** and **cholesterol**. Plant sources such as sunflower seeds and peanuts are rich in **unsaturated fats**.	Fats and oils are an important source of energy (see page 62). They are especially valuable as an **energy store** because they are insoluble in water. They also provide **insulation** – electrical insulation around nerve cells (see page 156) and thermal insulation beneath the skin (page 146) – and form part of cell membranes. **Steroid hormones**, including sex hormones, are made from cholesterol.	Fats and oils are digested in the small intestine and absorbed as fatty acids and glycerol. Some lipids contain **saturated fatty acids** and others contain **unsaturated fatty acids** (with at least one carbon–carbon double bond). The body can store unlimited amounts of fat, contributing to obesity (see page 68). The incorrect balance of saturated and unsaturated fatty acids, or an excess of cholesterol, can cause diseases of the circulation (see page 106).
Proteins		
Meat, fish, eggs from animals, and legumes (peas and beans) and pulses from plants. One of the best sources of protein is the soya bean. This contains very little fat (unlike most animal sources) and so is suitable for people with health problems caused by fat (see page 106). Soya beans can be flavoured and textured to make them taste and feel like meat – this **textured vegetable protein** is used as 'artificial' meat. **Mycoprotein** is also a low-fat substitute for meat derived from fungi.	Many functions, including ■ enzymes (catalysts) (page 40) ■ transport molecules, such as haemoglobin (page 96) ■ structural materials, as in muscles (page 124) ■ hormones, such as insulin (page 148) ■ in defence against disease, such as antibodies (page 118)	Digested in the stomach and small intestine, and absorbed as amino acids. Twenty different amino acids are needed to make up all of the different proteins in the human body. Some of these must be supplied in the diet as the body cannot make them – these are the **essential amino acids**. Proteins from animal sources usually contain all 20 amino acids, but plant proteins often lack one or two of the essential amino acids. Deficiency of protein causes poor growth – in extreme cases it may cause **marasmus** or **kwashiorkor** (see page 69).

Essential amino acids – cry baby

One factor that determines how comfortable babies feel is the supply of a 'pleasure chemical', called **serotonin**, in the brain (see neurotransmitters, page 155). An essential amino acid called **lysine** is needed to make serotonin. Lysine is in short supply in some artificial milks. Babies fed on these milk substitutes can't manufacture enough serotonin, they feel uncomfortable and they CCCRRRYYY! Natural mother's milk contains an adequate supply of lysine.

Vegetarians must ensure that their diet contains a wide range of protein sources because very few plants contain all the essential amino acids. An ideal vegetarian meal containing all the essential amino acids is baked beans on toast (which also contains a high proportion of dietary fibre).



▲ The protein values of some common foods

7.2 Food and the ideal diet: vitamins, minerals, water and fibre

OBJECTIVES

- To list the constituents of an ideal diet
- To know the functions of each component of an ideal diet

Vitamins and minerals

Vitamins and minerals are essential for the body to be able to use the other nutrients efficiently. They are needed in only very small amounts. There are many different vitamins and minerals, and they are usually provided in the foods of a balanced diet.

Vitamins			
Water-soluble	**Food source**	**Symptoms of deficiency**	**Comments**
C (ascorbic acid)	Cherries, citrus fruits e.g. limes, lemons, oranges, and fresh green leafy vegetables	Scurvy – production of collagen fibres in the body is affected.	Vitamin C also seems to protect cells from ageing.
Fat-soluble	**Food source**	**Symptoms of deficiency**	**Comments**
D (calciferol)	Liver, dairy products, eggs, fish liver oil	Rickets – bones are soft and may bend, because vitamin D is needed for the absorption of calcium.	Can be made by the body, just under the skin, but only if there is plenty of sunlight.

Minerals			
	Food source	**Symptoms of deficiency**	**Comments**
Iron	Red meat, liver, some leafy vegetables, e.g. spinach	Anaemia – iron is needed to produce **haemoglobin** for red blood cells. A shortage causes weakness as oxygen needed for respiration cannot be transported efficiently.	Iron is added to foods when metal utensils are used in cooking – the amount of iron in a piece of beef is doubled when the meat is minced in an iron mincer ready for making burgers!
Calcium	Milk, cheese and fish	Several problems ■ weak bones and teeth ■ poor clotting of blood ■ uncontrolled muscle contractions ('spasms').	Calcium shortage causes **rickets**, the same deficiency disease caused by insufficient vitamin D.

Water

Water forms about 70% of the human body. Two-thirds of this water is in the cytoplasm of cells, and the other third is in tissue fluid and blood plasma. Humans lose about 1.5 litres of water each day, in urine, faeces, exhaled air and sweat – this must be replaced. It is obtained in three main ways:

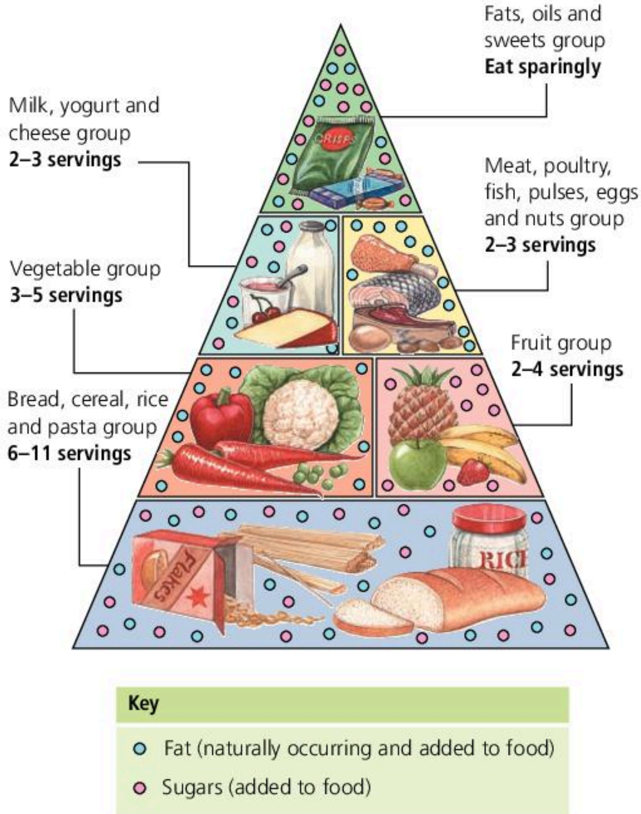
- as a drink
- in food, especially salad foods such as tomatoes and lettuce
- from metabolic processes (look at the equation for aerobic respiration on page 123 – water is one of the products).

A loss of only 5% of the body's water can lead to unconsciousness, and a loss of 10% would be fatal. We shall look further at how the body conserves water on page 140.

Fibre

Dietary fibre is the indigestible part of food, largely cellulose from plant cell walls, which provides bulk for the faeces. Plenty of fibre in the diet stretches the muscles of the gut wall and helps push the food along by peristalsis (see page 76). A shortage of fibre can cause constipation, and may be a factor in the development of bowel cancer.

Summary of a balanced diet



▲ Food guide pyramid: choosing to eat these amounts of different kinds of foods each day provides a balanced diet. People choosing a **vegetarian** or **vegan** diet need to adjust this scheme. They may choose to eliminate meat, fish and poultry, for example, but will then need to replace them with alternative sources of protein.

Q

1 Table 1 shows the composition and energy content of four common foods.

Food	Energy content / kJ per g	Composition per 100g					
		Protein / g	Fat / g	Carbohydrate / g	Vitamin C / mg	Vitamin D / µg	Iron / mg
A	3700	0.5	80	0	0	40	0
B	150	1.2	0.6	7	200	0	0
C	400	2.0	0.2	25	10	0	8
D	1200	9.0	1.5	60	0	0	0

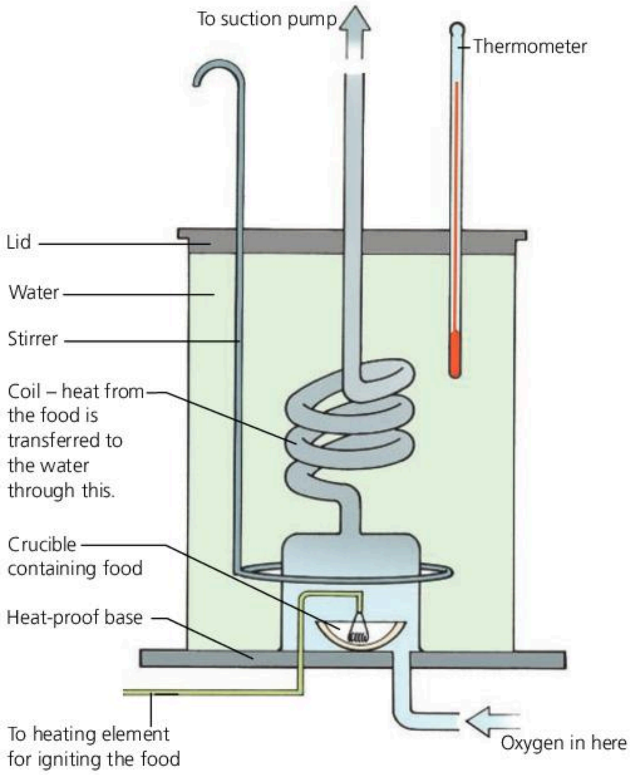
▲ Table 1

a Which food would be best to prevent rickets? Explain your answer.
b Which food would be best for a young person training for cross-country running? Explain your answer.
c Which food would be most needed by a menstruating woman? Explain your answer.
d Which food would be the most useful to a body-builder? Explain your answer.
e Which food would be most dangerous for a person with heart disease? Explain your answer.

7.3 Food is the fuel that drives the processes of life

OBJECTIVES

- To know that food has an energy value
- To know how to calculate the energy value of different foods
- To understand that different people have different demands for energy



Measuring the energy in food

Energy is released from food by respiration, which is an oxidation process, similar in some ways to combustion – if food is combusted (burned), it releases energy, mainly as heat. We can work out the energy value of any particular type of food by assuming that respiration releases the same amount of energy in total as combustion does. The energy value is found using a **food calorimeter** or **bomb calorimeter**, shown in the diagram opposite. A weighed sample of food is completely burned in an atmosphere of oxygen. The heat released by this combustion is transferred to a known volume of water, which rises in temperature as a result. The energy value of the food can be calculated as follows:

$$\text{energy value of food in calories per gram} = \frac{\text{temperature rise / °C} \times \text{volume of water / cm}^3}{\text{mass of food sample / g}}$$

$$\text{energy value in kilojoules per gram} = \frac{\text{energy value in calories per gram}}{1000} \times 4.2$$

Energy values of different foods

The three main energy-providing organic molecules found in food are fats, carbohydrates and proteins. Each has a different energy value:

Fats	39 kJ per g
Proteins	20 kJ per g
Carbohydrates	17 kJ per g

Carbohydrates provide most of our energy, not because there is most energy available per gram in carbohydrates, but because we eat more grams of carbohydrates than of proteins or fats.

Units of energy

The SI unit of energy is the joule (J). The amount of energy contained in food is measured in either joules (J) or calories (cal).

1000 J = 1 kJ (kilojoule) 1000 cal = 1 kcal (kilocalorie)

A calorie is an older unit of energy that is still often used. A calorie is the amount of energy needed to raise the temperature of 1 cm^3 of water by 1 °C.

1 calorie = 4.2 joules

Joules and calories are small amounts of energy so kilojoules and kilocalories are more frequently used to describe the energy values of foods. In popular nutrition guides, the calories referred to are actually kilocalories and are often spelt Cal, with a capital C.

The energy content information given on the packaging of many foods has been calculated by burning a sample of the food in a food calorimeter.

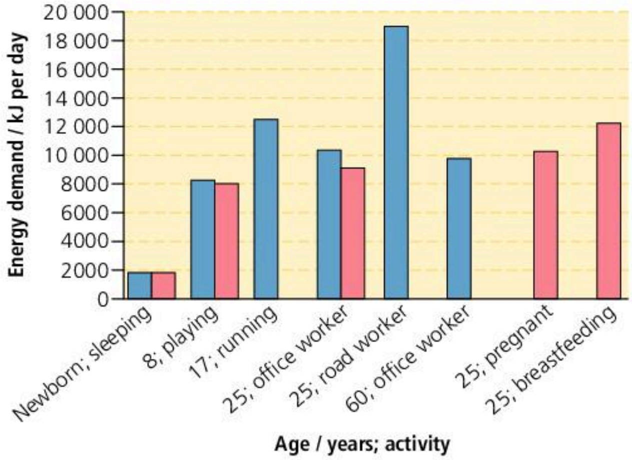
Our energy requirements

The total of all the chemical reactions in the body is called **metabolism**. It is driven by the energy from respiration, so the amount of energy needed depends on how many metabolic reactions a person is carrying out. The amount of metabolism depends on several factors:

- The processes required simply to stay alive. These processes include breathing, excretion, thinking and keeping a constant body temperature. The energy consumed in one day by these processes is called the **basal metabolic rate** (BMR). The BMR is different for males and females, and gets less as a person gets older.
- The amount of **activity** or **exercise** – this requires muscular work and extra temperature regulation. This energy demand can be very little (in a sedentary office worker, for example) or very great (in a road worker, for example).
- Pregnant and breastfeeding women use more energy than many other women of the same age and occupation. A fetus or baby needs **energy for growth** (as well as extra iron, calcium and protein).

$$\text{energy requirement per day} = \text{BMR} + \text{activity}$$

The bar chart below illustrates the energy demands for different people. Three factors affect the body's energy requirements – **age**, **sex** and **occupation**.



▲ Energy requirements for different people

Q

1 Table 1 shows the daily energy needs of different people. Table 2 shows the energy content of four foods.

a What is the daily energy need for an active 8-year-old boy?

b How many grams of Food 3 would meet the energy needs of a male office worker?

c How much more energy does a labourer need than a male office worker each day? Show your working.

d **i** From the foods given in Table 2, which ONE would be the best for the labourer to eat? Give a reason for your choice.

ii If the labourer ate only the food you have suggested in your answer to **i**, what is the least amount he should eat to meet his daily energy need? Show your working.

e The heat energy in foods can be measured experimentally by burning food under a known mass of water. The temperature rise of the water is recorded. The number of joules received by the water from 1 gram of food can be calculated using the following formula:

Heat gained by water from Y grams of food

$$= \frac{\text{mass of water} \times \text{temperature rise} \times 4.2}{Y} \text{ J per g}$$

Use the following data and the formula to work out the number of joules released from 1 gram of food which caused the rise in temperature of the water.

Mass of water = 20 g
Temperature rise = 18°C
Mass of food = 2 g

Person	Occupation	Daily energy need / kJ
Active girl aged 8 years	Schoolgirl	8 000
Active boy aged 8 years	Schoolboy	8 400
Woman	Office worker	9 500
Man	Office worker	10 500
Active girl aged 15 years	School girl	11 800
Active boy aged 15 years	School boy	14 700
Man	Labourer	18 900

▲ Table 1

Food	1	2	3	4
Energy content / kJ per 100 g	3 800	130	1 050	400

▲ Table 2

7.4 Balancing energy intake and energy demand: problems causing malnutrition*

OBJECTIVES

- To understand that different people have different demands for energy
- To understand that energy intake must be balanced by energy use

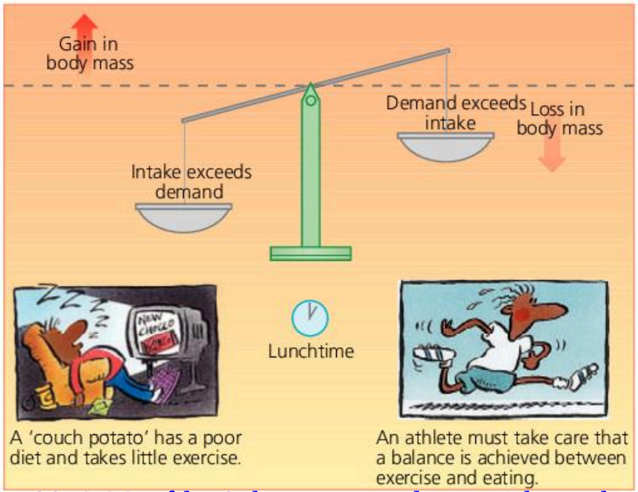
Malnutrition means literally 'bad feeding'. This 'bad feeding' could include:

- eating too much of all foods, so having a balanced diet but consuming more than is needed
- having too little food
- eating foods in the wrong proportions, for example, gaining too many kilojoules from fats and too few from carbohydrates.

Too much energy

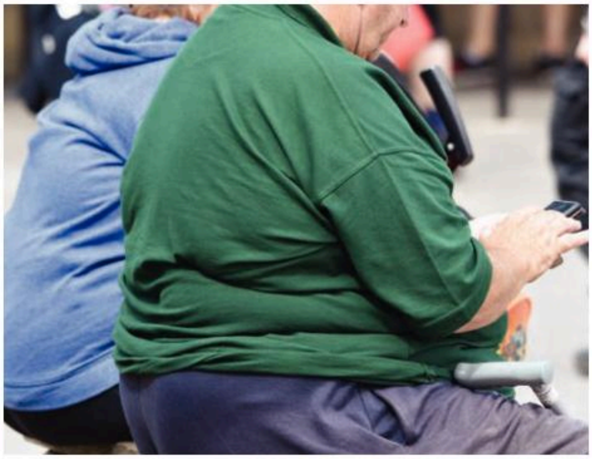
The need for energy is related to **age**, **sex** and **activity**.

If the diet contains more energy than the body needs, the excess will be stored as **glycogen** or **fat**; if it contains less energy than the body needs, then the body's own tissues will be broken down to be respired. The diagram below shows the importance of an **energy balance**.



Storing excess food: overnutrition

The body can store a limited amount of glycogen, which allows the body to continue working even if the last meal was some time ago. However, the body can store an almost unlimited amount of fat to help the body survive periods without food. Our food intake should not be so great that we store an unhealthy amount of fat.



▲ A person whose fat storage is beyond a healthy limit is said to be **obese**

The 'ideal' body mass differs from person to person, and depends on height and age. A person who is obese is at risk from a number of life-shortening diseases, including **diabetes**, **breathing difficulties**, **atherosclerosis** (narrowing of the arteries) and **arthritis**. Obesity is one of the most widespread results of malnutrition in the western world. The recent COVID-19 pandemic has shown that obesity is also a risk factor for infected individuals – they are less likely to recover from treatment in intensive care.

Losing body mass

The energy balance diagram shows that to lose body mass, it is necessary to reduce energy intake below energy use. This can be done in two ways:

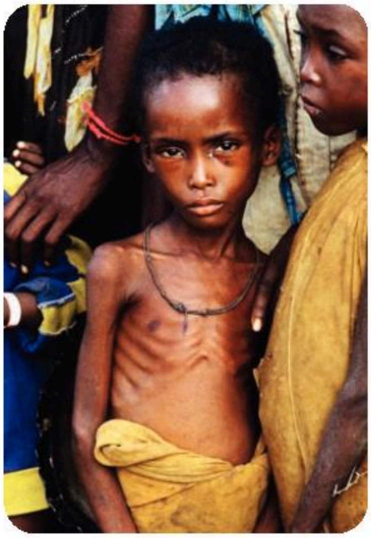
- by eating less 'high-energy' food, which will **reduce the energy intake**
- by taking more exercise, which will **increase the energy use**.

The best approach is to combine both methods, controlling the diet and also taking more exercise. Many people who rely on diet alone have great difficulty in controlling their body mass.

◀ This child has kwashiorkor. The absence of protein means that muscle development is very slow, and the limbs have a stick-like appearance. The swollen abdomen is caused largely by water from the blood plasma remaining behind in the body tissues. The liver is also swollen because it is working hard to make the proteins needed by the body from an inadequate dietary supply.

Malnutrition can also mean undernutrition: too little food

In the developing countries of the world, many people have diets which are neither adequate nor balanced. In other words, they do not receive enough energy to drive metabolism, nor do they take in the nutrients they need for growth and development. These people, often children, suffer from many deficiency diseases – shortage of iron means they are often anaemic, and a limited supply of vitamin C means that many of them have scurvy, for example. The most obvious signs of their malnourished state, however, are often caused by **protein deficiency**. There are two extremes of protein deficiency – **kwashiorkor** and **marasmus**.



◀ Marasmus is caused by insufficient levels of all nutrients in the diet

Kwashiorkor

In kwashiorkor, the child may not have received enough of its mother's milk (often because another child has been born) and may be forced onto a diet that is too high in carbohydrate (often maize). As a result the child may eat enough 'energy' food, but because the diet is poor in protein when its body should be developing quickly, the mental and physical development of the child may be impaired.

Marasmus

In marasmus, the child has symptoms of general starvation – there is not enough 'energy' food nor enough protein. All the body tissues waste away, and the child becomes very thin with a wrinkled skin.

Causes and treatments

Kwashiorkor and marasmus are both serious conditions. They are common in countries where drought conditions have led to poor harvests, or where people have left their homes because of civil war. Aid offered to these people must include both energy foods and the nutrients needed for growth. Powdered milk is often provided, because it is light and easy to transport. However, it must be rehydrated with clean water otherwise water-borne diseases such as cholera may result. There is more information on famine and its causes on page 268.

Q

1 True or false?

a A person suffering from malnutrition is has too little protein in their diet.

b Arthritis is more common in obese people because their diet contains too much fat.

7.5 More about malnutrition*

OBJECTIVES

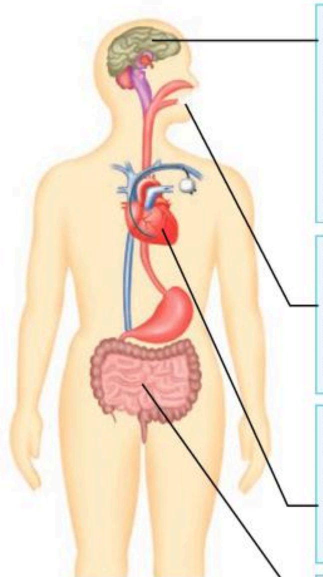
- To understand that malnutrition might not be the same as undernutrition
- To name and explain some examples of malnutrition in the developed world

Malnutrition in the developed world

As well as the problem of obesity, caused by taking in more energy than is needed for the body's metabolism and activity, there are other problems caused by an unbalanced diet for many people in developed countries. These problems, and the 'unbalanced diet' that causes them, are outlined in the figure opposite.

Pregnant and breastfeeding women may show signs of deficiency of calcium (rickets) or iron (anaemia). Some women who cover their bodies completely may not receive enough sunlight to produce vitamin D in their skin, and so may suffer from rickets.

▼ Dangers of an unbalanced diet



High blood pressure
Too much **salt** in the diet can cause water to be drawn into the blood and blood pressure to rise, eventually damaging delicate blood vessels (page 102) including those in the brain.

Tooth decay
A diet with a high content of **acidic**, **sugary foods** can cause damage to tooth enamel and dentine (see page 75).

Coronary heart disease
Too much **saturated fat** and **cholesterol** can cause blockage to blood vessels supplying oxygen to heart muscle (page 106).

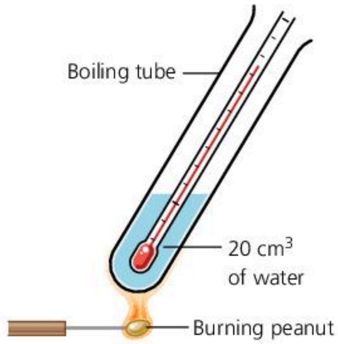
Constipation and bowel cancer
Too little **fibre** means that faeces are not passed as regularly as they should be – the person is **constipated**. Bacteria can work on some of the trapped faeces and release chemicals that cause **colon (large bowel) cancer**.

Don't forget obesity!
Too many kilojoules – the most common problem of undernutrition in the developed world (see page 65).

ENERGY IN FOOD

A class of students used the apparatus shown here to investigate the energy content of a peanut.
They first recorded the temperature of the water (T_1) and weighed the nut. The nut was held in a Bunsen burner flame until it caught fire, and then placed under the boiling tube.

The students recorded the maximum temperature the water reached (T_2), and then repeated the experiment twice more. A typical set of results from one pair of students is shown in the table in Q1 opposite.



1 **a** Copy and complete the table of results.

b Add a further column and include the energy value of the peanut in kJ per g.

c Calculate the mean energy value of the peanut as found by these students. Why is the mean value more valid than any single value that they obtained?

d Can you suggest any improvements to the apparatus so that the students' value might be closer to the 'professional' one (24.5 kJ per g)? Redraw the apparatus showing your suggestions.

e What features of the method helped to improve the validity of the results? How could the students have treated the results differently to improve their validity further?

T_1 / °C	T_2 / °C	$T_2 - T_1$ / °C	Volume of water / cm^3	Energy transferred to water / kcal	Mass of nut / g	Energy value / kcal per g
22	78				0.45	
22	74				0.52	
21	75				0.47	

2 An absence of what from the diet causes the disease kwashiorkor?

A Fat
B Fibre
C Sugars
D Protein

3 Poor diet can lead to bad health.
Match each fact about diet with the harm it may cause. Write the letter and number to show your answer, for example, **a–4**.

Fact about diet	Harm caused
a too much salt	**1** constipation
b too little iron	**2** high blood pressure
c too much fat	**3** slow growth of muscles
d not enough fibre	**4** anaemia
e too little protein	**5** hardening of the arteries

4 Scientists recommend that we eat more fibre in our diet. They have compared the intake of fibre with the chance of developing cancer of the colon.
The scatter graph at the right shows their results.

a State which country has the largest proportion of people with colon cancer.

b Calculate how much more likely a person from the UK is to have colon cancer than a person from Nigeria. Show your working.

c State which **two** of the following foods are good sources of fibre:
wholemeal bread cheese chocolate
apples eggs pizza

7.6 Human nutrition converts food molecules to a usable form

OBJECTIVES

- To know that the process of nutrition involves several stages
- To know the basic layout of the human alimentary canal

Definition: nutrition is the taking in of nutrients which are organic substances and mineral ions, then absorbing and assimilating them.

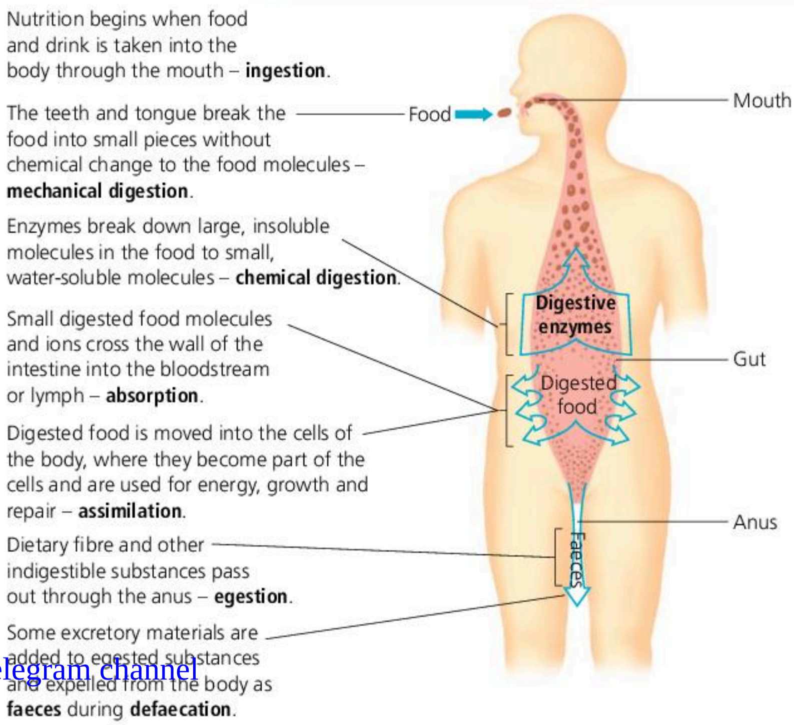
Nutrition involves a sequence of processes

Living things obtain food molecules from the environment. These molecules are not usually exactly the same as the biological molecules the organism needs to carry out its life processes. The processes of nutrition convert the food molecules into a form that can be used by the organism. In humans and many other animals, these processes take place in the **alimentary canal** (sometimes called the **gut**). The alimentary canal is a specialised tube running from the front of the animal (starting at its **mouth**) to the rear (ending at its **anus**). While the food is inside the tube it is not available to the body tissues. The food molecules must be changed into a form that can cross the gut wall and then be transported to the places where they will be used or stored. The processes of nutrition are described in the diagram below.

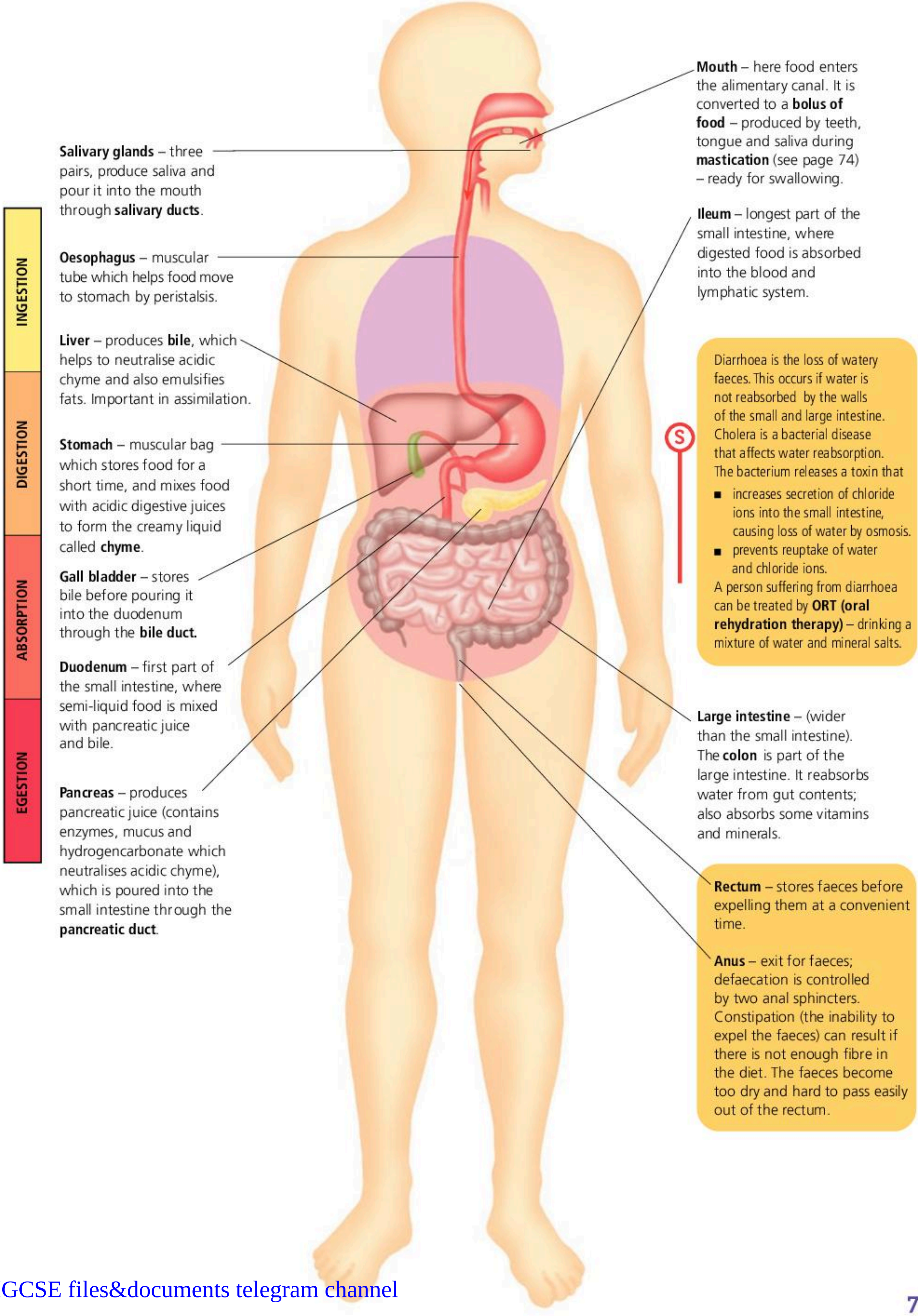
The alimentary canal is highly specialised in humans. The food molecules are converted to a usable form in a clear sequence, with each part of the gut being adapted to carry out particular functions. The layout of the alimentary canal is shown in the diagram opposite, and we shall see how its organs work in the next few pages.

Q

1. List, in their correct sequence, the processes that make up nutrition.
2. What is the difference between the following?
   - **a** chemical and mechanical digestion
   - **b** absorption and assimilation
   - **c** egestion and excretion
3. Why are the epiglottis and the soft palate important in efficient feeding?
4. Name three glands that add juices to the alimentary canal.



▶ Nutrition is a sequence of processes involving ingestion, digestion, absorption and egestion



S

Diarrhoea is the loss of watery faeces. This occurs if water is not reabsorbed by the walls of the small and large intestine. Cholera is a bacterial disease that affects water reabsorption. The bacterium releases a toxin that

- increases secretion of chloride ions into the small intestine, causing loss of water by osmosis.
- prevents reuptake of water and chloride ions.

A person suffering from diarrhoea can be treated by **ORT (oral rehydration therapy)** – drinking a mixture of water and mineral salts.

7.7 Ingestion provides food for the gut to work on

OBJECTIVE

- To understand the part played by teeth and the tongue in preparing food for the alimentary canal

Mastication produces a bolus

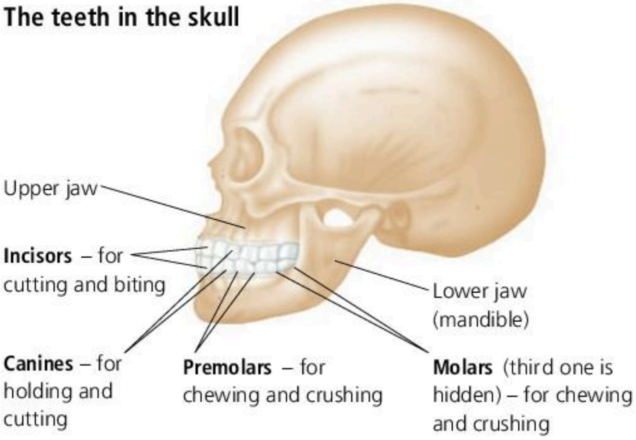
The first stage in processing food for use by the organism is taking the food into the gut. Once the food has been caught or collected, and perhaps cooked or processed in some other way, it is placed in the mouth. Here it is cut up by the teeth, and the pieces are mixed with saliva by the tongue. This cutting and mixing is called **mastication** (chewing), and produces a ball of food called a **bolus**. The bolus is swallowed and passed on to the next parts of the gut. The teeth play an important role in chewing, and it should be no surprise that:

- the structure of a tooth is closely related to its function
- there are different types of teeth adapted to deal with all types of food.

Human teeth and their function

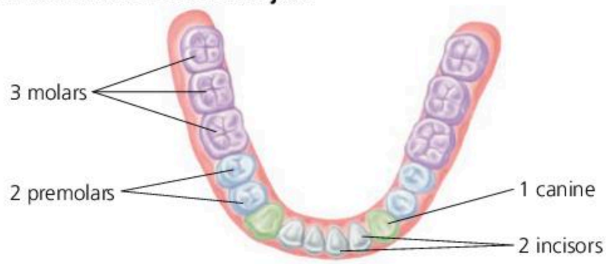
The structure and function of a human tooth are shown in the diagram below. This type of tooth is called a molar, found towards the back of the jaw. The diagram above right shows the four different types of human teeth, and the part each of them plays in mastication.

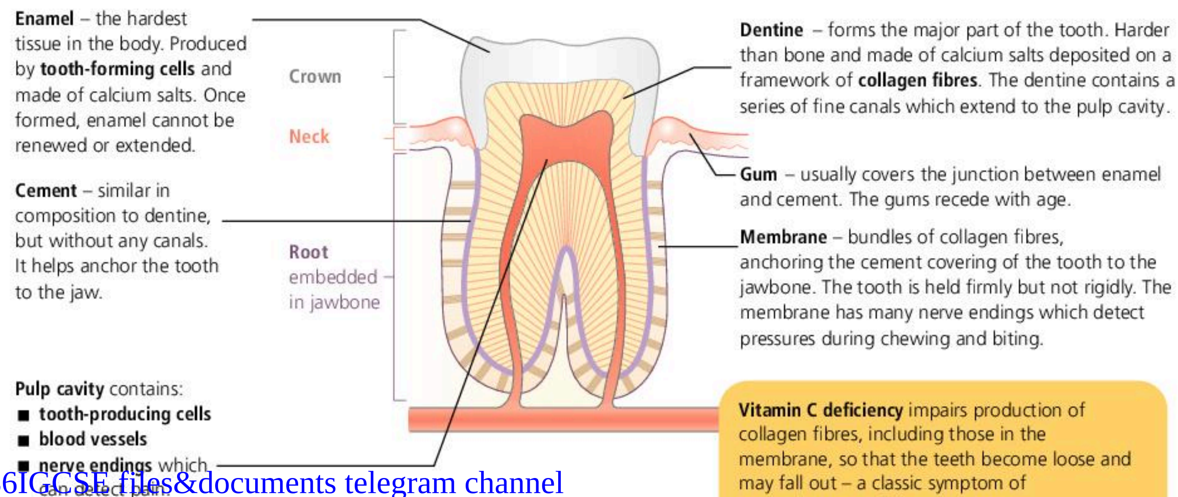
The teeth in the skull



Side view of the four types of tooth

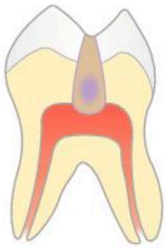
Surface view of the lower jaw





Vitamin C deficiency impairs production of collagen fibres, including those in the membrane, so that the teeth become loose and may fall out – a classic symptom of scurvy (see page 64).

Decay begins in enamel – **no pain**.



Decay penetrates dentine and reaches pulp – **severe toothache**.

Bacteria now infect pulp and may form abscess at base of tooth – **excruciating pain**.

Decayed part of tooth is drilled out by a dentist.

Hole is filled with amalgam or plastic, and may be coated with plastic.

Two sets of teeth

Humans, like other mammals, have two sets of teeth during their life. The first set is the milk dentition, which begins to grow through the gums one or two teeth at a time at around five months old. By about 18 months, most children have a set of 20 teeth – there are fewer molars ('cheek teeth') than in an adult because the jaw is too small to hold any more. Between the ages of 7 and 12 years these milk teeth fall out and are replaced by larger adult teeth. Eight new cheek teeth are added, with a further four (the wisdom teeth) appearing at the back of the jaw by about the age of 17 years. The individual now has the complete adult or permanent dentition of 32 teeth.

Western-style malnutrition may cause dental decay

A diet that provides too much energy can cause obesity (see page 68). Much of this energy-rich food will be in the form of refined sugars such as sucrose (cane sugar) which is used to sweeten many foods. These sugars may also be used by bacteria in the mouth to carry out their own life processes.

The bacteria produce a sticky matrix which traps food particles and forms a coating of **plaque** on the teeth. The bacteria in the plaque convert sugars in the food to acids. These acids remove calcium and phosphate from the enamel, allowing bacteria to reach the softer dentine beneath. This is the start of **dental decay** or **dental caries**. The dentine decays rapidly and the pulp cavity may become infected. The tooth will need dental treatment, as shown in the diagrams on the left.

Dental decay, and the gum disease that often goes along with it, can be prevented by:

- eating food with a low sugar content
- avoiding drinking too many fizzy drinks – the acids in these drinks damage tooth enamel
- regular and effective brushing of teeth at least twice a day to prevent the build-up of plaque – plaque begins to reform after about 24 hours
- if brushing is not convenient, finishing a meal with a crisp vegetable or fruit, followed by rinsing with water.

Q

1. How do we know that a tooth is a living structure?
2. Imagine yourself on a sailing ship several hundred years ago. Explain, simply, why the sailors were losing their teeth.
3. **a** What is dental caries?
   b How does it begin?
   c Suggest **two** ways in which caries can be prevented or reduced.

7.8 Digestion prepares useful food molecules for absorption

OBJECTIVES

- To know that digestion converts large insoluble molecules into smaller, soluble molecules
- To understand that enzymes catalyse the breakdown of food
- To list examples of enzymes involved in digestion of carbohydrates, proteins and fats, and to know where they perform their tasks
- To understand that undigested food must be expelled from the gut

The diet contains three types of food molecule in large amounts – carbohydrates, proteins and fats. When ingested, these molecules may be too large to cross the gut wall and too insoluble to be transported in the watery blood plasma. **Digestion** is the breakdown of large, insoluble food molecules into small, water-soluble molecules. Digestion uses **mechanical** (chewing) and **chemical** (enzymatic) processes.

Digestive enzymes

In digestion, food molecules are broken down by **hydrolysis** reactions (breakdown with water), catalysed by a series of enzymes. There are different enzymes for the hydrolysis of each food type; each enzyme works in different regions of the gut. The basic process of hydrolysis is the same for all the food molecules (see page 36):

large, insoluble molecule $\xrightarrow[\text{+ water}]{\text{enzyme}}$ small, soluble molecules

Carbohydrate digestion begins in the mouth

The saliva contains an enzyme called **salivary amylase** (a carbohydrase). This enzyme catalyses the conversion of the insoluble polysaccharide starch to the soluble, simpler sugar called maltose:

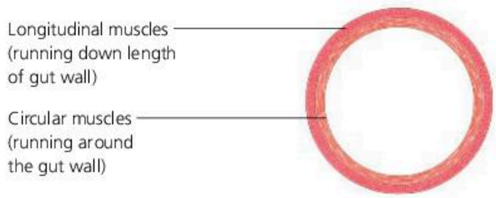
starch $\xrightarrow[\text{+ water}]{\text{amylase}}$ maltose

The saliva also contains mucus, which lubricates the food, and hydrogencarbonate, which provides the ideal conditions of pH (alkaline) for amylase to work. The starch is not usually all converted to maltose in the mouth because the food does not remain there for very long.

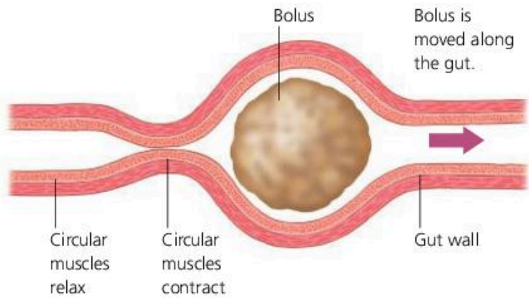
Passing to the stomach

Mastication produces a bolus of food, as we saw on page 74. The tongue pushes the bolus to the back of the mouth, and it is then swallowed (see opposite page) and enters the **oesophagus**. The oesophagus or gullet is a muscular tube leading from the mouth to the stomach. The bolus is forced down the oesophagus more quickly than can be explained by gravity alone. (It is even possible to swallow food when standing on your head!) Waves of muscular contraction push the bolus down towards the stomach, as shown in the diagram below. These waves of contraction are called **peristalsis**, and they occur throughout the length of the gut. The reason why fibre is important in the human diet is that without it the gut contents are very liquid, and the muscles of the gut cannot squeeze the food along by peristalsis.

Cross-section of gut showing muscle layers



Longitudinal section of gut showing peristalsis



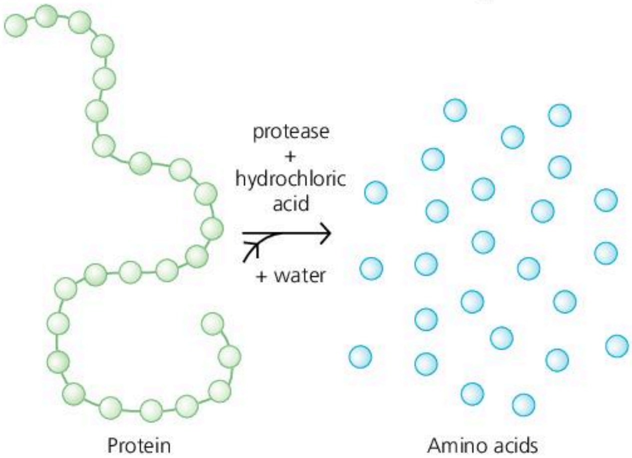
▲ Peristalsis is a wave of muscular contraction that moves food along the gut. Mucus lubricates the bolus, helping it to move along.

Protein digestion begins in the stomach

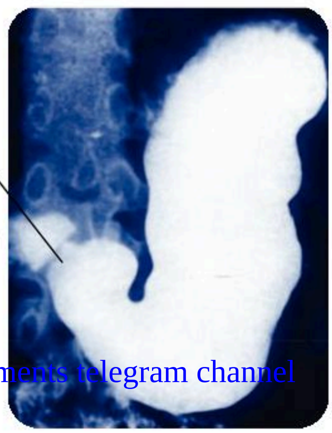
The stomach is a muscular bag with a lining that contains digestive glands. These glands produce three important secretions:

- **mucus**, which protects the walls of the stomach from attack by gastric (stomach) juices
- pepsin, a **protease** or protein-digesting enzyme
- **hydrochloric acid**, which provides the acidic conditions needed for the action of pepsin and denatures the enzymes in harmful microorganisms ingested with food.

Inside the stomach the food is churned up with the gastric juices. The long protein molecules are broken down by hydrolysis to smaller molecules called amino acids, as shown in the diagram below.



The pH in the stomach is too low (too acidic) for the action of amylase, so the digestion of carbohydrate comes to a halt whilst the food is in the stomach. The churning action of the stomach muscles mixes the food into a creamy liquid called **chyme**. Once the food is sufficiently liquid, it squeezes past a ring of muscle at the foot of the stomach, the **pyloric sphincter**, and enters the **duodenum**, the first part of the small intestine.

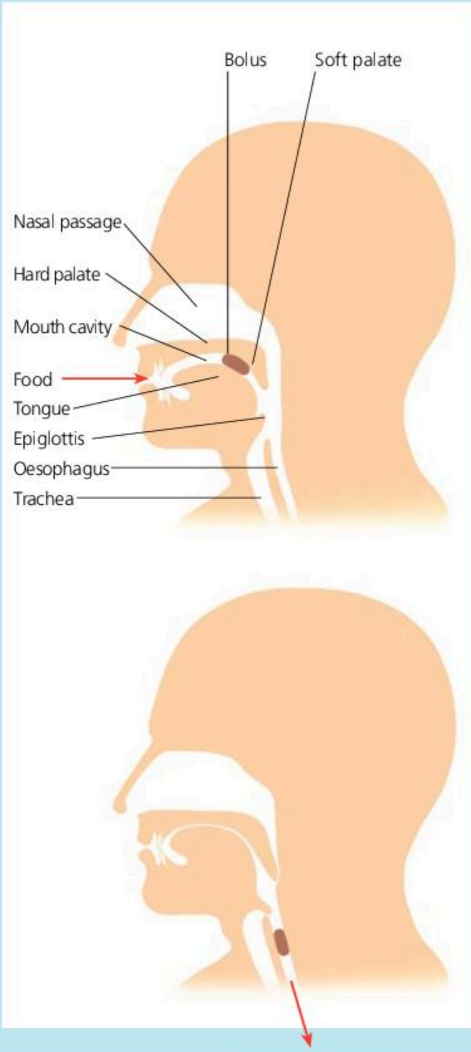


▶ This X-ray was taken after the patient swallowed a barium meal. The barium makes the stomach show up on the X-ray. Food is passing through the pyloric sphincter.

The swallowing reflex

It is important that the bolus of food travels down the oesophagus and not down the trachea (windpipe), or it might block the trachea and prevent breathing. A flap of muscle, the **epiglottis**, is forced across the top of the trachea whenever food is swallowed, ensuring food does not enter the trachea. We don't have to think about this swallowing reflex, but it can be overruled if we try to eat and talk at the same time!

At the bottom of the oesophagus, just where it joins the stomach, is a ring of muscle called the cardiac sphincter. When the bolus reaches this sphincter, the ring of muscle relaxes to allow the bolus through into the stomach. If the stomach contents pass upwards through this sphincter and make contact with the wall of the oesophagus, they cause a burning sensation known as 'heartburn'. This can be treated using an alkaline ('antacid') solution.



Food bolus is moved down the oesophagus.

Digestion of food molecules is completed in the small intestine

The liquid chyme contains partly digested food molecules. The digestion of these food molecules is completed in the small intestine, using digestive juices which contain:

- enzymes from the pancreas
- enzymes from the intestine wall
- bile from the liver.

The enzymes from the pancreas carry out three tasks – **amylase** completes the conversion of starch to maltose, trypsin (another **protease**) completes the breakdown of proteins to amino acids, and **lipase** converts fats to fatty acids and glycerol. These enzymes work best at around pH 8 (slightly alkaline conditions), and the juice from the pancreas also contains hydrogencarbonate which neutralises the acid coming through from the stomach.

S Lipase is helped in its action by **bile**, which is made in the liver and stored in the gall bladder from where it is released when needed. Bile **emulsifies** the fats – it converts them from large globules into much smaller droplets, giving a greater surface area for the lipase to work on, as shown in the diagram.

Bile also contains hydrogencarbonate to help neutralise the acid from the stomach. Enzymes on the wall of the small intestine include **maltase,** which completes the breakdown of maltose to glucose. All the starch has now been converted to glucose. The table opposite lists the digestive juices and their actions.

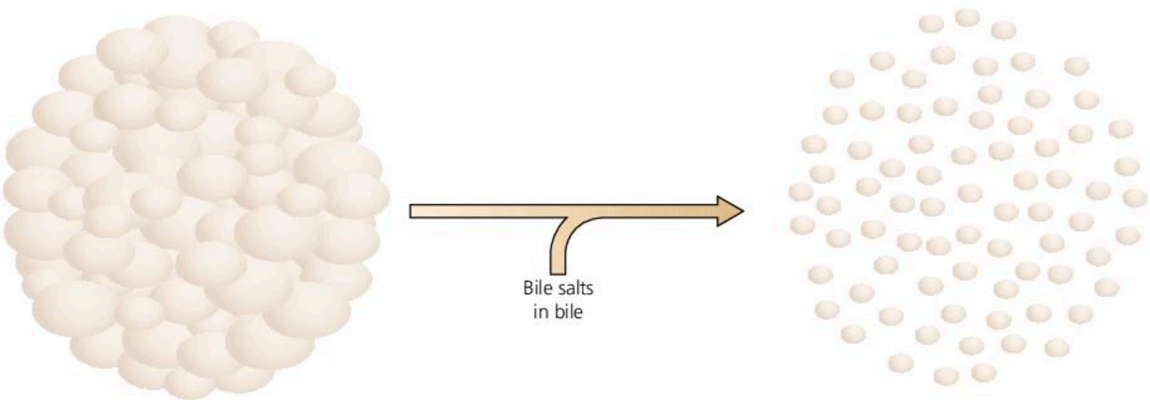
Water and digestion

The digestive juices are largely made up of **water** – this is one of the major requirements for water within the body. This water is the solvent for the biochemical reactions of digestion and is also used in the hydrolysis reactions that split up the large, insoluble food molecules. The juices also contain **mucus** which protects the wall of the gut from being digested by its own enzymes.

Egestion removes undigested food

Food may contain some molecules that cannot be digested by the enzymes of the human gut. Examples include substances in plant cells, such as the cellulose in cell walls and the lignin in wood. These make up '**dietary fibre**' (page 64). Water is first absorbed from the gut contents that remain after digestion, and this indigestible food is then expelled. This process is called **egestion**. Some excreted materials, such as salts in the bile, may be added to the indigestible foods to form the **faeces**. The faeces are stored temporarily in the rectum. When full, the rectum sets off a reflex action which causes its muscles to contract and squeeze the faeces out through the anus. Humans have a sphincter at the anus which can prevent this **defaecation** happening at an inconvenient time! The control of this sphincter has to be learned – babies simply fill their nappies when the rectum is full.

▼ Emulsification of fats provides a larger surface for lipase to act on



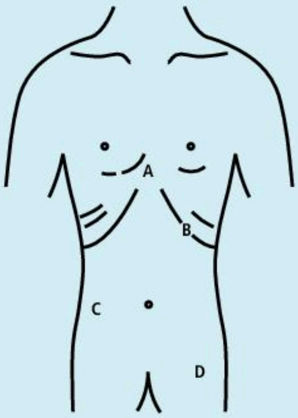
S

Region of gut	Digestive juice	Enzymes	Substrate	Product(s)	Other substances in juice	Function of other substances
Mouth	Saliva from salivary glands	Salivary amylase	Starch	Maltose	Hydrogencarbonate	Alkaline (pH 7.5) environment for amylase
Stomach	Gastric juice from glands in wall of stomach	Pepsin (protease)	Proteins	Amino acids	Hydrochloric acid	Acidic (pH 2) environment for pepsin; kills bacteria
Small intestine (duodenum)	Pancreatic juice from pancreas	Pancreatic amylase Trypsin (a protease) Lipase	Starch Protein Emulsified fats	Maltose Amino acids Fatty acids and glycerol	Hydrogencarbonate	Neutralises chyme: alkaline environment for enzymes
	Bile from liver (stored in gall bladder)	None			Bile salts Hydrogencarbonate	Emulsifies fats – converts globules to smaller droplets Neutralises chyme
Small intestine (ileum)	Intestinal juice from cells on villi	Maltase on the surface membrane of the epithelium lining the small intestine	Maltose	Glucose		

▲ The human digestive juices and their actions: note how starch and proteins are broken down in several stages catalysed by different enzymes

Q

1 In 1822, Alexis St Martin, a Canadian fur trapper, was wounded in his left side by a shotgun blast. Luckily the accident occurred close to an army fort where one of the surgeons, William Beaumont, was able to treat St Martin. The wound healed very slowly, and left a small hole in the side of the young man. Beaumont realised that this gave him a unique opportunity to study what was happening in his patient's stomach.



a Which letter on the outline above represents the most likely position of the hole?

b Beaumont described one of his investigations as follows: 'Juice was extracted from the stomach and placed in a small vial. A solid piece of boiled, recently salted beef weighing three drachms was added. The vial was corked and kept under controlled conditions. A similar piece of beef was suspended on a string into the man's stomach.'

- **i** Suggest one condition around the vial that Beaumont would have kept constant.
- **ii** What control experiment should Beaumont have performed?
- **iii** Why did Beaumont use 'boiled, salted beef'?

c After two hours, Beaumont recorded the following results: 'Beef in vial – the cellular texture seemed to be entirely destroyed, leaving the muscular fibres loose and unconnected, floating about in fine, small shreds, very tender and soft. Beef in stomach – I drew out the string, but the meat was all completely digested and gone.'
Use your knowledge of digestion to explain the difference between the changes in the vial and those in the stomach.

2 The liver produces a liquid which is added directly to the partly digested food in the small intestine.

a Name the liquid.

b Describe how it helps digestion.

3 Describe, in the correct sequence, how the protein and starch in a ham sandwich are broken down ready for absorption.

4 Digestive juices contain enzymes, water and some other substances. Name two of these other substances. State which digestive juice contains them, and state what function they perform.

7.9 Absorption and assimilation make food available

OBJECTIVES

- To understand that digested food in the gut is still 'outside' the body
- To know how the small intestine is adapted to the function of absorption of digested food
- To understand the part played by the liver in the assimilation and distribution of absorbed foods

Absorption of the products of digestion

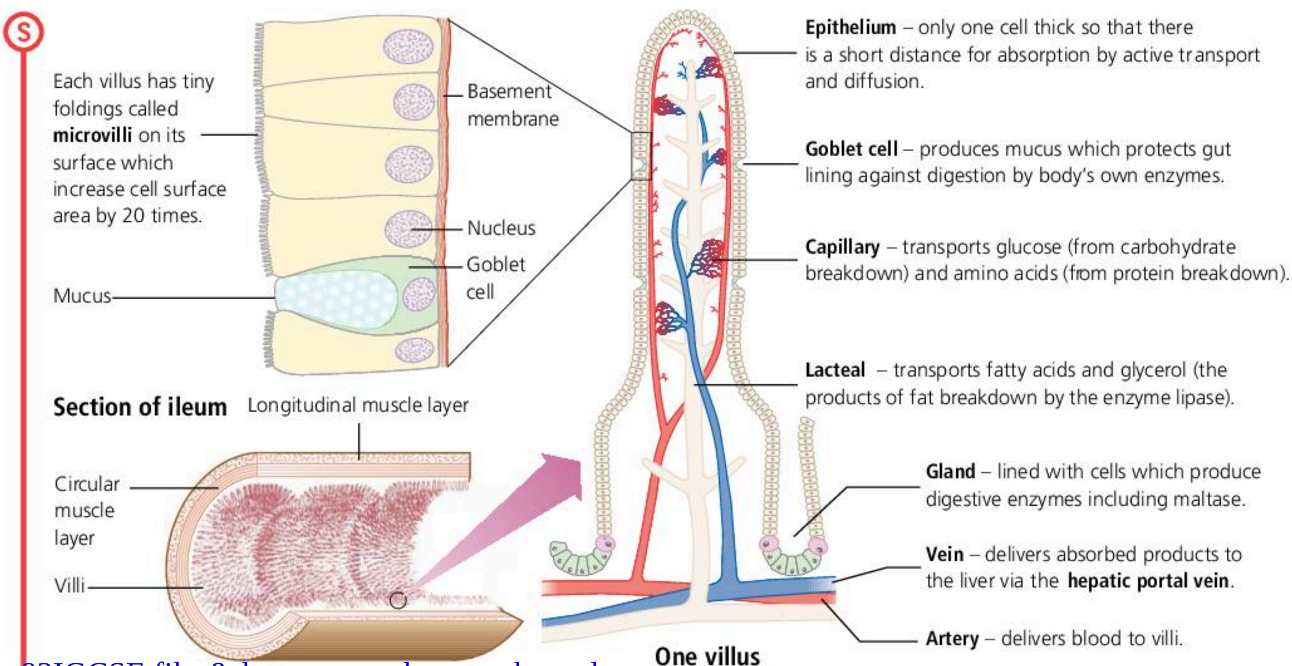
Enzymes in the gut convert large, insoluble molecules to small, soluble molecules. These digested food molecules are transported across the lining of the gut into the blood or lymph, a process called **absorption**. They can then be distributed to the parts of the body where they will be used.

Most absorption happens from the **ileum**, the lower part of the small intestine. The ileum is very well adapted to perform this task:

- It is **very long**, about 6 m in an adult human, so food takes a long time to pass through it, and there is enough time for absorption to occur.
- The surface of the ileum is **highly folded**, which gives a much larger surface area for absorption than a simple tube would.

The lining of the ileum is folded into hundreds of thousands of tiny finger-like structures, the **villi**, which project out into the liquid digested food. The structure of a villus, and its adaptations to increase absorption, are shown in the diagram below.

Following absorption in the small intestine, the contents of the gut are mostly water and indigestible matter. After water absorption in the ileum, most of the remaining water is reabsorbed into the bloodstream from the **colon**, part of the large intestine. Some minerals and vitamins are also absorbed here.

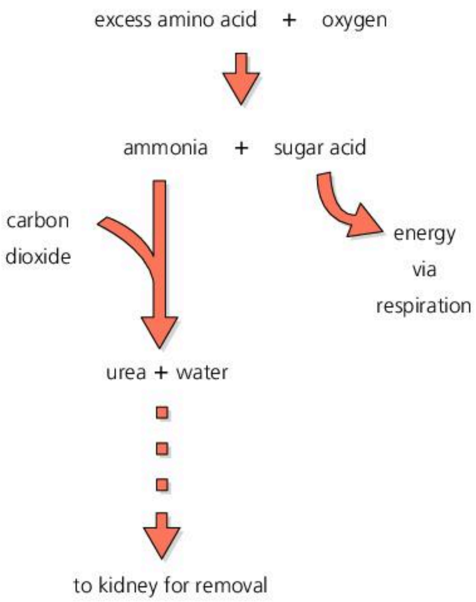


The liver and assimilation

Digested food is absorbed into the bloodstream. Each type of absorbed food has a particular function in the body, so it is important that food molecules of the right type are available at the right time in the right place. The **liver** 'sorts out' digested food molecules, and all foods absorbed into the capillaries of the villi are sent first to the liver.

The liver has many functions – at least 500 different biochemical reactions go on inside its cells. These functions include:

- manufacture of bile, which is important for the digestion of fats
- storage of glucose as glycogen
- interconversion of glucose and glycogen, which keeps the glucose concentration constant for the working tissues of the body (see page 148)
- interconversion of amino acids – the liver can convert some amino acids into others that the body might require in a process called **transamination**; these amino acids can be built up to proteins, including plasma proteins such as **fibrinogen**
- excretion of excess amino acids – the amino part of the amino acid is removed in a process called **deamination** (see page 140) and excreted in the urine as urea



- removal of old red blood cells from the circulation and storage of the iron they contained
- breakdown of alcohol and other toxins, called **detoxification**.

A combination of transamination and deamination makes sure that there is always a 'pool' of amino acids available for use by the cells of the body.

As a result of these and other activities, the liver provides ideal concentrations of food molecules for the working of the body tissues. Each type of tissue uses food molecules for different purposes – for example, muscle cells manufacture muscle protein, bone cells take up calcium and phosphate to make bone, and all cells use glucose to release energy by respiration.

The processes of moving food molecules into the cells where they are used is called **assimilation**.

Alcohol and the liver

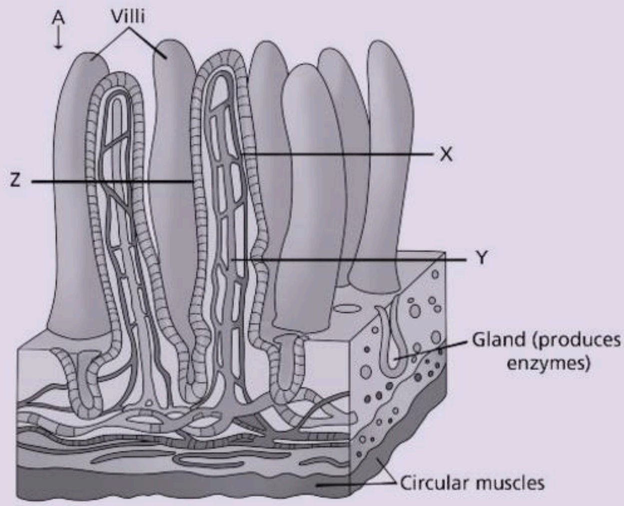
The liver receives all the molecules that the gut absorbs from food. As well as useful molecules such as glucose and amino acids, this may include harmful molecules such as drugs or poisons. **Alcohol** is a drug (a molecule that affects the normal working of the body) which passes quickly to the liver after being absorbed from the stomach and ileum. The cells of the liver convert this alcohol to another substance which does not pass through to the rest of the body's circulation. Unfortunately, in working to protect the other tissues, the liver is likely to harm itself. The substance produced from alcohol can be dangerous to liver cells in high concentrations and can cause a serious disease called cirrhosis of the liver. If the liver is damaged by excessive alcohol consumption, then the whole body is affected. For example, the blood glucose concentration cannot be controlled efficiently if the liver has been damaged.

Q

1. In what way is the blood supply to the liver unusual?
2. Name two substances stored in the liver, and two that are converted to different substances.
3. How is the structure of the villus is adapted to its function.
4. What are goblet cells? Where else do you think they might be found apart from in the gut?
5. Some microorganisms infect the gut lining so that water cannot be absorbed. What effect(s) might this have on the infected person?

Questions on human nutrition and health

1 The diagram shows a group of villi from the alimentary canal.



a Identify the parts labelled X, Y and Z. [3]

b Suggest **one** function of the circular muscles. [1]

c State the part of the alimentary canal where villi are located. [1]

d Name **three** substances that pass from A on the diagram into the villus. [3]

e With reference to the diagram, explain the significance of diffusion and active transport in the alimentary canal. [4]

2 The liver performs important functions in the digestion and assimilation of food. One of these is the production of an alkaline digestive juice that breaks down large globules of fat.

a **i** Name the digestive juice secreted by the liver. [1]

ii Explain how this digestive juice reaches the food in the small intestine. [2]

iii Explain why this digestive juice is alkaline. [2]

iv Describe how this juice plays a part in the digestion of fat. [3]

b Explain what is meant by the term **assimilation**. Use an example to help your explanation. [2]

3 John and Paul were eating their school lunch. Later, they decided to look up the nutritional value of some of the foods in a book. The book had a table showing what 100 g of each food contains.

a Use Table 1 below and your biological knowledge to answer the following questions.

i Which food shown in the table would be best for preventing scurvy? [1]

ii John ate a sandwich containing 100 g bread, 50 g of cheese and 10 g of butter. How much energy did he take in? Show your working. [2]

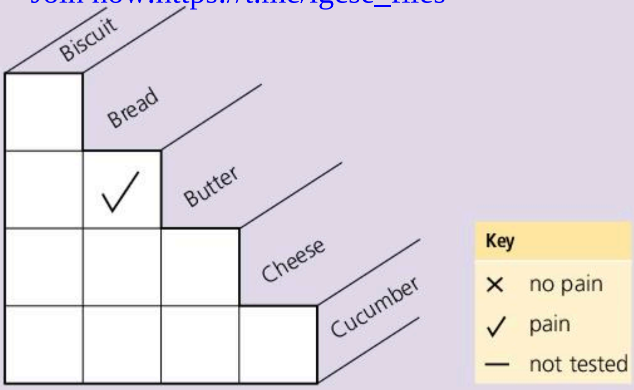
b Paul had been complaining of pain after eating and so went to the doctor.
The doctor wanted to find out if Paul was allergic to any foods.
She asked Paul to eat two different foods at each meal and record whether he suffered any pains afterwards.
This is what he noted down.

Food eaten	**Pain**
Bread and butter	yes
Bread and cheese	yes
Cheese and biscuits	yes
Cheese and cucumber	no
Bread and cucumber	yes

i The doctor asked Paul to complete a chart.
Using Paul's note, copy and complete the chart according to the key given on the next page. The result for bread and butter has been done for you.

Food	Energy / kJ	Animal protein / g	Plant protein / g	Calcium / mg	Iron / mg	Vitamin C / mg
Biscuits	2000	2	5	100	1.5	0
Bread	900	0	9	100	1.7	0
Butter	3000	0.5	0	15	0.2	0
Cheese	1600	26	0	800	0.4	0
Cucumber	40	0	0	25	0.3	8

▲ Table 1



[3]

ii From the chart, the doctor could identify the foods to which Paul was allergic. Which are they? [2]

iii Use Table 1 to identify which substance in the foods was the cause of the allergy. [1]

iii The doctor said that the substance which caused Paul's allergy was destroying the villi in his small intestine. She said that this might slow down Paul's growth. The reason for this poor growth is that the absorption of soluble foods is reduced. Explain why the loss of villi leads to reduced absorption. [1]

4 Complete the following paragraph.
The production of loose, watery faeces is called ________ . This is due to reduced absorption of water in the ________ and ________ . This condition can be caused by a bacterium, and is called ________ . A person suffering from the condition can be treated by ________ . [5]

5 a The table below summarises some of the processes of digestion. The table is incomplete. Copy and complete the table by inserting the missing words. [4]

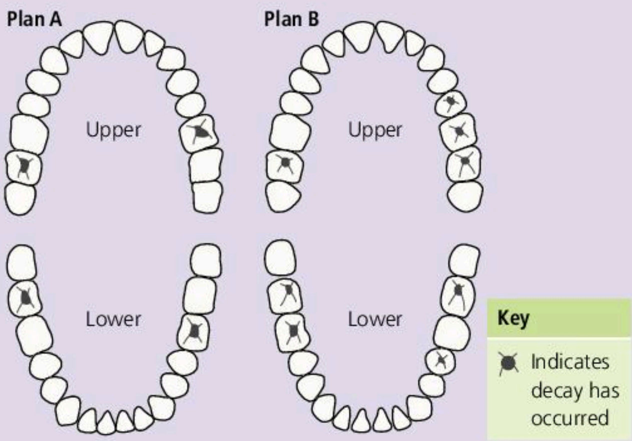
Ingested food material	Digestive enzyme	Soluble end products of digestion
	amylase	maltose
protein		
		fatty acids and glycerol

b Some of these products are carried in the blood to the liver.

i Name the blood vessel which carries these products. [1]

ii Describe the processes that occur when an excess of amino acids arrives at the liver. [3]

6 The diagrams below show plans of the teeth in the upper and lower jaw. Plan A is from a 27-year-old woman called Hannah; plan B is from a 27-year-old woman called Caitlin.



The two women have different diets. One consumes a lot of sugary foods and fizzy drinks, the other prefers apples and milk.

a State which woman has the sugary, acidic diet. Support your answer with numerical data. [2]

b Suggest other reasons for the difference in the number of decayed teeth between the two women. [2]

c Why is it important that both plans are from women, and each is aged 27? [2]

d Explain why decay is more likely in the cheek teeth. [2]

e How would these plans have been different if they had been taken when the women were 10 years old? [1]

7 The table below shows the effect of pH on the time taken for the complete breakdown of a starch solution in the presence of an enzyme.

pH	5.0	5.5	6.0	6.5	7.0	7.5	8.0	9.0
Time taken / min	20.00	15.00	8.00	4.00	1.25	1.25	3.00	8.00
Rate of reaction								

a Copy and complete the table. Assume that the rate of reaction is the same as $\frac{1}{\text{time taken}}$. [2]

b Plot the results in the form of an appropriate graph. [4]

c What is the optimum pH for this enzyme? [1]

d Name **one** region of the gut where this pH would be found. How is this pH kept constant? [2]

e Suggest **two** chemical tests that could be carried out on samples of the solution to show that starch is being broken down. [2]

f In this experiment pH is the input or independent variable, and rate of reaction is the outcome or dependent variable. Suggest **three** fixed variables which must be kept constant if these results are to be valid. [3]

8 The table below shows the energy value of a number of products from the Mars company.

a Copy and complete the table to show the energy value of each product in kJ per 100 g (take care – some energy values are shown for 25 g; others are for whole bars or packets). [2]

b Draw a bar chart showing the products in descending order of energy value (the one with the highest energy value on the left). [4]

c For a 50 g portion, which product would be:

i the least fattening [1]

ii the most fattening? [1]

d A Mars bar weighs 65 g. What is its energy value in kilojoules? [1]

e While sitting watching television, a boy of 15 uses about 6 kJ per minute.

i How long would it take him to use all the energy obtained from the Mars bar? [1]

ii What is he using this energy for? [1]

f While playing football, the same boy uses, on average, 30 kJ per minute. How long would it take him to use up the energy obtained from the Mars bar? [1]

g A football match lasts for 90 minutes. If the boy ran for half of the game, would he have used more energy or less than the Mars bar provided? How could his body cope with any difference between energy demanded and energy supplied? [2]

Name of product	Energy value / kJ per 25 g, unless otherwise stated	Energy value / kJ per 100 g
Bounty, 60 g	490	
Maltesers	504	
Mars	454	
Milky Way	490	
Minstrels, 49 g	870	
Snickers	504	
Treets, 42 g	1040	
Twix	504	

8.1 Transport systems in plants

OBJECTIVE

- To appreciate that water and dissolved substances are transported around the plant in specialised transport tissues

Xylem and phloem

Substances need to be transported for long distances throughout a plant's body – sugars, for example, are produced in the photosynthesising cells of the leaves and may need to be transported to storage cells in the roots. The water and ions absorbed by the roots may be required by cells at the growing tip (the **meristem**) of the shoot. These long-distance transport functions are carried out by two specialised plant tissues – the **xylem** and the **phloem**. These are tubes running through the plant, collected together in groups in the **vascular** (transport) **bundles**, as shown in the diagram opposite.

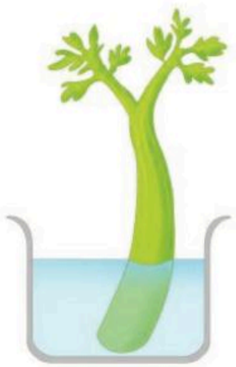
Moving vital substances from sources to sinks

The transport tissues are arranged in the stem and root as shown opposite, to offer:

- the most efficient transport of materials from **sources** (where they are taken in or made) to **sinks** (where they are used or stored)
- the most effective support in air (the stem) and soil (the root).

The transport functions of xylem and phloem have been investigated in a number of ways, as shown in the diagram below.

TRACING XYLEM



Procedure

1. Cut a piece of celery and stand it in a coloured solution (suitable stains include eosin [red] and methylene blue [blue!]).
2. Leave for a few hours.
3. Carefully (CARE! SHARP SCALPELS) cut off about 5 cm of the celery, and use a hand lens to look for the stain. The coloured solution has been carried up the **xylem**.

Extension: You could also try:

a. Carefully (using the scalpel) scrape away the outside tissues of the celery to trace the xylem. What happens as the stem branches to the leaves?
b. Use a pale-coloured (e.g. white) flower, such as a carnation. You can change its colour, just as florists do!

Transport of the products of photosynthesis

Aphids (greenfly) are serious pests of many crops. They can take food meant for the growing regions of plants by inserting their mouthparts (the **stylet**) into the plant tissues.

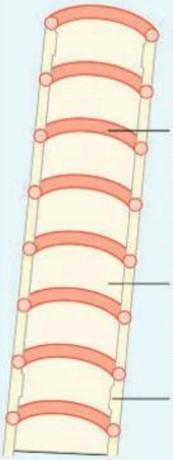
If feeding aphids are anaesthetised with carbon dioxide their bodies can be 'flicked away' from the plant surface, leaving the stylet in place. The contents of the phloem, the **sap**, will slowly leak out of the stylet and can be analysed. The results show that the phloem transports sucrose (sugar), the main product of photosynthesis.

Application: aphids eat themselves to death!

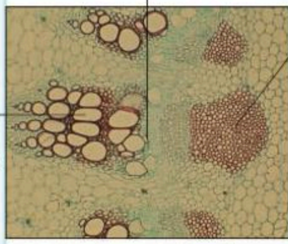
Many insecticides kill useful insect species as well as pests. **Systemic** insecticides are sprayed onto the plant and absorbed into the phloem tissues, so they only kill aphids.

Xylem tissue contains long **xylem vessels** adapted for the rapid transport of water and **dissolved mineral ions.** Movement is always **up** the stem.

Longitudinal section of xylem vessels



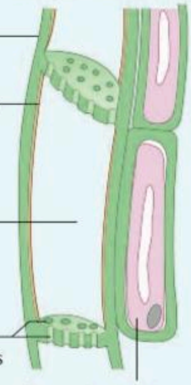
Cambium tissue (see page 194) contains cells which divide by mitosis to produce more phloem and xylem.

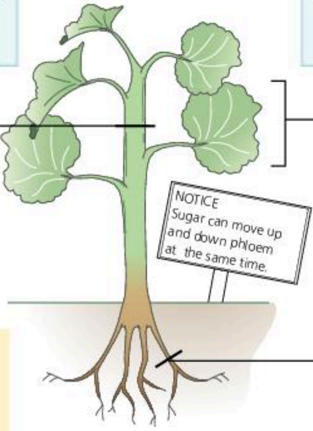


Vascular bundle (× 100).

Phloem tissue contains **sieve tubes** and **companion cells.** It is adapted for transport of the **organic products of photosynthesis** i.e. sugars (transported as **sucrose**) and amino acids.

Longitudinal section of phloem sieve tubes

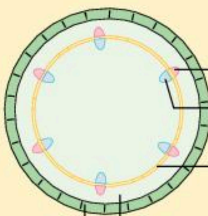




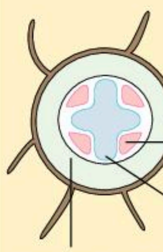
The position of phloem and xylem in the leaf is shown on page 51.

Direction of transport varies with the seasons!
Sucrose is transported **from** stores in the root **to** leaves in spring, but **to** stores in the root **from** photosynthesising leaves in the summer and early autumn.
Whatever the time of year the movement of sugars and amino acids **(translocation)** is from **source** to **sink**. In other words, sucrose and amino acids are translocated from the region where they are made or absorbed to the region where they are stored or used.

Stem – vascular bundles are arranged in a ring with soft cortex in the centre, helping to support the stem.



Root – root hairs are extended cells of the epidermis.



▲ The transport tissues xylem and phloem are arranged in vascular bundles. They transport water and dissolved substances around the plant.

Q

1. Name the two vascular tissues in flowering plants. Which tissue divides to form the vascular tissues?
2. What is a **source**? Suggest two examples in a flowering plant.
3. Why does the direction of sugar transport vary from season to season?
4. Why must sugar be transported to **sinks** such as growing points and roots?
5. Many dyes are water soluble. Xylem vessels reach up from roots to flower petals. How could these two observations be useful to a florist?

8.2 Uptake of water and minerals by roots

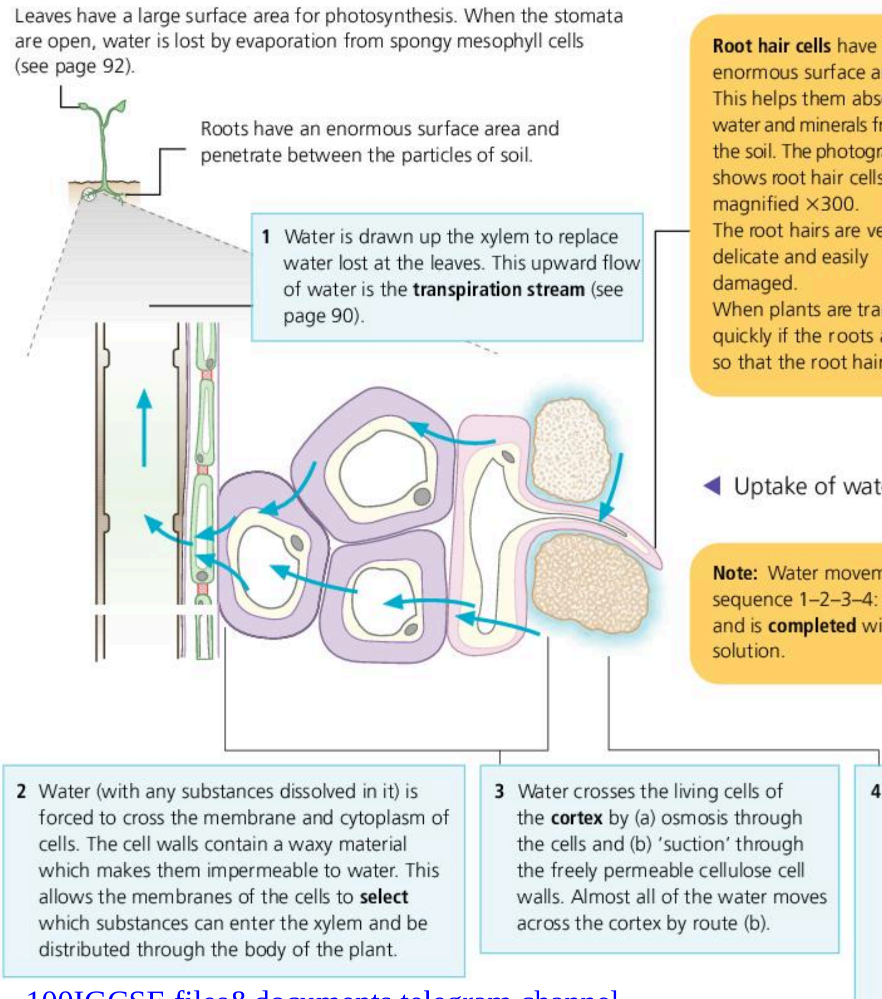
OBJECTIVES

- To understand that water may enter and leave cells by osmosis
- To understand that dissolved substances may enter and leave cells by diffusion and active transport

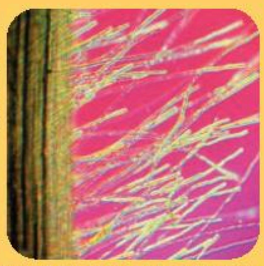
Plants need water and minerals

Plants need to obtain certain raw materials from their environment. The roots of the plant are adapted to absorb both minerals and water from the soil. **Water** is essential to support the plant, as a reagent in many biochemical reactions and also as a transport medium (see page 256). The diagram below shows how water enters the plant through **root hair cells**.

Minerals have a number of individual functions and together have a great effect on the water potential of the plant tissues. Minerals from the soil are absorbed in the form of **ions**, for example, magnesium enters the root as Mg^{2+} ions and nitrogen enters as nitrate NO_3^- ions. If the soil solution contains higher concentrations of these ions than the root hair cell cytoplasm, the ions can enter by diffusion (see page 30). However, plants can continue to take up ions even if the concentration gradient is in the wrong direction, that is, if the concentration of the ions is higher inside the cell than in the soil solution.



Root hair cells have an enormous surface area. This helps them absorb water and minerals from the soil. The photograph shows root hair cells magnified ×300. The root hairs are very delicate and easily damaged.



When plants are transplanted they recover much more quickly if the roots are kept in a ball of soil or compost so that the root hairs are not disturbed.

◀ Uptake of water by root hair cells

Note: Water movement through the plant occurs in the sequence 1–2–3–4: it **begins** with loss from the leaves, and is **completed** with water absorption from the soil solution.

Osmosis: a reminder

A cell's membrane controls the entry and exit of materials to and from the cell (see page 30). A typical plant cell such as that found in the mesophyll layer of the leaf has a high concentration of solutes. Therefore, water will enter a plant cell by osmosis from an environment with a high water potential, until the water inside the cell forces the cell membrane up against the cellulose cell wall.

When a plant cell contains plenty of water, the internal pressure of the cell contents against the cell wall supports the cell. The cell is said to be **turgid**, and turgidity helps support the plant. If the plant does not have a good supply of water, the cells lose their turgidity and slowly collapse. The cells are said to be **flaccid** and the plant is wilted.

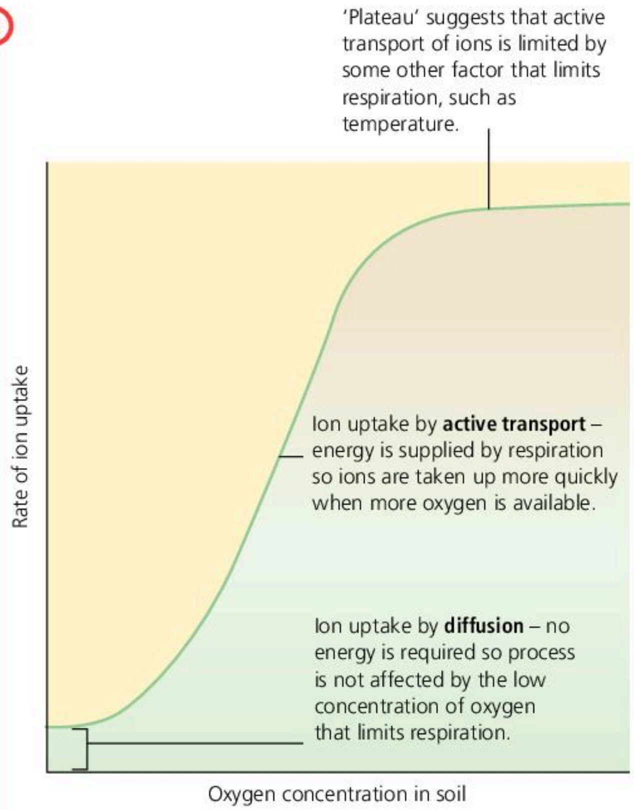
Active transport: application

To increase crop yields, farmers may drain fields that are liable to flooding. If the soil is not waterlogged, more oxygen in soil air spaces is available to the plants, so the rate of aerobic respiration in root cells is faster. This provides more energy for active transport, so that the growing plants will more quickly absorb mineral ions present in the soil. Farmers may also cover their fields with black polythene. This absorbs heat and helps to raise the soil temperature, so that seed germination and ion uptake by young roots will be faster.

Experiments on the uptake of ions also show that:

- the cells can select which ions enter from the soil solution
- any factor that affects respiration, for example lack of oxygen or low temperature, can reduce the uptake of ions. The diagram below shows some results that support these observations.

The explanation of these observations is that the root hair cells use **active transport** to carry out the selective uptake of ions against a concentration gradient, using energy from respiration (see page 34).



▲ Ion uptake depends on respiration

Q

1. Does a solution containing many molecules of dissolved sugar and amino acids have a high or a low water potential? Explain your answer.
2. Define osmosis in terms of water potential.
3. How does the strength of the cellulose cell wall help plants to support themselves?
4. A scientist investigated the uptake of magnesium ions by the roots of young cereal plants. He made the following observations:
   - **a** The rate of uptake was increased by raising the temperature, so long as it did not exceed 40°C.
   - **b** Uptake stopped if the roots were treated with cyanide, an ion that prevents respiration.
   - **c** Ions were taken up even if they were present at a lower concentration in the solution around the roots than in the root cells themselves.
   - **d** If ion uptake continued for some time, the concentration of sugars in the root cells decreased.

   What can be deduced from each of these observations?

8.3 Transpiration: water movement through the plant

OBJECTIVES

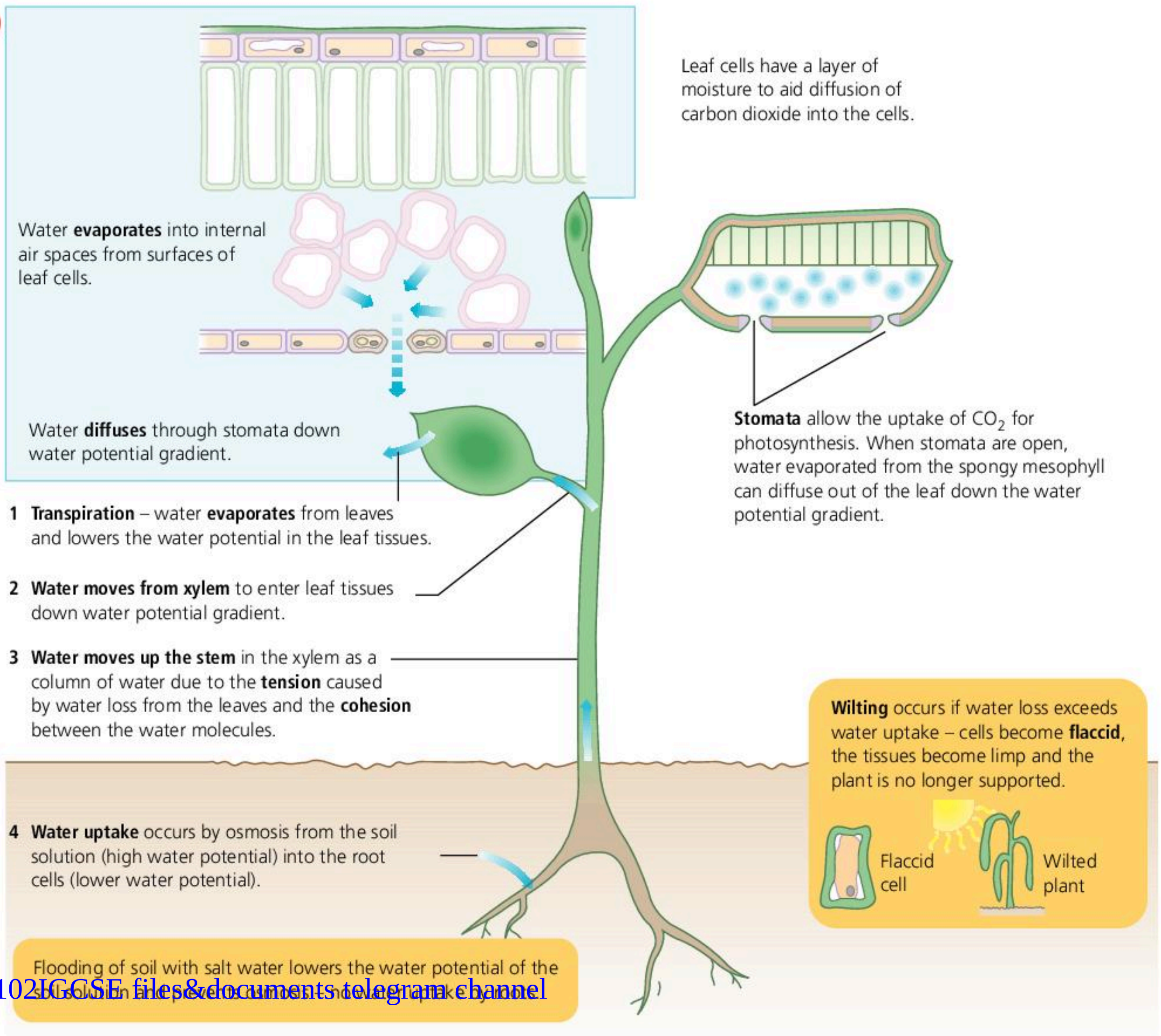
- To recall that water movement through a plant begins with water loss from the leaves
- To understand that water is lost from leaves via the stomata, through which the exchange of gases between the leaf and the atmosphere also occurs
- To describe how the leaf surface most involved in water loss can be identified
- To understand how environmental conditions can affect water movement through plants

Evaporation from leaves

Water evaporates from the parts of a plant that are exposed to the atmosphere – for example, the whole shoot system of a terrestrial plant and the upper leaf surfaces of a floating aquatic plant. The greatest loss of water takes place through the **stomata** (singular **stoma**), minute pores on the leaf surface (see page 50). There are usually more stomata on the lower surface of leaves than on the upper surface.

Water movement through a plant begins with the diffusion of water vapour out of the leaf and evaporation from the leaf surface (spongy mesophyll). 98% of the water taken up by a plant is lost to the atmosphere by transpiration.

S



The lower surface is less exposed to the warming effects of the Sun's radiation, which would speed up the evaporation rate. Loss of water from the leaf is shown in the diagram on the opposite page.

Water cannot diffuse *into* the leaf through the stomata, because the air spaces inside the leaf are completely saturated. Instead, water must be absorbed from the soil solution and drawn up through the plant (see page 88). This flow of water through the plant to replace the losses by evaporation from the leaf is called the **transpiration stream**, shown in the diagram on the opposite page.

Transpiration is affected by **leaf structure** and by **conditions in the atmosphere** because water is lost through the stomata to the atmosphere (see opposite). These factors can be investigated using the **potometer** shown below.

Leaf structure may reduce transpiration

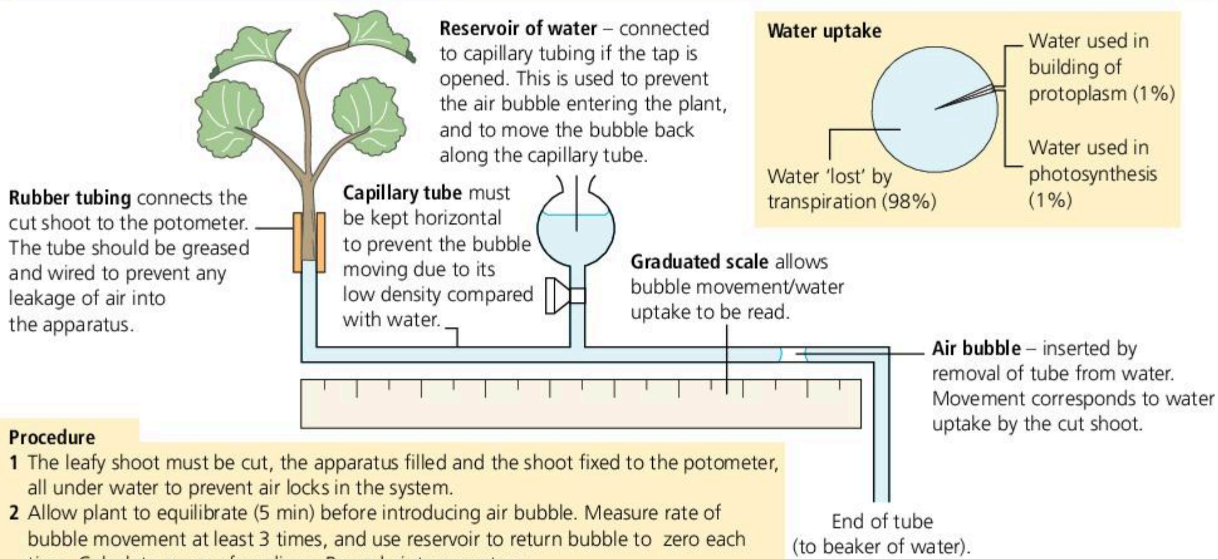
- Thick, waxy cuticle reduces evaporation from epidermis.
- Stomata may be sunk into pits which trap a pocket of humid air.
- Leaves may be rolled with the stomata on the inner surface close to a trapped layer of humid air.

- Leaves may be needle shaped to reduce their surface area.

Atmospheric conditions may affect transpiration

- **Wind** moves humid air away from the leaf surface and increases transpiration.
- **High temperatures** increase the water-holding capacity of the air and increase transpiration.
- **Low humidity** increases the water potential gradient betwee leaf and atmosphere and increases transpiration.
- **High light intensity** causes stomata to open (to allow photosynthesis) which allows transpiration to occur.

USING A BUBBLE POTOMETER



Procedure

1. The leafy shoot must be cut, the apparatus filled and the shoot fixed to the potometer, all under water to prevent air locks in the system.
2. Allow plant to equilibrate (5 min) before introducing air bubble. Measure rate of bubble movement at least 3 times, and use reservoir to return bubble to zero each time. Calculate mean of readings. Record air temperature.
3. Rate of water uptake per unit area of leaves can be calculated by measuring leaf area.

▲ The bubble potometer measures water uptake (water loss by transpiration plus water consumption for cell expansion and photosynthesis).

Q

1 Shops which sell flowers sometimes spray the leaves of expensive plants with a waxy substance. Explain why they do this.

8.4 The leaf and water loss

OBJECTIVES

- To understand that stomata are opened to allow carbon dioxide to enter the leaf, and that this allows water vapour to diffuse out of the leaf
- To describe adaptations of leaves to reduce water losses

Stomata and water loss

Water is lost by evaporation and diffusion from the leaf surface. This water loss happens because the stomata need to open so the leaf can take in carbon dioxide as a raw material for photosynthesis. Plants can open and close the stomata, which helps to minimise water loss whilst allowing photosynthesis to continue. The position and operation of the stomata is explained on page 50, which also shows the adaptations of the leaf to photosynthesis.

Adaptations of plants

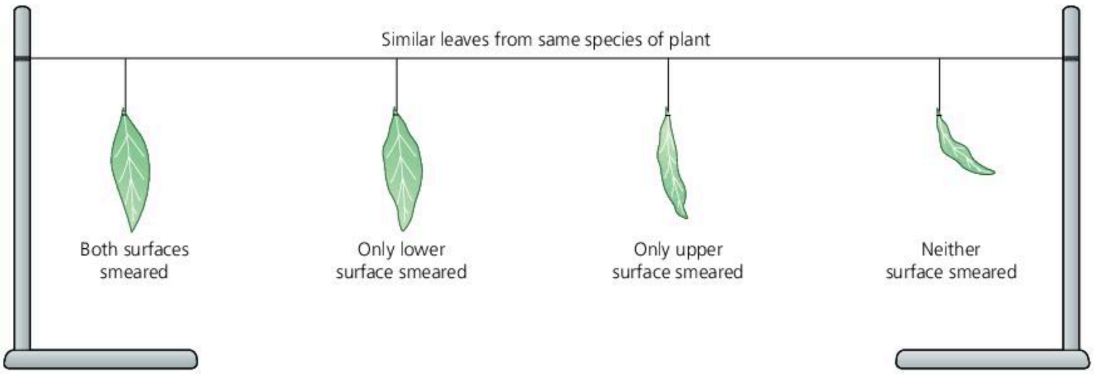
The diagrams opposite show how plants may be adapted to the availability of water.

INVESTIGATION OF WATER LOSS FROM LEAF SURFACES

Cobalt chloride paper is blue when dry, and pink when wet. It is handled with forceps to avoid moisture from the fingers affecting its colour. The paper is attached to the upper and lower leaf surfaces using microscope slides. The paper attached to the lower surface of the leaf turns pink, showing that water is lost mainly from the lower surface. This technique gives a *qualitative (non-quantitative)* comparison.

Measuring the mass changes of leaves can be used to give a quantitative comparison of water loss from different leaf surfaces. A number of leaves are smeared with petroleum jelly as shown in the diagram below. They are weighed and then left in a drying atmosphere for 48 hours, and reweighed at intervals. Some typical results from this investigation are shown in the table.

Leaf number	Initial mass / g	Final mass / g	Percentage change in mass
1	4.2	4.1	
2	4.6	4.4	
3	3.9	2.5	
4	4.1	2.5	



▲ These measurements are made on leaves which have been detached from the plant. It is difficult to measure water loss from the leaves of an intact plant but relatively simple to measure water uptake using a **potometer** (see page 91).

Questions 1 to 4 refer to the investigation above.

1 Copy the table above. Calculate the percentage change in mass for each leaf.

2 Why did leaf 3 lose a greater proportion of its mass than leaf 2?

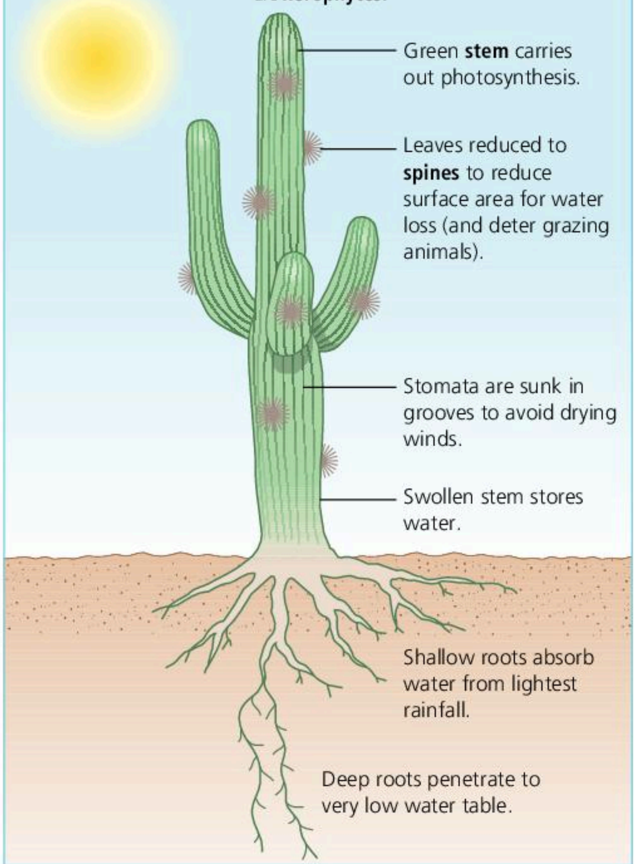
3 Why was it important that leaves of the same species were used?

4 How could the results be made more reliable or valid?

S

Adaptations of plants to reduce water loss in different environments

Cacti are well adapted to hot, dry environments (deserts). They are **xerophytes.**



Aquatic (pond) plants have leaves with:

- little lignin in the xylem, because the leaf is supported by the water
- a very thin cuticle, because water conservation is not a problem
- stomata on the **upper** surface to allow CO_2 uptake from the atmosphere.

These plants are **hydrophytes**.

Wilting and leaf fall

When water is in short supply, plants may reduce water loss by:

- wilting – leaves collapse and stomata close to reduce heat absorption and evaporation/diffusion of water
- leaf fall – in very severe conditions, e.g. when water is frozen during winter, plants allow the leaves to fall off so that no water loss can occur. No photosynthesis can take place, but the plants can remove chlorophyll from the leaves for storage before allowing leaves to fall.

Q

1 The diagram shows a leaf of marram grass, a plant that grows in dry, windy environments on sand dunes. The photograph below shows a transverse section of marram grass leaf as seen under a microscope.

a Copy the diagram of the leaf, and draw a line to show the direction in which a transverse section is cut.

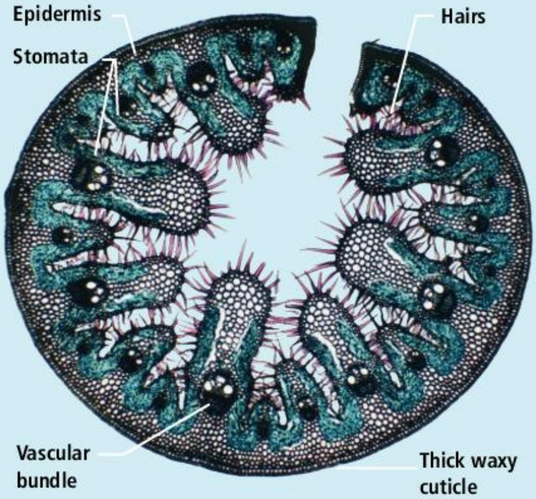
b The positions of several stomata are labelled on the photograph. If sufficient light is available, oxygen is released from the leaf through the stomata.

- **i** Name the process that produces oxygen.
- **ii** Which gas is consumed during this process?
- **iii** Name and define the process by which the oxygen moves from leaf to atmosphere.

c Water vapour will also be lost from the leaf's internal surface when the stomata are open. Use the diagram and the photograph to suggest three ways in which the structure of the marram grass leaf helps to reduce water loss.

d Give three reasons why plants require water.

e Why is it particularly important that a plant growing in sand dunes should reduce water loss?



2 Copy and complete the following paragraph.

The movement of water through the plant begins at the leaf surface, and a stream of water called the ______ is drawn up through the plant to replace these losses. The gas ______ is required for photosynthesis, and enters the leaves through pores called ______. These pores allow the loss of ______ to the atmosphere, and leaves show many adaptations to reduce this loss. These adaptations include ______, ______ and ______.

Questions on plants and water transport

1 Which of the following best defines osmosis?

A The movement of solutes down a concentration gradient.

B The movement of water up a water potential gradient.

C The movement of water, using energy from respiration.

D The movement of water down a water potential gradient. [1]

2 Which of the following is the main tissue for the movement of sucrose in a plant?

A Epidermis

B Xylem

C Phloem

D Stomata [1]

3 Which of the following best defines active transport?

A The movement of solutes along a concentration gradient.

B The movement of solutes against a concentration gradient.

C The movement of water using energy from sunlight.

D The movement of solutes against a concentration gradient, using energy from respiration. [1]

4 This question is about water uptake by plants. Using the potometer shown at the bottom of page 91, a student investigated the factors that influence water uptake by a plant. He obtained the following results.

Environmental condition	Time taken for bubble to move 10 cm / minute	Rate of bubble movement / cm per minute
A High light intensity	2	
B High humidity (plant enclosed in clear plastic bag)	50	
C Wind (electric fan blowing over plant surface)	2	
D Dark and windy	25	
E Dark and low humidity	40	

a Copy the table. Calculate the rate at which the bubble moves and complete the third column. Plot these results in the form of a bar chart. [6]

b Plants require light for photosynthesis. They 'anticipate' the need for carbon dioxide uptake during photosynthesis by opening their stomata under appropriate conditions. Does this help explain the results of experiment A? Explain your answer. [3]

c Water is lost from leaves by evaporation and diffusion if the stomata are open, and a suitable water potential gradient exists. Use this information to explain the results of experiments B and E. [2]

d Explain the results of experiments C and D. [2]

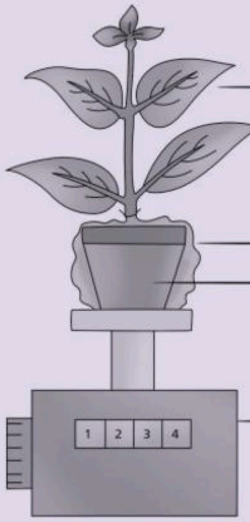
5 Copy and complete the following paragraphs.

a The cells of green plants absorb water by ________. Plant cells rely on water for ________, as a medium for biochemical reactions, as a ________ and as a raw material for ________. [4]

b Water is obtained by plants from the soil solution. The water enters the plant through its ________. These structures are well adapted to the absorption of water. There are ________ growing on their epidermis which greatly increase the ________ over which water absorption can take place. In addition to water, these structures also absorb ________ such as ________ which is required for the synthesis of chlorophyll and ________ which is required for the manufacture of amino acids and proteins. These substances are absorbed by a process called ________ because it requires a supply of energy. [7]

c Water is used as a transport medium for both ions and sugars. Mineral ions are transported within the main water flow through the plant in the ________ tissue. Sugars are transported in the living cells of the ________. These specialised tissues are grouped together into ________ bundles. [3]

6 Water loss by a potted plant can be investigated using the apparatus shown below.



The plant was allowed to stand close to an open window for 7 days, and the loss in mass each day was measured and recorded in the table below.

Day	1	2	3	4	5	6	7
Loss of mass / g	3.2	3.8	4.9	6.7	4.6	7.9	5.1

a Plot a bar chart of these results. Place time on the horizontal axis and loss in mass on the vertical axis. [4]

b Suggest the likely weather conditions on days 4 and 6. Explain your answers. [4]

c Draw two more bars, on day 2 and 7, to suggest how the results might have been different if the leaves were rolled rather than flattened. Explain your answer. [3]

d State the name of the process by which a plant loses water through its leaves. [1]

9.1 Transport systems in animals use blood as the transport medium

OBJECTIVES

- To understand why animals need a circulatory system
- To know that a transport system has four components
- To know the structure and functions of the components of the blood

All living organisms require energy, which is released from food and oxygen in the process of respiration (page 122). All living cells in the body (for example in the brain, liver, kidney and muscle) need energy, and so glucose and oxygen must be transported throughout the body. In some small animals (especially those with a flat body such as the flatworm in the photograph), substances are transported in and out of the body, and from one tissue to another, by the process of **diffusion**.

▲ The flatworm is very thin and has a high surface area to volume ratio. Its volume is made up of working cells that need various substances including oxygen, which can diffuse in across the large surface. The distance from the surface to all the cells is small.

Large complex organisms, such as humans, have a small surface area in relation to their relatively large volume. As a result, cells near the centre of the body are some distance away from contact with the atmosphere, and may also be some distance from the gut where food is digested. Cells inside such large organisms cannot gain enough oxygen and glucose by diffusion alone.

A mass flow system

To supply oxygen and glucose, as well as other substances, large organisms have a specialised **transport system**. This system, called the **blood system** in all vertebrate animals, is an example of a **mass flow system**. A mass flow system carries large volumes of fluid to all parts of the organism. A system like this has four parts:

- A **medium** – the fluid that flows in the system and carries materials around the body. This is the **blood**.
- A **system of tubes** that carries the fluid from place to place. These are the **arteries** and **veins**.
- A **pump** that supplies pressure to keep the fluid moving through the tubes. This is the **heart**.
- **Sites of exchange** that allow materials delivered by the blood to enter the tissues that need them. These are the **capillaries**.

▼ A whale has a large surface area, but its volume is too large for materials to be moved to and from its body cells by diffusion. The blue whale has a circulatory system made up of 4000 dm^3 of blood, pumped through 50 000 km of blood vessels by a heart the size of a small car.

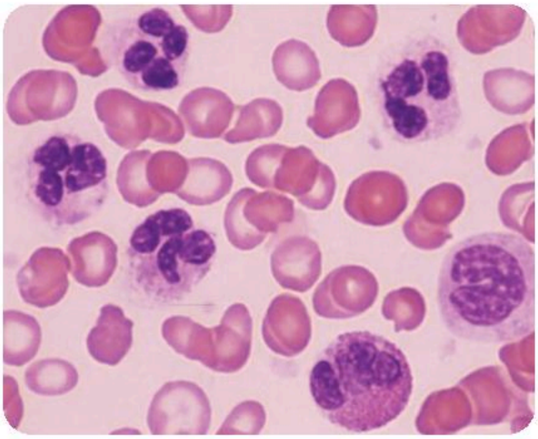
The blue whale's heart beats about 30 000 times a day. What is its heart rate in bpm (beats per minute)?

A shrew has a heart rate of about 900 bpm, a human of about 70 bpm and a horse about 40 bpm. Including the value for the blue whale, what pattern can you see relating size and heart rate?

Blood is the circulatory medium

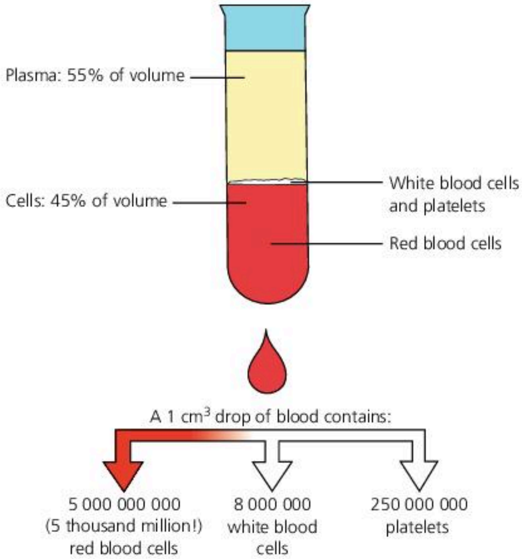
The average adult human has about 5 dm^3 of blood, which contains a number of blood cells suspended in a watery liquid (**plasma**). If a sample of blood taken from the body is allowed to stand, and a chemical added to prevent it clotting, it will separate into layers as shown opposite.

If a drop of blood is placed on a microscope slide and stained with a special dye, these different types of cell can be seen, as the photograph below shows.

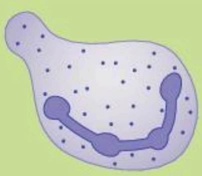
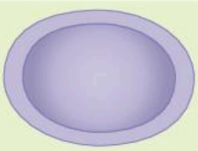


▲ Red blood cells are shown in pink; white blood cells have purple-stained nuclei, of several different shapes (platelets are not visible)

Blood cells are first formed in the bone marrow of long bones such as the femur (thigh bone), although they might be transported to other parts of the body before they become fully developed. The structure and function of different types of blood cell are shown in the table below.



▲ The red blood cells sink to the bottom, and the white blood cells and platelets settle on top of the red blood cells. The plasma forms a clear, straw-coloured layer at the top.

Cell type	Appearance	Function	How the structure is suited to the function
Red blood cells (erythrocytes)		Transport oxygen from lungs to all respiring tissues. Prepare carbon dioxide for transport from all respiring tissues to lungs.	Contain **haemoglobin**, an iron-containing pigment which picks up oxygen at the lungs and lets go of it at the tissues. Have no nucleus, leaving more space for haemoglobin. Cells are small and flexible, so can squeeze through narrow capillaries.
White blood cells (phagocytes)		Remove any microorganisms that invade the body and might cause infection. The phagocyte engulfs the microorganism (see page 116).	Irregular shaped nucleus allows cell to squeeze through gaps in walls of capillaries. Enzymes in cytoplasm digest microorganisms once engulfed. Sensitive cell surface membrane can detect microorganisms.
White blood cells (lymphocytes)		Produce antibodies – proteins that help in the defence against disease (see page 118).	Large nucleus contains many copies of genes for the control of antibody protein production.
Platelets		Cell fragments involved in blood clotting.	Can release blood-clotting enzymes (see page 116).

Functions of the blood

The table on page 97 shows that one function of red blood cells is the transport of the respiratory gases, oxygen and carbon dioxide, between the lungs and the respiring tissues. The **plasma** also has transport functions. This watery liquid carries dissolved food molecules such as glucose and amino acids, waste materials such as urea, and some control molecules such as hormones. Because the plasma is largely water, it has a very high specific heat capacity (see page 256). This means that the plasma is able to distribute heat around the various parts of the body.

Defence against disease is another important function of the blood. The different roles of the blood are summarised below.

Functions of the blood

Regulatory functions – homeostasis

Blood solutes affect the water potential of the blood, and thus the water potential gradient between the blood and the tissue fluid. The size of this water potential gradient is largely due to sodium ions and plasma proteins. The blood solute level **regulates the movement of water** between blood and tissues.

Water plays a part in the **distribution of heat** between heat-producing areas such as the liver and areas of heat loss such as the skin.

Blood also helps to maintain an **optimum pH** in the tissues.

Too much alcohol in the blood can cause water to leave brain cells, causing pain and the sensation of thirst.

Protective functions

Platelets, plasma proteins (e.g. fibrinogen) and many other plasma factors (e.g. Ca^{2+} ions) protect against **blood loss** and the **entry of pathogens** by the clotting mechanism.

White blood cells protect against **disease-causing organisms**:

- **phagocytes** engulf them
- **lymphocytes** produce and secrete specific antibodies against them.

Transport functions

Soluble products of digestion/absorption (such as glucose, amino acids, fatty acids, vitamins and minerals) are transported from the gut to the liver and then to the general circulation.

Waste products of metabolism (such as urea, creatinine and lactate) are transported from sites of production to sites of removal, such as the liver and kidney.

Respiratory gases (oxygen and carbon dioxide) are transported from their sites of uptake or production to their site of use or removal.

Hormones (such as insulin) are transported from their sites of production in the glands to the target organs where they have their effects.

Support function

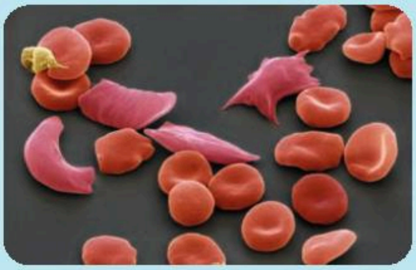
Erection of the penis is achieved by filling large spongy spaces with blood. The penis becomes soft when blood flows out more quickly than it flows in.

The blood detectives

A scientist who specialises in the study of blood is called a **haematologist**. A haematologist can tell a great deal from a tiny sample of blood. For example:

- **Anaemia**, an inability to transport enough oxygen, can be detected by noting a lower than normal number of red blood cells.
- **Sickle cell anaemia** shows some red blood cells shaped like sickles, as the photograph below illustrates.
- **Leukaemia**, a cancer of white blood cells, can be detected by high numbers of oddly shaped white blood cells.
- **AIDS** may be detected in its early stages by the presence of antibodies to the human immunodeficiency virus (HIV) in the plasma – the affected person is HIV positive. In the later stages of the disease, the number of white blood cells is very much reduced.
- **DNA fingerprinting**, which can be important in criminal investigations, can be carried out on nuclei extracted from white blood cells.
- **Diabetes** may be detected by a high glucose concentration in the plasma.
- **Eating disorders** may be detected by higher than normal concentrations of urea in the plasma.

▲ Using modern techniques of biochemistry, a single drop of blood can yield information about all the conditions described in this box



▲ Sickle-shaped red blood cells show the person has sickle cell anaemia. A sickle is a long hooked tool used for cutting crops.

1. Why do large organisms require a transport system?
2. A sample of human blood is collected and placed in a tube and centrifuged. The blood separates into two distinct layers.
   a. What are the two layers?
   b. Suggest one dissolved food substance found in the upper layer. Choose a substance for which there is a simple chemical test. Describe the test for this substance, and state what a positive result would be.
   c. There is a third, rather thin, layer between the two main components. What is this layer made of?
3. 'The structure of a cell is closely related to its function.' Is this statement correct for blood cells? Explain your answer.
4. The table shows the cell composition of three samples of blood.

	Sample from		
Cell count / number per mm^3	**Jill**	**Jenny**	**Jackie**
Red blood cells	7 500 000	5 000 000	2 000 000
White blood cells	500	6000	5000
Platelets	250 000	255 000	50

   a. Which person is most likely to have lived at high altitude recently? Explain your answer.
   b. Which person would be the most likely to become ill if exposed to a virus? Explain your answer.
   c. Which person's blood is least likely to clot efficiently? Explain your answer.
   d. Which person is likely to have an iron deficiency in her diet? Explain your answer.
   e. These three samples were all taken from 23-year-old women. Explain why this makes comparisons between them valid.
5. Use words from this list to complete the following paragraphs. The words may be used once, more than once or not at all.

epidermis, tissues, specialised, cells, blood, red blood cell, division of labour, organ

Large numbers of ____ that have the same structure and function are grouped together to form ____, for example ____. Several separate tissues may be joined together to form an ____ which is a complex structure capable of performing a particular task with great efficiency.

The structure of cells may be highly adapted to perform one function, i.e. the cells may become ____. One excellent example is the ____ which is highly adapted to carry oxygen in mammalian blood. If the different cells, tissues and organs of a multicellular organism perform different functions they are said to show ____.

9.2 The circulatory system

OBJECTIVES

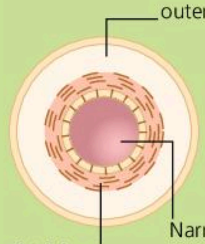
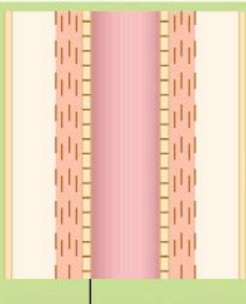
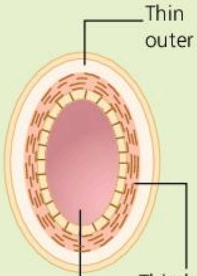
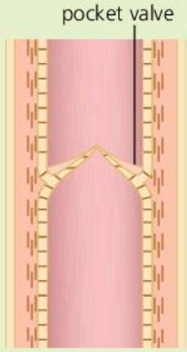
- To understand that the blood is directed around the body in a set of vessels
- To know the structure and function of arteries and veins
- To understand why humans have a double circulatory system
- To know the names of the main arteries and veins in the human body

Blood vessels – arteries and veins

Blood flows around the body in a system of tube-like **blood vessels**, arranged in such a way that they all eventually lead back to the heart. The blood flows *away* from the heart in vessels called **arteries**, and it flows back *towards* the heart in vessels called **veins**. Joining the arteries and veins are the **capillaries**, and we shall look at these on page 102. In humans (and in many other animals), the main artery is called the **aorta** and the main vein is called the **vena cava**. The structure and functions of arteries and veins are shown in the table below.

The human double circulation

The human circulation is outlined at the top of the page opposite. The arrangement is called a **double circulation** because the blood passes through the heart twice for each complete circuit of the body. The blood flows to the lungs under high pressure (so a large volume of blood flows past the lung surfaces in a short time). Then, having picked up oxygen at the lungs, the blood receives another 'boost' of pressure from the heart to drive it out to the tissues, where the oxygen is needed.

Structure			
Type of vessel	**Transverse section ('cut across')**	**Longitudinal section ('cut along')**	**Adaptations of structure to function**
Artery			■ Carries blood away from the heart to the tissues. ■ Blood is at high pressure. ■ Blood is rich in oxygen, low in carbon dioxide (except in the pulmonary artery). ■ Elastic walls expand and relax as blood is forced out of the heart. This causes the pulse that you can feel if you press an artery against a bone, for example in the wrist. ■ Thick walls withstand the high pressure of blood. Rings of muscle can narrow or widen the artery and control the blood flow in it according to the body's needs.
Vein			■ Carries blood from the tissues to the heart. ■ Blood is at low pressure. ■ Blood is low in oxygen, high in carbon dioxide (except in the pulmonary vein). ■ Valves prevent the backflow of blood. Blood is at low pressure, but nearby muscles squeeze the veins and help push blood back towards the heart. ■ Large diameter and thin walls reduce resistance to the flow of blood.

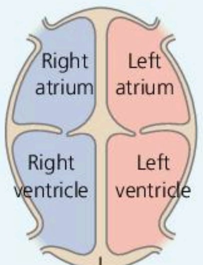
▲ The structure and functions of arteries and veins

High pressure – both ventricles pump out blood at high pressure, but the 'body' circuit has a pressure about 5× that in the 'lung' (pulmonary) circuit. This is because blood in the body circuit has so far to travel, and there are many branches in the circuit to take the high-pressure blood.

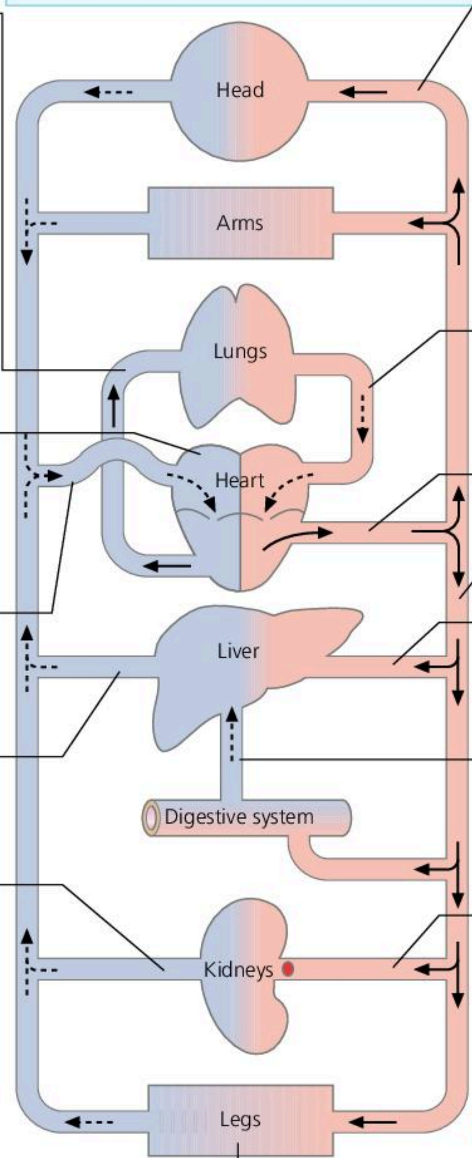
Pulmonary artery – unlike other arteries, this vessel carries **deoxygenated blood** which also has a **high carbon dioxide concentration**.

Too high! If pressure in the pulmonary artery is too high, tissue fluid or plasma can leak into the lungs. This sometimes happens to climbers at high altitude.

The heart (see also page 104)



This wall (the septum) separates oxygenated blood from deoxygenated blood.



Pulmonary vein – unlike other veins, this vessel carries **oxygenated blood**. It has the **highest oxygen** and **lowest carbon dioxide** concentration in the circulation.

Aorta – the main artery of the body; supplies oxygenated blood, at high pressure, to the organs and tissues of the body.

Vena cava – the main vein of the body; returns deoxygenated blood at low pressure from organs and tissues to the heart.

Hepatic artery – carries oxygenated blood to the liver.

Hepatic vein – returns blood with a regulated, optimum concentration of food substances to the circulation.

Hepatic portal vein – carries blood containing variable amounts of the absorbed products of digestion from the digestive system to the liver.

Renal vein – blood with reduced urea concentration is returned to the circulation.

Renal artery – carries oxygenated blood with a **high concentration of urea** to the kidneys.

Key

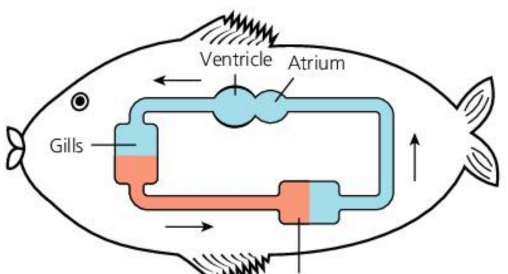
Blood at low pressure ◄- - - - - - - -

Blood at high pressure ◄————

Capillaries link arteries and veins. They are present in all organs and tissues and are the site of exchange of materials between blood and tissue fluid (see next page).

Q

1. State two differences between arteries and veins, and say how these differences are related to the functions of these blood vessels.
2. Look at the diagram above. Follow the path of the red blood cell in the renal artery around the circulation and back to the renal artery. How many times does it pass through the heart? List the blood vessels and chambers of the heart that the cell passes through.



Fish have a **single** circulation – blood flows through the heart only once for each complete circuit of the body: but there is

- rapid fall in velocity and pressure as blood leaves the gills
- pressure too low for efficient kidney function as in mammals.

9.3 Capillaries: materials are exchanged between blood and tissues, and tissue fluid is formed

OBJECTIVES

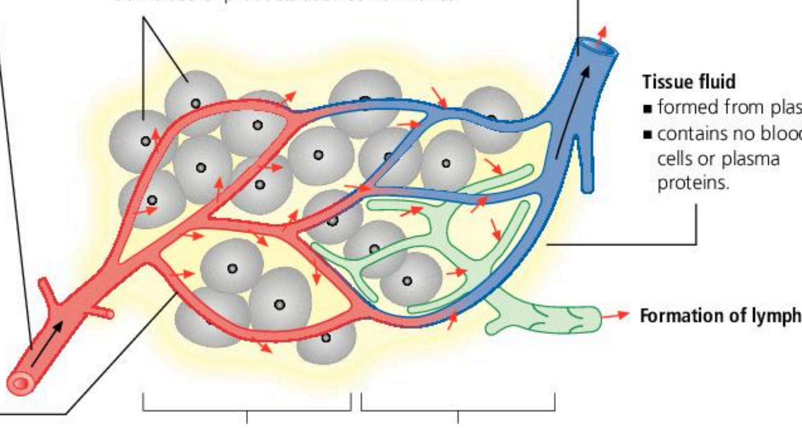
- To understand that substances carried in the blood must leave the circulation to reach the tissues
- To know that materials are exchanged between tissues and blood in the capillary beds
- To know how the structure of the capillaries is suited to the transfer of materials between blood and tissues

Tissue fluid leaves the capillaries

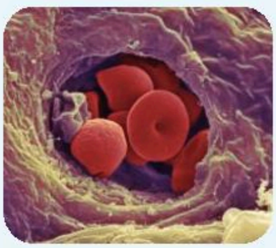
To reach the cells that need them, dissolved substances carried in the blood must leave the blood vessels and enter the tissues. At the same time, waste materials produced by the tissues need to enter the blood to be carried away. Dissolved substances move between the blood and tissues by **diffusion** across the walls of very fine blood vessels called **capillaries**. Networks or **beds** of capillaries extend through all the tissues, so every body cell is near to a capillary. The capillary beds are adapted to their function of exchange of substances in a number of ways:

- the walls of the capillaries are only one cell thick – substances do not have very far to diffuse through them
- the capillaries are highly branched so they cover an enormous surface area, giving more 'space' for diffusion to occur
- the capillary beds are constantly supplied with fresh blood, keeping up the concentration gradients of dissolved substances between blood and tissues. Without these concentration gradients diffusion could not occur.

The diagram shows how materials are exchanged between the blood and the tissues, and how **tissue fluid** is formed.



Capillary has:
- wall only one cell thick
- very large surface area.



Capillary walls are about 1 µm thick. The central tube (lumen) may only be the same diameter as the red blood cells, so they have to squeeze through the capillary in single file as they unload their oxygen.

Remember how substances cross membranes

Diffusion is:
- the movement of molecules
- down a concentration gradient
- until equilibrium is reached.

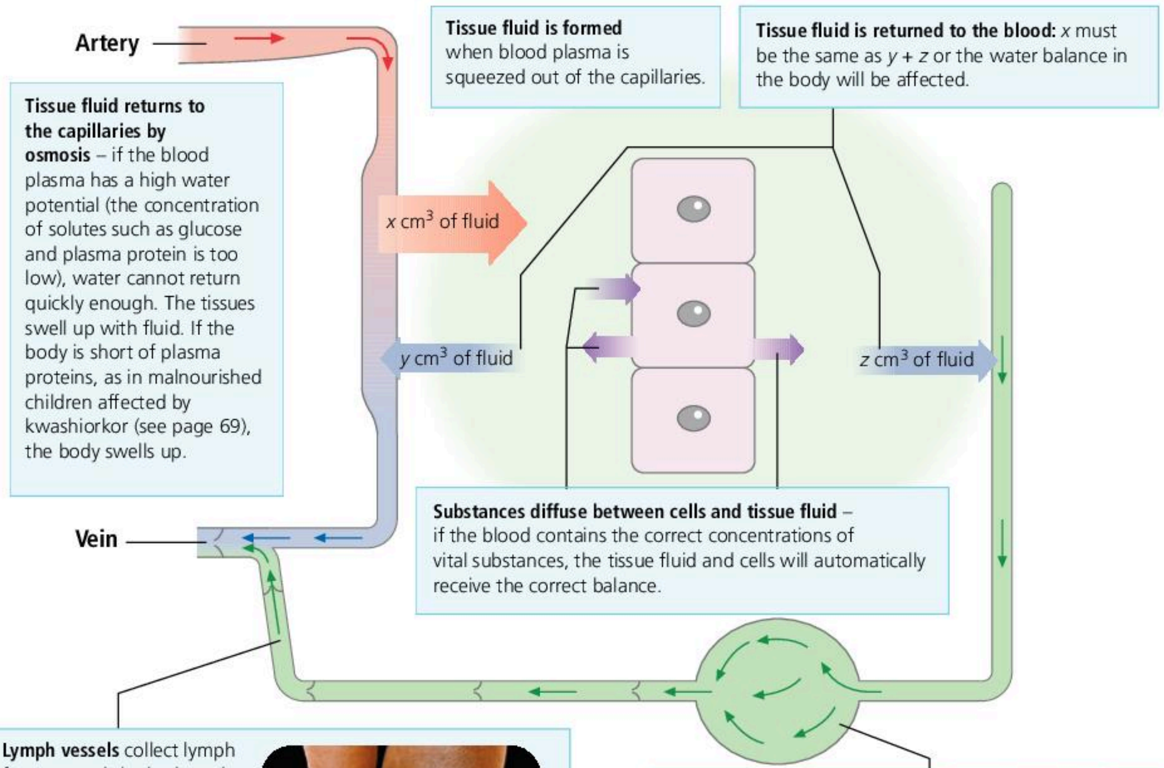
Osmosis is:
- the movement of water
- down a water potential gradient
- across a partially permeable membrane.

S

Problems with the return of tissue fluid

The diagram below shows in detail how tissue fluid is formed and returned to the blood. This tissue fluid is essential for the transport of dissolved substances between blood and cells. If anything goes wrong with this return of tissue fluid, the tissues swell up.

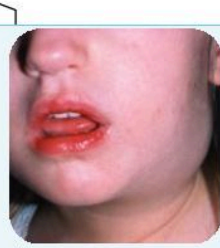
In **elephantiasis**, for example, a parasitic worm lodges in the lymph vessels in the groin and causes fluid to build up in the legs.



Lymph vessels collect lymph from around the body and return it to the blood, close to the heart. Blockage of the lymph vessels can produce severe swelling of tissues and organs on the side of the blockage furthest from the heart.

▲ Elephantiasis – the lymph vessels are blocked by swellings caused by parasitic worms

Lymph node – as lymph returns towards the blood vessels it is 'filtered' through lymph nodes. These contain cells called lymphocytes that can remove any harmful microbes that have infected the body (see page 118).



▲ Swollen glands caused by inflammation of lymph nodes

Q

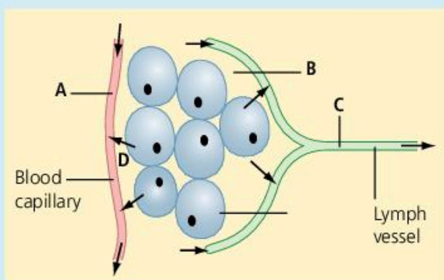
1 This diagram represents a group of body cells and some parts of the circulatory system. The arrows show movement of fluids.

a Name the fluids contained in spaces **A**, **B** and **C**.

b Name two substances that the cells remove from the fluid in **B**. Suggest two substances that the cells might add to the fluid in **B**.

c Describe how the fluid in **C** is returned to the circulation.

d Give a reason why the process shown at **D** might be inefficient. What would be the result of this for the body? How could it be corrected?



9.4 The heart is the pump for the circulatory system

OBJECTIVES

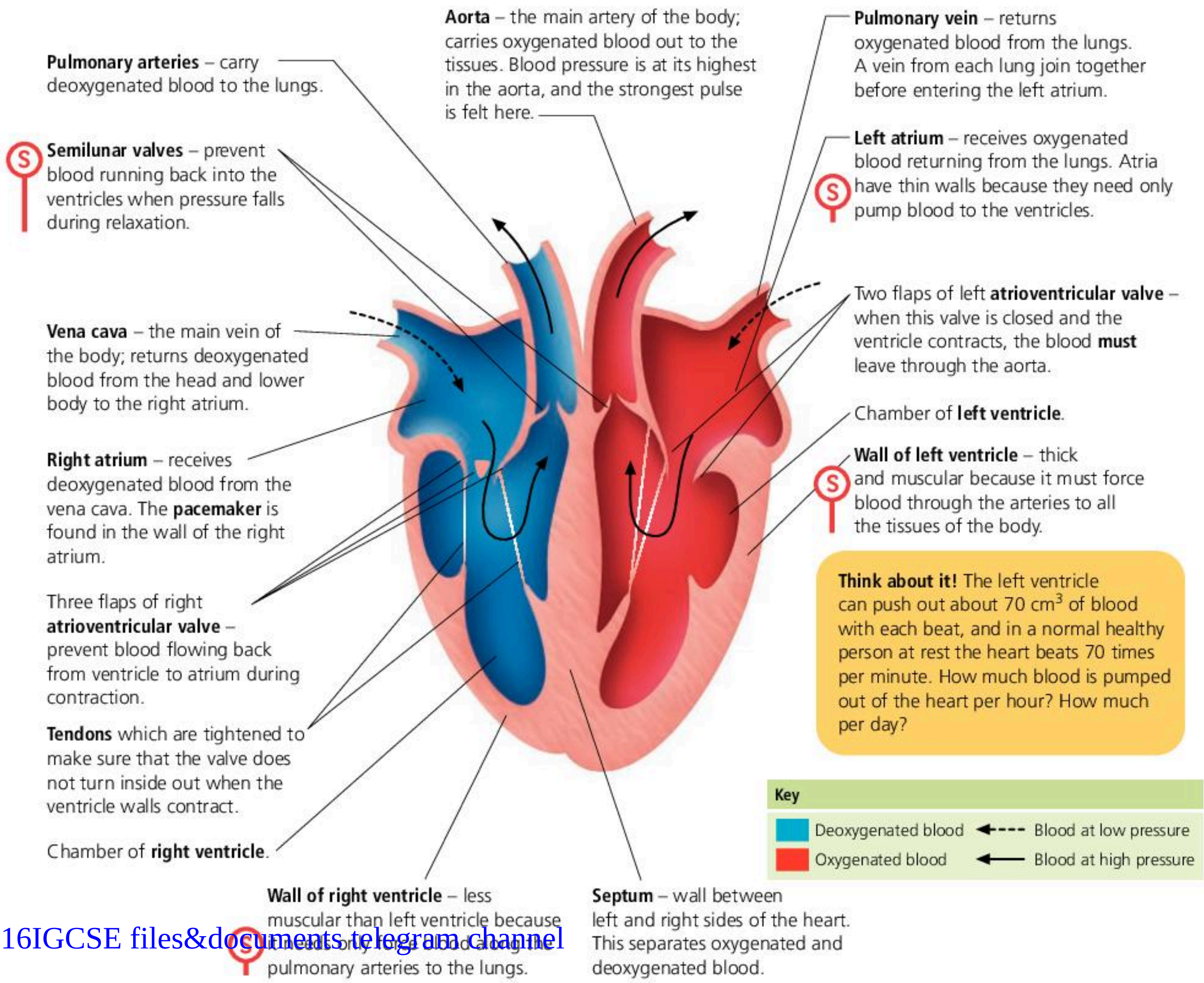
- To know that the blood is pumped around the circulatory system by the action of the heart
- To know that the heart is a muscular organ with four chambers
- To understand how the flow of blood through the circulation is maintained

The heart of a mammal pumps blood through the circulatory system. It provides the pressure that forces the blood through arteries, capillaries and veins. The pressure is generated by the squeezing of the walls of the heart against the incompressible fluid blood. The heart walls can squeeze the blood because they are made of **muscle**, and the muscle contracts rhythmically.

A double pump

The heart is divided into two sides, each of which acts as a pump. The right side of the heart pumps deoxygenated blood coming from the tissues out to the lungs. The left side pumps oxygenated blood coming from the lungs out to the tissues. A much greater pressure (about five times as much) is needed to force blood out to the extremities of the body than is needed to drive blood to the lungs. Because of this, the left side of the heart is much more muscular than the right side.

Even though the two sides of the heart generate different pressures, they work in the same way and have the same parts, as shown in the diagram below.



Think about it! The left ventricle can push out about 70 cm^3 of blood with each beat, and in a normal healthy person at rest the heart beats 70 times per minute. How much blood is pumped out of the heart per hour? How much per day?

Remember that:

- The **atrium** receives blood at low pressure from the veins (coming from the lungs or tissues).
- The **ventricle** pumps blood at high pressure out to the arteries (to the lungs or tissues).
- **Valves** make sure that the blood flows in the right direction.

The beating of the heart is controlled by a pacemaker

In a healthy person, the heart beats about 70 times a minute during normal levels of activity. This rate is enough to supply blood containing oxygen and nutrients to tissues.

The muscular walls of the heart differ from other muscles in that they never become tired or **fatigued**, because each contraction of the heart is immediately followed by a relaxation. Even when the heart is beating at its fastest during severe exercise (see page 132), the period of relaxation allows the muscle to recover so it does not fatigue.

The pattern of contraction and relaxation is kept going by electrical signals sent from a region of the heart called the **pacemaker**. This is a specialised piece of tissue in the wall of the right atrium. It is sensitive to the swelling of the heart wall as blood enters the heart from the main veins. The signals from the pacemaker make sure that:

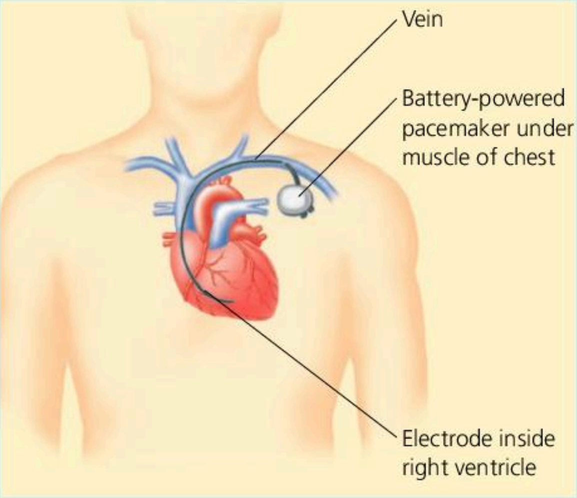
- the atria contract just before the ventricles, so that blood flows from atria to ventricles
- the heartbeat is fast enough to meet the demands of the tissues for oxygen and nutrients, and for the removal of wastes.

If the pacemaker does not work as well as it should, an artificial electronic pacemaker can be fitted inside the chest (see box on the right).

Artificial pacemakers – help for the heart

The beating of the heart is controlled by the natural pacemaker in the wall of the right atrium. If this pacemaker is damaged, pumping goes on automatically at about 30 beats per minute. This is less than half the normal rate, and is only enough to keep a very inactive person alive.

An artificial pacemaker can help people whose natural pacemaker does not work well. This artificial pacemaker is made up of a box containing batteries and an electronic timing device. It is placed in a cavity under the muscle of the upper chest as shown below, and a wire is fed down a vein into the right ventricle. The timing device sends a small electrical charge which triggers the beating of the heart. This is set to give a basic rate of 72 beats per minute. The latest pacemakers can sense changes in breathing, movement and body temperature, and make exactly the right adjustments to heart rate. The battery in the pacemaker is usually replaced every year or so, under local anaesthetic.



▲ An artificial pacemaker

1 **a** Name the chamber of the heart that receives blood from the lungs.
b Explain what happens to the blood in the ventricles when the muscle in the ventricle walls contracts.
c The muscle around the atria is thinner than the muscle around the ventricles. Suggest a reason for this.

2 A doctor listening to the heartbeat through a stethoscope hears two sounds as the blood flows through the heart: 'lup-dup lup-dup lup-dup'.
a From your knowledge of the working of the heart, suggest how these two sounds are produced.
b The doctor records 72 beats per minute. How long a period would there be between two consecutive 'lup' sounds? Explain your answer.

9.5 Coronary heart disease

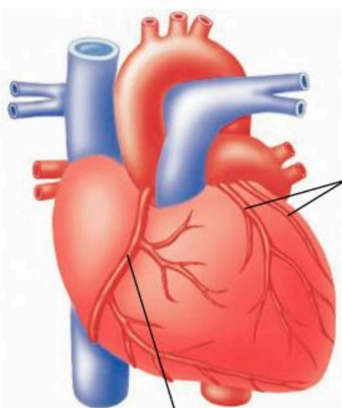
OBJECTIVES

- To know that the heart muscle requires a supply of oxygen, glucose and other nutrients
- To know that the heart muscle has its own blood supply through the coronary arteries
- To understand that factors such as lifestyle, diet and family history may affect the efficiency of the coronary arteries
- To know that coronary heart disease is one of the major causes of death in the developed world

The supply of blood to the heart muscle

Heart muscle contracts to push blood through the vessels of the circulation. This contraction is work, and it requires energy. The energy is made available by aerobic respiration, so the working cells of the heart need glucose and oxygen for respiration.

The blood passing through the chambers on the left side of the heart carries oxygen and glucose, but the heart cells cannot use these because the muscular walls are very thick and the blood is too far away. The heart muscle has its own blood supply, delivered to capillary beds in the walls of the heart through the **coronary arteries**. The coronary arteries branch off from the aorta, just where the aorta leaves the left ventricle. The heart therefore has a high-pressure supply of blood loaded with oxygen and glucose. Once these useful substances have been removed by the heart muscle cells and replaced with wastes such as carbon dioxide, the blood returns to the circulation



▲ The coronary arteries branch off the aorta, supplying the surface of the heart with oxygenated blood at high pressure

through **coronary veins** which pour blood into the vena cava. The coronary circulation is shown below left. The activity of the heart can be checked in a number of ways:

- **making an ECG (electrocardiogram)**. There should be a regular pattern of the flow of electric current through the heart muscle.

Any irregularity could be a sign of heart disease.

- **measuring pulse rate**. This should be regular, allowing for exercise or activity. Any unusual changes could indicate problems in the heart's nervous system.
- **heart sounds**. The regular 'lub-dup' sound of the heart is caused by the heart valves closing in sequence (atrioventricular then semilunar). Leaking valves can make the sound less clear.

Coronary heart disease

The supply of blood to the heart muscle may be interrupted if any of the coronary arteries become blocked. The heart muscle cells are deprived of glucose and oxygen, and poisonous wastes such as lactic acid build up (see page 124). Part of the heart muscle stops contracting, causing a **heart attack**. This can be damaging or even fatal, because other tissues in the body no longer receive their supplies of oxygen and nutrients if the heart stops beating.

What causes the coronary arteries to become blocked? A healthy coronary artery may be narrowed by atheroma so that blood flow through it is restricted. This person has **coronary heart disease** (**CHD**).

The risk of developing CHD is increased by:

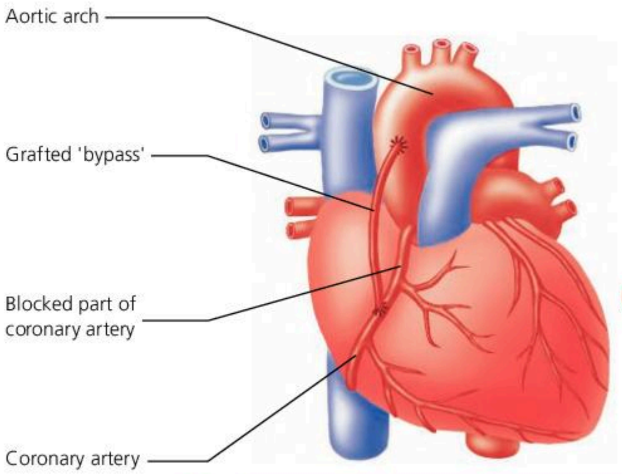
- **poor diet** – high levels of cholesterol or saturated fatty acids in the blood
- **poor lifestyle** – smoking, lack of exercise, stress
- **genetic factors** – being male, having a family history of heart disease.

Anyone with a genetic risk of developing heart disease should obviously take care that he or she does not have a poor diet or lifestyle. Many middle-aged men, the highest risk group, help to prevent heart disease by taking half an aspirin a day (this seems to help stop small clots forming which could block the arteries) and/or by drinking a small quantity of alcohol (red wine may be the most beneficial).

If a doctor suspects that a patient has CHD, an **angiogram** is carried out. This gives a picture of the state of these arteries (see below). If the coronary arteries are blocked, a **coronary artery bypass** operation may be carried out, as shown below.

Avoid the problem!

- Don't smoke
- Avoid fatty foods
- Take regular aerobic exercise



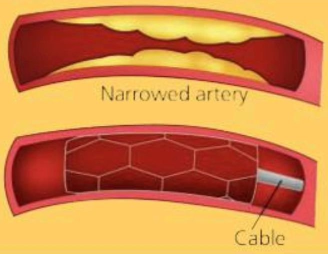
Men are more at risk of CHD than women – but men can't avoid CHD by changing their gender!

In a **coronary artery bypass operation** a blood vessel is removed from another part of the body and stitched into place between the aorta and the unblocked part of the coronary artery. Sometimes an artificial vessel is used. The bypass increases blood flow and reduces the likelihood of angina (chest pain).

Angioplasty can also help.

A special cable is passed into the narrowed artery and used to insert a metal 'cage' which forces the artery open

Blood can now flow more easily



The metal 'cage' (stent) is placed in the artery and the cable is withdrawn.

1 a The heart muscle has its own supply of blood from vessels that run all over its surface. What is the name of these vessels?

b In some people these vessels can become blocked with a fatty substance containing cholesterol. Explain the effects that blocking these blood vessels would have.

2 Look at the graphs. Graph A shows the relationship between the death rate for CHD and the blood cholesterol level. Graph B shows the relationship between cholesterol levels and age, for men and women.

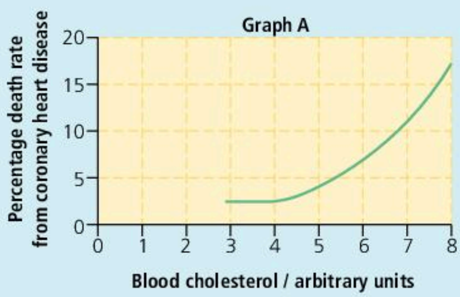
a At which ages do men and women show the same blood cholesterol level?

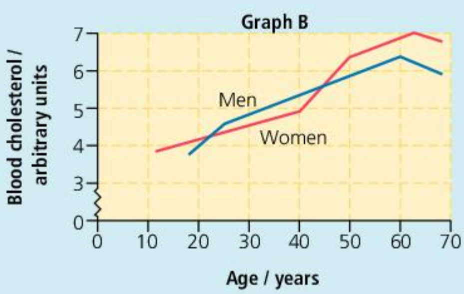
b Use the information in the graphs to explain why the death rate from CHD is higher for men than for women between the ages of 25 and 45 years.

c Use the graphs to determine the level of blood cholesterol that would keep the death rate from CHD at a minimum.

d What does your answer to **c** suggest about cholesterol as the only cause of CHD?

e What sort of person is most at risk from CHD?





Questions on circulation

1 Which is the correct pathway taken by blood flowing through the human circulatory system?

A body → vena cava → left atrium → left ventricle → lungs

B left ventricle → aorta → body → vena cava → right atrium

C lungs → pulmonary artery → left atrium → left ventricle → aorta

D right ventricle → aorta → lungs → body → right atrium [1]

2 In a single circulation of a fish, the blood flows through the heart once during a complete circulation of the body. What type of blood leaves the heart?

A Deoxygenated blood at high pressure

B Deoxygenated blood at low pressure

C Oxygenated blood at high pressure

D Oxygenated blood at low pressure [1]

3 Management of coronary heart disease may involve a number of actions. Which one of the following is the treatment of CHD?

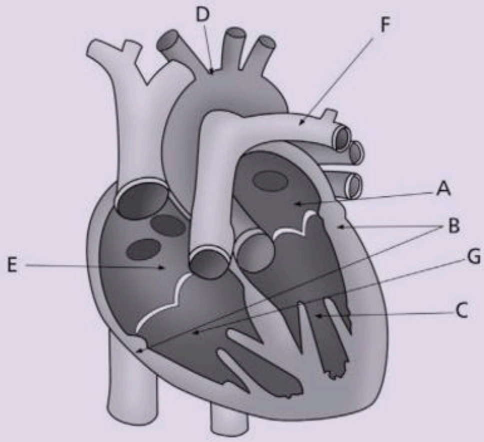
A Angioplasty

B Eating more saturated fats

C Putting stents into coronary arteries

D Taking more exercise [1]

4 The diagram below shows a section through a human heart.



a Name the structures labelled A, C and E. [3]

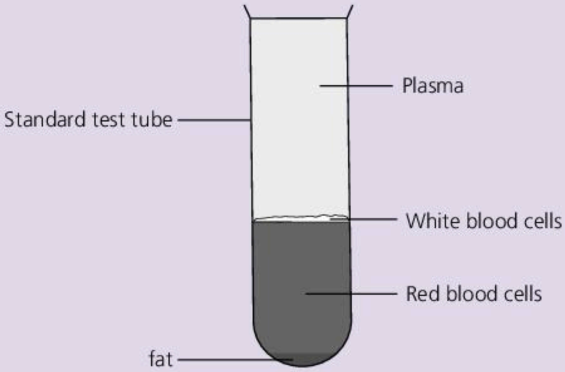
b State the function of the structure labelled B. [1]

c State the letter which represents:

i the vessel taking blood from the heart to the lungs [1]

ii the vessel taking blood from the heart to organs such as the liver. [1]

5 Diagram A shows a sample of human blood, collected and spun to separate the different components.

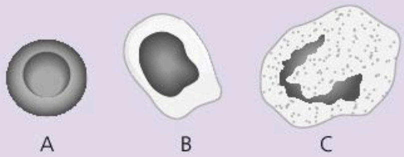


▲ Diagram A

a Diagram A is drawn to scale. Calculate the percentage of red cells, white cells and plasma in whole blood. Show your working. [3]

b Name **two** dissolved substances that would be present in the plasma. [2]

c Diagram B shows three types of cell found in human blood.



▲ Diagram B

d Use the letters to identify:

i a cell which manufactures and releases antibodies [1]

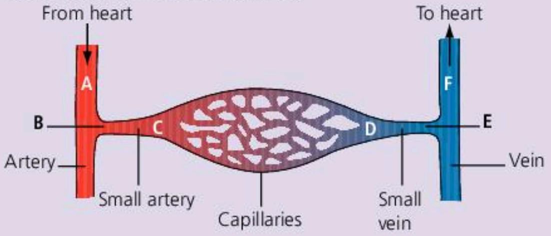
ii a cell which contains a high concentration of hemoglobin [1]

iii a cell which identifies and engulfs bacteria [1]

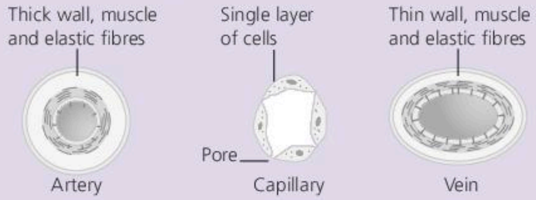
iv a cell which transports oxygen around the body. [1]

6 The following diagrams are concerned with the exchange of materials between the blood and tissues.

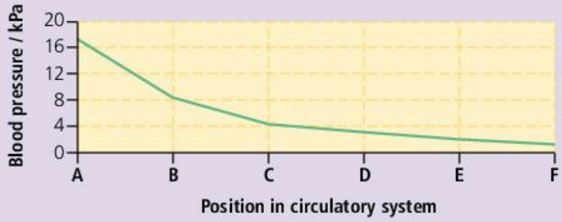
Part of the circulatory system



Sections through blood vessels *(not to scale)*



Average blood pressure at different positions in the circulatory system



a What happens to the blood pressure as the blood travels from **A** to **F**? [1]

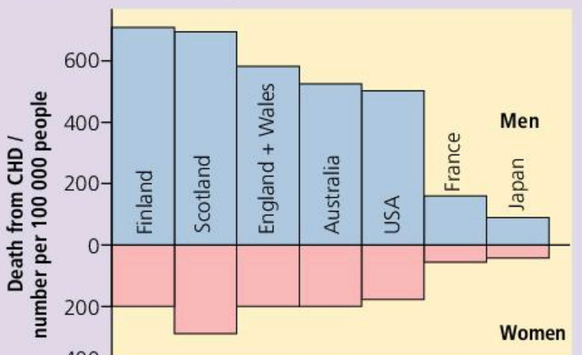
b The highest pressure is found in the artery. Why is this important for the delivery of materials to the cells? [1]

c Veins have structures along them, not shown in the diagram, to help return blood to the heart. What are these structures called? [1]

d How can the small arteries help control the distribution of blood to tissues which have a high demand for oxygen and nutrients? [2]

e Use information shown in the diagrams to explain how the structure of capillaries allows substances to pass from them to surrounding cells. [3]

7 The bar chart below shows how the risk of CHD varies in different parts of the world.



A US citizen is almost three times as likely to develop CHD as a French citizen. Medical scientists suggested that this difference could be due to

either diet or inheritance. They set up a study of 1000 French nationals who had emigrated to the US, and who had taken up the American lifestyle, including diet.

a How many of these people would you expect to develop CHD if:

i diet is responsible [1]

ii inheritance is responsible? [1]

b All the people in this study were male, and non-smokers. Why was this important to the validity of the results? [2]

8 The following tables show the effects of smoking and blood cholesterol levels on the risk of developing CHD.

Cigarettes smoked per day	Relative risk of CHD
0	1
5	1.2
10	1.5
15	2.0
20	2.5
25	2.9
30	3.2

▲ Effect of smoking

Cholesterol level	Relative risk of CHD
Male, normal	1
Female, normal	0.3
Male, 30% above normal	1.4
Male, 45% above normal	2.0
Male, 75% above normal	3.1

▲ Effect of blood cholesterol level

a Plot the two sets of results in an appropriate way. [4]

b i Which appears to carry greater risk, smoking 10 cigarettes per day or having a blood cholesterol level 45% above normal? [1]

ii How much more likely is a man who smokes 30 cigarettes per day and has a 75% higher than normal blood cholesterol level to develop CHD than a non-smoking woman with normal blood cholesterol level? [2]

9 Suggest how:

a lifestyle **b** diet **c** inheritance

may cause problems with the circulatory system. [3]

10.1 Diseases and immunity

OBJECTIVES

- To understand what is meant by disease
- To appreciate that disease may have a number of causes
- To understand that some microorganisms may cause disease

What is disease?

The process of homeostasis maintains optimum conditions for body function (see page 144). However, sometimes the mechanisms of homeostasis cannot cope with changes in the internal environment of the body. A person in this situation will show **signs** (such as a raised body temperatures) and experience **symptoms** (such as feeling tired). The person is no longer 'at ease' but is 'dis-eased'. Disease, then, is the state of the body when it cannot cope with changes by the normal homeostatic methods.

Classification of diseases

There are two main classes of disease – **infectious** and **non-infectious**. Infectious diseases are caused by some other living organism, usually a microorganism. They can be 'caught', or passed on from one individual to another and so are also called transmissible diseases. These diseases are caused by a living organism, called a **pathogen**. Infectious diseases can be classified according to how the disease-causing organism is passed from one individual to another, as illustrated below.

Non-infectious diseases are not 'caught' from another individual. These diseases may have a number of causes, illustrated opposite.

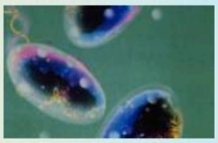
Patterns of disease vary in time and space

In the eighteenth century, many British children died from bacterial infections. With the development of antibiotics, immunisation programmes and

Infectious diseases

These are caused by organisms, called pathogens, which may spread in a number of ways:

In infected water e.g. *Cholera* bacteria



In droplets in the air e.g. influenza virus, SARS-CoV-2 (coronavirus)

By direct contact (contagious) e.g. athlete's foot – fungus or head lice – insects

In contaminated food (causes food poisoning) e.g. *Salmonella* bacteria or pork tapeworm

By animal vectors e.g. *Plasmodium* protoctist (causes malaria) via *Anopheles* mosquito

Via body fluids e.g. hepatitis B virus or human immunodeficiency virus (HIV) (causes AIDS)

Typical symptoms of disease include:

- **sweating/fever** due to resetting of body's thermostat
- **vomiting/diarrhoea** due to body's attempts to clear gut of irritants
- **pain** due to release of toxins by pathogens.

A doctor might use a thermometer to recognise a sign such as raised body temperature.

▲ Infectious diseases. Parasites such as tapeworms and head lice are not considered to cause 'diseases' by some people, but they do cause distress to the person affected by them and the body is less 'at ease' when it has been colonised by such a parasite. Parasites may be thought of as causing long-term disease.

Non-Infectious diseases

Degenerative – organs and tissues work less well as they age. This is thought to be due to changes in body chemicals caused by **free radicals** such as the peroxide ion e.g. heart attacks, cataracts, hardening of the arteries.

Deficiency – poor diet may deprive the body of some essential substance e.g. scurvy is caused by lack of vitamin C – see page 64.

Allergy – sensitivity to some antigen in the environment, e.g. hay fever (pollen is the antigen) – see page 118.

Environmental – some factor in the environment may trigger a dangerous or abnormal reaction e.g. overexposure to ultraviolet radiation may cause abnormal cell division leading to skin cancer.

Inherited/metabolic – some failure in the body's normal set of chemical reactions, e.g.

- sickle cell anaemia (abnormal haemoglobin, page 223)
- cystic fibrosis (production of thick mucus)
- diabetes (failure to produce enough insulin, page 149).

These conditions are due to alterations in the genes.

Psychological/mental – changes in the working of the brain may lead to abnormal behaviour, e.g. schizophrenia, depression.

Self-induced – some abuse of the body may affect its function, e.g. lung cancer caused by cigarette smoking, cirrhosis of the liver caused by alcohol abuse.

improved public hygiene, deaths from infectious diseases in the UK are now much less common. Smallpox was a major killer worldwide until the 1960s, but effective vaccination has now eliminated this disease (see page 114).

In the Western world, the major killers are now 'diseases of affluence', caused by our relatively wealthy lifestyle. Along with accidents, coronary heart disease and cancer cause most deaths in the UK, largely the result of smoking, eating too many sugary and fatty foods, and lack of exercise.

Infectious diseases that are spread by vectors (e.g. malaria spread by mosquitoes) are naturally confined to those parts of the world in which the vector can live and breed. In the same way, diseases spread by the number of people likely to meet an infected individual. In recent years, there has been concern over the possible spread of infectious diseases because:

- Easier travel by air means that diseases can be carried from one country to another before the infected person develops any symptoms, e.g. COVID-19 caused by coronavirus infection.
- Global warming has increased the range of some insect vectors.
- A greater dependence on communal eating and fast food has led to the easier transmission of organisms that cause food poisoning.

Q

1. Suggest three ways in which microbes might be harmful to humans, and three ways in which they might be helpful. Give examples to support your suggestions.
2. Suggest three causes of non-infectious diseases, and give one example of each.
3. How can infectious diseases spread? Give examples to support your answer.
4. What is the difference between the signs and the symptoms of a disease? What are the causes of 'typical' disease symptoms?
5. Suggest why measles is very rarely fatal in the UK yet still ranks among the top five killer diseases in the developing world.
6. How have changes in human lifestyle contributed to the spread of infectious diseases?

10.2 Pathogens are organisms that cause disease

OBJECTIVES

- To recall that a pathogen is an organism that causes disease
- To give examples of different types of pathogen and the diseases they cause

Pathogens are parasites

Any organism that affects the body to cause disease is a pathogen (or pathogenic organism). Pathogens are parasites, that is, they live on the body of a host and cause it some harm:

- **by secreting poisons (toxins)** – this is especially common from bacteria. The toxins have different effects, for example the organism *Clostridium botulinum* produces a deadly nerve poison, whereas bacteria of the *Salmonella* group release a toxin which irritates the lining of the gut.
- **as a result of multiplication** – the organism may reproduce quickly and produce such a large colony that it damages cells directly, as in malaria, or it uses up compounds which should be used by the host cell, as in polio. Many viruses multiply and cause host cells to burst.
- **as a result of the immune response** – when the host detects pathogens, it directs more blood to the site of infection. This can cause swelling and soreness, and usually causes a rise in body temperature.

There are many pathogens that are parasites on humans, causing diseases. The following table illustrates the range of pathogenic organisms.

Pathogen type	Size	Disease in humans
Virus	About 1 nm (1/1000 μm)	Influenza AIDS
Bacterium (prokaryote)	About 1 μm	Cholera Food poisoning
Protoctist	Up to 1 mm	Dysentery Malaria
Fungus	May be extensive	Athlete's foot Ringworm
'Worms'	Up to several meters	Tapeworm *Toxocara*

Viruses

Viruses are responsible for many of the most serious human diseases. Viruses differ from the true living organisms in that they cannot survive and reproduce outside the cells of their host – every virus is a parasite. The structure of viruses was described on page 18. Remember that viruses are so small that they can pass through filters and screens which will trap any other organism. We use an electron microscope to study viruses.

Bacterial diseases

The structure of bacteria and their importance to humans are outlined on page 292. Some bacteria cause serious human diseases, cholera (see page 110) and TB for example.

TB is now the infectious disease that causes most deaths worldwide, due to:

- poor disease control programmes
- resistance to antibiotics (see page 174)
- co-infection with HIV
- a rapid increase in the population of young adults, the age group most at risk from TB.

Any bacterial disease can be treated with antibiotics.

Controlling the spread of disease

Transmissable diseases are caused by pathogens so controlling these diseases often involves preventing the spread of these organisms. Important techniques include:

- hygienic food preparation (see opposite)
- good personal hygiene
- waste disposal (page 286)
- sewage treatment (page 282).

Individuals and communities all contribute to the control of disease.

10.3 Preventing disease: safe food

OBJECTIVES

- To understand how microorganisms can affect human food supplies
- To understand the dangers of food poisoning
- To understand how the risks of food poisoning can be minimised

Human foods need to be protected from microorganisms for two reasons:

- the microorganisms might be decomposers and spoil the food
- the microorganisms might be pathogenic and cause disease.

Food poisoning

Food poisoning is caused by eating contaminated food which contains harmful numbers of food-poisoning microbes. The symptoms of food poisoning may be due to:

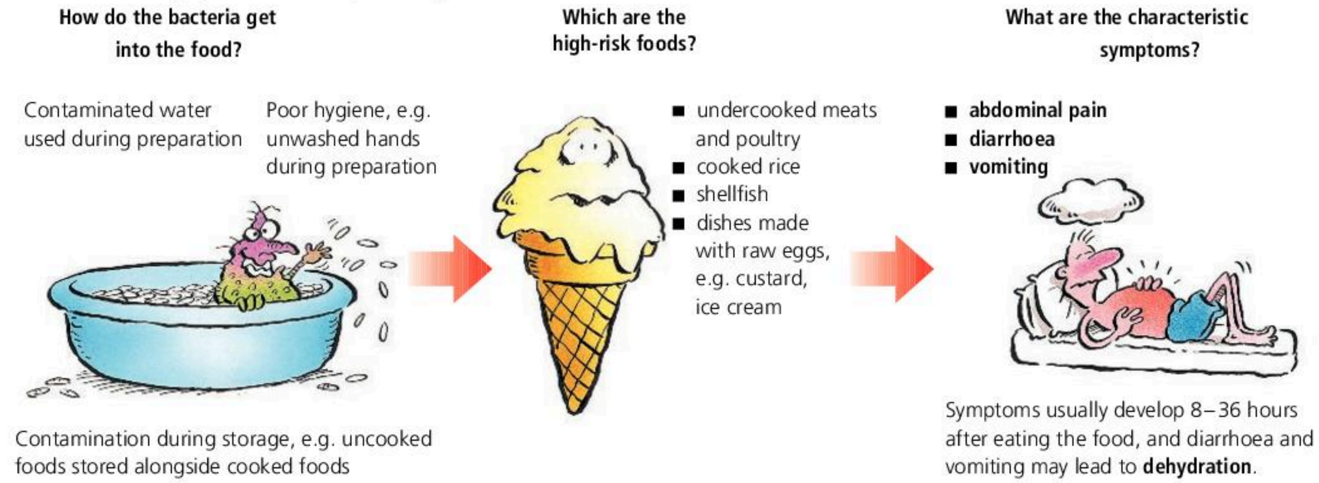
- the microorganism 'feeding' on the host tissues as it reproduces
- toxins released onto the food by the microorganism or released inside the host as the microorganism reproduces.

A number of bacteria can cause food poisoning, including *Clostridium botulinum* (found in soil, fish and meat – it makes the most deadly nerve toxin produced by a living organism), *Listeria monocytogenes* (found in soft cheeses and pâtés, and becoming more common as we eat more 'convenience foods') and the *Salmonella* group. The diagram below shows some questions and answers about bacteria and food poisoning. Thorough cooking kills any bacteria in food, but food may become contaminated after being cooked, or may not be cooked well enough.

The following principles of good food hygiene help to prevent food poisoning:

- Avoid contamination of food by bacteria – wash hands, cooking utensils and surfaces carefully during food preparation, and package food carefully during transport and storage.
- Prevent any bacteria that do gain entry to food from multiplying.
- Destroy any remaining bacteria – cook the food thoroughly.

The causes and symptoms of food poisoning



Q

1 State which of the following is least likely to cause food poisoning.

A Raw crabmeat
B Ice cream
C Roast meat
D Raw fish

2 One of the symptoms of food poisoning is diarrhoea. Explain what causes this condition. Suggest why the condition is so dangerous.

10.4 Individuals and the community can fight disease together

OBJECTIVES

- To understand that the fight against disease involves several levels of responsibility
- To provide examples of individual, community and worldwide responsibilities

The fight against disease has three levels:

- personal – for example, each individual can take responsibility for his or her own social habits
- communities – for example, local health services must be correctly managed and financed
- worldwide – for example, many nations carry out vaccination programmes (see page 119).

Personal responsibility

The individual can reduce his or her chances of contracting some diseases by:

- having good personal hygiene
- eating a balanced diet
- taking regular exercise
- not smoking
- controlling alcohol intake.

Community responsibility

Living close together in towns and cities means we share many facilities which affect our health.

Community health responsibilities include:

- Providing safe drinking water and treating sewage (see page 282)
- removing refuse (see diagrams below and opposite)
- providing medical care for the unwell
- monitoring standards of health and hygiene.

Worldwide responsibility

The **World Health Organization (WHO)** aims to raise the level of health of all the citizens of the world so that they can lead socially productive lives. They have had some successes:

- reduction in infant mortality, by providing a better diet for mothers and their infants
- elimination of smallpox, by a well-coordinated vaccination programme
- reduction in malaria, by a variety of control measures such as draining swamps
- improved provision of safe water, by the construction of water-treatment plants.

Refuse disposal in land-fill sites

Advantages

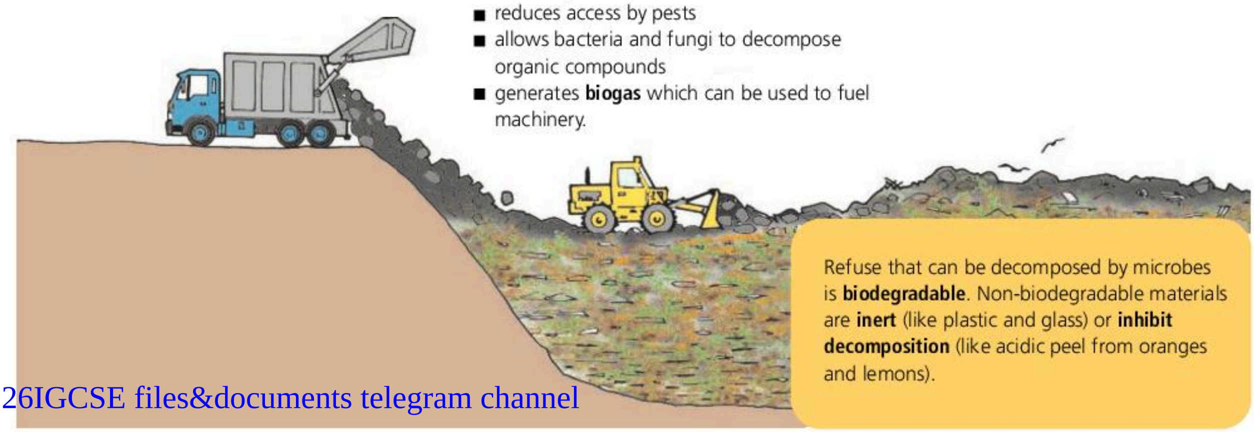
- Can help **land reclamation,** e.g. in filling old quarry workings.
- Can be made economical in terms of space:
  - – lorries use rams to compress rubbish
  - – very deep pits can be used.
- Can be situated well away from residential areas, reducing impact of smells and unsightly rubbish.

Disadvantages

- Sites can attract **pests**, such as flies, rats and gulls. These might spread disease (e.g. flies contaminate food) or leave a mess (e.g. gulls leave droppings).
- Ecologically important areas such as marshes and heathland may be used as dumps.

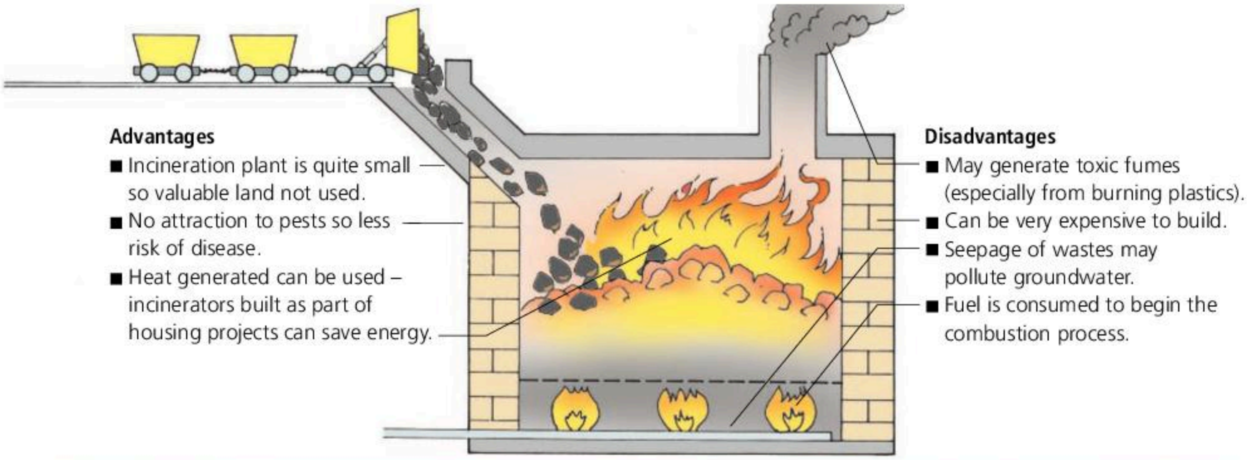
Refuse may be buried under 0.5m of soil. This

- reduces access by pests
- allows bacteria and fungi to decompose organic compounds
- generates **biogas** which can be used to fuel machinery.



Refuse that can be decomposed by microbes is **biodegradable**. Non-biodegradable materials are **inert** (like plastic and glass) or **inhibit decomposition** (like acidic peel from oranges and lemons).

Refuse disposal by incineration



▲ Open rubbish dumps are a source of infection. Waste food is infected with harmful microbes, which may be spread by rats, birds such as the Marabou stork, and humans.

Q

1. Suggest two steps an individual can take to reduce the risk of a named disease.
2. What are the responsibilities of a community health service?
3. Name one viral and one bacterial sexually transmitted infection (STI).
4. For any one named STI suggest how individuals, local communities and scientists worldwide might be involved in its control.

10.5 Combating infection: blood and defence against disease

OBJECTIVES

- To recall what is meant by disease
- To recall that disease can be caused by pathogens, which must first invade the body
- To understand that the body may be able to defend itself against pathogens

Disease is often caused by the invasion of the body by another organism. Organisms that cause disease in this way are called **pathogens** and their attacks on the body result in **infections**.

The skin and defence against disease

The outer layer of the skin, the epidermis, is waxy and impermeable to water and to pathogens (although microorganisms can live on its surface). Natural 'gaps' in the skin may be protected by **chemical** secretions, for example:

- the mouth leads to the gut which is protected by hydrochloric acid in the stomach
- the eyes are protected by lysozyme, an enzyme that destroys bacterial cell walls, in the tears
- the ears are protected by bactericidal ('bacteria-killing') wax.

Physical defences against the entry of microorganisms include the cilia and mucus-secreting cells of the respiratory pathways (see page 129). If the potential pathogens do penetrate these first lines of defence, they might reproduce quickly in the warm, moist, nutrient-filled tissues. Further defence depends upon the **blood**.

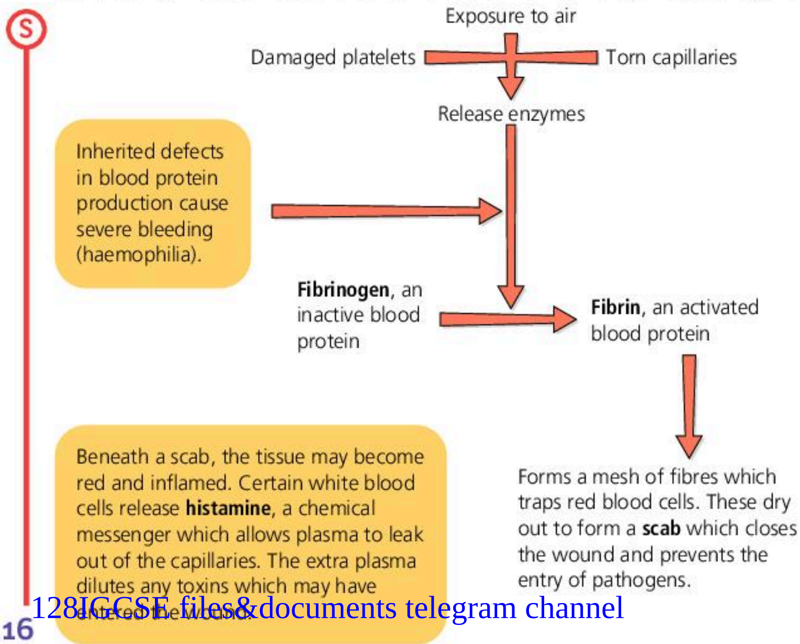
Bleeding and clot formation

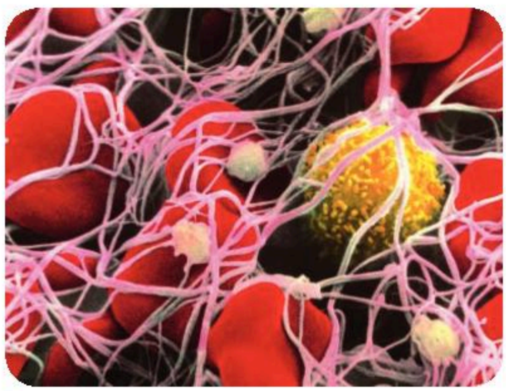
Blood clotting seals wounds. The blood clot limits the loss of blood and also prevents entry of any pathogens. Clotting depends on **platelets** and **blood proteins**, as outlined in the diagram below.

White blood cells and defence

Organisms that gain entry to the tissues are removed or destroyed by **white blood cells**. These white blood cells must attack only invading organisms and not the body's own cells (although this does happen sometimes, see page 119). The white blood cells recognise foreign particles such as bacteria, or perhaps large molecules such as proteins in snake venom, and react against them. These foreign particles are called **antigens**. Potential pathogens have antigens on their

Blood clotting reduces loss of blood and seals the wound against pathogens

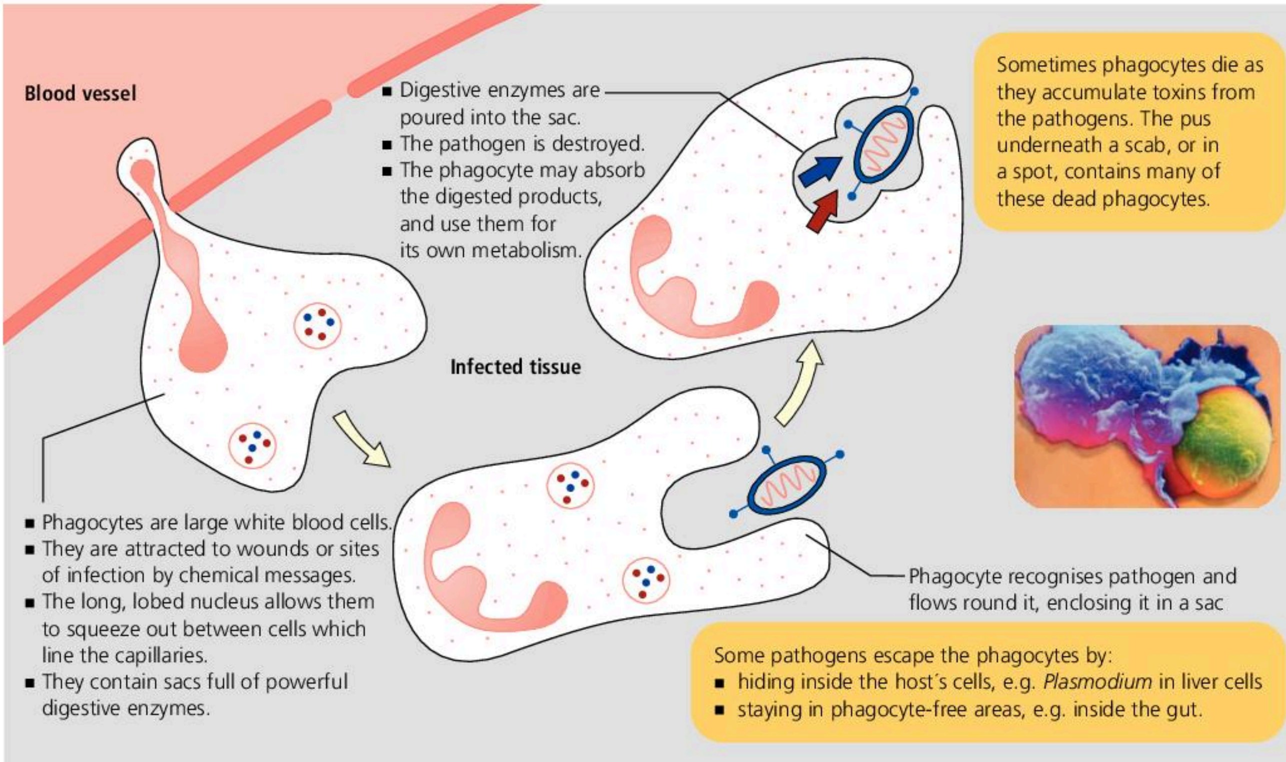




▲ Fibrin fibres trap blood cells to form a scab

S

Phagocyte action



surface, and they are recognised and destroyed by **phagocytes** and by **antibodies**. Phagocytes engulf and then destroy the pathogens with digestive enzymes, as outlined above. Antibodies are described on page 118.

There are many phagocytes present in areas of the body likely to suffer infection. The exposed surfaces of the lungs, for example, are patrolled by phagocytes. If the lungs are regularly attacked by the free radicals in tobacco smoke, large numbers of phagocytes collect and may become disorganised. They can destroy lung tissue rather than foreign particles, leading to the disease **emphysema** (see page 135).

i

First aid can save lives

Severe blood loss, or haemorrhage, can cause a number of problems. Following an accident there may be so much blood loss that the blood pressure falls to dangerously low levels. This may affect the function of vital organs such as the heart, brain and kidney.

If the victim has no pulse or is not breathing, steps are taken to restart these essential functions.

If there is considerable bleeding, the first-aider applies firm pressure to the site of the injury. The victim should not be moved unless he or she is in danger. No attempt should be made to clean wounds – this may force a foreign body such as a glass fragment deeper into the wound.

Organisations such as St John Ambulance in the UK provide training in first aid.

Q

1 Suggest how the skin may limit the entry of pathogens to the body. Why is it necessary to prevent the entry of pathogens?

2 This question concerns the process of blood clotting.
- **a** Why might blood clotting be necessary?
- **b** When could blood clotting be a disadvantage?
- **c** Blood clotting occurs in a number of stages. This is quite common in biological processes, because it allows **amplification**. Each step produces a product which can trigger many repeats of the next step – for example, each enzyme molecule released from a platelet can catalyse the conversion of 100 inactive protein molecules to their active form.
  - **i** Suggest how this amplification might be an advantage in a rapid response to wounding.
  - **ii** If there were five steps, each allowing an amplification of 100, how many 'product' molecules would be present at the end of the complete process for each 'signal' molecule released at the start of the process?

3 Describe the process of phagocytosis. Suggest two ways in which the structure of a phagocyte is related to its function. Suggest two ways in which a pathogen might avoid phagocytosis.

10.6 Antibodies and the immune response

S

OBJECTIVES

- To know what an antibody is
- To understand how antibodies are involved in defence against disease
- To understand how memory cells protect against infections
- To know how the immune response can be enhanced
- To understand the production and use of monoclonal antibodies

An antibody is a protein

An **antibody** is a protein produced by the body in response to an antigen. Each different antigen stimulates the production of the particular type of antibody that will destroy that antigen. Antibodies are made by white blood cells called **lymphocytes**. They defend the body as shown below.

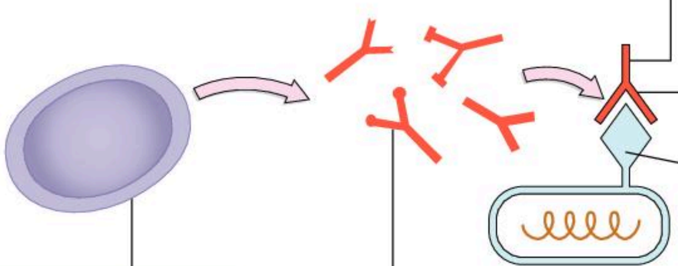
Once the lymphocytes have learnt to make a particular type of antibody in response to the antigens on an infective organism, the body begins to recover as the organisms are destroyed. It takes a few days to produce antibodies, so the infected individual will show some symptoms of the disease (a high temperature, for example).

Immunity

After an infection, some lymphocytes are kept as 'memory cells', which help the body to defend itself against further attacks by the same antigen. This 'memory' may last for years, and the body is said to be **immune** to the disease. There are different types of immunity, as shown opposite.

The action of white blood cells – lymphocytes

Scientists estimate that humans can make up to 1 000 000 different antibodies – enough to account for every pathogen or 'foreign' substance we might ever meet!



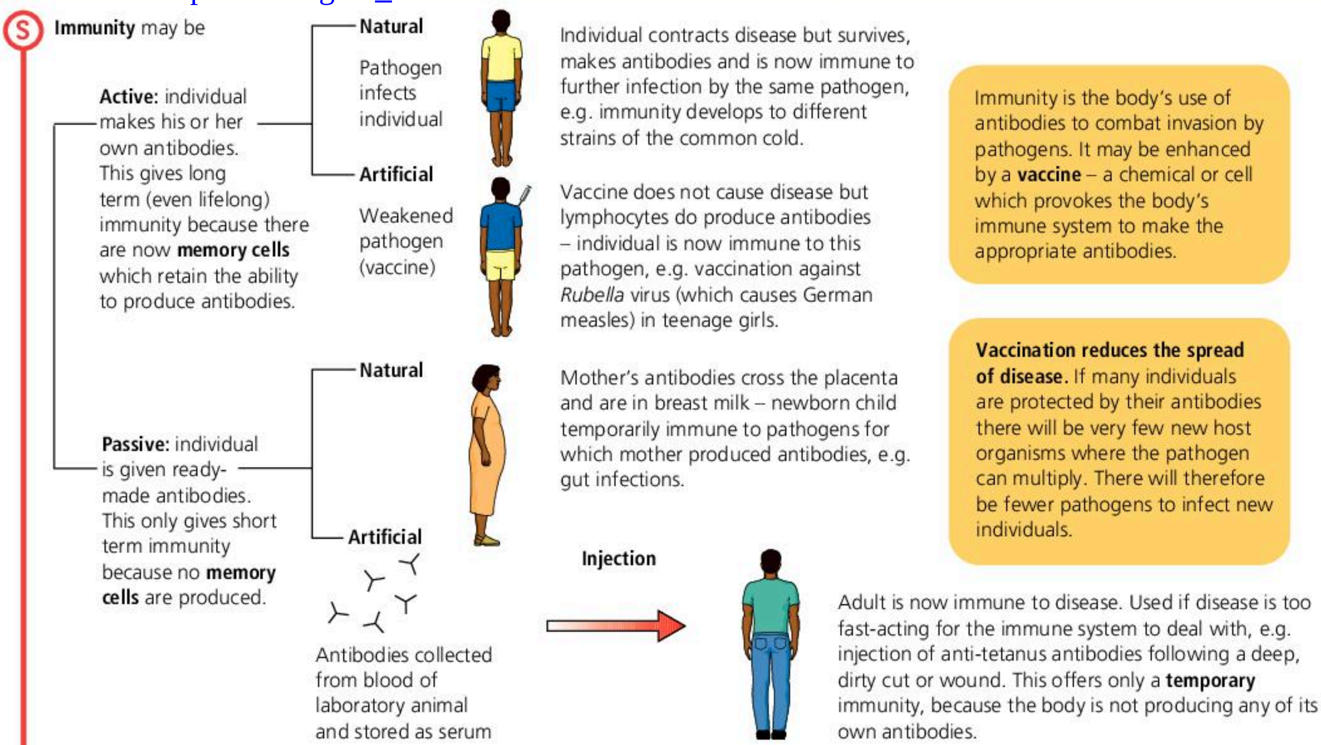
ymphocytes are a type of white blood cell:
- found in circulating blood and in the lymph nodes (see page 103)
- have a large nucleus and no granules in the cytoplasm
- stimulated by contact with pathogens
  oduce **antibodies**.

Antibodies are:
- proteins produced by lymphocytes
- able to recognise, bind to and help to destroy pathogens
- always Y-shaped.

'Labelled' pathogens may be destroyed by:
- sticking together in clumps so they can be **ingested by phagocytes**
- T-lymphocytes, which **burst membranes around the pathogen**
- antibodies directly – a few antibodies may actually destroy the pathogen's cell

An **antigen** is:
- a protein or carbohydrate on the surface of the pathogen
- able to provoke the immune system of the host.

Pathogens may evade the immune system by mutation – they change and produce different antigens which the host has not learned to



Immunity is the body's use of antibodies to combat invasion by pathogens. It may be enhanced by a **vaccine** – a chemical or cell which provokes the body's immune system to make the appropriate antibodies.

Vaccination reduces the spread of disease. If many individuals are protected by their antibodies there will be very few new host organisms where the pathogen can multiply. There will therefore be fewer pathogens to infect new individuals.

Some problems with the immune response

The activity of the immune system saves all our lives, many times over. There are occasions, however, when it may actually reduce the likelihood of survival. These are described below.

Autoimmune diseases are caused by the body producing antibodies which destroy its own cells. Why this should happen is not known. An example is Type I diabetes where the body destroys its own insulin-producing cells by an immune reaction.

Transplant rejection – the most common organ transplant in Britain is the kidney transplant (see page 143), but heart, intestine, lung, liver and pancreas transplants are becoming more common. The recipient's lymphocytes may recognise antigens on the surface of the donor organ as foreign and slowly destroy it. This problem of rejection is being overcome by:

- drugs that suppress the immune system of the recipient long enough to allow the transplanted organ to become established
- matching tissues wherever possible, for example by seeking out relatives of people needing bone marrow transplants, because relatives are more likely to have similar antigens to the recipient.

Monoclonal antibodies

Scientists need a good supply of 'pure' antibodies to work with. They produce these by combining the properties of two types of cell:

- **lymphocytes** are very efficient at producing anitbodies but cannot be grown in large numbers outside the human body
- **tumour cells** cannot produce antibodies but divide very well in artificial culture.

Cells formed by joining together lymphocytes and tumour cells – called hybridomas – can produce enormous quantities of one desirable kind of antibody *and* survive for long periods in artificial culture. The antibodies produced in this way are called **monoclonal antibodies** ('mono' means one type and 'clonal' means a group of identical dividing cells). They have many uses in medicine, industry and research.

Q

1. How do antibodies recognise pathogens?
2. State one difference in structure between a lymphocyte and a phagocyte.
3. Explain how a single infection by a pathogen can provide lifelong protection against a disease.

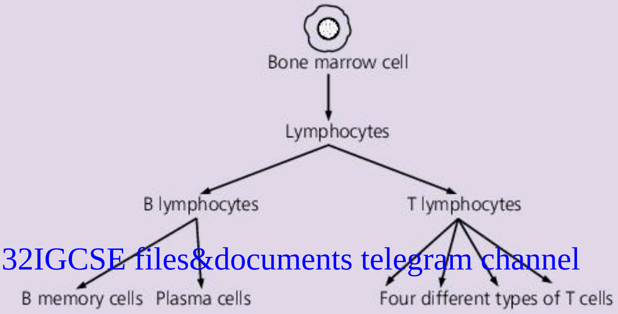
Questions on blood and defence against disease

1 A pathogen is an organism that:
- **A** feeds on dead and decaying organisms
- **B** lives in an organism and causes disease
- **C** lives inside a host organism without causing harm
- **D** spreads disease organisms from infected to uninfected people [1]

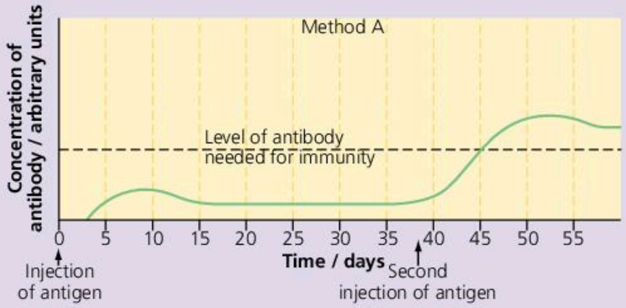
2 During an immune response:
- **A** lymphocytes and specific phagocytes divide to make antibodies
- **B** all lymphocytes divide to produce cells that make antibodies
- **C** phagocytes engulf and completely digest bacteria
- **D** specific lymphocytes divide to produce cells that make antibodies [1]

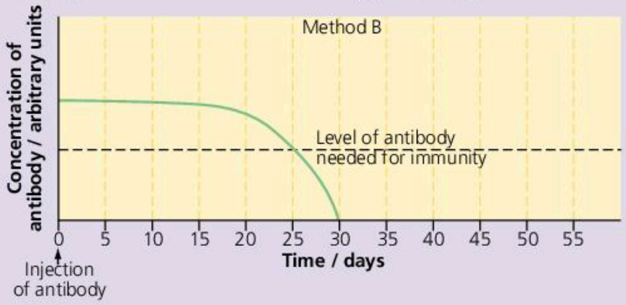
3 Some microorganisms, such as the bacteria that cause cholera, enter the body in our food and cause disease.
- **a** State the term given to a disease-causing organism. [1]
- **b** State **two** ways in which food can become contaminated with microorganisms. [2]
- **c** Some diseases are transmitted in food and water. State **four** other ways in which infectious diseases can be transmitted. [4]

4 a Give **three** natural ways in which the body can prevent the entry of pathogens. [3]
- **b** How can a baby acquire immunity from its mother after birth? [2]
- **c** The diagram below shows how the human body can respond to the entry of a pathogen by producing B and T lymphocytes.
  - **i** Explain how the B lymphocytes protect the body from pathogens. [2]
  - **ii** Describe **one** way in which the T lymphocytes protect the body after a second infection by the same pathogen. [2]



- **d** Mr Jones landed at the airport after a holiday abroad. He read in a newspaper that typhoid had broken out in the town where he spent the last three days of his holiday. Typhoid is a dangerous disease which usually causes illness between 7 and 14 days after infection.
  The graphs below show two ways in which a person can acquire artificial immunity. Method A involves the injection of an antigen, method B an injection of antibody. Which of the methods shown in the graphs would provide the best protection, from typhoid, for Mr Jones? Give a reason for your answer. [2]





5 Read the following article carefully, then answer the questions based on it.

Blood plasma carries red blood cells, white blood cells and platelets to all parts of the body. It also carries many solutes (dissolved substances) – these include oxygen, carbon dioxide, urea, hormones, glucose and amino acids.

In a normal healthy person the number of white blood cells may vary, but is usually no more than 8000 per mm^3 of blood. If a person has an infection, the number of white blood cells may rise to 40 000 per mm^3 of blood.

In a healthy person living at sea level, there are about 5 000 000 red blood cells per mm^3 of blood. The cells are regularly replaced from the bone marrow. Old, worn-out red blood cells are removed from the blood by the liver, after about 120 days of carrying out their function. Each cell carries oxygen from the lungs to the tissues, combined with a protein called haemoglobin. Haemoglobin will also combine with carbon monoxide, a gas in car exhaust fumes and cigarette smoke. Carbon monoxide combines with haemoglobin about 250 times more readily than oxygen does, and the combination does not break down.

a Name **two** soluble substances transported in the blood plasma. For each substance you name, suggest where it might be coming from and where it might be going to. [4]

b What is the maximum number of white blood cells normally found in 1 mm^3 of blood? What can cause this number to increase? [2]

c In a healthy person, what is the ratio of red blood cells to white blood cells? [1]

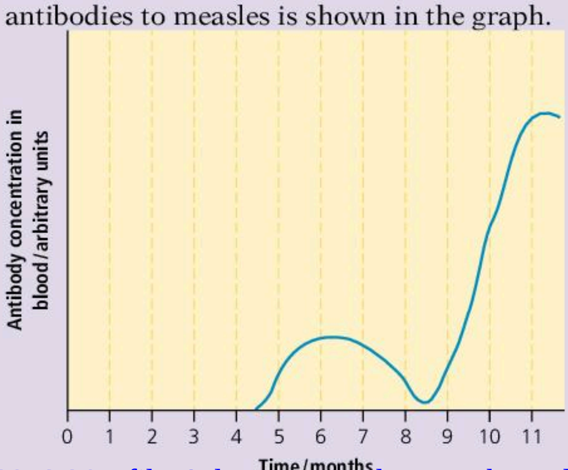
d Name **two** sources of carbon monoxide. [2]

e What happens to the amount of oxygen transported if a person breathes in carbon monoxide? Explain your answer. [2]

f How long would it take the blood of the person in part **e** to regain its full ability to carry oxygen? Explain your answer. [2]

g Liver is a good dietary source of iron. Why? [1]

6 A child received a first vaccination against measles at four months of age and then a booster at eight months. The concentration of antibodies to measles is shown in the graph.

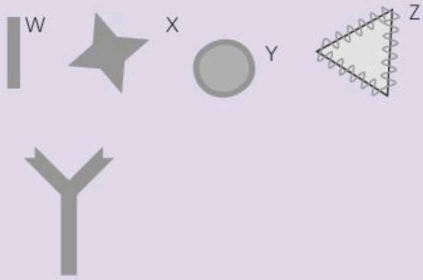


a Explain why no antibodies were present in the blood for the first week. [2]

b The response to the two injections of the vaccine is different.
Use the information in the graph to describe and explain how the response to the booster at eight months differs from the response to the first injection at four months. [2]

c Suggest why further boosters of this vaccine may be given. [2]

7 The diagram below shows four different antigens and an antibody molecule.



a The antibody forms a complex with **one** of the antigens.
State which one and explain your answer. [2]

b There is no vaccine for chicken pox. A child has been vaccinated against several diseases including measles, tetanus and rubella.
The child catches chicken pox and has the symptoms of the disease.

i Use the information in the diagram to explain why it is possible to be immune to many diseases, but still be ill with another disease, such as chicken pox. [3]

ii Some people see that certain diseases are becoming rare and believe that there is no longer any need for vaccination. Suggest why vaccination against diseases must continue to be carried out even if there are no cases of the disease for many years. [2]

8 Which row in the table shows the correct functions of the components of the blood?

	Plasma	Red blood cells	Platelets
A	transport of ions	clotting	oxygen transport
B	antibody formation	oxygen transport	clotting
C	transport of ions	oxygen transport	clotting
D	oxygen transport	clotting	antibody formation

[1]

11.1 Respiration provides the energy for life

OBJECTIVES

- To understand that energy is needed to carry out work
- To appreciate that different forms of energy can be interconverted
- To be able to list some of the energy-demanding processes in living organisms
- To describe how the process of respiration releases energy from chemical foods

Energy conversions in living things

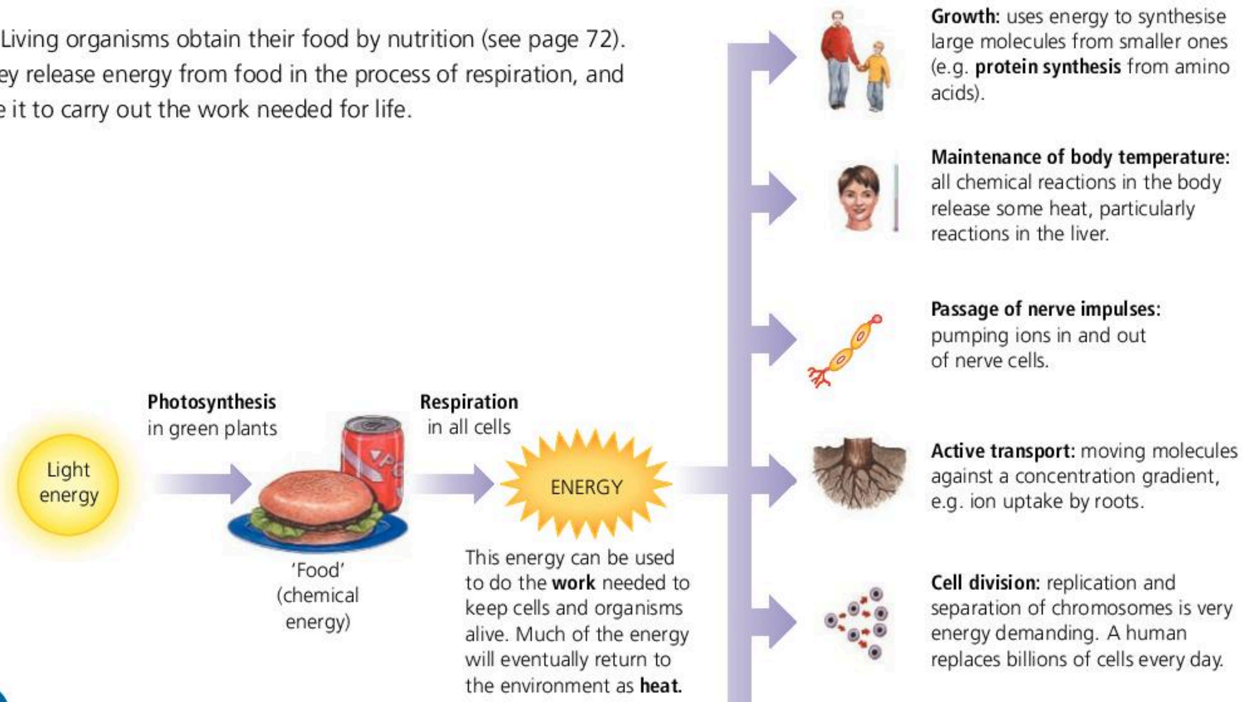
Energy can be defined as 'the capacity for doing work'. The processes that keep organisms alive (for example, pumping ions from one side of a membrane to another) usually require work to be done. It is clear, therefore, that life requires energy.

Life also depends on energy **conversions**. The first and most important energy conversion in living things is **photosynthesis**. This process is described in greater detail on page 46, but in energy terms it can be described simply as:

light energy from the Sun
⇓
converted in green plants
⇓
chemical energy in organic molecules

A second energy-conversion process releases the chemical energy stored in organic food molecules and converts it to energy forms that organisms use to stay alive. This process is called **respiration**. Respiration is the set of chemical reactions that break down nutrient molecules in living cells to release energy. Respiration involves the action of **enzymes in cells** (see page 40). The diagram at the bottom of the page shows some of the uses of energy by living organisms.

▶ Living organisms obtain their food by nutrition (see page 72). They release energy from food in the process of respiration, and use it to carry out the work needed for life.



Q

1 True or False.

a Most of the energy in our diet is used for movement.

b Ions only move from the intestine to the blood by diffusion.

What is respiration?

Respiration involves the **oxidation** of food molecules, and energy is released during the process. These food molecules all contain carbon, hydrogen and oxygen and the complete oxidation process converts these to carbon dioxide and water. Complete oxidation occurs only if oxygen is present. For example:

words: glucose + oxygen → energy + carbon dioxide + water

symbols: $C_6H_{12}O_6 + 6O_2 \rightarrow \text{energy} + 6CO_2 + 6H_2O$

Definition: respiration is the release of energy from food substances, and goes on in all living cells. So much energy is released in this process that, if it was all released at once, the cell might be damaged.

The energy is released in small 'packets' which can then drive the reactions that keep the cell alive. These energy packets act as a short-term store of energy. The one used most commonly by cells is a molecule called **adenosine triphosphate (ATP)**.

The reactions are summarised in the following equation.

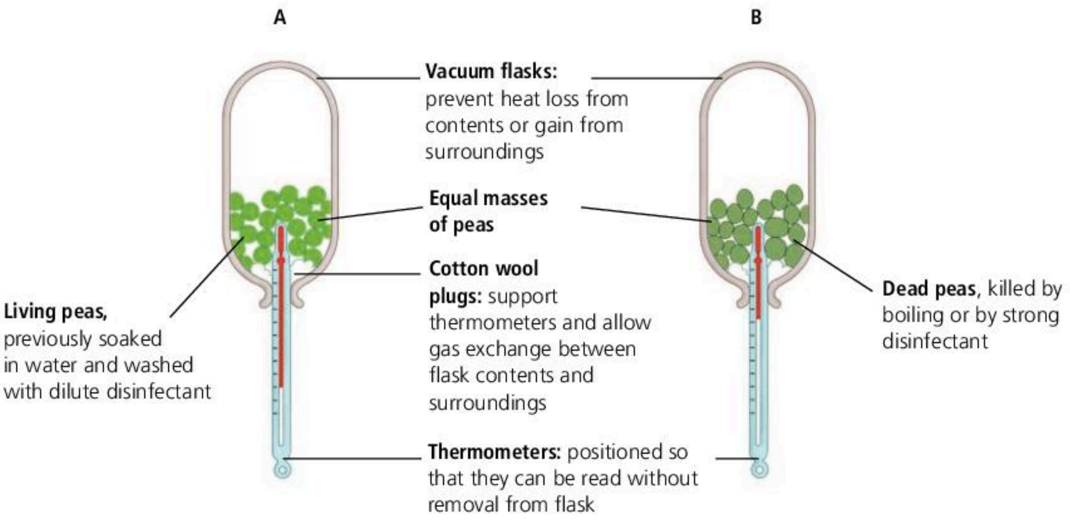
glucose + oxygen

→ ATP → 'work' in cells

carbon dioxide + water

This process, which releases energy in the presence of oxygen, is called **aerobic respiration** ('aerobic' means 'in air'), and takes place in the **mitochondria** (see page 24). The reactions involve enzymes, and some energy is 'lost' as heat.

VACUUM FLASK EXPERIMENT



- Apparatus is assembled as shown.
- Temperature readings are taken immediately, and then every day for 4–5 days.

In an experiment like this one, the following results were obtained:

Time / days	Temperature / °C	
	A	B
0	20	20
1	23	20
2	25	20
3	27	21
4	28	21
5	28	21

a Explain these results.
b Why is it important to include flask B?
c Disinfectant kills bacteria – why is this important?

11.2 Contraction of muscles requires energy supplied by respiration

OBJECTIVES

- To know that respiration is the source of energy for muscular work
- To understand that anaerobic respiration is less efficient than aerobic respiration and produces a toxic product
- To understand that exercise is limited by the build-up of lactic acid

How muscles contract

Muscles contract and pull on bones to move the skeleton. Muscles are collections of very long **muscle fibres**. When lots of fibres shorten at the same time, the muscle contracts.

Muscular work requires energy

Aerobic respiration

Work must be done to contract muscle. **The energy** for this comes from **aerobic respiration**, defined as chemical reactions that use oxygen to break down nutrient molecules to raise energy. The word and chemical equations are:

glucose + oxygen → energy + carbon dioxide + water

$$C_6H_{12}O_6 + 6O_2 \rightarrow \text{energy} + 6CO_2 + 6H_2O$$

The oxygen comes from the air. It is taken in at the lungs and carried around the body in the blood, pumped by the heart. Glucose comes from food digested in the gut, and is also carried in the blood. Muscles have extensive capillary beds to supply glucose and oxygen for respiration, and to carry away carbon dioxide. The blood also carries away heat that is produced during respiration.

Anaerobic respiration

When we work very hard our muscles use up a lot of energy. The heart and lungs, even working flat out, cannot supply enough oxygen to provide this energy by aerobic respiration. Muscles can release energy from food without using oxygen by a process called **anaerobic respiration**: the release of energy from glucose in the absence of oxygen.

The word equation is:

glucose → energy + lactic acid

Anaerobic respiration has two drawbacks:

- It gives only about one-twentieth of the energy per glucose molecule that aerobic respiration yields.
- Lactic acid is poisonous – if it builds up in the cells it inhibits muscular contraction, which leads to fatigue and, eventually, death.

S This harmful lactic acid is carried out of the muscles in the blood. It is transported around the body to the heart, liver and kidneys where it is oxidised to **pyruvate**, which can be used to release energy by aerobic respiration. The heart, the liver and the kidneys will need extra oxygen to get rid of this lactic acid, provided by the deep, fast breathing that follows hard exercise. This extra oxygen is the **oxygen debt**.

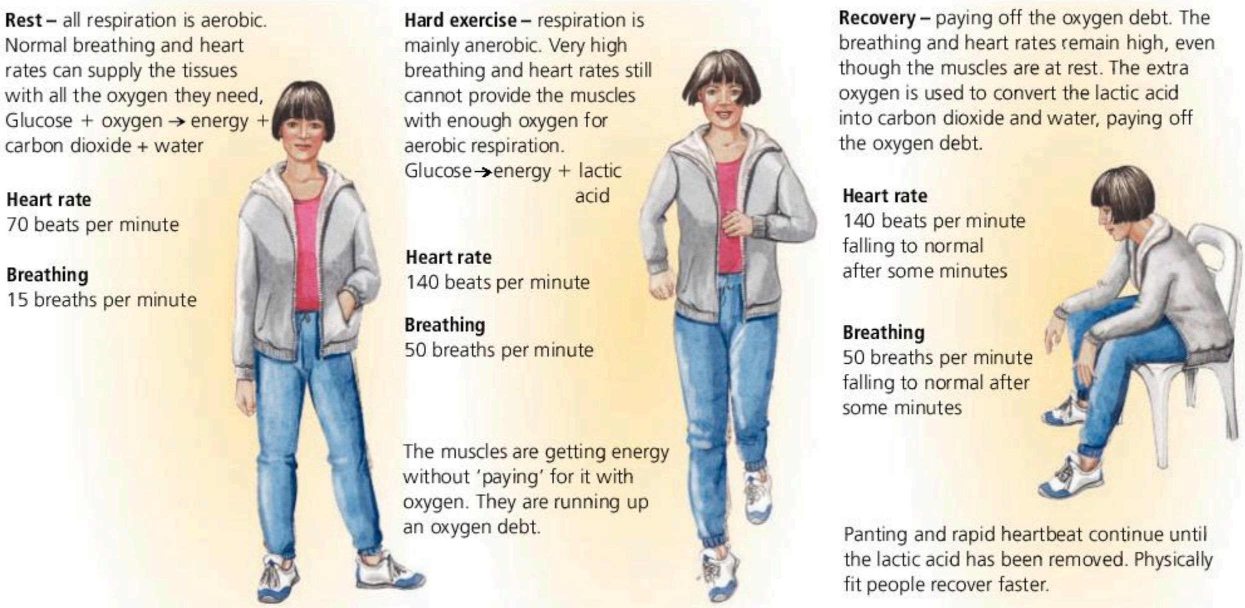
Q

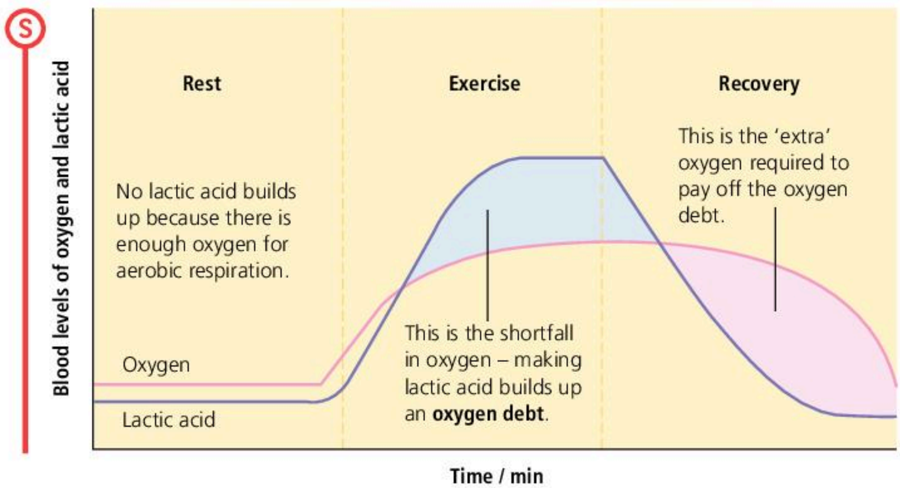
1 One of the comparisons between aerobic and anaerobic respiration shown below is incorrect. Which one?

	Respiration	
	Aerobic	**Anaerobic**
A	Uses oxygen gas	Does not use oxygen gas
B	Produces ethanol or lactic acid	Produces no ethanol or lactic acid
C	Large amount of energy released	Small amount of energy released
D	Mitochondria involved	Mitochondria not involved
E	Carbon dioxide always produced	Carbon dioxide sometimes produced

2 What is meant by energy transformation? Briefly describe one energy transformation that is important to living organisms. What eventually happens to all of the energy taken in by living organisms?

The diagram below shows the part played by aerobic and anaerobic respiration during rest, exercise and recovery.





Anaerobic respiration is important in other organisms such as yeast, for brewing and baking (page 298)

Glucose → alcohol + carbon dioxide

$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$

▲ Trained athletes can exercise for longer than people who do not usually exercise before they build up an oxygen debt

Q

3 The concentration of lactic acid in the blood of a runner was measured at intervals before, during and after she ran for 10 minutes. The results are shown in the table below.

Time / minutes	Concentration of lactic acid / arbitrary units
0	18
10	18
15	56
25	88
35	42
50	21
65	18

a Plot this information in the form of a graph.

b What was the lactic acid concentration at the end of the run?

c For how long did the concentration of lactic acid increase after the end of the run?

d Why did the blood still contain lactic acid after the run?

e In which tissues was the lactic acid produced?

f How long after the run was it before the oxygen debt was paid off?

11.3 The measurement of respiration

OBJECTIVE

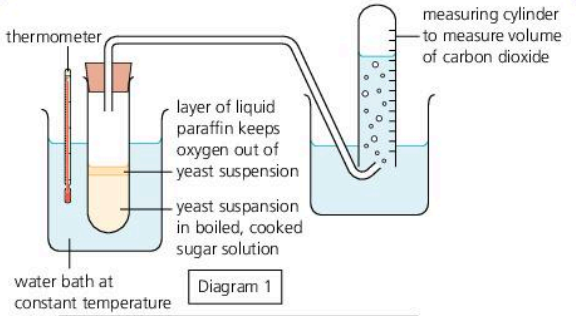
- To explain how it is possible to detect and measure the process of respiration

An obvious 'sign of life' is that respiration is taking place because we know respiration is essential for life (page 2). We can demonstrate that respiration is happening, and we can even measure how quickly it is going on.

The equation for anaerobic respiration in yeast (page 125) shows that carbon dioxide is released. The volume of CO_2 released at different temperatures can be measured using the apparatus opposite.

Ideally, the temperature of the water bath would be controlled by a heater and thermostat.

1 MEASUREMENT OF RESPIRATION IN YEAST



Glucose → (Enzymes) Carbon dioxide gas + Ethanol

To investigate aerobic respiration we need to use some different living organisms. Germinating seeds are useful for this experiment because they are chemically very active (the fast growth during germination requires a great deal of energy). Animals such as blowfly larvae (maggots) or woodlice can also be used, although they are rather more difficult to handle.

2 MEASUREMENT OF OXYGEN CONSUMPTION USING A RESPIROMETER

The apparatus shown in the diagram on the next page is used.

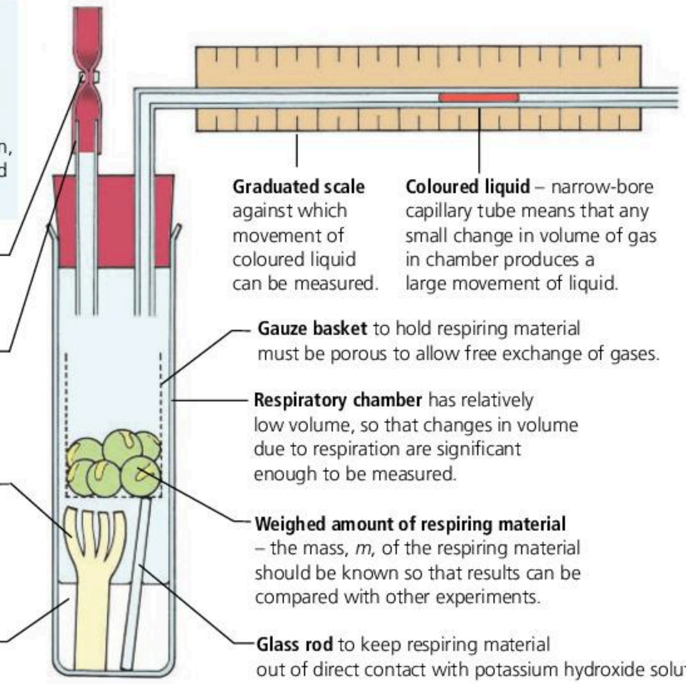
- **a** A measured mass of living organisms is put in the chamber.
- **b** First, the spring clip is open, so that an equilibrium of temperature and pressure is set up between the chamber and the surroundings.
- **c** After five minutes or so, the spring clip is closed and the movement of the coloured liquid along the capillary tube is observed. The time taken for it to move a measured length along the tube is noted.
- **d** The living organisms are removed and the experiment is repeated.

Using this apparatus, a group of students obtained the following data.

Experiment	Distance moved / mm	Time taken / s	Relative oxygen consumption / mm per s
1 Seeds	39	100	
2 Seeds	42	100	
3 Seeds	24	60	
4 Maggots	46	90	
5 Maggots	55	100	
6 Maggots	30	60	

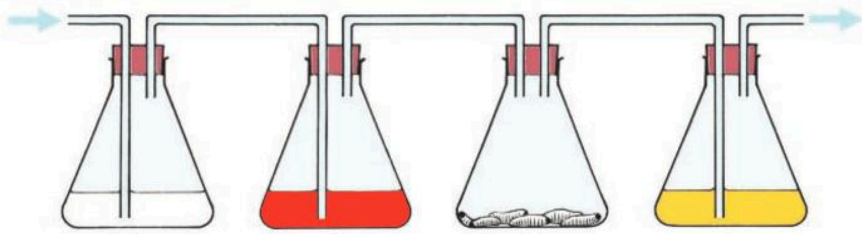
(S) The effect of temperature on respiration can be investigated using this apparatus. The respiratory chamber can be placed in a thermostatically controlled water bath and the measurements made at a series of temperatures (see Q.3).

Principle: Carbon dioxide produced during respiration is absorbed by potassium hydroxide solution. If the system is closed to the atmosphere, a change in volume of the gas within the chamber must be due to the consumption of oxygen.
The change in volume, i.e. the oxygen consumption, is measured as the movement of a drop of coloured liquid along a capillary tube.



3 MEASUREMENT OF CARBON DIOXIDE RELEASE

To detect carbon dioxide released by respiring organisms, we can use an **indicator solution**. For example **hydrogencarbonate indicator** is purple at high pH (alkaline), red around neutral pH and orange-yellow at low pH (acidic).
The diagram shows the apparatus.



Using limewater		Clear		Turns cloudy/milky

Q

1 **a** In experiment **1** why did the students take more than one set of readings for each group of organisms?
b Calculate the mean relative oxygen consumption for the seeds and for the maggots. Suggest a reason for the difference.

2 The students repeated the experiment with no living organisms in the chamber. The coloured liquid did not move at all. Why was this important?

3 In an extension of this investigation, the students measured the effect of temperature on the rate of oxygen consumption by the maggots. They obtained the following results:

Temperature / °C	Relative oxygen consumption / mm per s
15	0.3
25	0.6
35	1.1
45	0.8
55	0.2
65	0.0

a Plot these results on a graph, and explain the shape of the curve.
b In this investigation, identify the **independent** (input) **variable** and the **dependent** (outcome) **variable**.
c Suggest any **fixed variables**. (Refer to page 312 if you are unsure about these terms.)

In experiment **2**:

4 What is the purpose of the potassium hydroxide solution?

5 What does the indicator solution in flask **B** show?

6 How can you explain the change in flask **D**?

7 Suggest a control for this investigation, and explain why it is a suitable control.

8 Suggest any visible change that might happen in flask **C**. Explain your answer.

12.1 Gas exchange supplies oxygen for respiration

OBJECTIVES

- To understand why living organisms must obtain oxygen from their environment, and why they must release carbon dioxide to their environment
- To know the properties of an ideal gas exchange surface
- To be able to identify the parts of the human gas exchange system

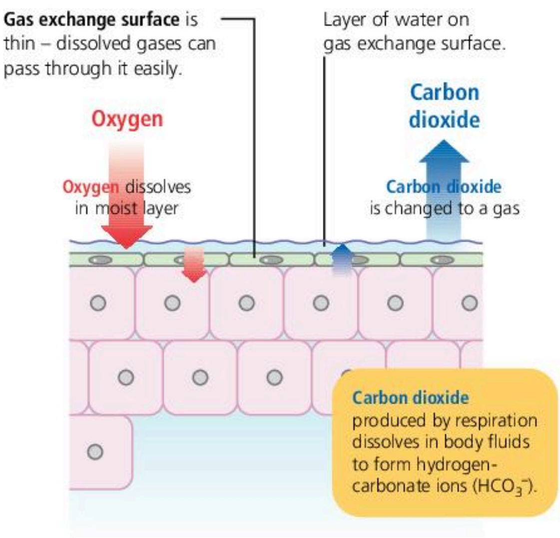
Exchanging oxygen and carbon dioxide

Respiration uses oxygen to 'burn' (oxidise) food and so release the energy that cells need to stay alive. Respiration produces carbon dioxide and water vapour as waste products:

glucose + oxygen → energy + carbon dioxide + water

Living organisms must be able to take oxygen from the air and get rid of carbon dioxide to the air. Swapping oxygen for carbon dioxide in this way is called **gas exchange** (or **gaseous exchange**).

Gas exchange takes place through a **gas exchange surface**, also known as a **respiratory surface**. The diagram below shows how the process happens. The properties of an ideal respiratory surface are given in the table above right.



▲ A gas exchange surface allows cells to obtain the oxygen they need for respiration, and get rid of the carbon dioxide they produce

Property of surface	Reason
Thin (ideally one cell thick)	Gases have a short distance over which to diffuse.
Large surface area	Many molecules of gas can diffuse across at the same time.
Moist	Cells die if not kept moist.
Well ventilated	Concentration gradients for oxygen and carbon dioxide are kept up by regular fresh supplies of air.
Close to a blood supply	Gases can be carried to and from the cells that need or produce them.

Gas exchange in humans

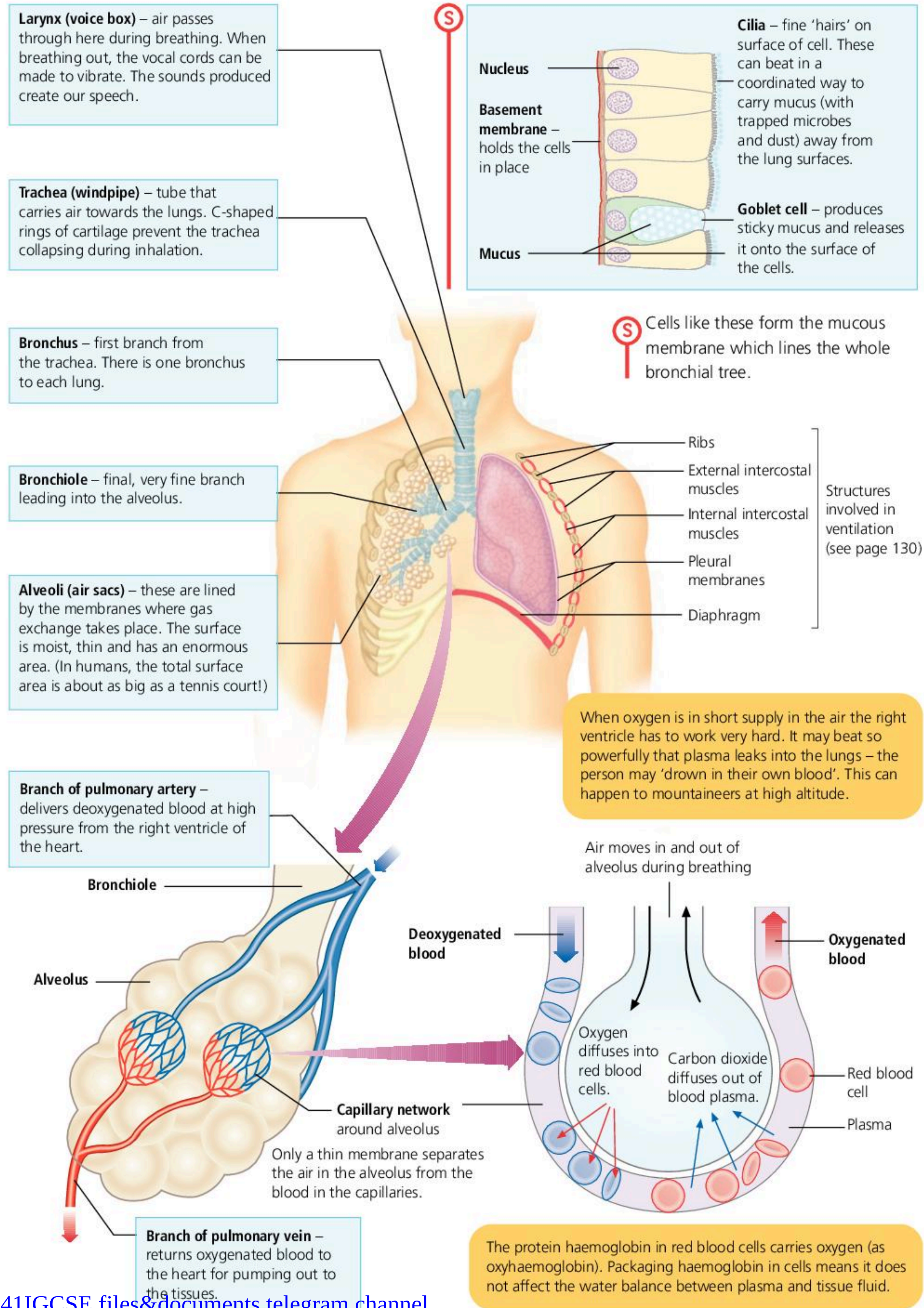
Like other mammals, humans are active and maintain a constant body temperature. This means they use up a great deal of energy. Mammals must have a very efficient gas exchange system.

The gas exchange system in humans is shown opposite and is made up of:

- a **respiratory surface** – membranes lining the alveoli (air sacs) in the lungs
- a **set of tubes** to allow air from the outside to reach the respiratory surface. This set of tubes has many branches, and is sometimes called the 'bronchial tree'
- a **blood supply** (carried by the pulmonary artery and pulmonary vein) to carry dissolved gases to and from the respiratory surface
- a **ventilation system** (the intercostal muscles and the diaphragm) to keep a good flow of air over the respiratory surface.

Q

1. What are the properties of an ideal gas exchange surface?
2. List the structures through which a molecule of oxygen passes to get from the atmosphere to the cytoplasm of a named working cell.
3. Most larger animals transport oxygen in red blood cells. What are the advantages of transporting oxygen in this way? How is a red blood cell adapted to its function of oxygen transport?
4. What is the difference between respiration and gas exchange?


Larynx (voice box) – air passes through here during breathing. When breathing out, the vocal cords can be made to vibrate. The sounds produced create our speech.
Trachea (windpipe) – tube that carries air towards the lungs. C-shaped rings of cartilage prevent the trachea collapsing during inhalation.
Bronchus – first branch from the trachea. There is one bronchus to each lung.
Bronchiole – final, very fine branch leading into the alveolus.
Alveoli (air sacs) – these are lined by the membranes where gas exchange takes place. The surface is moist, thin and has an enormous area. (In humans, the total surface area is about as big as a tennis court!)
S
Nucleus
Basement membrane – holds the cells in place
Mucus
Cilia – fine 'hairs' on surface of cell. These can beat in a coordinated way to carry mucus (with trapped microbes and dust) away from the lung surfaces.
Goblet cell – produces sticky mucus and releases it onto the surface of the cells.
S Cells like these form the mucous membrane which lines the whole bronchial tree.
Ribs
External intercostal muscles
Internal intercostal muscles
Pleural membranes
Diaphragm
Structures involved in ventilation (see page 130)
When oxygen is in short supply in the air the right ventricle has to work very hard. It may beat so powerfully that plasma leaks into the lungs – the person may 'drown in their own blood'. This can happen to mountaineers at high altitude.
Branch of pulmonary artery – delivers deoxygenated blood at high pressure from the right ventricle of the heart.
Bronchiole
Alveolus
Capillary network around alveolus
Only a thin membrane separates the air in the alveolus from the blood in the capillaries.
Branch of pulmonary vein – returns oxygenated blood to the heart for pumping out to the tissues.
Air moves in and out of alveolus during breathing
Deoxygenated blood
Oxygenated blood
Oxygen diffuses into red blood cells.
Carbon dioxide diffuses out of blood plasma.
Red blood cell
Plasma
The protein haemoglobin in red blood cells carries oxygen (as oxyhaemoglobin). Packaging haemoglobin in cells means it does not affect the water balance between plasma and tissue fluid.

12.2 Breathing ventilates the lungs

OBJECTIVES

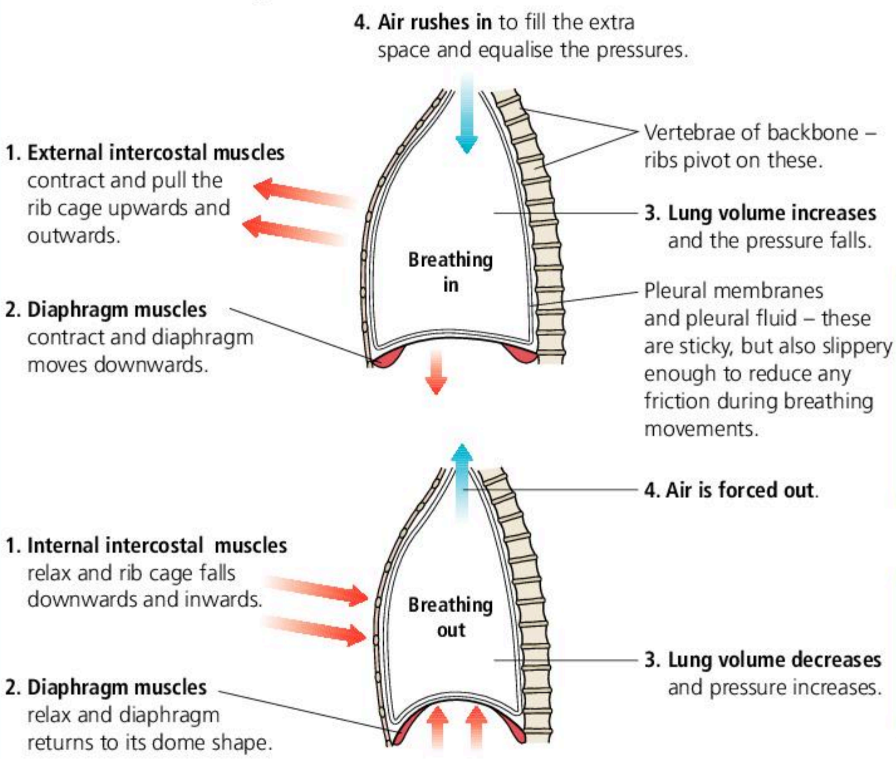
- To understand the muscular movements involved in the ventilation of the lungs
- To know how the efficiency of breathing can be measured
- To understand how breathing is affected by exercise
- To appreciate that the function of the lungs may sometimes need to be supported

Breathing is the set of muscular movements that gives the respiratory surface a constant supply of fresh air. This means there is always a concentration gradient between the blood and the air in the alveoli for both oxygen and carbon dioxide. As shown below, breathing is brought about by:

- the action of two groups of muscles – the **intercostal muscles** and the **diaphragm**
- the properties of the **pleural membranes** that surround the lungs.

The pleural membranes 'stick' the outside of the lungs to the inside of the chest cavity. The lungs themselves do not have any muscles, but the 'stickiness' of the pleural membranes means that the lungs will automatically follow the movements of the chest wall. If the volume of the chest cavity increases, the volume of the lungs will increase at the same time. The pressure inside the lungs will decrease as the volume gets bigger.

Air always moves down a pressure gradient, from a region of higher air pressure to a region of lower air pressure. If the air pressure in the lungs is less than the pressure of the atmosphere, air will move into the lungs along a pressure gradient. In the same way, if the air pressure in the lungs is greater than the pressure of the atmosphere, air will move out of the lungs along a pressure gradient.



Summary:
Extra lung volume created by
- rib cage moving up and out
- diaphragm moving down

↓
pressure falls
↓
air rushes into lungs

There are **two** sets of intercostal muscles. The **external** intercostal muscles contract during breathing in. The **internal** intercostal muscles are used during coughing and sneezing, for example.

▲ The intercostal muscles ('intercostal' means 'between the ribs') and the diaphragm work together to alter the volume of the chest cavity. Changing the volume of the chest cavity will automatically change the pressure of air inside it. (It is a law of physics that pressure × volume is a constant – in other words, if pressure increases then volume must decrease, and vice versa.)

Air is breathed in, gas exchange happens in the alveoli, and the air is breathed out again. The composition of the inspired (breathed-in) air is therefore different from the composition of the expired (breathed-out) air, as shown in the table.

Component of air	Inspired (inhaled) air / %	Expired (exhaled) air / %	Reason
Oxygen	21	18	Oxygen has diffused from the air in the alveoli into the blood
Carbon dioxide	0.04	3*	Carbon dioxide has diffused from the blood into the air in the alveoli
Nitrogen	78	78	Nitrogen gas is not used by the body
Water vapour	Very variable	Saturated	Water evaporates from surfaces in the alveoli
Temperature	Very variable	37°C	Heat is lost to the air from the lung surfaces

▲ Composition of inhaled and exhaled air

* The **increase in carbon dioxide concentration** can be detected with **limewater** (turns milky/cloudy) or **hydrogen carbonate indicator** (turns from red to yellow-orange), as shown on page 127.

Asthma*

Breathing is difficult, and an asthma sufferer may become very distressed. Air cannot easily move along the pressure gradient because:

- the muscles in the wall of the bronchi contract
- the lining of the bronchi 'leaks' a sticky mucus.

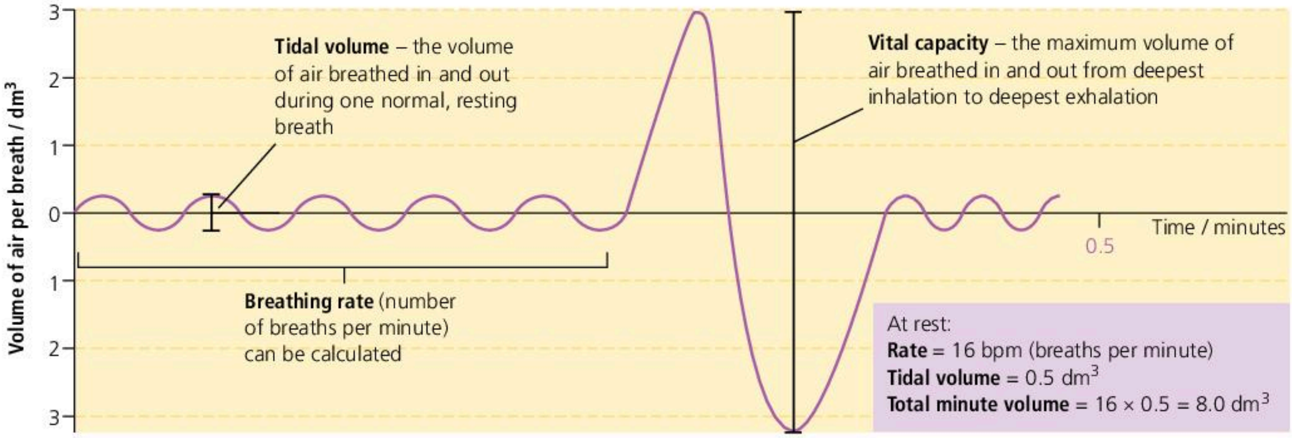
An asthma attack can be brought on by various factors including allergy to pollen or dust (or fur), emotion, breathing in cold air, smoke (page 134), air pollution (page 270) and exercise. Treatment involves:

- removal of the factor causing the asthma
- use of a **bronchodilator** – usually a spray containing a drug which relaxes the bronchial muscles.

Measuring the efficiency of the lungs

The amount of air that enters and leaves the lungs is measured using a **spirometer**. A person breathes in and out of a mouthpiece connected to a chamber. Inside the chamber a piston moves up and down, and its movements are measured electronically. The changes in volume during breathing are plotted on a graph called a **spirogram**, shown below.

S ▼ A spirogram gives a great deal of information about someone's breathing and the efficiency of their lungs. The lung volumes are expressed in the SI unit dm^3. 1 dm^3 is the same as 1 litre.



Exercise and breathing

During exercise the muscles work hard, and need to release more energy by respiration. Greater volumes of air must therefore be breathed in and out, by:

- increasing the **breathing rate** – more breaths per minute
- increasing the **tidal volume** – more air per breath.

These two changes can increase the volume of air passing in and out of the lungs from the typical 8 dm^3 per minute at rest to 50–60 dm^3 per minute during strenuous exercise.

Q

1 Explain the part played by the intercostal muscles and diaphragm in breathing.

2 What can be learned from a spirogram?

3 Why are there differences in the oxygen and carbon dioxide compositions of inhaled air and exhaled air?

▲ The effect of exercise on breathing can be measured after a race

At rest: CO_2 concentration in blood, and blood pH, are kept at safe levels (see page 144 – homeostasis)

Exercise:
- deeper, more rapid **breathing** (so more CO_2 lost from lungs)
- deeper, more rapid **heartbeat** (so more blood pumped to tissues to carry CO_2 away)

Any alteration in blood CO_2 concentration is detected by sensors in the brain. Nerve impulses are then sent to muscles in the chest and the heart.

Changes in breathing and bloodflow keep CO_2 concentration and blood pH at safe levels.

Other factors affecting breathing rate

As well as exercise (see also page 125), some other factors affect breathing rate:

Factor	Effect
Smoking	Increase, due to the effect of **carbon monoxide** (see page 135).
Anxiety	Increase, due to the effect of **adrenaline** (see page 168).
Drugs	Some cause an increase, e.g. **amphetamines** because they are stimulants. Some cause a decrease, e.g. **alcohol** and **barbiturates** because they are depressants (sedatives).
Environmental	Increased by **high CO_2 concentration** (see page 270). Sometimes increased by **high temperature or humidity**, as an attempt to lose body heat by panting (see page 146).
Altitude	Increased by **low O_2 concentration** in the atmosphere. Climbers at high altitude breathe quickly and with a low tidal volume – this can cause problems of dehydration.
Weight	Can increase because fat makes lung ventilation harder (i.e. tidal volume falls). Can decrease if excess body weight is a symptom of low thyroid gland activity.

Questions on exercise and breathing

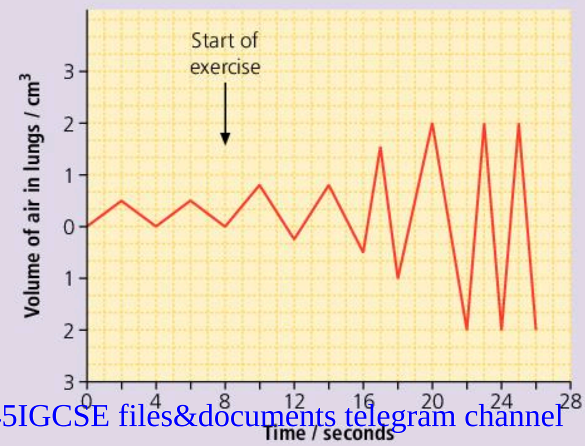
1 Two boys were asked to take part in an investigation into the effect of exercise on breathing. The number of breaths they took in each half minute was measured and recorded, first of all while sitting still, then when recovering from two minutes of hard exercise. The results are shown in the table below.

Time / minutes	Activity	Number of breaths in each half minute	
		Tom	Alan
0.0		7	8
0.5		7	8
1.0	Sitting still	7	8
1.5		7	8
2.0			
2.5			
3.0	Exercise (step-ups)		
3.5			
4.0		24	24
4.5		23	17
5.0		18	13
5.5		15	10
6.0	Recovery (sitting)	12	10
6.5		12	9
7.0		10	8
7.5		8	8
8.0		8	8
8.5		7	8

a Draw a graph to show the changes in breathing rate over the time period of this investigation. Plot both lines on the same axes. [5]

b Which boy appears to be fitter? Explain your answer. [3]

The teacher of the class was interested in the changes in breathing during the exercise period. She used a sensor, computer interface, monitor and printer to obtain the following information on another member of the class.



c What is the ratio of the volume of a breath during exercise to the volume of a breath at rest? [2]

d Calculate the rate of breathing, in breaths per minute, during strenuous exercise. [1]

e Using the data gathered, describe two effects of exercise on breathing. [2]

f The computer could also measure the effects of exercise on heart rate. Suggest what these effects might be. [2]

g What is the benefit to the body of the effects described in **e** and **f**? [2]

2 On a visit to a sports physiology laboratory, a student underwent a series of tests. He was made to exercise on a treadmill, and the following information was collected.

Heart rate / beats per minute	Total heart output / dm^3 per minute	Output per beat / cm^3
55	4.0	
70	4.8	
80	5.2	
90	5.6	
120	6.0	
140	6.0	
150	5.8	
170	4.6	

a Copy the table and complete it by calculating the output per beat for each heart rate value. [2]

b Plot a graph of total output (vertical axis) against heart rate (horizontal axis). On the same graph plot output per beat (vertical axis) against heart rate. [4]

c Describe the relationship between:
  i heart rate and total output [1]
  ii heart rate and output per beat. [1]

d **i** Even during severe exercise, the heart rate seldom rises above 140 beats per minute. Use the data in the table to explain why this is so. [2]
  ii Well-trained athletes can keep up a heart rate of 170 beats per minute. Suggest how their output per beat may be different from that of an untrained person such as the student. [1]

e Distance runners often have low resting heart rates. How might this be of advantage to them? [2]

f Increased total output means that more blood can be delivered to active tissues. As heart rate increases, so does breathing rate. Suggest why. [2]

12.3 Smoking and disease*

OBJECTIVES

- To understand that smoking tobacco is harmful to health
- To list some of the harmful components of tobacco smoke and the damage they cause
- To understand why it is so difficult to give up smoking

The risks of smoking

Many national advertising campaigns stress that smoking is harmful. At the same time, the manufacturers of cigarettes emphasise the 'glamorous' side of smoking. However, manufacturers have to include, by law, a statement on their advertisements and cigarette packets that 'smoking can seriously damage your health'.

Life insurance companies routinely ask 'Do you smoke?' because they are aware that smokers are more likely to die younger. Whether or not to take up smoking is the most important health decision that many of us will ever make. For this reason, everyone should know about the possible effects of smoking. Nobody who starts smoking now can say 'But I didn't know the risks' when they suffer the effects of their smoking habit later in life.

How is smoking harmful?

Smoking is inhaling the smoke from burning tobacco (and paper). This smoke can harm the lungs and respiratory passages for a number of reasons:

- it is hot
- it has a drying effect
- it contains many harmful chemicals.

The heat and dryness irritate the lungs, but the main dangers of smoking come from the chemicals in the burning tobacco. There are over 1000 known chemicals in tobacco smoke. These include tars, carbon monoxide, sulfur dioxide, nicotine and even small quantities of arsenic and plutonium! When doctors treat lung diseases with medicine, the molecules of the medicine are delivered in a spray; the droplets of water in the spray carry the medicine down through the respiratory tubes and deep into the lungs. Burning tobacco produces tiny droplets of water too, and these carry the harmful chemicals deep into the lungs in just the same way as a medicine spray. It would be hard to find a more efficient way of delivering harmful chemicals to the lungs than smoking! Some of these dangerous chemicals, and the effects they have on the body, are shown on the opposite page.

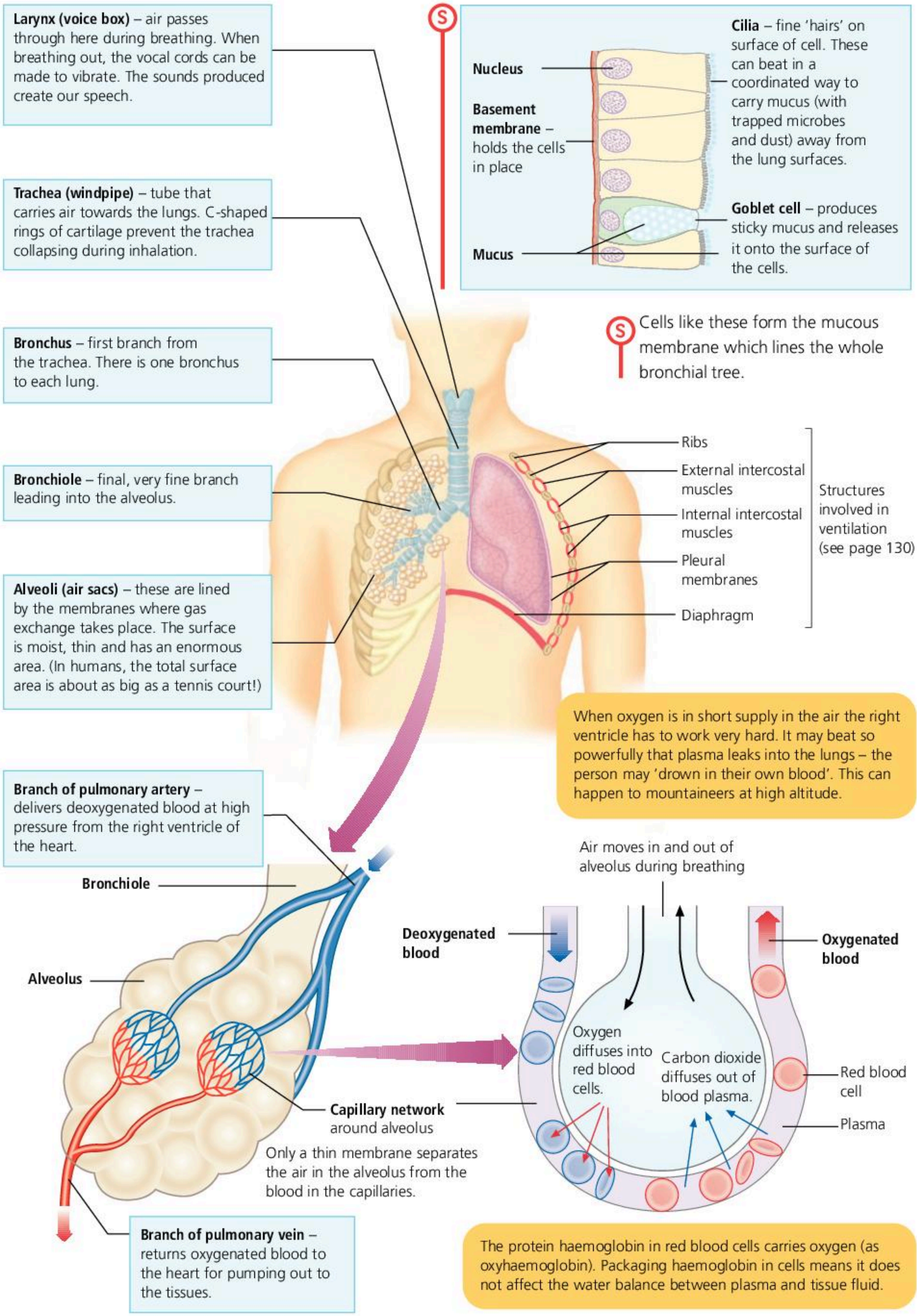
Why is it so difficult to give up smoking?

In many ways, nicotine is the most dangerous of the chemicals in tobacco smoke. As well as affecting the heart and blood pressure directly, nicotine makes a person become **addicted** to smoking. Addiction comes in two forms:

- in **physical addiction**, the body cannot function properly in the absence of the chemical because it has partly replaced a natural body chemical
- in **psychological addiction**, the addicted person links smoking with comfort or lack of stress – when they feel stressed they may automatically reach for a cigarette.

Q

1. How is smoke harmful to the lungs?
2. What is the difference between physical and psychological addiction? How can smokers be helped to overcome their addiction?
3. Suggest three harmful effects of smoking other than damage to the lungs and breathing passages.
4. Why are smokers more likely to develop infections of the lungs than non-smokers?
5. Draw a single cube with a side of 10 cm, and then the same cube divided into smaller cubes each with a side of 1 cm.
   - **a** How many small cubes fit into the large cube?
   - **b** What is the surface area of each small cube?
   - **c** What is the total surface area of all of the small cubes?
   - **d** What is the surface area of the large cube?
   - **e** Use your answers to explain why emphysema sufferers are often very breathless.



When oxygen is in short supply in the air the right ventricle has to work very hard. It may beat so powerfully that plasma leaks into the lungs – the person may 'drown in their own blood'. This can happen to mountaineers at high altitude.

The protein haemoglobin in red blood cells carries oxygen (as oxyhaemoglobin). Packaging haemoglobin in cells means it does not affect the water balance between plasma and tissue fluid.

12.4 How do we know that smoking causes disease?*

OBJECTIVES

- To understand the statistical evidence linking smoking to disease
- To be able to design an epidemiological investigation

Sir Richard Doll's research into smoking

We know today that smoking causes disease, but how have we found this out? The diseases could result from living in a polluted environment, or exposure to chemicals at work, or diet, or any number of other factors.

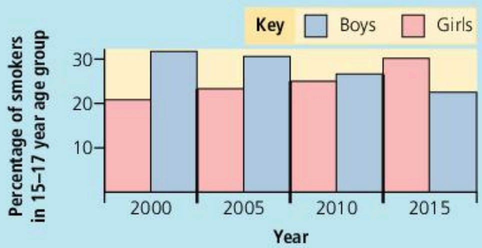
Sir Richard Doll was an **epidemiologist** – he studied patterns in the distribution of diseases. He was particularly interested in comparing the habits and environment of people who developed lung disease with people who did not. His results were very valuable because he collected data in a scientific way, removing many variables from his studies. For example:

- he carried out many of his studies on doctors, so he could rule out profession as a cause of lung disease
- he separated data for people living in cities from those living in the countryside, so environment was not causing large differences between people in one study group.

Some examples of epidemiological studies that related lung disease and early death to smoking tobacco are shown on the opposite page. The box shows some data about smoking in the UK and other countries.

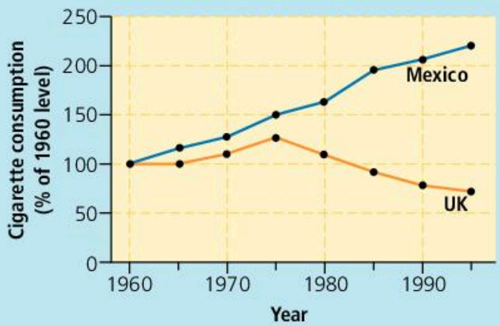
Some disturbing data

Fewer boys are taking up smoking in the UK than 20 years ago (good news) but more girls are now smoking (bad news). Can you suggest reasons for these changes?



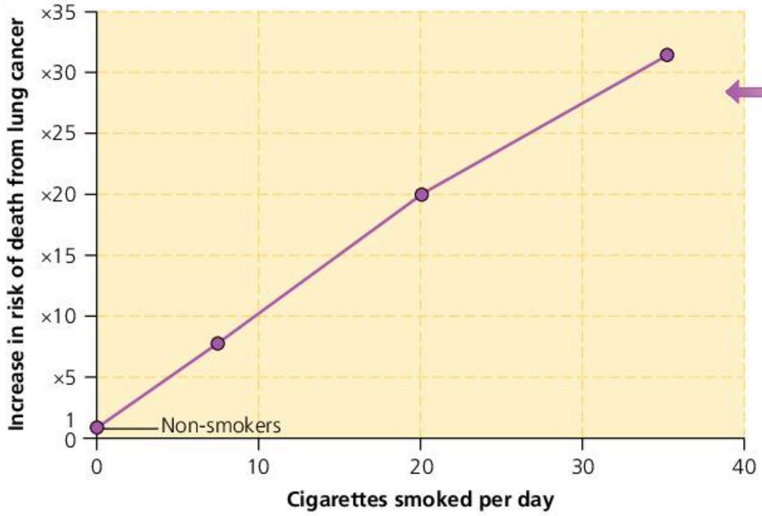
Cigarette sales in the UK have fallen because people are becoming more aware of the health risks of smoking. Advertising campaigns emphasise the dangers, and smoking is banned in many public places to reduce 'passive smoking' (breathing in someone else's cigarette smoke). Tobacco companies are focusing on selling to developing countries where people are less aware of the health risks. The rise in lung disease in the UK in the 1980s and 1990s was repeated 20 years later in these countries.

The number of cigarettes sold in the UK and in Mexico, 1960–1995.



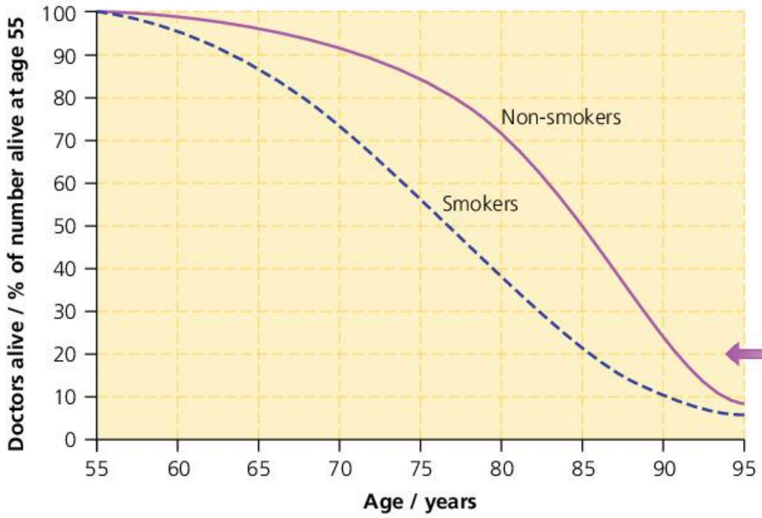
The cigarette companies are now targeting countries such as some of those in Africa to increase their profits.

Evidence linking smoking with lung cancer



Results of a **prospective study** – looking forward and suggesting that if smoking was an important cause of lung disease and death, then early death would be more likely in smokers than in non-smokers

A correlation between two variables does not necessarily prove that one of the variables causes the other – it might be that heavy smokers develop lung cancer because they are exposed to some other environmental factor, or that individuals with a genetic make-up that carries a risk of lung cancer are also 'genetically' more likely to smoke. The work of Richard Doll and others is so convincing because it has eliminated many other environmental factors. However, it is likely that the development of lung cancer is a complex process. It is probably **multifactorial**, involving both genetic and lifestyle factors.



Results of a **retrospective study** – looking back at the lifestyle, occupation and environment of people who have died from lung cancer

▲ In 1962, the Royal College of Physicians published a report on smoking and health, which suggested a clear link between cancer and smoking. For example, among a sample of doctors living in similar-sized cities, those who smoked regularly were more likely to develop cancer of the lung.

1 What is meant by the term epidemiology?

2 Suggest two factors other than cigarette smoking that might increase the risk of developing lung cancer.

3 How much more likely to die of lung cancer is a person who smokes 25 cigarettes a day than someone who does not smoke at all?

4 One epidemiological study has suggested that living close to power lines can cause leukaemia. How would you try to prove this link?
- Which populations would you study?
- How old would they be?
- Which sex?
- Which occupation?
- How about their diet?

In what way do you think the results of your study might be useful?

5 In a typical laboratory experiment, data are collected by manipulating one variable and measuring the responding change in another, with all other identifiable variables kept constant (see page 318). Why can this approach not be used to investigate the effect of smoking on the development of lung disease in humans?

Questions on respiration and gas exchange

1 Copy the following paragraph and complete it by filling in the missing words.
Use words from the following list. Each word may be used once, more than once or not at all.

oxygen, carbon dioxide, pulmonary, energy, hydrogencarbonate, thin, capillaries, alveoli, diffusion, respiring, left atrium, surface area

Deoxygenated blood arrives at the lungs in the ______ artery. Oxygen has been removed from the blood by cells that are ______ to release ______ needed to carry out their functions. This blood also contains a relatively high concentration of the gas ______, which is carried dissolved in the plasma as ______ ions. Each artery branches many times to form ______, which are well adapted to allow the exchange of gases because they are ______-walled and have a very large ______. These small vessels lie very close to the ______ of the lungs, and it is here that gas exchange takes place. The gas ______ moves out of the blood and the gas ______ moves into the blood. Both gases move by the process of ______. Oxygenated blood then leaves the lungs in the ______ vein that returns blood to the heart at the chamber called the ______. [10]

2 The table below provides information about the composition of inhaled and exhaled air.

	Air breathed in (inhaled air)	Air breathed out (exhaled air)
Nitrogen	79.0%	79.0%
Oxygen	20.97%	16.9%
Carbon dioxide	0.03%	4.1%
Water vapour	variable	saturated

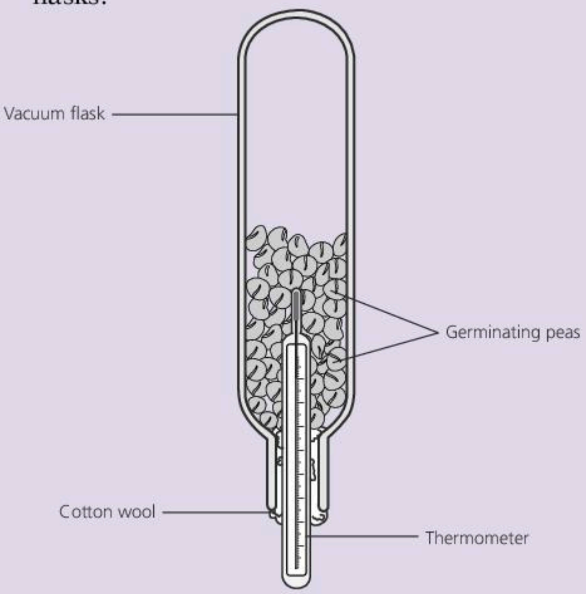
a State which sample contains the most oxygen. Explain why. [2]

b Explain the results for the percentage of nitrogen gas. [1]

c Name the process which results in the changes in the percentage of carbon dioxide. [1]

d Suggest why the percentage of water vapour in inhaled air varies. [1]

3 The apparatus shown was used to investigate whether living organisms release heat energy. Some pea seeds were divided into three samples of equal mass. The samples were treated as follows, and then placed into sterilised vacuum flasks.



- Sample 1 was soaked in water at 15°C for 24 hours and then placed in flask A.
- Sample 2 was soaked in water at 15°C for 24 hours, boiled, cooled again to 15°C and then placed in flask B.
- Sample 3 was soaked in water at 15°C for 24 hours, washed with a mild disinfectant and then placed in flask C.

The thermometer was used to measure the temperature in each of the flasks over a period of 72 hours. The results are shown in the table below.

Time / h	Flask A / °C	Flask B / °C	Flask C / °C
0 (start of experiment)	15	15	15
12	25	15	18
24	40	15	22
36	48	15	25
48	50	15	28
60	52	15	32
72	54	15	38

a On the same axes, plot a graph of the three sets of results. [5]

b Name the process that caused the rise in temperature in flasks A and C. [1]

c Suggest why the pea seeds were soaked before being placed in the flasks. [2]

d Explain the results for flask B. [2]

e Explain the difference between the results for flasks A and C. [2]

f Suggest a reason for the inclusion of flask B. [1]

4 These diagrams show apparatus that can be used to explain the mechanism of breathing.

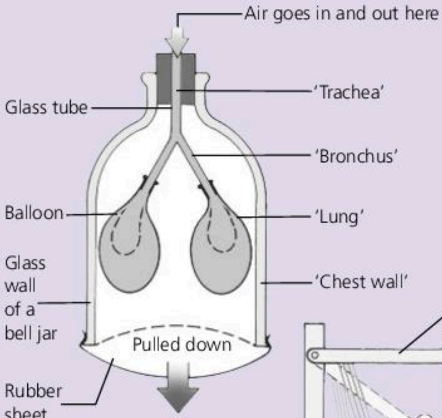


Diagram A

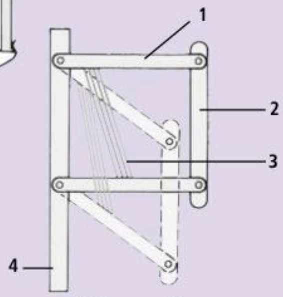


Diagram B

Look at diagram A.

a What does the rubber sheet represent? [1]

b What will happen to the balloons when the rubber sheet is pulled downwards? [1]

c What phase of the breathing cycle is represented when the rubber sheet is allowed to return to its resting position? [1]

d In what way is this model an incomplete demonstration of the mechanism of breathing? [1]

Look at diagram B.

e What parts of the human ventilation system do the labels **1**–**4** represent? [4]

5 This table shows the causes of death of cigarette smokers in Great Britain.

Cause of death	Percentage of deaths
Lung cancer	8
Bronchitis and emphysema	17
Circulatory diseases	20
Other causes (not related to smoking)	55

a What percentage of smokers dies from smoking related diseases? [2]

b Present the data in the form of a bar chart *or* a pie chart. Which will display the information in the best way? Explain your answer. [4]

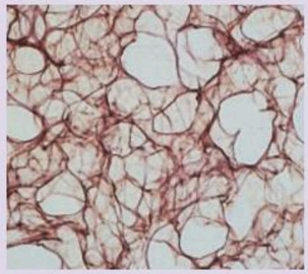
c Emphysema is a disease caused by smoking.

The photographs below show normal lung tissue and lung tissue from a person with emphysema.

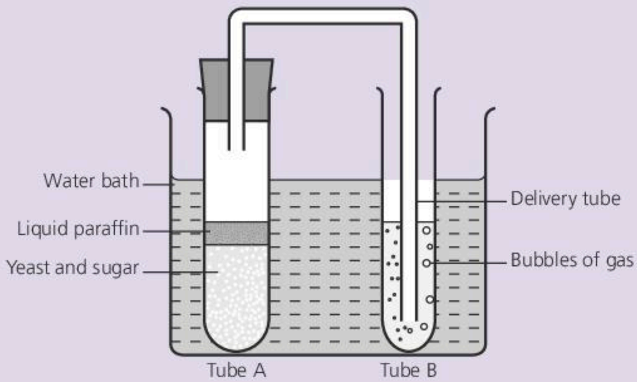
i Describe **two** differences between the normal lung tissue and the lung tissue from a person with emphysema. [2]

ii How will these differences affect the supply of oxygen to the blood in the person with emphysema? [2]


Normal lung tissue (×40).


Lung tissue from a person with emphysema (×40).

6 A test tube containing some yeast and sugar solution was placed in a water bath as shown in the diagram below. After ten minutes, the rate of bubbling was measured. The experiment was then repeated with the water bath at each of the temperatures shown in the table below.



Temperature / °C	10	20	30	40	50	60
Number of gas bubbles per minute	5	12	20	26	28	14

a Draw a graph of these results. [4]

b Suggest the function of the liquid paraffin. [1]

c Name the process in the yeast cells which produces the bubbles of gas. [1]

d Write a word equation for this process. [2]

e Explain the results at 60°C. [2]

f Suggest **two** reasons why the yeast cells would die in tube A after about one week at 40°C. [2]

13.1 Excretion: removal of the waste products of metabolism

OBJECTIVES

- To understand that living cells produce wastes
- To name some human waste products
- To name the organs involved in excretion
- To understand the functions of the kidney

Homeostasis (page 144) means keeping a constant environment around the cells of the body. This involves providing cells with essential raw materials, but also means removing waste products. These waste products can be very toxic (poisonous), for example:

- **Carbon dioxide**, produced during respiration, dissolves in plasma and tissue fluid to form a weak acid (carbonic acid, H_2CO_3) which can denature enzymes and other proteins at high concentrations.
- **Urea**, produced in the liver during deamination of excess amino acids (see page 81), can denature enzymes.
- **Salts**, which can be in excess in the diet, can have an effect on the water potential of the blood.

Excretion is the removal of toxic materials, the waste products of metabolism and substances in excess of requirements.

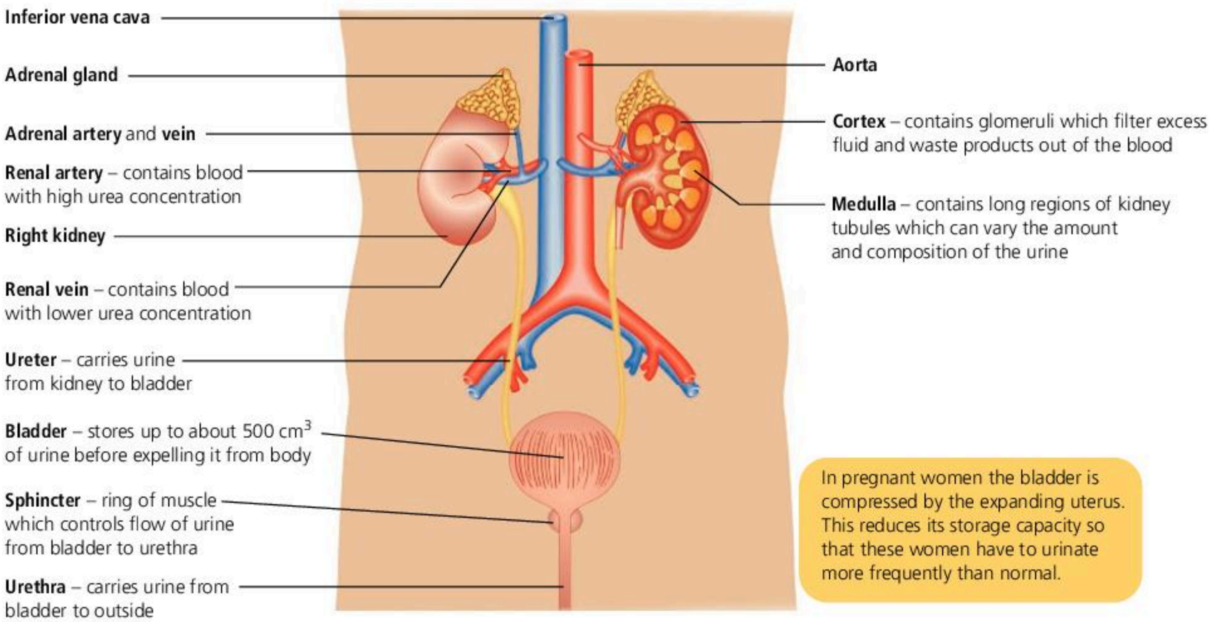
The role of the kidney

The kidneys are specialised organs that:

- remove the toxic waste product **urea** from the circulating blood – they carry out **excretion**
- regulate the **water content** of the blood – they carry out **osmoregulation**.

The structure of the kidneys is well adapted to enable them to carry out these processes.

- Each kidney receives a good supply of blood at high pressure through the **renal artery**.
- Each kidney contains hundreds of thousands of tubes, the **nephrons** (kidney tubules), that can filter substances from the blood.
- Each kidney has an exit tube, **the ureter**, to carry away the **urine** (a solution of wastes dissolved in water).
- The kidney is under close control by a **feedback system** so that water saving is always exactly balanced to the body's needs.



In pregnant women the bladder is compressed by the expanding uterus. This reduces its storage capacity so that these women have to urinate more frequently than normal.

▲ The kidneys receive blood from the renal artery, remove urea and a variable amount of water from it and return the modified blood to the circulation through the renal vein. The wastes removed from the blood are eventually expelled from the body through the urethra after being stored in the bladder.

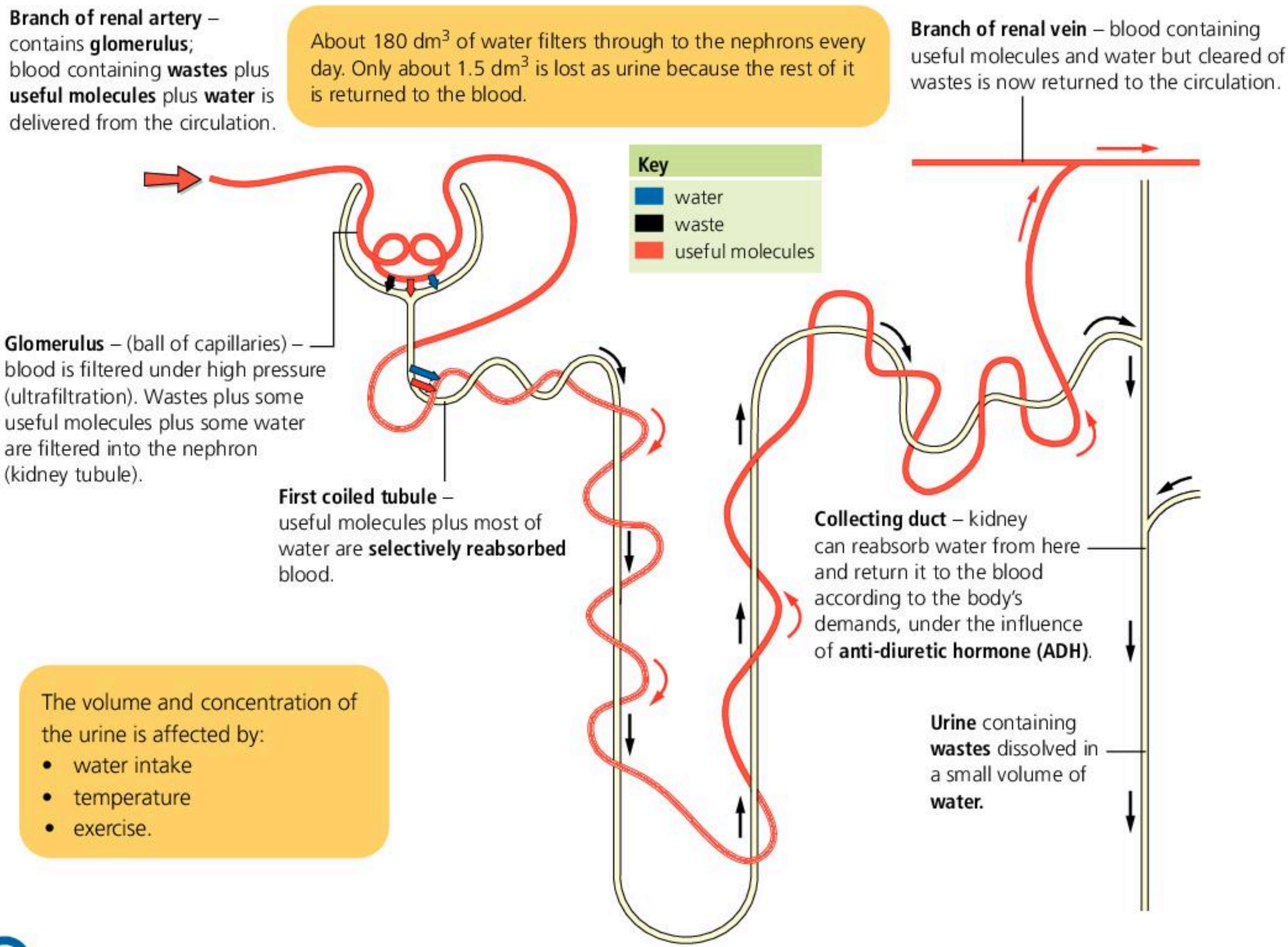
The structure of the kidney

The kidneys and their blood vessels are located in the abdomen, as shown in the diagram opposite. The kidneys constantly produce urine which then passes to the **bladder**.

▼ The kidney is made up of many nephrons (kidney tubules). Substances are filtered out of the blood into the nephron. Useful molecules and most of the water are reabsorbed into the blood.

The functional unit – the kidney tubule (nephron)

Each kidney contains hundreds of thousands of long tubes called **nephrons**, each with its own branch of the renal artery and vein. Each nephron works in exactly the same way, so the function of the kidney can be explained by considering the working of just one of these kidney tubules, as shown below.



The volume and concentration of the urine is affected by:
- water intake
- temperature
- exercise.

1 Define the terms excretion and osmoregulation.

2 Name two waste products of metabolism. State their source and how they are removed from the blood.

3 Copy and complete the following paragraph.
The main excretory organ in the mammal is the ____. There are two of these, each supplied with blood through the ____ and each composed of many thousands of tubules called ____. Each of these tubules receives materials from the blood after filtration in the ____ capsule. The tubules then remove useful substances such as ____ from this filtrate by the process of ____. The remaining waste or excess materials pass down the tubule and leave the excretory organ via the ____. They are collected for temporary storage in the ____. Eventually a dilute solution of these wastes, the urine, leaves the body through the ____.

13.2 Dialysis and the treatment of kidney failure*

OBJECTIVES

- To explain how body water is regulated
- To explain how kidney disease can be treated

Osmoregulation

The final part of each nephron, the **collecting duct**, removes water from the filtered solution passing down inside the tubule and returns it to the blood. The body can control the amount of water that is returned to the blood in this way, and balance it with the amount of water taken in in the diet and the amount of water lost from the body by other means. This vital control of water balance is called **osmoregulation**. Water is the most common substance in the body, and has many functions (see page 256). The average daily intake and loss of water by different methods is outlined in the diagram below.

Kidney failure

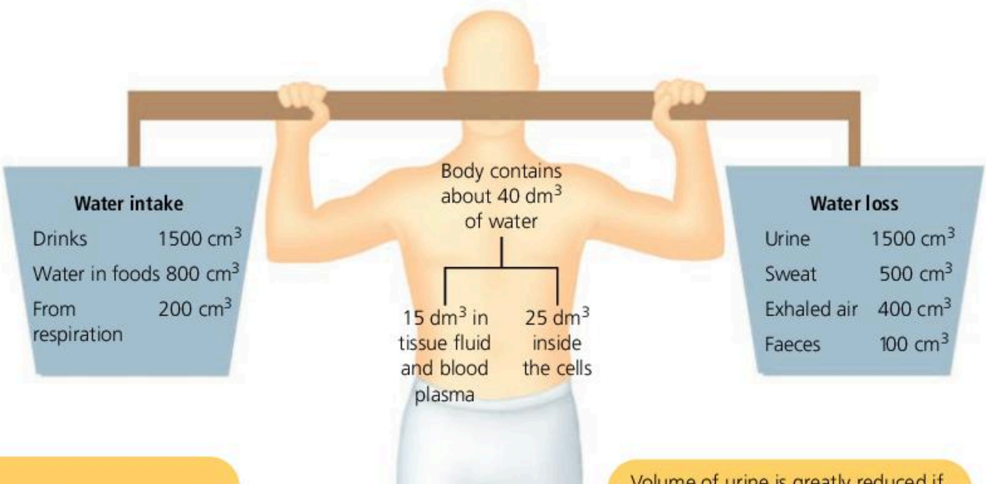
Damage to the kidneys, perhaps through infection or following an accident, can stop the nephrons working efficiently. The body can no longer control the composition or amount of urine formed, so the content of the blood plasma and tissue fluid is not kept at its optimum. Death may follow quite quickly if the kidney failure is not corrected. Two types of treatment are available:

- **dialysis** using a kidney machine (an artificial kidney)
- **kidney transplant**.

Dialysis and the artificial kidney

A kidney machine takes a patient's blood, 'cleans' it and returns the blood to the circulation. This process is called **dialysis**. Wastes diffuse out of the blood, across a partially permeable membrane, into a fluid that is constantly renewed. In this way urea is removed from the blood without altering any of its other features. The diagram on the opposite page shows the workings of a kidney dialysis machine.

Intake varies greatly depending on the type of food available. Some desert animals gain 90% of their water from respiration. Camels don't store water in their hump, but fat. Water is released when the fat is respired.



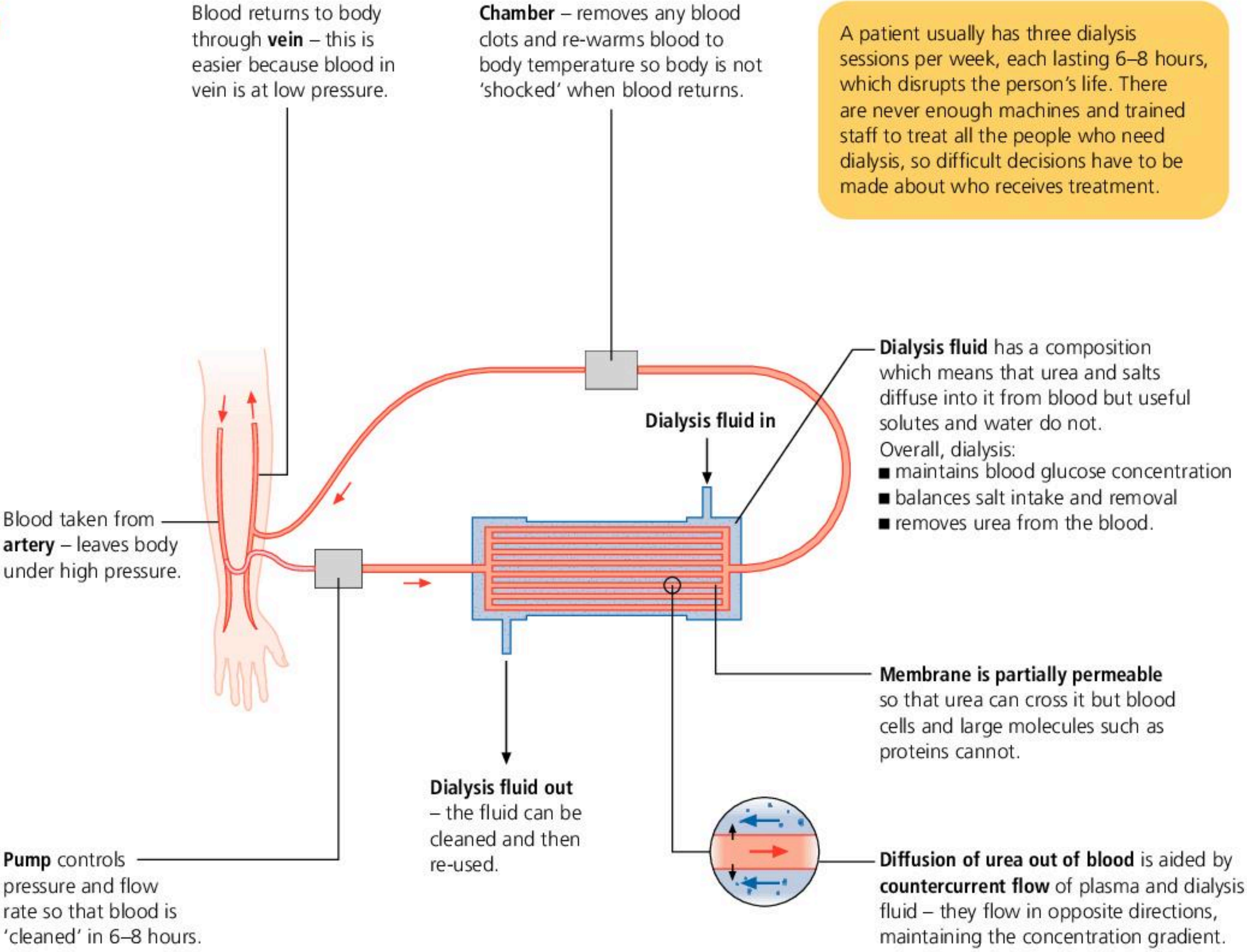
Isotonic sports drinks provide rapid rehydration. They contain:

- **glucose and salts,** which are quickly absorbed so that
- **water follows by osmosis.**

Volume of urine is greatly reduced if more water is lost through sweating, for example during exercise.

Diarrhoea can greatly increase water loss. Severe cases can cause death by dehydration.

▲ The water excreted in the urine is adjusted so that total water intake and total water loss are balanced



A patient usually has three dialysis sessions per week, each lasting 6–8 hours, which disrupts the person's life. There are never enough machines and trained staff to treat all the people who need dialysis, so difficult decisions have to be made about who receives treatment.

Kidney transplants

A **kidney transplant** involves surgically transferring a healthy kidney from one person (the **donor**) to a person with kidney failure (the **recipient**). It is relatively simple to connect up the donor kidney in the recipient's body, but a problem arises with **tissue rejection**. The recipient's immune system will attack the donor kidney and slowly destroy it (see page 119) unless the recipient takes drugs to stop this happening. Blood groups and tissue types of donors and recipients are carefully matched to reduce the likelihood of rejection. Successful kidney transplants have advantages over dialysis treatment:

- In the long term, a transplant is much cheaper.
- The patient's life is less disrupted once they have recovered from the operation.

Q

1. The body must maintain a water balance.
   a. Why does the body need water?
   b. How is water gained by the body?
   c. How is water lost by the body?
2. The water balance of the body is maintained by negative feedback. Explain what this term means.
3. Why is a kidney transplant considered better than dialysis? What problems are associated with kidney transplantation?

14.1 Homeostasis: maintaining a constant internal environment

OBJECTIVES

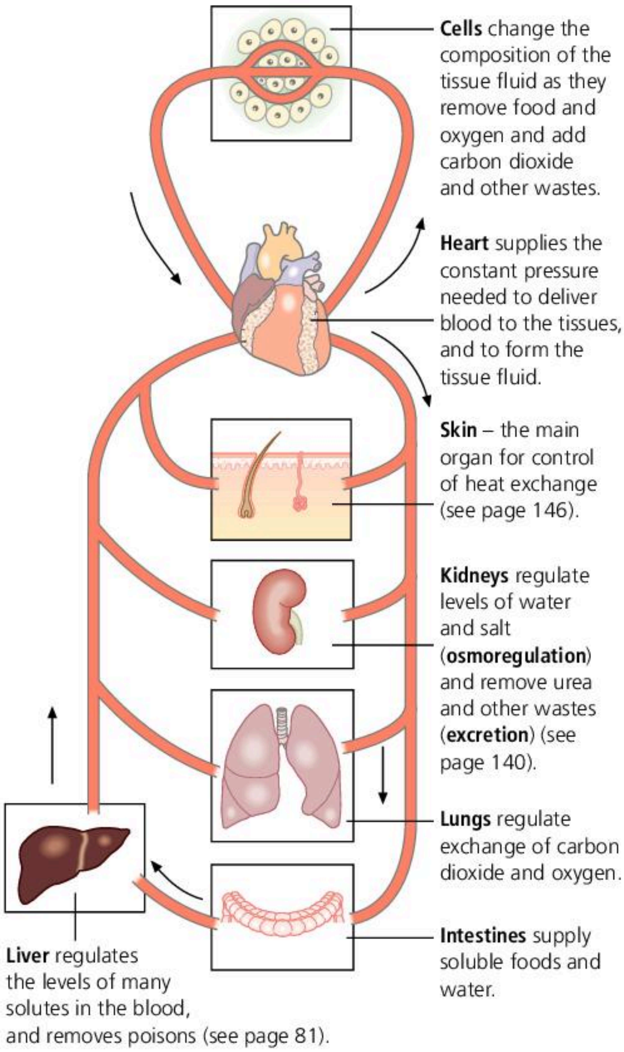
- To be able to define the term homeostasis
- To understand why the body must keep constant conditions around its cells
- To remember that tissue fluid surrounds all cells
- To understand the principle of negative feedback
- To know the organs involved in homeostasis

The cells in any living organism will only function properly in the correct conditions. The conditions *outside* the body (the **external environment**) are continuously changing – for example, temperature on a cool day might vary from 0°C out of doors to 20°C indoors. The body has mechanisms for adjusting conditions *within* the body (the **internal environment**) so that conditions around the cells remain constant.

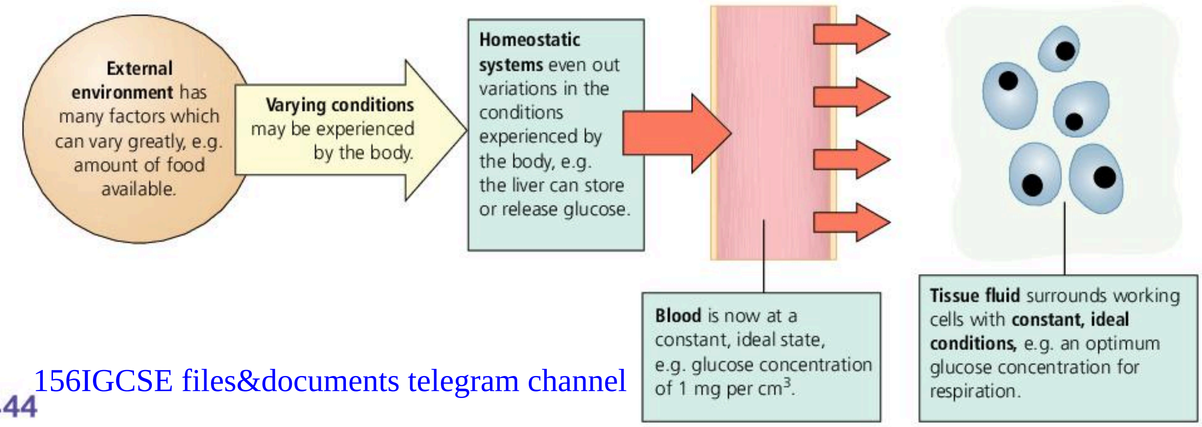
Keeping the internal environment constant

The blood cells lie in the blood plasma, and other cells are surrounded by tissue fluid (see page 102). Conditions in the blood (and therefore in the tissue fluid) are maintained at an **optimum** – the best values for the cells to function. The maintenance of a constant internal environment is called **homeostasis**.

Homeostasis involves several organs, but the basic principle is always the same, as shown below. The diagram on the right shows some of the organs involved in homeostasis, and the particular conditions in the tissue fluid which they regulate.



▲ Many organs play a part in homeostasis. (A more accurate diagram of the human circulation is given on page 100.)



How is homeostasis brought about?

The work of these organs must be coordinated to achieve homeostasis. Information about the conditions in the body is continuously fed to the brain from **sensory receptors** around the body.

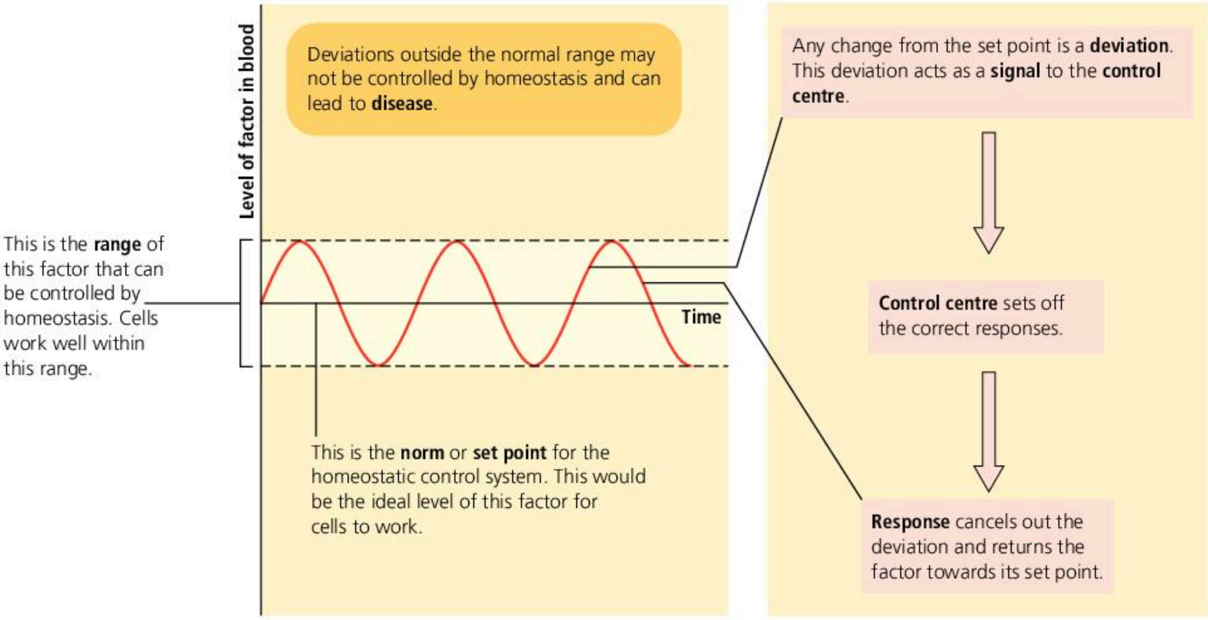
For example, if the body temperature rises, temperature receptors in the skin send information to the brain. In response, the brain starts off mechanisms that will lower the body temperature again. The same temperature receptors 'inform' the brain when the temperature is back to normal. Homeostasis depends on this continual **feedback** of information, as explained in the diagram below.

To summarise:

- Homeostasis is the maintenance of a constant internal environment.
- Homeostasis involves control by negative feedback.
- In negative feedback, a change sets off a response that cancels out the change.

Flying with 'George'

An aeroplane may be flown by an automatic pilot, sometimes called 'George'. This involves a series of feedback controls that correct any slight deviation from the aircraft's flight path. For example, if the plane tips to one side, a gyroscope detects the deviation and sends an electronic signal to the computer. This computer then sends out another signal to the plane's ailerons (levelling flaps) and the flight path is corrected.



▲ In homeostasis, deviation from a set point acts as the signal that sets off the correction mechanism. This negative feedback keeps variable factors within the narrow range suitable for life.

Q

1 Copy and complete the following paragraph.
Cells work best when conditions around them remain constant. Cells are bathed in _____ fluid, and many systems work to keep the composition of this fluid constant. Each system has _____, which detect any changes from the _____ (the ideal conditions for the cells). The changes are then communicated to the _____, usually along _____ neurones. The central control area then sets off the correct responses. These responses cancel out the original change and so this sort of control is often called _____.

2 Copy and complete the following table.

Homeostatic organ	Factor controlled
Liver	
Lungs	
	Water content of blood
	Heat loss or gain
Intestines	

3 Use the principle of feedback control to compare the regulation of blood glucose level in humans (see page 148) with the maintenance of a stable temperature in an aircraft cabin.

14.2 Control of body temperature

OBJECTIVES

- To understand why body temperature must be controlled
- To know the difference between heat and temperature
- To understand the part played by the skin in control of temperature
- To appreciate that control of body temperature is an example of negative feedback

The importance of a constant temperature

Many biological and physical processes are affected by temperature. For example:

- enzymes work best at their optimum temperature, and are denatured by wide deviations from this
- cell membranes become more fragile as temperature rises
- diffusion rates are increased by higher temperatures, and decreased by lower ones
- liquids such as blood become more viscous (thicker) as the temperature falls.

Heat and temperature

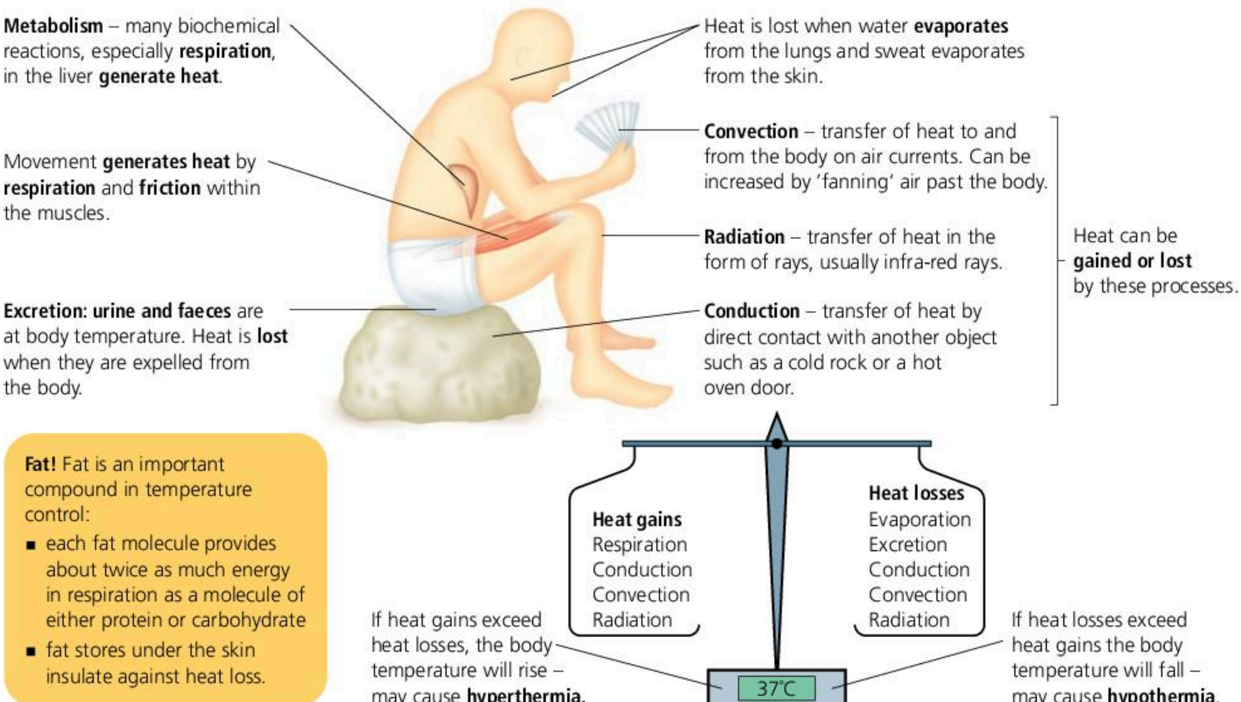
Heat is a type of energy, so it can be 'held' by an object or passed from one object to another. Temperature is a measure of how concentrated the heat energy is in an object, such as the human body. A body will rise in temperature if it gains heat energy.

Birds and mammals are **endotherms** ('inside heat') – they can maintain a constant body temperature by generating heat internally. Humans have several mechanisms which work non-stop to balance heat production against heat loss, as shown in the diagram below. This balance is achieved by a **temperature control centre** in the **hypothalamus**, a region of the brain. The diagram opposite shows the negative feedback systems that control body temperature in an endotherm.

The role of the skin

As the barrier between the body and its environment, the skin is also the main organ concerned with heat loss and heat conservation.

▼ An endothermic animal maintains an ideal body temperature by balancing heat losses and heat gains



Fat! Fat is an important compound in temperature control:

- each fat molecule provides about twice as much energy in respiration as a molecule of either protein or carbohydrate
- fat stores under the skin insulate against heat loss.

S

During **fever**, the body's temperature may be reset 2–3°C higher.

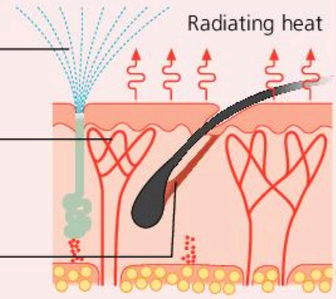
Higher temperatures denature proteins of infecting bacteria more rapidly than they affect human proteins. Blood flows to the hypothalamus through vessels at the back of the neck. A nosebleed can be stopped by placing a cold object on the back of the neck – the hypothalamus reacts to the 'cooled' blood by closing down skin blood vessels. As a result, the nosebleed stops.

Skin increases heat loss by:

Evaporation (sweat)

Radiation (vasodilation of arterioles leading to surface capillaries)

Convection (relaxation of hair erector muscles so hair lies flat)



Increase → **Detector** → **Integrator in brain** → **Corrective mechanisms:** attempt to increase heat loss

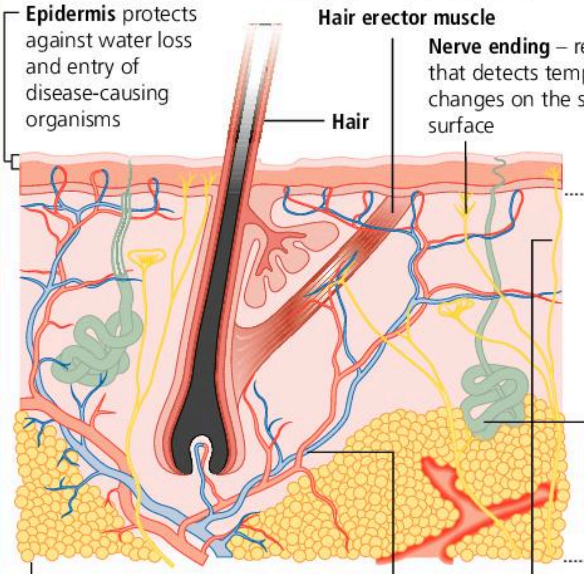
Norm

The **optimum temperature** for the body's activities is about 37°C

Norm

Decrease → **Detector** → **Integrator in brain** → **Corrective mechanisms:** attempt to conserve heat …

The structure of the skin is adapted for temperature control



… and to generate more heat

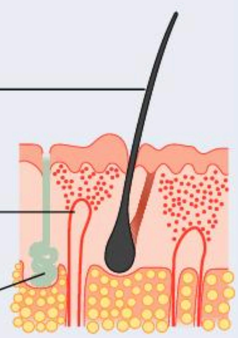
- **shivering** – muscular activity generates heat
- **adding extra clothing** – insulation reduces heat loss
- **eating more** – eating stimulates heat production by respiration …
- … or **turn on the central heating!** (Humans can control their **external** environment too.)

Skin reduces heat loss by reducing:

Convection (contraction of hair erector muscles raises hairs and traps a layer of still air)

Radiation (vasoconstriction of arterioles leading to surface capillaries shunts blood away from skin)

Evaporation (sweat glands do not secrete sweat)



▲ The structure of the skin is adapted for temperature control

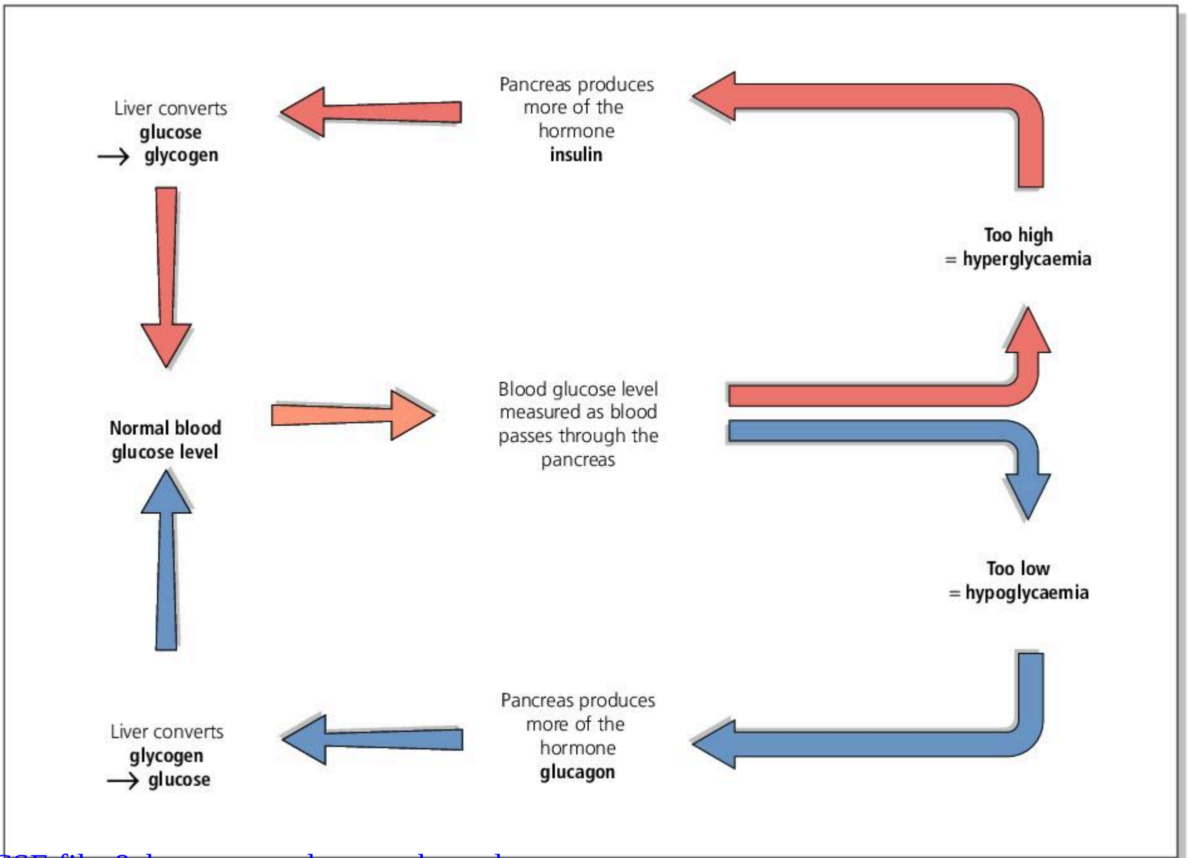
14.3 Control of blood glucose

One of the functions of adrenaline is to increase the concentration of glucose in the blood for respiration. However, constant high concentrations of glucose in the blood are harmful.

The ideal concentration of glucose in the blood is normally maintained by two further hormones, **insulin** and **glucagon**. These are secreted by cells in the pancreas in response to changes in blood glucose concentration. They affect liver, fat tissue and muscle.

- **Insulin** is released when blood sugar is too high. It stimulates the removal of glucose from the blood.
- **Glucagon** is released when blood sugar is too low. It stimulates the release of glucose into the blood.

Insulin controls the conversion of **glucose** to **glycogen**; glucagon controls the conversion of **glycogen** to **glucose**. Glucose is a simple sugar and is soluble in blood plasma and cell cytoplasm. Glycogen is a polysaccharide (see page 36) and is insoluble. Glucose is therefore the usable form of carbohydrate and glycogen is the storage form of carbohydrate. The way in which the blood glucose level is kept within safe limits is shown in the diagram below.



▲ Blood glucose level is under feedback control by the hormones insulin and glucagon

Blood glucose level

Glucose is the cells' main source of energy, and it must always be available to them for respiration …

… so the body keeps a constant amount of glucose in the blood. This blood glucose level is usually maintained at about 1 mg of glucose per cm^3 of blood.

Glucose + oxygen
↓
Carbon dioxide + water
+
Energy
↓
Cells can carry out work

Clinistix are thin strips of plastic with a small pad at the bottom. The pad contains an enzyme and a dye. If glucose is present, the enzyme uses it to change the colour of the dye. A Clinistix dipped into a urine sample from a diabetic person will give a positive result within seconds. Clinistix ar an excellent example of the medical uses of enzymes (see page 294).

What is diabetes?

Diabetes is a condition in which the blood glucose concentration is higher than normal.

- **Type I diabetes** is usually the result of the pancreas failing to secrete enough insulin.
- Symptoms include
  – excessive thirst, hunger or urine production
  – sweet smelling breath
  – high 'overflow' of glucose into urine (test with Clinistix).
- Long–term effects if untreated include
  – premature ageing
  – cataract formation
  – hardening of arteries
  – heart disease.
- Treatment is by regular injection of pure insulin – much of this is now manufactured by genetic engineering (see page 292).
- A diet that contains too much fat and too much sugar can also cause a form of diabetes. This **Type II diabetes** can be controlled by adjusting the diet to limit fat and sugar, and does not need injection of insulin. This 'non–insulin–dependent' diabetes is a common problem for obese people.

Q

1 This list contains a number of statements about diabetes. Complete the statements by matching a letter from the with a number.

a A hormone which reduces blood glucose concentration	**1** glucagon
b Clouding of the lens in the eye	**2** pancreas
c Organ which secretes hormones responsible for controlling blood glucose concentration	**3** cataract
d A hormone which increases blood glucose concentration	**4** respiration
e Process which releases energy from glucose, for example	**5** Insulin

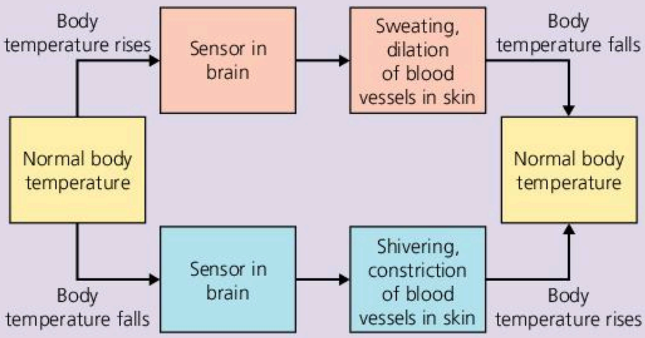
Questions on excretion and homeostasis

1 a What is hypothermia? [1]

b Why are old people particularly at risk from hypothermia? [1]

c Why do you think children lose heat very quickly? [1]

2 This diagram shows how body temperature is controlled.



a Use this information to explain how humans control body temperature. [4]

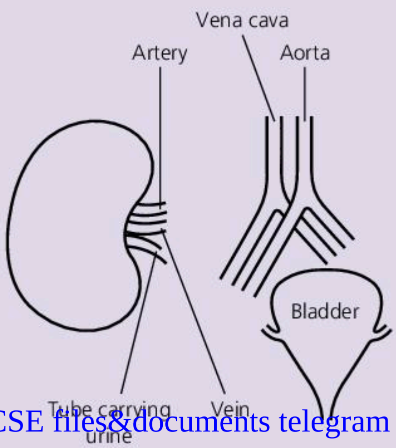
b Explain how shivering affects body temperature. [1]

c How does the liver contribute to body heat? [2]

d Use the diagram to explain the meaning of 'negative feedback'. [2]

3 If a person's kidneys are diseased he or she may have a kidney transplant. The transplanted kidney is connected to blood vessels which go into and out of the leg.

a Copy and complete the diagram on the next page to show clearly how the artery, vein and tube carrying urine should be connected in a transplant operation. [2]



b Sometimes a transplanted kidney is rejected. Explain why rejection may occur. [2]

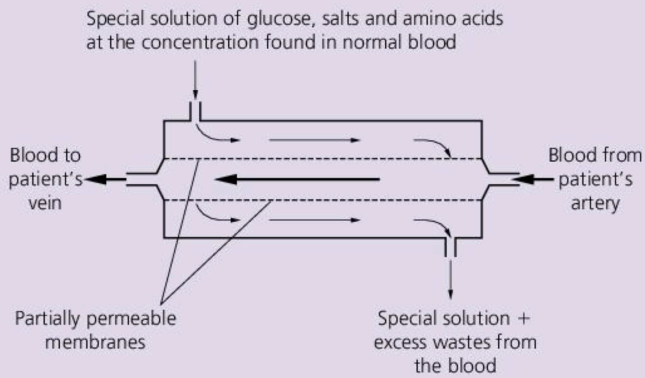
c Below is a record of how much urine a healthy man produced each day during one week. The man's diet included the same amount of water each day.

Day	Volume of urine produced / cm^3
Monday	1540
Tuesday	1470
Wednesday	1510
Thursday	1240
Friday	1450
Saturday	1770
Sunday	1520

i Calculate the average (mean) volume of urine produced each day. [2]

ii Suggest, with reasons, why the amount of urine produced was quite different on two of the days. [2]

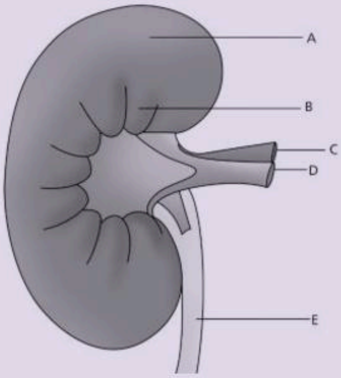
4 A person who suffers kidney failure may be treated every few days by dialysis. This uses an artificial kidney machine. The diagram shows the working of a kidney machine. In this machine a special solution flows around the outside of an inner tube which carries the patient's blood.



a How is the waste substance urea removed from the blood by dialysis? [1]

b It is better for the body if a kidney transplant operation is performed instead of having to undergo dialysis every few days. Apart from the improved convenience, why is a kidney transplant better than dialysis treatment? [2]

5 The diagram below shows a kidney and its blood supply.



a **i** Name parts A to E. [5]

ii State the functions of structures C and D. [2]

b Ammonia is produced by all animals as a waste product of their metabolism. Ammonia produced by humans is converted to urea. Explain why this is necessary. [2]

The table shows the composition of blood plasma in the renal artery, filtrate in Bowman's capsule and urine.

Substance	Concentration / g per dm^3		
	Blood plasma in renal artery	Filtrate in Bowman's capsule	Urine
Urea	0.2	0.2	20.0
Glucose	0.9	0.9	0.0
Amino acids	0.05	0.05	0.0
Mineral ions	8.0	8.0	16.5
Protein	82	0.0	0.0

c Explain why:

i four of the substances shown in the table are present in the filtrate, but protein is not [2]

ii glucose and amino acids are not present in the urine [1]

iii the concentration of urea and mineral ions is higher in the urine than in the filtrate [2]

iv the blood in the renal artery has a higher concentration of urea than blood in the renal vein. [2]

6 During an investigation into heat loss, four tubes were set up as shown in the diagram below.

The same volume of very hot water was placed in each tube.

The temperature of each tube was recorded every two minutes for 10 minutes.

The results are shown in the table below.

	Temperature / °C			
Time / mins	Tube A	Tube B	Tube C	Tube D
0	83	84	82	83
2	81	83	81	80
4	80	82	80	75
6	78	82	79	71
8	75	81	78	66
10	72	80	76	61

a **i** During the investigation, the thermometers were kept in the middle of the tubes and did not touch the glass. Suggest a reason for this. [1]

ii Explain the difference in the rate of temperature fall in tubes A and B. [2]

b **i** A new born baby is sometimes wrapped in aluminium foil. Use the results of the investigation in part **a** and your own knowledge to explain why this is done. [2]

ii Explain why it could be harmful to go out in wet clothing on a windy day. [2]

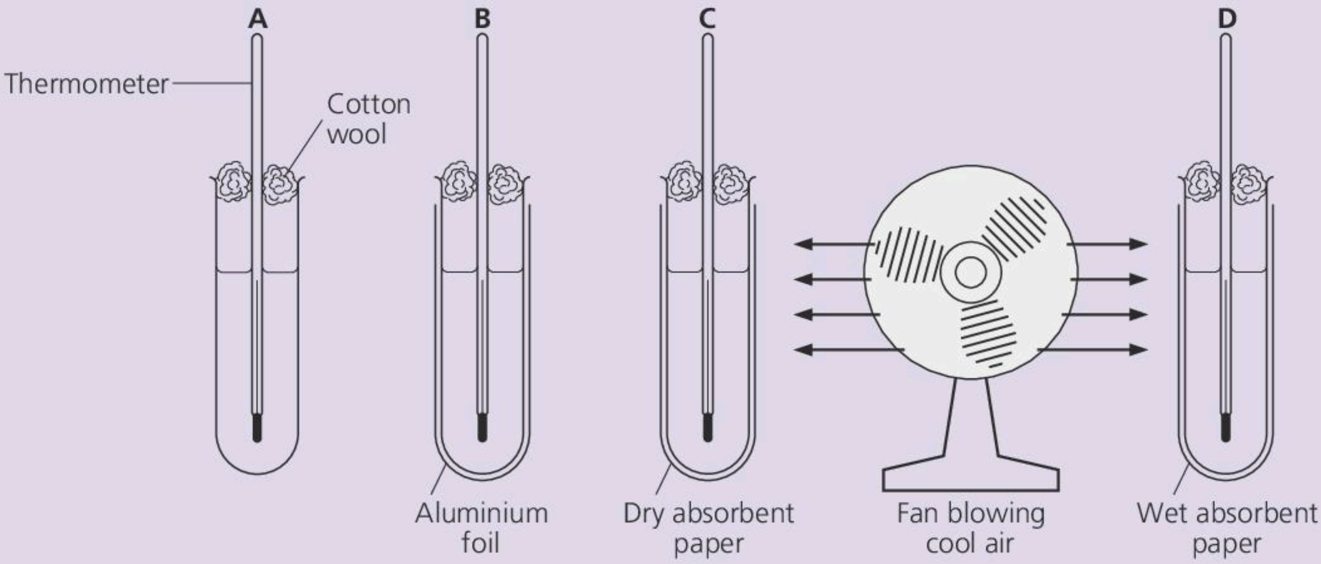
c Sweating is an important method of controlling the temperature of the body. Use the results of the investigation in part **a** and your own knowledge to explain how sweating helps to keep the body cool. [3]

d **i** On a hot day, we sweat more but produce less urine than on a cold day, even if we drink the same amount of liquid. The change in the volume of urine produced is controlled by anti-diuretic hormone (ADH).

Explain how ADH helps to maintain the correct amount of water in our bodies. [3]

ii The control of the water level in the body by ADH is an example of negative feedback.

What is meant by **negative feedback**? [2]



7 a What is homeostasis? [1]

b Copy and complete this table to explain how the kidneys, lungs, liver and skin are involved in this process. [2]

c For any one of the organs that you have described in your table, suggest how negative feedback is involved in its operation. [4]

Name of organ	One body 'factor' controlled by this organ

8 The graph shows information about kidney transplants.

Use this information to answer the following questions.

a Calculate the percentage increase in the number of people on the waiting list in 2014 compared to 1998.
Show how you work out your answer. [3]

b What problem does the graph show? [1]

A big problem with all organ transplants is that the person receiving the organ may reject it.

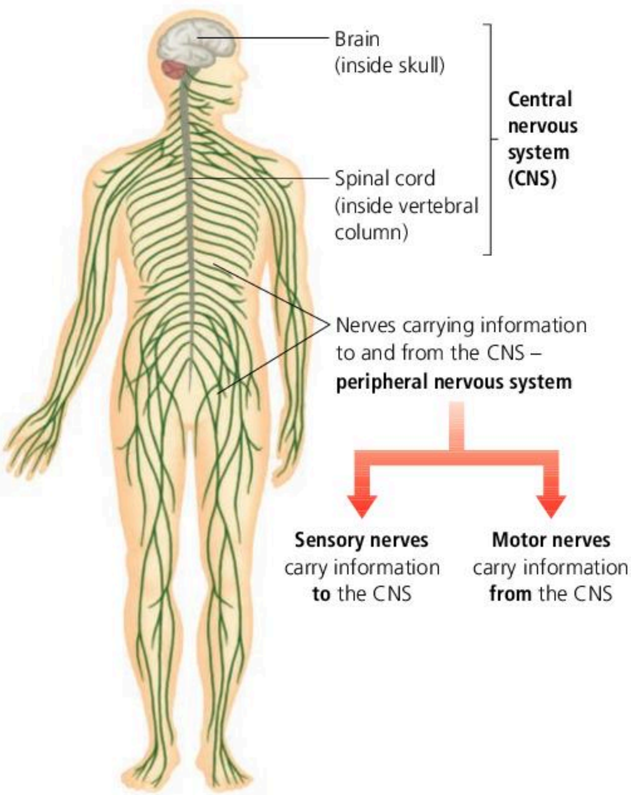
c What type of cell is involved in rejecting the organ which has been transplanted? [1]

d How do these cells lead to the transplanted organ being rejected? [2]

14.4 Coordination: the nervous system

OBJECTIVES

- To understand that different cells and tissues must work in a coordinated way
- To know that there are two systems of coordination in mammals
- To understand that the structure of a neurone is highly adapted to its function



▲ The arrangement of the human nervous system

Working together

There are millions of cells and many different tissues and organs in the body of an animal such as a mammal. The cells and organs do not all work independently – their activities are **coordinated**, which means that they work together, carrying out their various functions at certain times and at certain rates, according to the needs of the body.

Coordination in mammals is achieved through two systems, each with its own particular role. The **nervous system** deals with rapid but short-lasting responses, whereas the **endocrine system** brings about slower, longer lasting responses. The two systems are compared in the table below.

The nervous system

In mammals and other vertebrates, the nervous system is arranged as shown in the diagram on the left. It consists of a **brain** and **spinal cord**, which together form the **central nervous system** (**CNS**), connected to the various parts of the body by the **peripheral nervous system**. This is made up of **nerves**, collections of many long thin nerve cells called **neurones**.

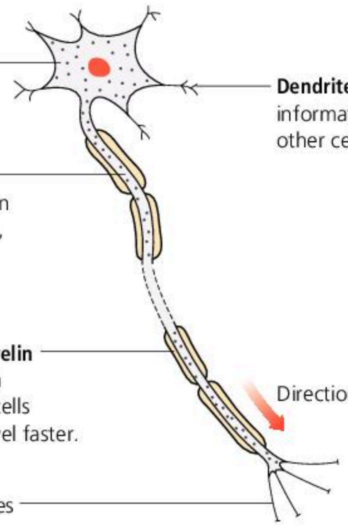
Information flows along the nervous system as follows. A **receptor** detects a change in conditions (a **stimulus**). A message is carried from the receptor to the CNS by a **sensory neurone**. After processing, a message is sent from the CNS to an organ (an **effector**) that carries out a **response**. A **motor neurone** carries this message.

The endocrine and nervous systems compared

Comparison	Nervous system	Endocrine system (see page 166)
Speed of action	Very rapid	Can be slow
Nature of message	Electrical impulses, travelling along nerves	Chemical messengers, travelling in the bloodstream
Duration of response	Usually completed within seconds	May take years before completed
Area of response	Often confined to one area of the body – the response is **localised**	Usually noticed in many organs – the response is **widespread**
Examples of processes controlled	Reflexes such as blinking; movement of limbs	Growth; development of reproductive system

Nerves and neurones

All the information carried by the nervous system travels along specialised cells called neurones (sometimes just called nerve cells). The structure of a single neurone, is well adapted to its function of carrying information, as shown on the right.

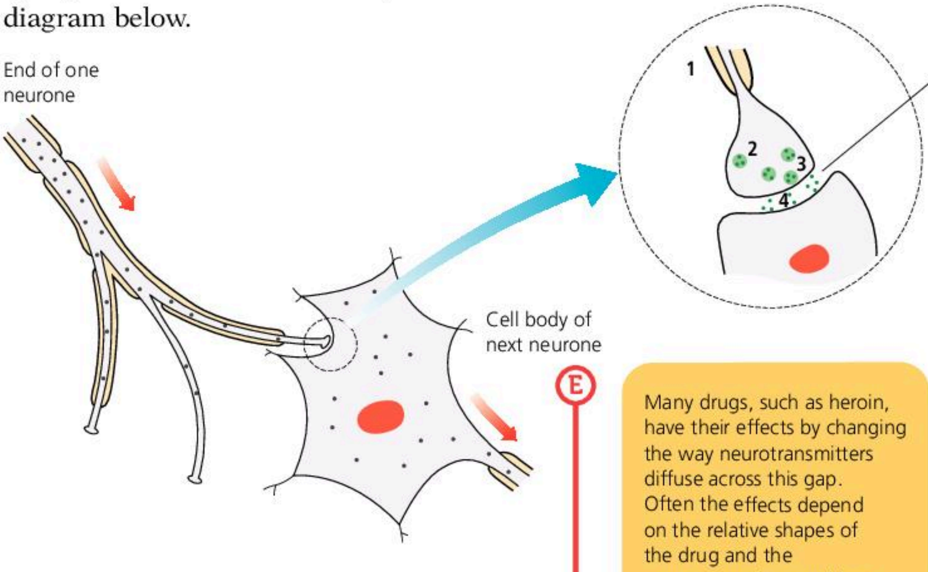


▲ A nerve is made of many neurones. This **motor neurone** carries information from the CNS to an effector.

Nerve impulses

Messages pass along neurones in the form of **electrical impulses**, called **action potentials,** which travel very quickly from one end of a nerve cell to the other. In a living mammal the impulses always travel along a neurone in a certain direction. They are then passed on to another neurone, to a muscle cell or to a gland cell.

The end of the neurone is separated from the next cell by a tiny gap, visible under a microscope, and the impulses can only cross this gap in one direction. This gap, called a **synapse**, acts like a valve as explained in the diagram below.



▲ Impulses travel along a neurone in the direction that allows the mammal to respond to changes in its environment. They can only pass across the synapse in this direction.

Many drugs, such as heroin, have their effects by changing the way neurotransmitters diffuse across this gap. Often the effects depend on the relative shapes of the drug and the neurotransmitter, and how they 'fit' the receptor.

1. Suggest two similarities and two differences between the endocrine system and the nervous system. What is the importance of these differences?
2. Explain how the structure of a neurone is related to its function.
3. Explain the difference between:
   - **a** motor and sensory neurones
   - **b** central and peripheral nervous systems.
4. How does a nerve impulse:
   - **a** pass along a neurone
   - **b** cross a synapse?

14.5 Neurones can work together in reflex arcs

OBJECTIVES

- To understand that neurones work together in a reflex arc
- To understand that all reflex arcs are important for survival

Neurones act together in many complex ways to bring about the correct response to a stimulus. The simplest type of response is called a **reflex action**. A reflex action is a rapid automatic response to a stimulus, for example jerking your hand away from a sharp or hot object. The nerve pathway involved in the reflex action is called a **reflex arc**, shown in the diagram on the opposite page.

Reflexes and survival

All reflex actions have evolved to help us survive. The table below lists four reflexes, and shows how each helps us survive.

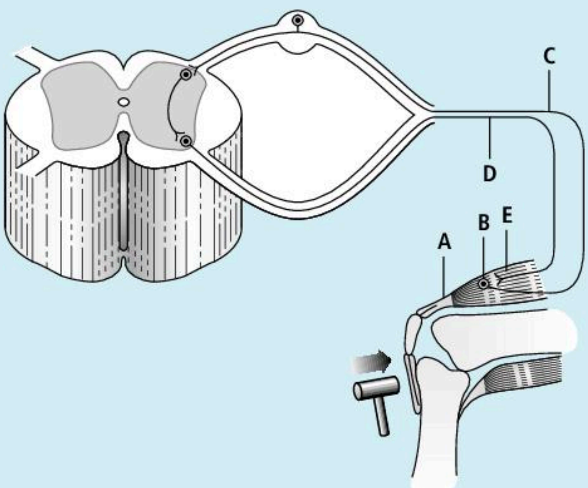
The size of the pupil can change quickly and automatically in response to changes in the intensity of light. This reflex action, described in more detail on page 163, prevents damage to the retina.

A reflex is an involuntary action. Voluntary actions only take place if the brain is involved in initiating the action (see page 158).

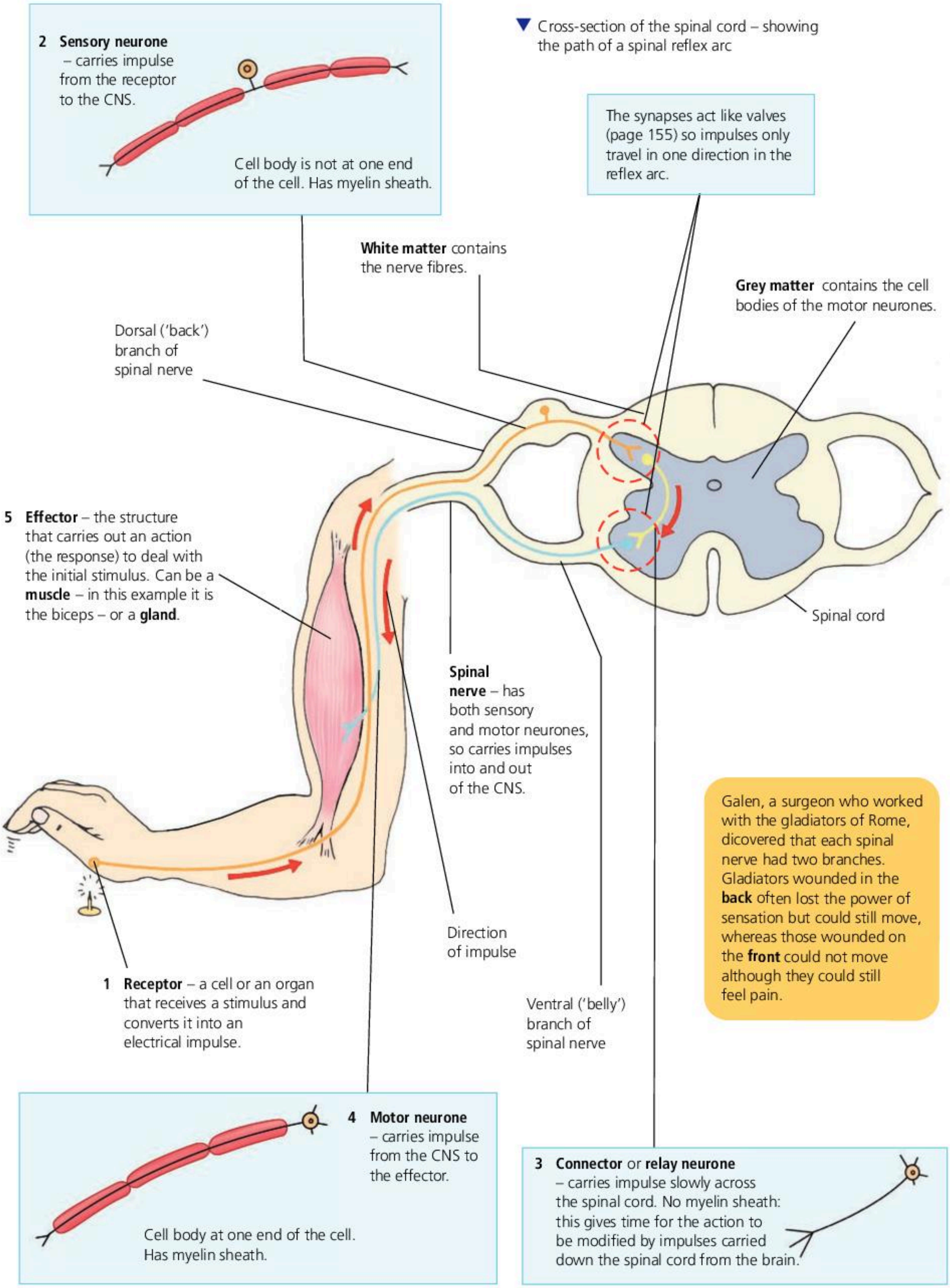
Name of reflex	Stimulus	Response	Survival value
Coughing	Particles making contact with the lining of the respiratory tree	Violent contraction of the diaphragm and internal intercostal muscles	Prevents lungs being damaged or infected, so that gas exchange remains efficient
Pupil reflex	Bright light falling on the retina	Contraction of the circular muscles of the iris	Prevents bleaching of the retina so that vision remains clear
Knee jerk	Stretching of the tendon just under the knee, holding the kneecap in place (a doctor may tap this tendon to test the reflex)	Contraction of the muscles of the upper thigh so that the leg straightens	The leg can support the body's weight during walking
Swallowing	Food particles making contact with the back of the throat	Contraction of the muscle of the epiglottis, which closes off the entrance to the trachea	Prevents food entering the respiratory pathway, so that the lungs are not damaged

Q

1. The diagram opposite shows the route taken by nerve impulses to bring about the knee-jerk reflex.
   - **a** Name the structure tapped by the hammer. How does this set off the reflex action?
   - **b** Name the structure that carries impulses towards the spinal cord.
   - **c** Which structure **A**–**E** is responsible for the response in this reflex action?
   - **d** The distance between structure B and the spinal cord is about 30 cm. Assuming that the impulses travel at 100 m per s, how long should it take for an impulse to travel through this reflex arc?
   - **e** Careful measurement suggests that the actual time taken for the impulse to travel through this arc is 2 or 3 times this value. Can you explain why?



▼ Cross-section of the spinal cord – showing the path of a spinal reflex arc



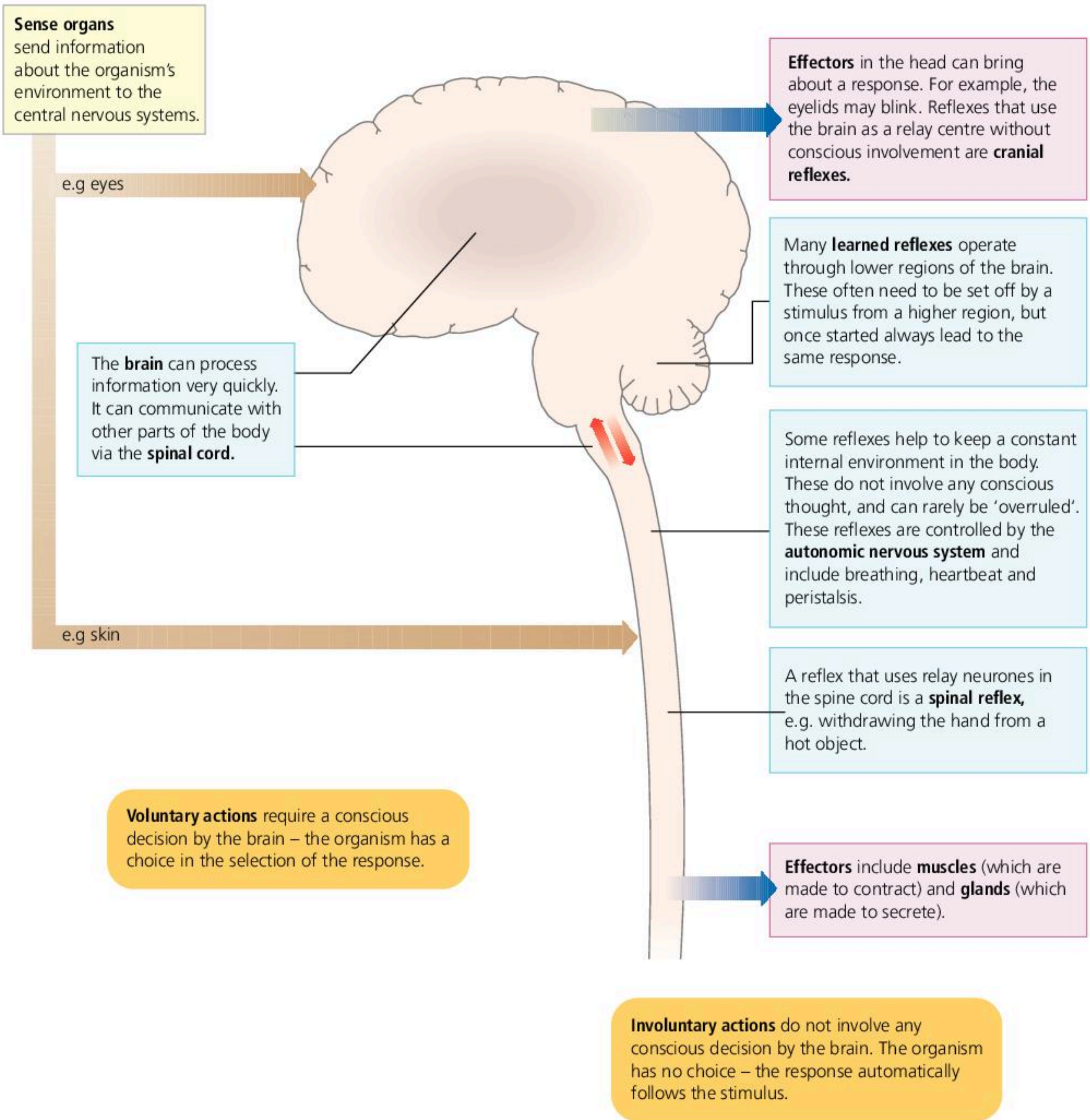
Galen, a surgeon who worked with the gladiators of Rome, discovered that each spinal nerve had two branches. Gladiators wounded in the **back** often lost the power of sensation but could still move, whereas those wounded on the **front** could not move although they could still feel pain.

14.6 Integration by the central nervous system

OBJECTIVES

- To understand that the central nervous system integrates and coordinates the responses of the body
- To understand the difference between voluntary and involuntary actions

The central nervous system (CNS) processes information from receptors and passes instructions to effectors to tell the organism how to respond. This complex series of operations, referred to as **integration**, is outlined below.



In simple terms:

Stimulus → **Sense organ** → **Central nervous system** → **Effector** → **Response**

Involuntary actions

Reflexes concerned with the 'housekeeping' tasks of the body, such as breathing, do not reach the conscious level of the brain. They are dealt with by the **autonomic** branch of the nervous system.

Responses may be more complex than a simple reflex arc. For example, the CNS may store information as **memory** and then compare an incoming stimulus with a previous one. It chooses the correct response for this particular situation, and sends information out to the effectors to bring about the appropriate action. Each time a particular stimulus leads to a certain response, the impulse passes along the same route, so that reflex actions become **learned reflexes**. Talking and cycling are examples of learned reflexes. Whether or not a reflex has been learned, it is an **involuntary action** – a particular stimulus always leads to the same response.

Voluntary actions

During evolution, the front of the spinal cord became highly developed to form the brain. The advanced development of the brain, particularly those parts that deal with learning, sets mammals (and especially humans) apart from 'lower' animals. The brain is involved in **voluntary actions,** in which a conscious choice is made about the response to a particular stimulus.

Conditioned reflexes

Conditioned reflexes are learned reflexes in which the final response has no natural relationship to the stimulus. In an experiment, a Russian scientist, Ivan Pavlov, rang a bell when he fed dogs. The dogs then salivated in response to the bell, even when no food was given. The natural stimulus (the food) had been replaced by an unnatural one (the sound of the bell). Conditioned reflexes can be 'unlearned' if the unnatural stimulus is not repeated with the natural one – if the food was produced without the bell over a period of time, the dogs would no longer salivate at the sound of the bell.

1 Reaction times for a class were measured using a computer to calculate the time taken for each student to press the space bar after seeing a light.
The table opposite shows the results for student 1.

a Calculate the mean reaction time of this student. Why is the mean value useful?

The mean class results are shown in the table below. (You have just calculated the result for student 1.)

Student number	Reaction time / ms	Student number	Reaction time / ms
1		16	150
2	220	17	300
3	130	18	140
4	220	19	230
5	210	20	150
6	250	21	190
7	190	22	180
8	200	23	240
9	220	24	120
10	240	25	170
11	140	26	160
12	280	27	190
13	210	28	210
14	330	29	270
15	270	30	200

Attempt	1	2	3	4	5	6	7	8	9	10
Reaction time / ms	330	340	290	320	320	280	270	290	400	260

b Place the students' reaction times into groups by copying and completing the table below. Draw a bar chart of the results.

Reaction time / ms	Number of students in group
110–150	
160–200	
210–250	
260–300	
310–350	

c The teacher suggested that this reaction time could affect driving ability – a motorcycle travelling at 55 km per h would cover about 15 m in a second. How far would the motorcycle travel before:

i the student with the shortest reaction time pulled the brake lever

ii the student with the longest reaction time pulled the brake lever?

d In a further experiment a loud noise was made at the same time as the light was shown. Eventually the student began to respond when just the noise was made. How does this result explain the meaning of the term 'conditioned reflex'?

14.7 Receptors and senses: the eye as a sense organ

OBJECTIVES

- To understand that receptors are the first stage in reflex arcs
- To know the different types of stimulus to which a mammal is sensitive
- To know that a sense organ combines receptors with other cells
- To know the structure and function of the eye

Receptors detect changes in the environment

A **stimulus** is a change in the environment that affects an organism. All living organisms are **sensitive** – they can respond to stimuli. Animals, including mammals, have a nervous system which receives information from the environment, decides how to respond and then tells the body. A **receptor** is a part of the nervous system that is adapted to receive stimuli. Receptors can be classified according to the type of stimulus they respond to, as shown in the table.

Receptor type	Responds to stimulus	Example in humans
Photoreceptor	Light	Rod cells in retina of eye
Chemoreceptor	Chemicals	Taste buds
Thermoreceptor	Changes in temperature	Thermoreceptors in skin
Mechanoreceptor	Mechanical changes such as changes in length	Hair cells in ear (hearing and balance), touch receptors in the skin

▲ Classification of receptors

Think about it! We are not aware of any stimulus until the impulse reaches the correct area of the brain. The receptor can be working perfectly but unless the sensory nerve and brain are working, the 'sense' will be incomplete – we 'see' with our brain as much as our eyes.

Receptors are transducers

All receptors are **transducers**, which means they convert one form of energy into another. They convert the energy of the stimulus (such as light energy) into the kind of energy that the nervous system can deal with (electrical impulses). The general principle of receptor action is outlined in the diagram opposite.

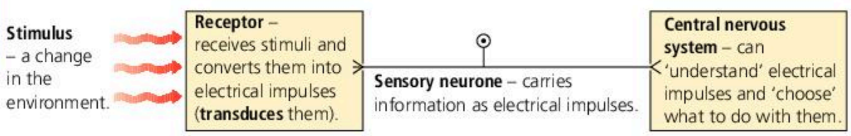
The senses

Our **senses** are our ability to be aware of different aspects of the environment. For example, the sense of sight allows us to be aware of light stimuli, detected by photoreceptors. The photograph opposite shows the different human senses, and the stimuli to which they are sensitive.

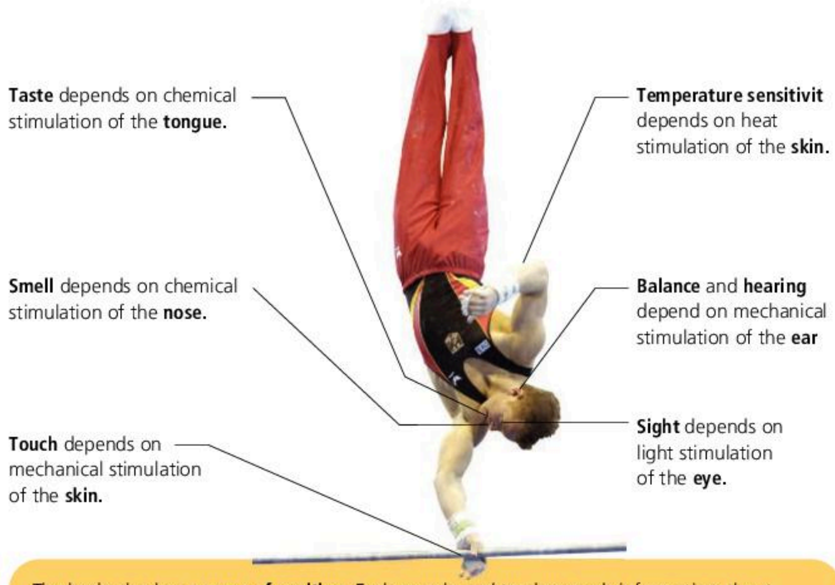
The receptor cells that provide our senses do not work on their own. They need a supply of blood to deliver nutrients and oxygen and remove wastes. Receptors may need help in receiving the stimulus, and receptor cells are often grouped together with other tissues to form a **sense organ**. The other tissues allow the receptor cells to work efficiently.

The working of the eye illustrates the involvement of other tissues in the operation of a sense organ, as described opposite.

Note that the senses are detected by receptors in structures on the outside of the body, and mainly around the head. This is because the stimuli come from outside the body, and the head is often the first part of the body that goes into a new environment. There are also many **internal** receptors inside the body. These detect blood temperature and pH, for example, and are vital in the process of homeostasis (see page 144).



All receptors work in the same way – they convert one form of energy (the stimulus) into another form that the nervous system can understand



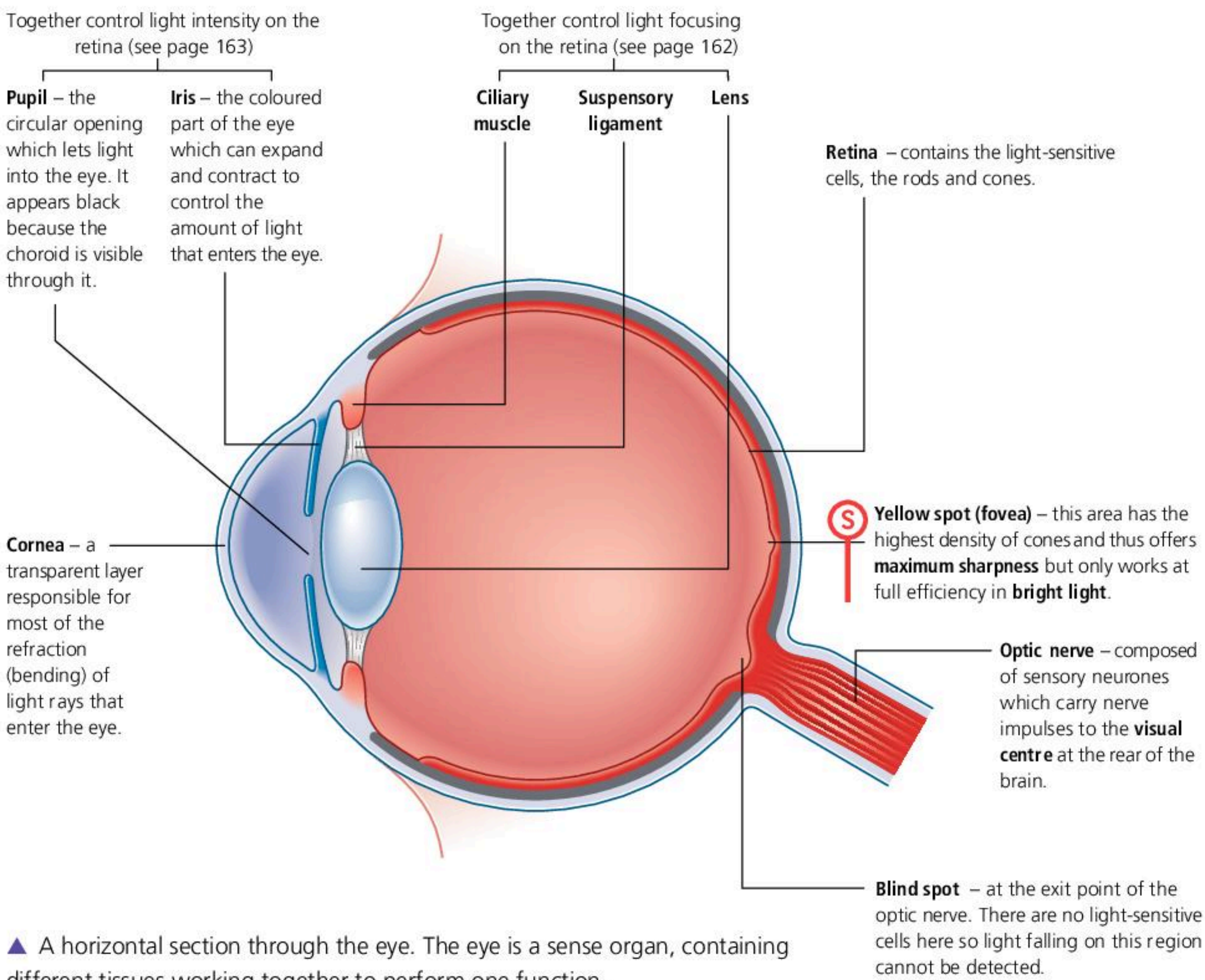
The body also has a **sense of position**. Each muscle and tendon sends information about how stretched it is to the central nervous system (CNS). The CNS interprets this so that we 'know' where each part of the body is in relation to the other parts (see how easy it is to

The eye as a sense organ

The eye is an example of a sense organ. It contains:

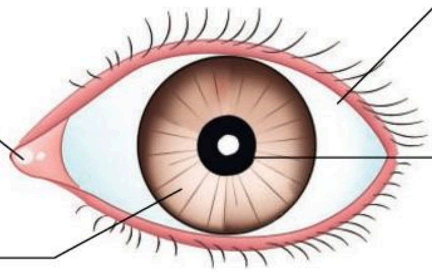
- **receptors** – the rod and cone cells on the retina
- **systems for making the most of the light stimulus**, including the lens and the iris
- **its own blood supply** and **physical protection** via the choroid and the sclera.

The diagram below shows the arrangement of the structures in the eye.



▲ A horizontal section through the eye. The eye is a sense organ, containing different tissues working together to perform one function.

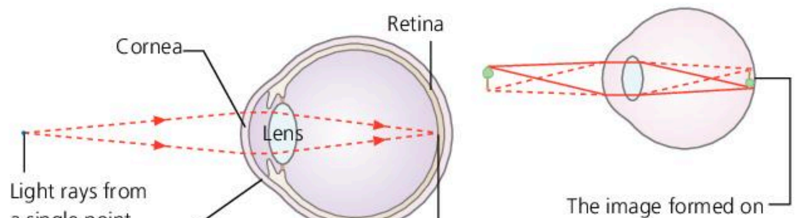
Rods and cones are photoreceptors on the retina



▲ Eye: front/surface view

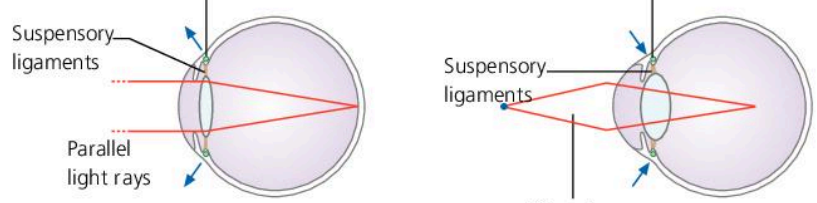
How a sharp image is formed on the retina

An **image** is formed when rays of light from an object are brought together (**focused**) onto the retina, as shown here.



Accommodation – adjusting for near and distant objects

The amount of **refraction** (bending) of the light is adjusted depending on the distance between the object and the eye. The light rays coming from very distant objects are parallel. They only need to be refracted a little to form a single, sharp, focused image on the retina. However, the lens does not need to be very powerful for this. The light rays coming from close objects are diverging. They need to be refracted more to form a sharp image on the retina, and the lens needs to be more powerful. The ability of the lens system to produce a sharp image of objects at different distances is called **accommodation**. As people get older the lens becomes less elastic and loses its ability to change shape. This makes it harder to refocus quickly on objects at different distances. Smokers may experience this problem earlier than non-smokers because smoke 'ages' molecules in the lens.



Distant object
- Light needs to be **refracted** (bent) **less**.
- Ciliary muscles **relax**, eyeball becomes spherical.
- Ligaments are **tight**.
- Lens is pulled **long and thin**.

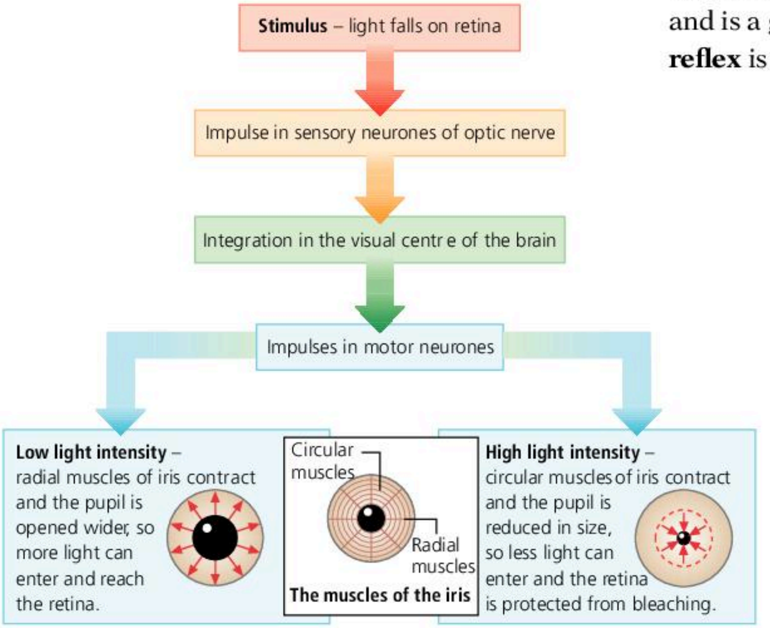
Close object
- Light must be **greatly refracted** (bent).
- Ciliary muscles **contract**, pull eyeball inwards (eyeball 'bulges' forward).
- Ligaments **relax**.
- Lens becomes **short and fat**.

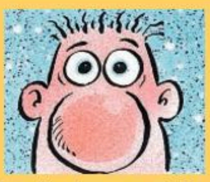
Relaxed or waking eyes are set for viewing distant objects so that images of close objects (such as alarm clocks!) are blurred.

Eyestrain is caused by long periods of close work. The ciliary muscles are contracting against the pressure of fluid in the eyeball.

The iris controls the light intensity at the retina

Light falls on the retina and stimulates the rods and cones to produce nerve impulses. These travel to the brain along the optic nerve. It is important that the rod and cone receptor cells are not over-stimulated. If too much light fell on them they would not recover in time to allow continued clear vision. The iris contains muscles that alter the size of the pupil, thereby controlling the amount of light that falls on the retina. This control is automatic, and is a good example of a reflex action. This **pupil reflex** is explained in this diagram.



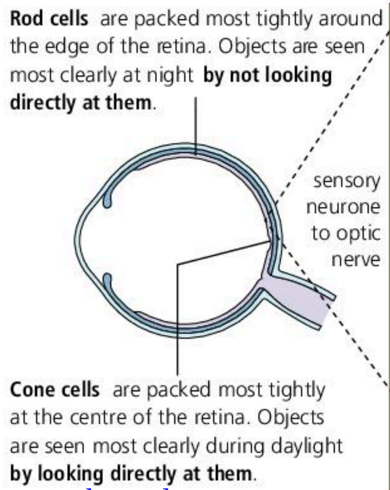


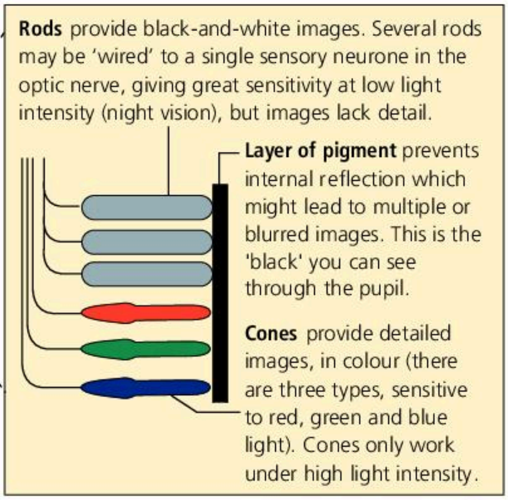
Adrenaline (see page 168) imitates this part of the reflex – pupils dilate.

Heroin imitates this part of the reflex – pupils constrict.

◀ The pupil reflex prevents bleaching of the retina by regulating the amount of light that enters the eye

The retina contains two types of light-sensitive cell, **rods** and **cones**, as shown in the diagram below.





Questions on coordination and response

1 Which receptor is responsible for detecting changes in light intensity?

A Eye
B Skin
C Ear
D Tongue [1]

2 Which type of cell is responsible for carrying information from a receptor to the CNS?

A Connector neurone
B Motor neurone
C Intermediate neurone
D Sensory neurone [1]

3 Copy and complete this paragraph. Use words from the list below. Each word may be used one, more than once or not at all.

rods, integration, colour, inverted, lens, motor, cornea, pupil, cones, iris, high, optic, retina

Light rays from an object are refracted by the ____ and the ____ which focus the light rays onto the ____. The amount of light that reaches this light-sensitive layer is controlled by the ____ which is able to adjust the size of the ____ (the black 'hole' in the front of the eye). There are two types of light-sensitive cells, the ____, which are responsible for ____ vision in low light intensity, and the ____, which are responsible for ____ vision in ____ light intensity. The image formed on the ____ is ____ and ____ than the object, but the nerve impulses that pass along the ____ nerve to the brain are interpreted so that they make sense. The ability of the brain to compare incoming information with previous experience, and to set off the correct response, is called ____. [6]

4 A group of students suggested that coffee is enjoyable because it speeds up the heart rate. They gave several groups of people different amounts of coffee one morning and collected the following information.

Number of cups of coffee drunk	Heart rate / beats per minute	
	Total	Mean
0	74, 76, 72, 72, 78, 68	
1	78, 78, 82, 72, 72, 70	
2	78, 78, 79, 87, 80, 72	
3	80, 82, 78, 81, 78, 76	
4	76, 78, 88, 90, 88, 86, 78	
5	80, 90, 88, 88, 94, 92	

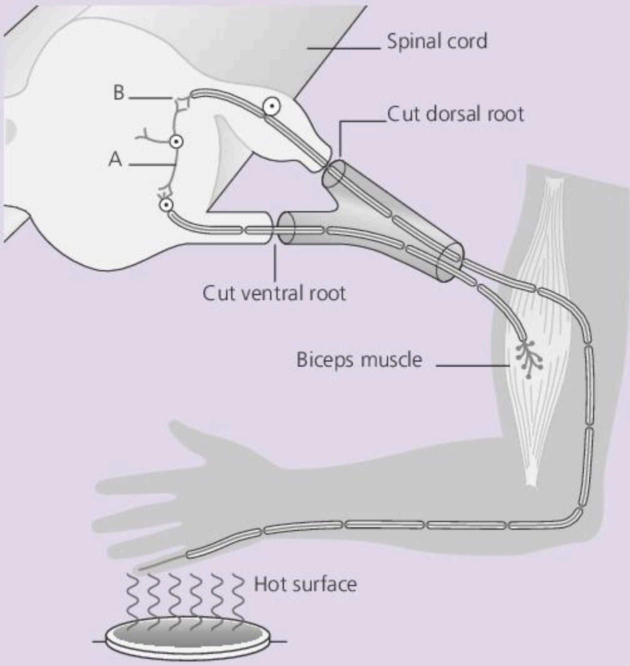
a Copy and complete the table by calculating the mean heart rate for each of the test groups. [2]

b Present your data in a suitable graphical form. [4]

c Does this data support the hypothesis that coffee affects the heart rate? [1]

d Suggest **three** precautions that the students should have taken to ensure that their data were valid. [3]

5 Study the diagram below, then answer the questions that follow.



a Name the type of neurone labelled A. What important function does it have? [2]

b Name the gap labelled B. [1]

c In what form is a message transmitted:

i along a nerve fibre [1]

ii across the gap B? [1]

d Give **two** examples of spinal reflexes, **two** of cranial reflexes and **one** conditioned reflex. [5]

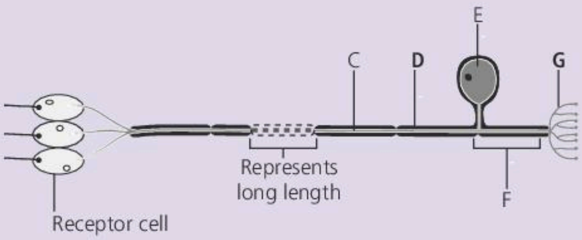
e How would sensation in the limb be affected if:

i the dorsal root (branch) was cut [1]

ii the ventral root was cut? [1]

f Would a reflex action occur in the limb when the dorsal root was being cut? Explain your answer. [2]

g Name the parts **C–G** on the diagram of a sensory neurone below. State two ways in which this neurone differs from a motor neurone. [7]



6 Bimla was sitting in a well-lit room. She covered one eye with an eye patch. A pencil was held in front of her eye for 10 seconds. Bimla focused on it and at the same time the thickness of her eye lens was measured using an optical instrument. The pencil was then moved a different distance from the eye. This was repeated over a short period. The results are shown in the table.

Distance from eye / cm	Thickness of lens / mm
10	4.0
20	3.6
30	3.2
50	2.9
100	2.7
150	2.6
200	2.6

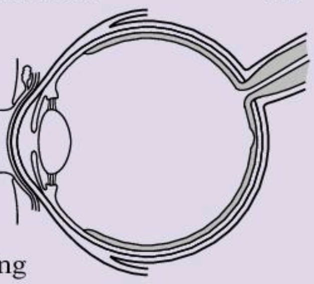
a Name the structures in the eye that bring about the change in the thickness of the lens. [2]

b In this investigation, which is the independent variable and which is the dependent variable? [2]

c Suggest two important fixed variables. Explain why they must be fixed. [3]

d How could the experiment be improved to make the data more reliable? [1]

7 a Copy the diagram of the eye. Use the letters listed below to label the diagram.



A Layer containing rods and cones

B Muscles controlling the amount of light entering the eye

C The source of tears

D A black layer containing blood vessels

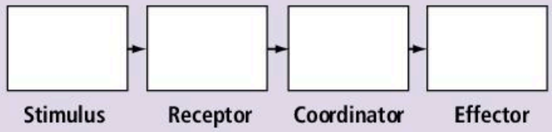
E A very thin layer which protects the surface of the eye from bacteria

F A tough white protective layer [6]

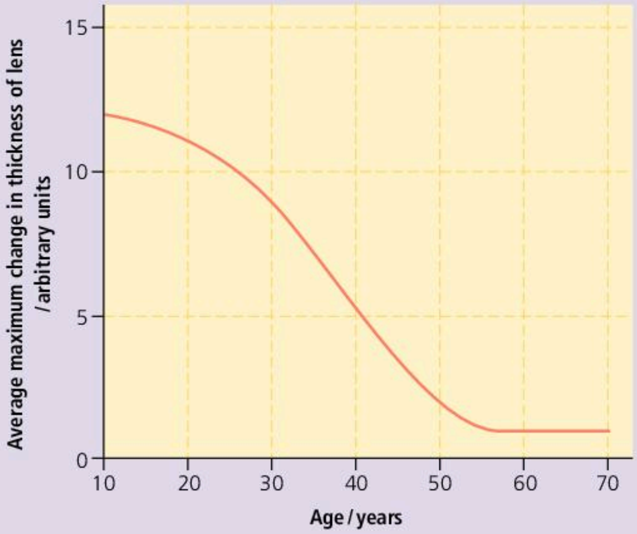
b In bright light the iris changes shape to reduce the size of the pupil.

i What is the advantage of this? [1]

ii For this purpose, name the stimulus, receptor, coordinator and effector. Copy and complete the diagram below. [2]



8 An experiment similar to that in question 6 was carried out. Data from a number of subjects were used to draw the graph below.



a At what age does the lens more or less lose the ability to change shape? [1]

b What effect will this have on the person's eyesight? [1]

c From the information in the graph, suggest why people over the age of 60 do not have to keep getting new glasses for reading. [1]

d In the condition called **cataract** the lens becomes very cloudy and must be removed. Which structure will now be the only way to converge light into the retina? How will this operation affect a person's eyesight? [2]

e Scientists know that cigarette smoking hardens the arteries. Some scientists believe that smoking also hardens the lens, making a change of shape more difficult. How could you investigate this? What controls would you need? [3]

14.8 The endocrine system

OBJECTIVES

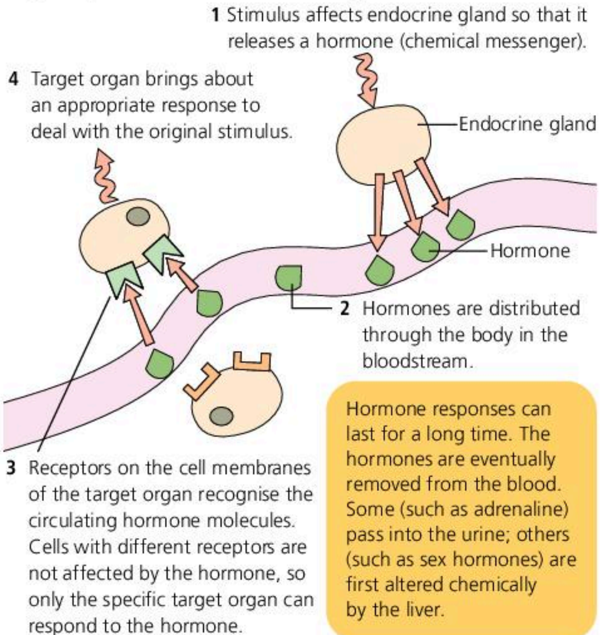
- To understand the need for a chemical system of coordination
- To define the terms hormone and endocrine organ
- To give examples of hormones in the human body

A second control system

The responses controlled by the nervous system happen quickly, but there are some responses that go on over a long period of time. Growth and development, for example, continue for years. Animals have a second coordination system, the **endocrine system**, which carries out this sort of control.

Ductless glands

The endocrine system is a series of organs called **glands**, which secrete chemicals called **hormones**. The endocrine glands are ductless glands – they secrete their hormones directly into the bloodstream. (Other glands, called exocrine glands (such as those in the digestive system), secrete substances through a duct or tube.) The hormones, once released, travel in the blood to any part of the body that is supplied with blood. The hormones affect only their **target organs,** as outlined in the diagram below.



Hormone responses can last for a long time. The hormones are eventually removed from the blood. Some (such as adrenaline) pass into the urine; others (such as sex hormones) are first altered chemically by the liver.

▲ The mechanism of hormone action

Hormones in humans

The main hormone-producing glands, and the hormones they produce, are shown in the diagram on the opposite page.

A comparison between hormonal and nervous co-ordination is shown on page 154.

Hormones control puberty in humans

Hormones control long-term processes, and often have widespread effects on the body. **At puberty** a person becomes physically able to reproduce. The development of sexual maturity is a good example of a hormone-controlled process (see page 189).

As a young person develops physically, certain signals are processed by the brain, which then instructs the pituitary gland to stimulate the **primary sex organs** – the testes in males and the ovaries in females. Sex hormones – **oestrogen** (in females) and **testosterone** (in males) – are released into the bloodstream and circulate throughout the body. They only affect the target organs which have receptors that recognise them. These target organs then carry out responses, such as the growth of body hair, which may continue for many years.

Hormone production is under feedback control

The production and secretion of hormones is accurately controlled by **feedback** – the hormones regulate their own production. As the level of hormone in the blood rises, it switches off (**inhibits**) its own production so that the level never gets too high. As the level of hormone in the blood falls, it switches on (**stimulates**) its own production so that the level never gets too low. **Feedback control** is very important in biology, particularly in homeostasis (see page 145). It is outlined in the diagram opposite.

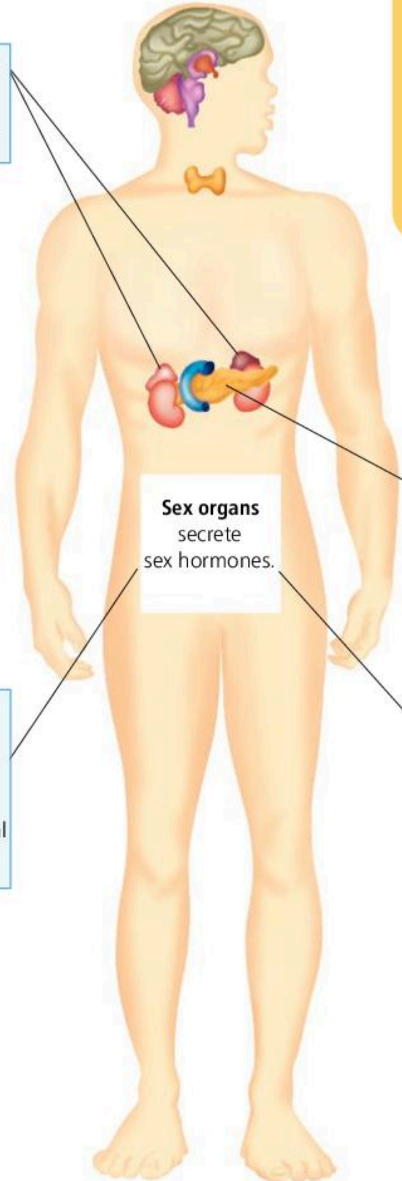
Hormones and food: growth hormones are widely used to increase meat production in domestic animals.

Q

1 a Name two of the enzymes secreted by the pancreas.
b Explain why blockage of the pancreatic duct – in cystic fibrosis – rarely affects control of blood glucose levels.

Endocrine organs and their secretions

Adrenal glands
- Adrenaline – control of preparing the body for action (see page 168).



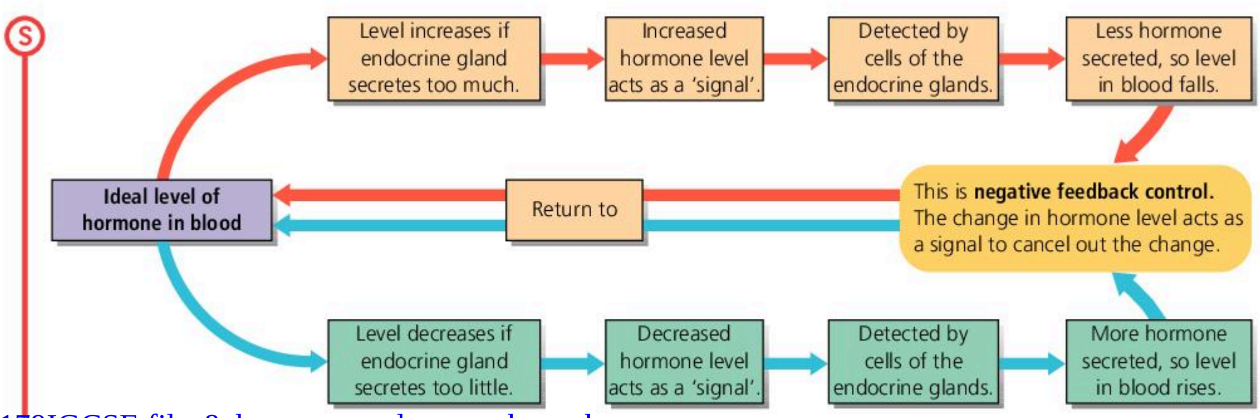
Human growth hormone
Sometimes the endocrine system does not function properly. An example is **pituitary dwarfism** – a person fails to grow and develop properly because of a lack of a hormone called **human growth hormone.** Treatment has been considerably improved in recent years by the production of human growth hormone by bacteria.

Pancreas
- Insulin and glucagon – control of blood sugar concentration (see page 148).

The pancreas is also an exocrine organ! It secretes digestive enzymes down a tube into the small intestine.

Ovaries in female
- Oestrogen and progesterone – control puberty in females, including development of breasts and hips. Also control the menstrual cycle and ovulation (see page 189).

Testes in male
- Testosterone – controls puberty in males, including deepening voice, stronger muscles and growth of body hair. Also controls development and release of sperm (see page 189).



▲ Feedback control regulates hormone levels in the blood

Adrenaline

One hormone that has been widely studied is **adrenaline**. This substance seems to bridge the gap between nervous and endocrine control. It is definitely a chemical messenger, and is released directly into the bloodstream, yet its actions are often very rapid indeed and may only last for a very short time. The widespread and instant effects of adrenaline are described below.

Skin becomes pale as blood is diverted away.

Deeper, more rapid breathing and airways become wide.

Heart beats more rapidly.

Blood is diverted away from digestive system to muscles by using sphincters (see page 102).

Adrenal glands (on top of the kidneys) release the hormone adrenaline.

Glycogen in muscles is converted to **glucose** and released into the blood.

Adrenaline is known as the 'flight or fight' hormone, released when the body is given a shock.
The overall effect is to provide more glucose and more oxygen for working muscles – preparation for action!

Hormones can be used as drugs in sport

The effects of hormones on the body's activities can be used to improve performance in sport. Some hormones which have been abused in this way are listed in the table below.

Hormone	Effect on body	Effect on sporting performance
Anabolic steroids	Increase growth of muscle. Reduce fat content of body.	Increase strength and power to weight ratio useful in 'explosive' sports such as sprinting and shot putting.
Cortisone	Repair of damaged tissues.	Allow rapid recovery after intensive training.
Testosterone	Stimulates male's aggressive behaviour.	Aggression can be important in contact sports like rugby.

BUT BEWARE!

- Drug abuse is illegal and can lead to lengthy bans for sportsmen and women.
- 'Artificial' hormones can switch off natural hormone production by feedback inhibition. Men may lose their sexual potency, gain body fat and develop 'squeaky' voices, and women may cease menstruation and ovulation (and sometimes develop excessive body hair).

▲ Liu Chunhong was stripped of her gold medal in the 69 kg weightlifting class at the 2008 Olympic Games. Samples of urine and blood re-tested four years later led to Liu and two other female weightlifters losing their medals and facing two-year bans from competition.

Questions on hormones

1 The table below lists some of the effects of hormones.
Match each hormone with its effect. Write the letter and number to show your answer, for example, **a–4**.

Hormone	Effect
a adrenaline	**1** development of sperm
b insulin	**2** secreted if blood glucose level falls
c testosterone	**3** increase in heart rate
d oestrogen	**4** produced by the pancreas as blood glucose level increases
e glucagon	**5** deposition of fat in the breasts

2 A dangerously aggressive animal is unlikely to fit into society. Aggression may be an important part of puberty in male animals, and may help to win females. Explain how negative feedback (feedback control) would keep aggression within acceptable limits in a young male animal. [4]

3 Copy and complete the following paragraph. Use words from the following list. Each word may be used once, more than once or not at all.

starch, glucose, insulin, oxygen, deep, intestines, muscles, pales, dilate, glycogen, stands upright, flight, fight, adrenaline, rapid

A human exposed to a severe shock responds by producing the hormone ____. This hormone causes the storage polysaccharide ____ to be converted to ____, a soluble sugar used to release energy via respiration. Aerobic respiration requires ____ as well as this sugar, and more of this gas is made available because the hormone causes ____ and ____ breathing. The body makes the most of its resources by adjusting blood flow to different organs – less blood flows to the ____, for example, and more flows to the ____. The face of a shocked person shows three effects of this hormone – the skin ____, the pupils ____ and the hair ____. Because of these effects this hormone is often called the ____ or ____ hormone. [6]

4 Normal blood glucose level is 1 mg per cm^3. Ten people with normal blood glucose levels were tested for blood glucose and plasma insulin levels over a period of six hours. The mean values for these measurements were calculated and recorded. The test period included two meals and a session of exercise. The results are shown in the table below.

Time / hours	Activity	Blood glucose level / mg per cm^3	Plasma insulin level / µg per cm^3
0	Meal eaten	1.0	10
0.5		1.5	20
1.0		1.0	40
1.5		0.8	25
2.0	Exercise started	0.8	15
2.5	Exercise finished	1.2	10
3.0		1.0	20
3.5		1.0	10
4.0	Meal eaten	1.0	10
4.5		1.4	20
5.0		1.0	35
5.5		0.8	40
6.0		0.8	10

a Present all the data in the form of a graph. [4]

b What effect does the period of exercise have on the blood glucose and plasma insulin levels? Explain your answer. [2]

c Suggest **two** other hormones that would change in concentration in the blood during exercise. Why are these hormones important? [2]

d Why is it good experimental technique to:

i take mean values for blood glucose and plasma insulin levels [2]

ii use only subjects with normal glucose levels? [1]

e How long after a meal does it take for the blood glucose level to return to normal? [1]

14.9 Sensitivity and movement in plants: tropisms

OBJECTIVES

- To recall that plants, like all living things, are sensitive to their environment
- To know that plants respond to stimuli by changes in their growth patterns
- To know that plant growth responses are controlled by hormones
- To appreciate the importance of plant growth responses
- To understand how plant hormones may be used commercially

Plants respond to their environment

Plants respond to their environment – they show **sensitivity** (**irritability**). Plant responses are rather slow compared with those of animals – plants respond to **stimuli** (to changes in their environment) by changing their growth patterns. These growth responses enable a plant to make the most of the resources available in its environment.

Plants respond to many stimuli, but two are of particular importance: **light** (the photo-stimulus) and **gravity** (the gravi-stimulus). A growth response carried out by a plant in response to the direction of a stimulus is called a **tropism**.

A **positive** response is a growth movement towards the stimulus, and a **negative** response is a growth movement away from the stimulus. For example:

- a stem growing towards light is a **positive phototropism**
- a stem growing upwards (away from gravity) is a **negative gravitropism**
- a root growing downwards (away from light but towards gravity) is a positive gravitropism but a negative phototropism.

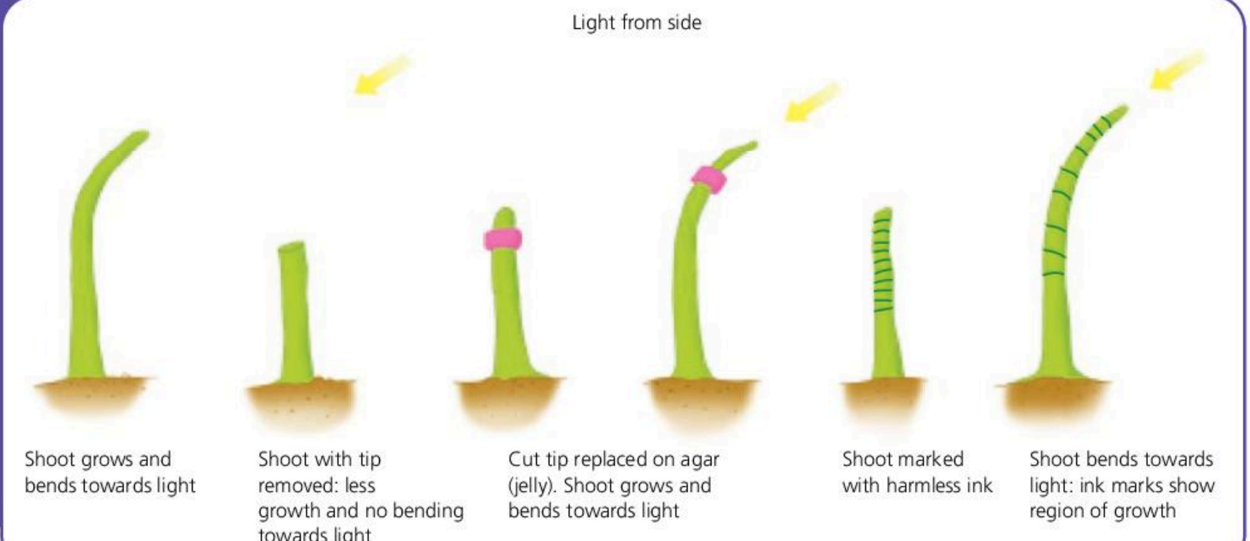
Roots are **positively gravitropic**:

- They grow into the soil, which provides a source of water and mineral ions.
- They provide an extensive system of support and anchorage for the plant.

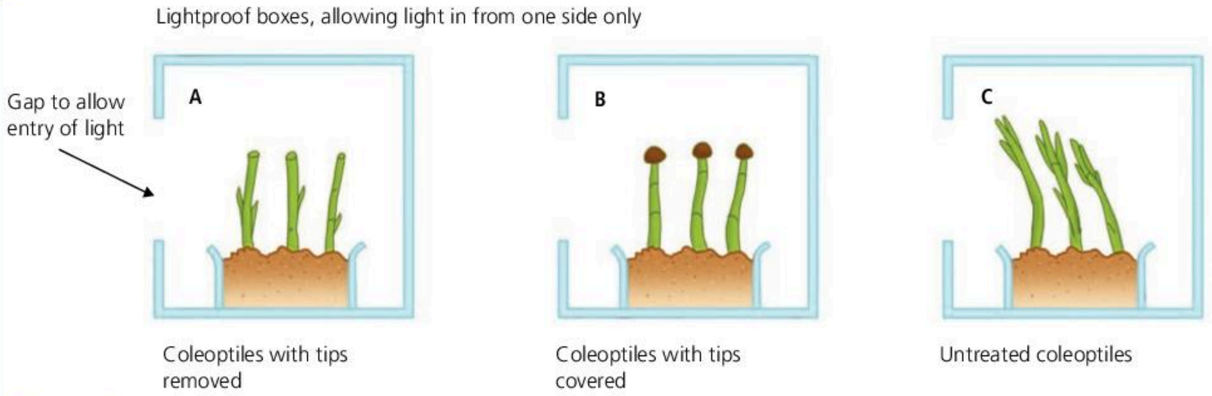
Shoots are **positively phototropic**:

- Leaves are in the optimum position to absorb light energy for photosynthesis.
- Flowers are lifted into the position where they are most likely to receive pollen. They will be held out into the wind, or may be more visible to pollinating insects.

EXPERIMENTS PROVIDE CLUES ABOUT PHOTOTROPISM



INVESTIGATION OF THE LIGHT-SENSITIVE REGION



Procedure

1. Three groups of coleoptiles (oat shoots) are treated as shown in A, B and C.
2. The coleoptiles are measured, and the lengths recorded.
3. The three groups are placed in the lightproof boxes and exposed to lateral (sideways) light for 2 or 3 days.
4. The coleoptiles are measured again, and the new lengths recorded.
5. Measure the coleoptiles and complete the table of results.

Box	A	B	C
Treatment of coleoptiles			
Mean length at start / mm			
Mean length at end / mm			
Change in length			
Direction of growth			

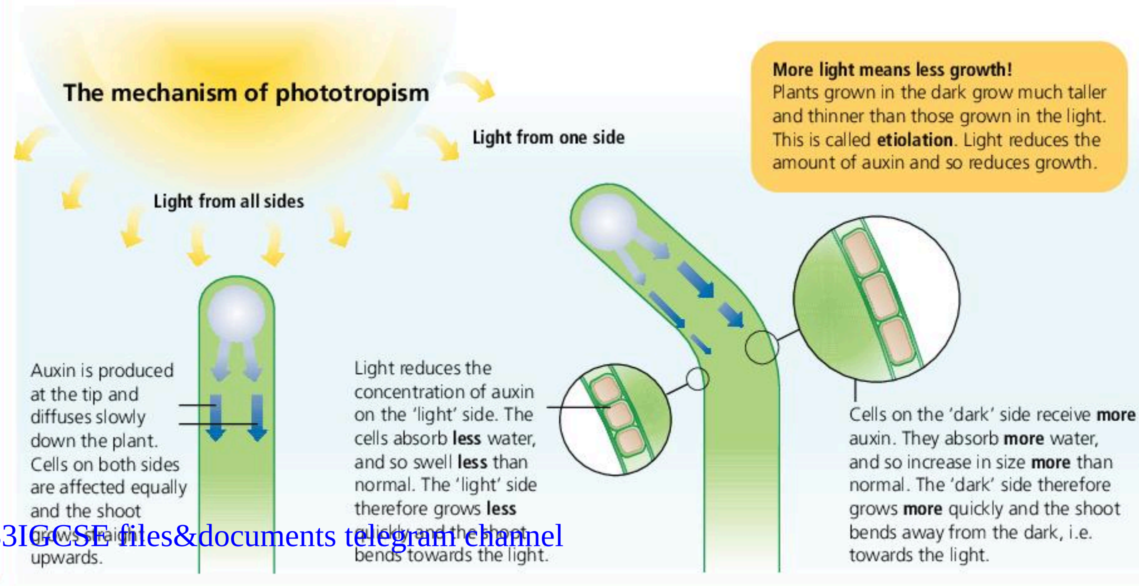
What conclusions can you draw? Explain your answers.

S Phototropism is controlled by auxin

Growth is a relatively slow response to a stimulus in animals (see page 166) and plants. Growth in plants is controlled by **plant hormones** or **plant growth substances**. These are sometimes grouped together as **'auxin'**, which means 'growth substance'. The following observations have been made about auxin:

- If the tip of a young shoot is cut off, the shoot can no longer respond to stimuli. This suggests that the tip produces the auxin.
- A shoot responding to a stimulus always bends *just behind* the tip. The auxin appears to travel from the tip (where it is made) to a region behind the tip (where it has its action).
- Auxin can diffuse back from the tip and can be collected in blocks of agar jelly. These blocks can then allow a decapitated tip to respond to light.
- When shoot tips are exposed to light from one side, auxin accumulates on the 'dark' side of the shoot. The auxin is somehow affecting the growth of the 'dark' side of the shoot.

The role of auxin in phototropism is shown below.

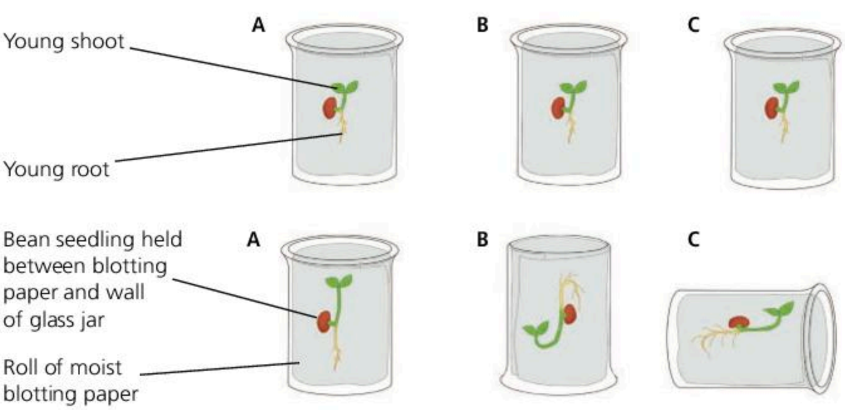


Plants respond to gravity: the mechanism of gravitropism

Many experiments can be carried out to investigate a plant's response to gravity. A useful organism for this type of experiment is the broad bean. Soaked beans germinate (see page 184) to provide obvious roots and shoots. These can be fixed inside a clear glass jar and their growth observed over a series of days. A simple experiment of this type is shown in the figure below.

It is obvious *why* the shoot grows away from gravity (i.e. is negatively gravitropic) because this means the leaves will be exposed to light energy for photosynthesis. It is more difficult to explain *how* the shoot grows in this way whilst the root is positively gravitropic. One suggestion is that the root and the shoot are responding to different growth substances, but scientists believe that the same growth substance (auxin) affects both roots and shoots. It seems likely that the root and shoot cells have **different levels of sensitivity** to auxin, so that the same concentration of this substance reduces cell expansion in roots but stimulates cell expansion in shoots.

INVESTIGATING HOW PLANTS RESPOND TO GRAVITY



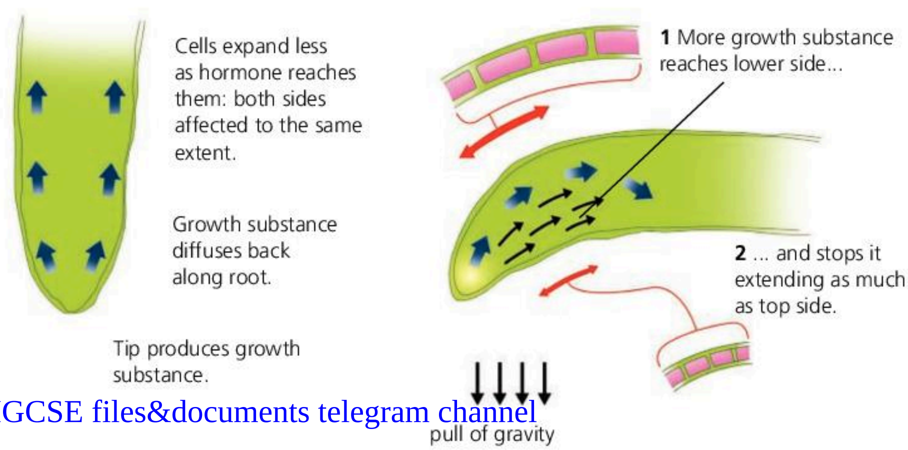
Procedure

1 Freshly germinated broad bean seedlings are fixed in position inside a glass jar.

2 Seedlings are allowed to grow for a further 5 days, with the jars placed as shown in **A**, **B** and **C**.

Root turns to grow downwards, shoot turns to grow upwards.

The mechanism of gravitropism



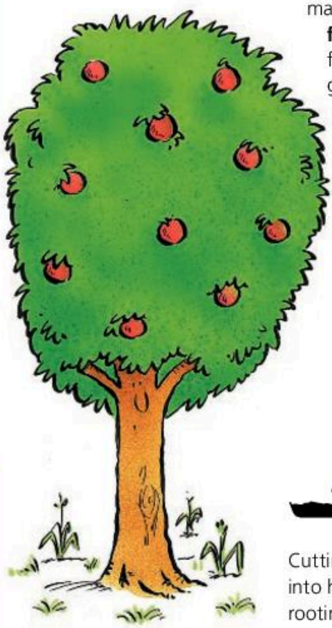
Take note: auxin inhibits (slows down) cell growth in roots, but stimulates (speeds up) cell growth in shoots!

Plant hormones have commercial uses

Humans put their knowledge of how hormones work in plants to good use. Being able to control the growth of plants is valuable, because plants are at the base of all human food chains. Some examples of the commercial use of plant hormones are illustrated above and in the diagram below.

Synchronised fruiting – spraying hormone onto fruits can make them develop at the same rate. This allows efficient picking of the crop by machine.

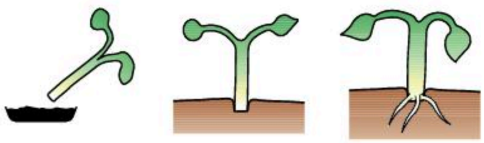
This happens naturally!
One ripe fruit in a bowl releases a hormone gas which makes the other fruit ripen.



Seedless fruits can be produced – a hormone spray can make fruits such as apples and grapes develop **without fertilisation**. No seeds are formed because no fertilisation has taken place. This also reduces the grower's dependence on pollinating insects.

Weeds can be killed – spraying with high concentrations of the synthetic hormone 2,4–D upsets normal growth patterns. Different plant species are sensitive to different extents, so this weed killing can be selective, e.g. grasses may be killed when shrubs survive.

Cuttings can be stimulated to grow roots. In this way a valuable plant can be cloned to provide many identical copies.



Agent Orange worked like this!
During the Vietnam war, hormone sprays were used to clear areas of vegetation and make bombing of bridges and roads easier. These sprays can also be used to clear vegetation from overhead power lines, where removal by hand could be expensive and dangerous.

Q

Copy and complete the following paragraphs.

1 The ____ of a growing shoot produces a plant hormone or ____. This substance causes cells behind the tip to ____ by the absorption of ____. When the shoot is lit from one side, more ____ accumulates on the dark side. As a result the cells ____ more and the shoot bends towards the light. This response is called ____ and offers several advantages to the plant, including greater access to light energy to drive the process of ____.

2 Plant hormones have many commercial uses. These include:

- the stimulation of ____ on cuttings, which allows growers to produce many ____ of valuable plants
- the control of ____, which allows growers to harvest economically with machinery
- the destruction of ____, which could otherwise compete with crops for ____, ____ and ____. Careful selection of hormone concentrations allows this destruction to be ____: only pest plants are killed.
- the production of ____ fruits because the hormone can make the plant develop a fruit without ____ taking place.

15.1 Antibiotics control bacterial diseases

OBJECTIVES

- To define the term **drug**
- To understand that fungi may produce antibiotics as part of their normal metabolic processes
- To define the term antibiotic
- To understand how penicillin works as an antibiotic
- To describe the large-scale production of antibiotics
- To understand the problems of antibiotic resistance

A drug is a chemical substance taken into the body where it can affect chemical reactions.

Natural antibiotics: penicillin

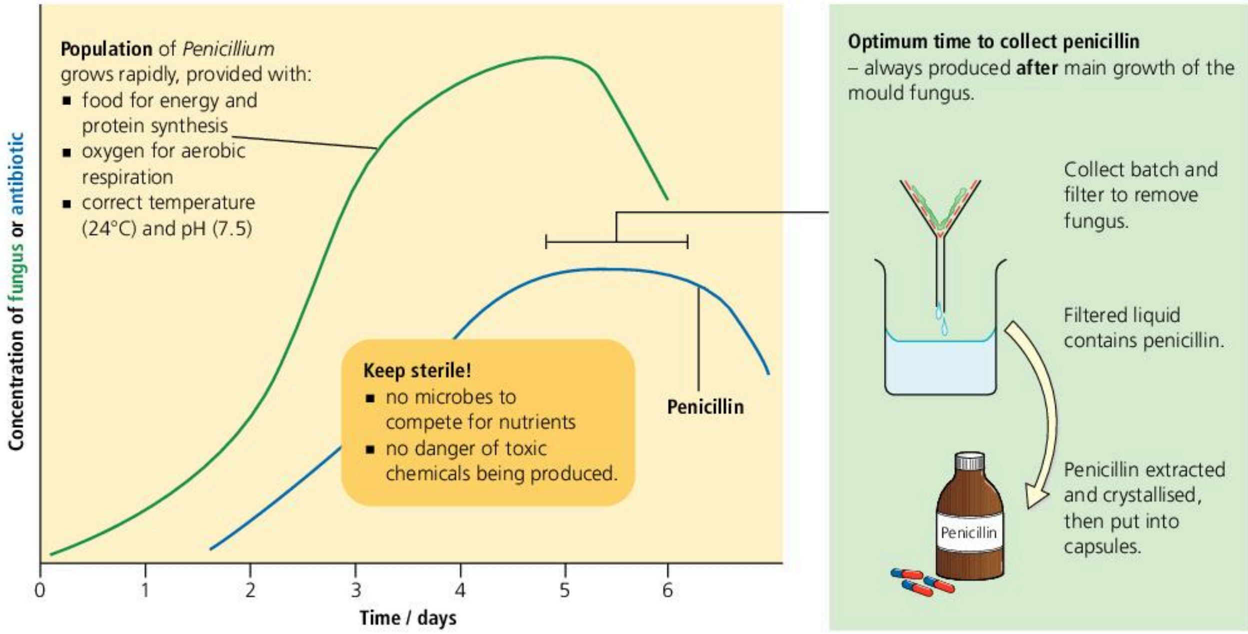
A fungus such as *Penicillium* absorbs food molecules from its environment, and then uses these molecules for its own metabolism. Sometimes a *Penicillium* mould will make substances that it secretes into its environment to kill off any disease-causing or competitive microorganisms. A product made by one microorganism to kill off another microorganism is called an **antibiotic**.

The first antibiotic to be discovered was called **penicillin** after the organism *Penicillium* that produced it. Antibiotics used in medicine work in various ways to inhibit the development of bacterial infections, without harming human cells.

- Penicillin prevents the bacterial cell walls forming (human cells do not have cell walls).
- Antibiotics only affect bacterial cells because other cell types are different to bacterial cells – viruses have no metabolism of their own, and do not make cell walls, for example.
- There is no benefit in taking antibiotics to treat viral diseases, such as influenza or the common cold.

Production of penicillin

The large-scale production of penicillin takes place in industrial fermenters. Penicillin is a **secondary metabolic product** – it is made when growth of the producer organism is slowing down rather than when it is at its maximum, as shown in the diagram below.



▲ Penicillin is produced by batch fermentation (see page 293)

S

Antiseptics are not the same as antibiotics

An **antibiotic** is used to **treat** a bacterial infection. An **antiseptic** can be used to **prevent** infection ('anti' = prevent, 'sepsis' = infection). Antiseptics are chemicals applied to the outside of the body, such as the skin, to kill microbes.

Disinfectants are also chemicals that kill microbes, but they are more powerful and are generally used on worksurfaces or lavatory bowls, where potentially harmful bacteria may be growing.

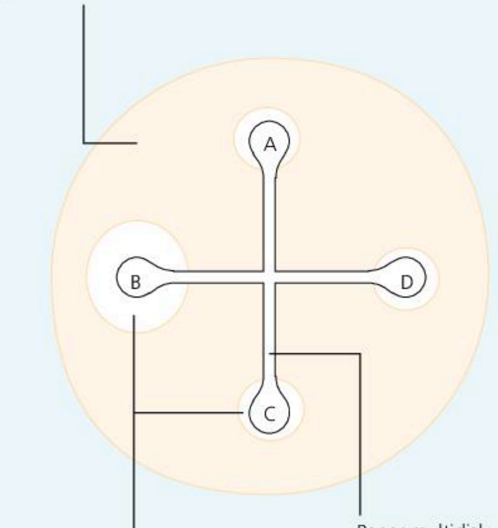
Antibiotic resistance

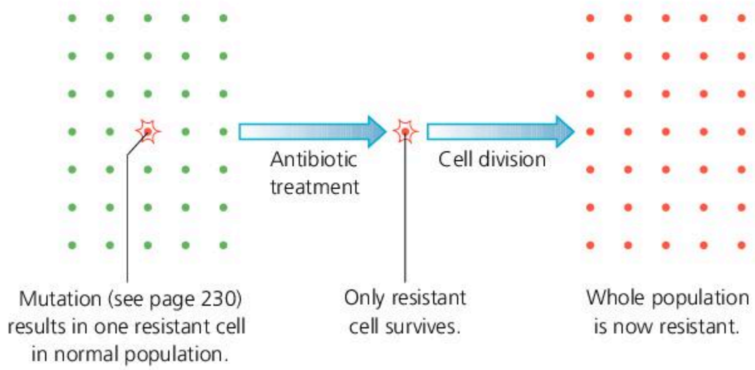
As the use of antibiotics increases, strains of bacteria that are **resistant** to the antibodies are developing, as shown below.

MRSA (methicillin-resistant *Staphylococcus aureus*)

Methicillin is a synthetic version of penicillin. It is a very useful antibiotic in controlling *Staphylococcus* and *Streptococcus* infections. Unfortunately, some bacteria have resistance to this antibiotic – they produce a protein which prevents the blockage of cell wall production.

The effectiveness of antibiotics can be compared using 'multidisks'





- The antibiotic is the **selection pressure** (see page 234).
- Resistance is the **survival advantage**.

NB The antibiotic does not **create** the resistance, but **selects** it in a population.

▲ Antibiotic-resistant strains of bacteria are formed by artificial selection. This is more likely to happen if:
- antibiotics are used unnecessarily
- people do not finish a course of prescribed antibiotics.

This allows some of the bacterial population to recover, and possibly develop strains that are resistant to the antibiotic.

Q

1. Distinguish clearly between the following pairs of terms:
   - **a** antiseptic and antibiotic
   - **b** antibiotic and antibody
   - **c** resistance and immunity
2. Purified penicillin is normally taken orally (by mouth). The crystals of the drug are enclosed in a capsule for distribution. Suggest three important properties of the material used to make the capsules.

16.1 Reproduction is an important characteristic of living organisms

OBJECTIVES

- To understand the importance of reproduction
- To know that there are different methods of reproduction

It is possible to tell whether an organism is living or not by testing for certain characteristics (see page 2). Included among these characteristics is **reproduction**, although reproduction is *not* necessary for an *individual* organism to survive.

However, no individual lives forever and if the *species* is to survive, the individuals must replace themselves before they die. This generation of new individuals is called **reproduction**.

Reproduction: a summary

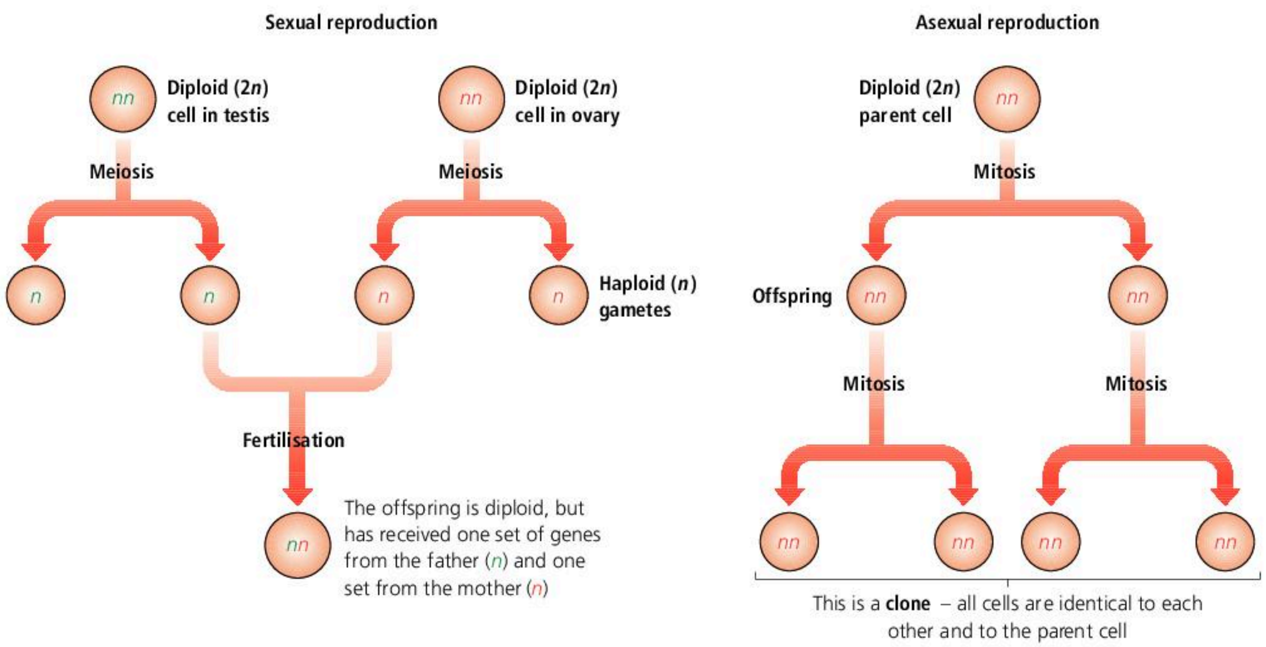
Living organisms can pass on their characteristics to the next generation (**reproduce**) in two ways.

Sexual reproduction:

- requires two organisms of the same species, one male and one female
- each individual produces sex cells (**gametes**)
- sexual reproduction always involves **fertilisation** – the fusion of the gametes to produce a zygote
- offspring receives some genes from each parent, so shows a mixture of parental characteristics
- each of the offspring is different to other offspring and to the parents.

Asexual reproduction:

- involves only one parent organism
- all the characteristics of this one parent are passed on to all of the offspring
- asexual reproduction produces genetically identical offspring from one parent
- many organisms reproduce asexually when conditions are favourable (e.g. when there is plenty of food), and build up their numbers quickly.



▲ Organisms can reproduce sexually or asexually

Sexual reproduction provides variation

The plant life cycle (page 178) and the human life cycle (page 188) both show sexual reproduction, which depends on the fusion of male and female **gametes**. Sexual reproduction consumes energy that otherwise could be used by the parent. However, it also leads to **variation** (see page 232). Sexual reproduction occurs in all advanced organisms.

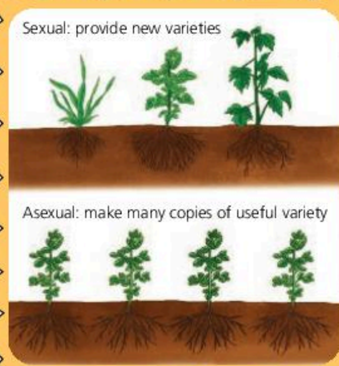
Asexual reproduction can be advantageous

Plants arrive in new locations by the dispersal of seeds. There are occasions, however, when a plant would benefit from simply producing many copies of itself. For example:

- When a single plant arrives in a new habitat, it can occupy this habitat if many copies can be produced quickly.
- When a plant is well suited to its habitat, any variation might be a disadvantage.

Sexual and asexual reproduction compared

Sexual reproduction and vegetative propagation both have advantages and disadvantages. Many plants make the best of both worlds, and reproduce both sexually and asexually.



	Advantage	Disadvantage
Sexual	■ Variation, so new features of organisms may allow adaptation to new environments	■ Two parents needed ■ Fertilisation is random, so harmful variations can occur
Asexual	■ Only one parent needed ■ Rapid colonisation of favourable environments	■ No variation, so any change in environmental conditions will affect all individuals

. . . and what's best for growing crops?

Sexual: new varieties of a plant can be developed. These might give a better yield, or tolerate dry conditions for example.

Asexual: varieties with useful features can be cloned to produce large numbers of identical crop plants.

BUT BE CAREFUL:
A clone of plants could all be susceptible to the same disease. For example, great hardship occurred in the Irish Potato Famine of 1845 when almost all of the potato crop was infected by the potato blight fungus.

1 Which of the following is the best definition of a **clone**?

A A cell produced by asexual reproduction

B A group of cells produced without fertilisation

C A group of cells which are genetically identical

D A cell which is identical to its parent cell

16.2 Reproduction in flowering plants: flowers

OBJECTIVES

- To understand the part played by flowers in the life of a flowering plant
- To be able to identify the parts of a typical flower
- To be able to state the functions of the parts of a flower

An individual plant, like any other living organism, eventually dies. For a *species* of plant to survive, the *individual* plants must be able to replace themselves. This is the process of **reproduction**, an essential part of the life cycle of the plant.

Sexual reproduction in plants

Flowering plants, as their name suggests, are able to reproduce using highly adapted structures called **flowers**. The life cycle of a flowering plant is outlined below.

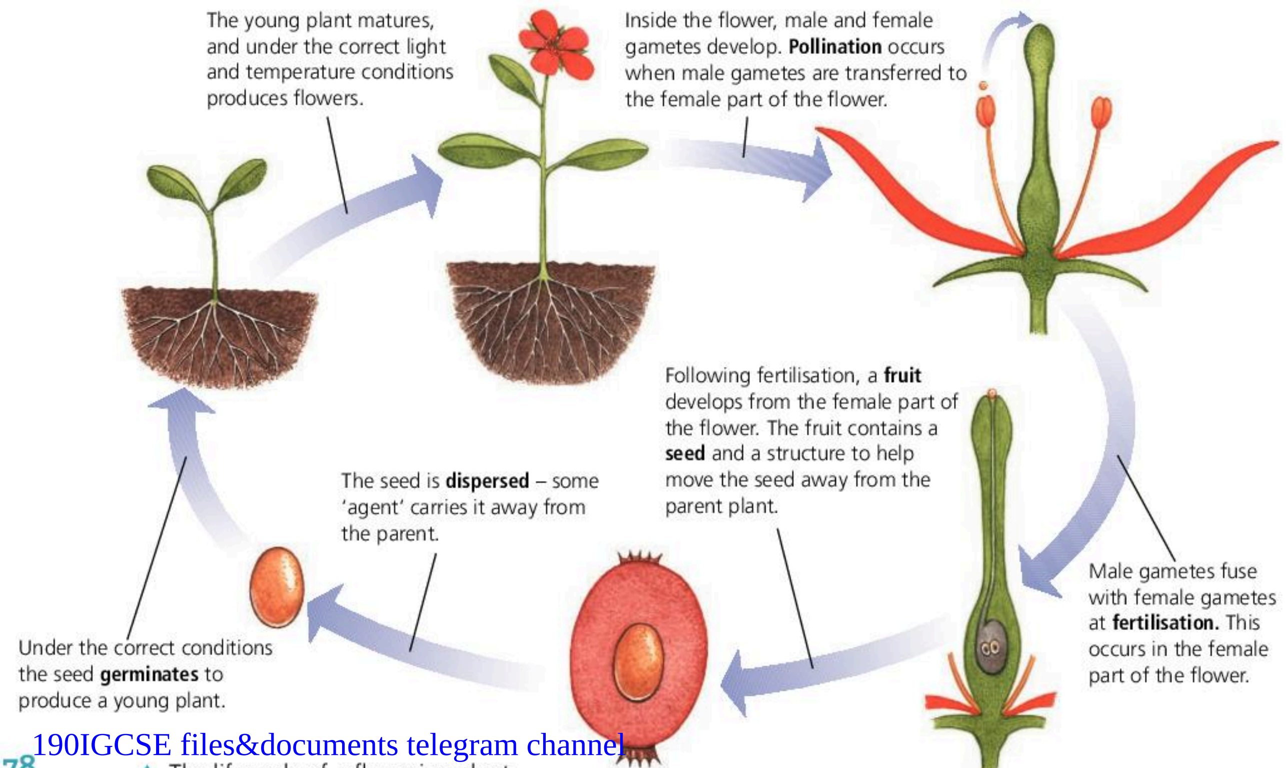
Flowering plants reproduce sexually. The following list shows the stages that can be recognised in the reproduction of flowering plants.

1. The young plant develops reproductive organs.
2. Sex cells (gametes) develop inside the reproductive organs.
3. The male sex cells are transferred to the female sex cells.
4. Fusion of male and female sex cells (fertilisation) occurs, and a zygote is produced.
5. The zygote develops into an embryo.
6. The embryo grows into a new young plant, and the cycle starts all over again.

Whereas animals move around freely (they are **motile**), plants live in a fixed position. So, in plants:

- Male gametes may have to be carried some distance to meet female gametes.
- Young plant embryos may have to be carried some distance to get away from their parents!

Most plants are **hermaphrodite**, that is, they have male and female sexual parts on the same individual. This means that the male gametes only have to travel a short distance to the female gametes.



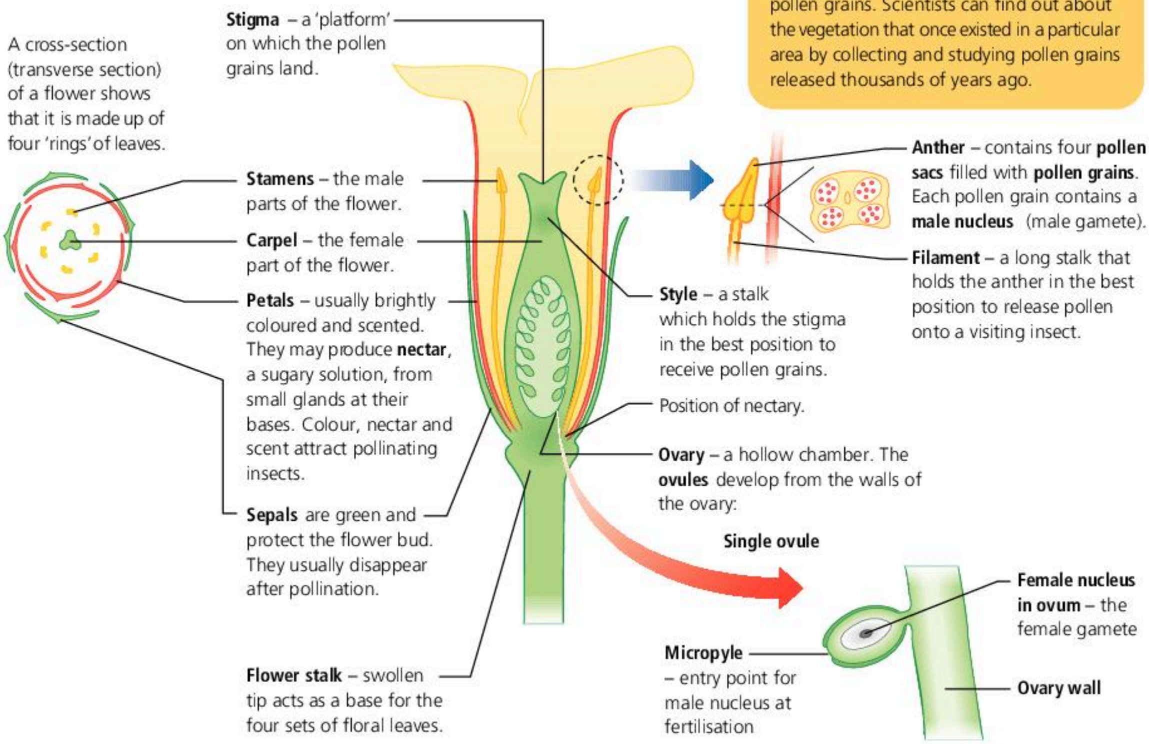
▲ The life cycle of a flowering plant

The formation of flowers

A flower is formed from a bud, which is a collection of cells at the end of a flower stalk. The cells receive hormone messages from the main plant body, and gradually develop into four rings of specialised leaves – the flower. These have the sole function of forming sex cells and making sure that fertilisation occurs.

The structure of a typical insect-pollinated flower is shown in the diagram below.

Each plant species has its own uniquely shaped pollen grains. Scientists can find out about the vegetation that once existed in a particular area by collecting and studying pollen grains released thousands of years ago.



▲ The structure of a flower: the convolvulus (morning glory). A flower grows from a flower bud and is specialised to produce and release the male and female gametes.

Q

1 Look at the table on the right. Match each part of a flower to its function. Write the letter and number to show your answer, for example, **a–5**.

Flower parts	Functions
a pollen	**1** to support the anther
b flower stalk	**2** to secrete a sugary solution
c style	**3** to contain the female gametes
d filament	**4** to protect the flower in bud
e anther	**5** to deliver the male gamete
f sepal	**6** to form a base for the flower
g petal	**7** to hold up the stigma
h nectary	**8** to attract insects
i ovary	**9** to produce pollen
j stigma	**10** to receive pollen

2 Copy and complete the following paragraph.
The life cycle of a flowering plant has a number of stages. A young plant develops when a seed ____. The plant matures until it produces a ____ which is a collection of leaves specialised for ____. Male gametes are transferred to the female part of the flower by ____ and fuse with female gametes at ____. Following this process the ovary develops into a ____ which contains a ____ and a structure to help move it away from the parent plant. This process, which is called ____, requires some agent or vector to remove the seed from the parent plant.

16.3 Pollination: the transfer of male sex cells to female flower parts

OBJECTIVES

- To define the term pollination
- To understand the difference between self-pollination and cross-pollination
- To describe how flowers may be adapted to pollination by insects or wind
- To describe how honey bees are adapted as insect pollinators

Self-pollination and cross-pollination

For sexual reproduction to occur, the male gametes must be transferred to the female part of the flower – this transfer is the process of **pollination**. The transfer may come about within the same flower (self-pollination) or from one flower to another of the same species (cross-pollination), as shown in the diagram on the right.

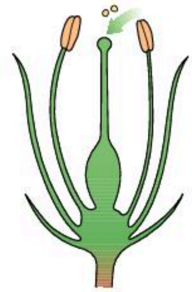
Cross-pollination offers many advantages, and some species make sure that it happens.

- Some have special proteins on the surface of the stigma that prevent pollen tubes forming if the pollen comes from the anthers of the same plant. These are **self-sterile** plants.
- In some plants, the anther and the stigma are so far away from one another in the flower that it is not very easy for pollen to travel from the anther to the stigma of the same flower.
- A few plants, such as ash, willow and holly, have separate male and female plants.

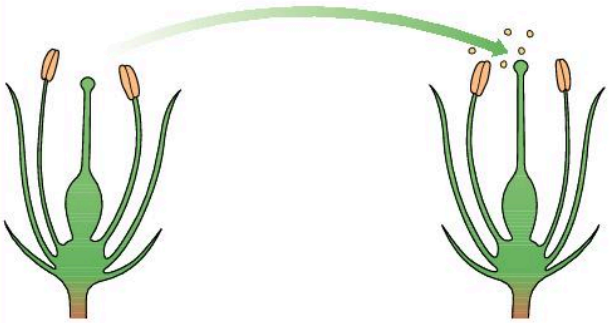
Pollination by wind and insects

Whether self- or cross-pollination occurs, some agent or vector is needed to carry the pollen grains from the anthers to the stigma. This agent is most often an insect or the wind. Flowers show many adaptations to successful **insect pollination** or **wind pollination**. Some of the insects that act as pollinators have also become adapted to make the most of their relationship with flowers. The honey bee, for example, feeds on nectar and pollen. The table on the opposite page shows how some plants are adapted for pollination by insects or plants.

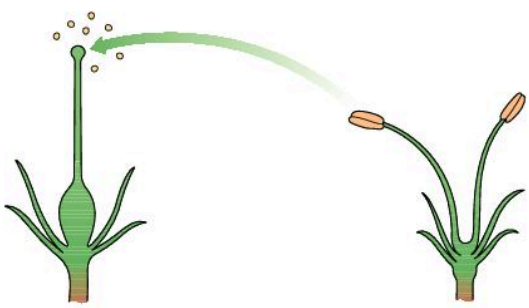
Pollination



In **self-pollination,** pollen is transferred from anther to stigma **of the same plant**. This is very efficient (the pollen doesn't have to travel very far) but does not offer much chance of genetic variation (see page 230).



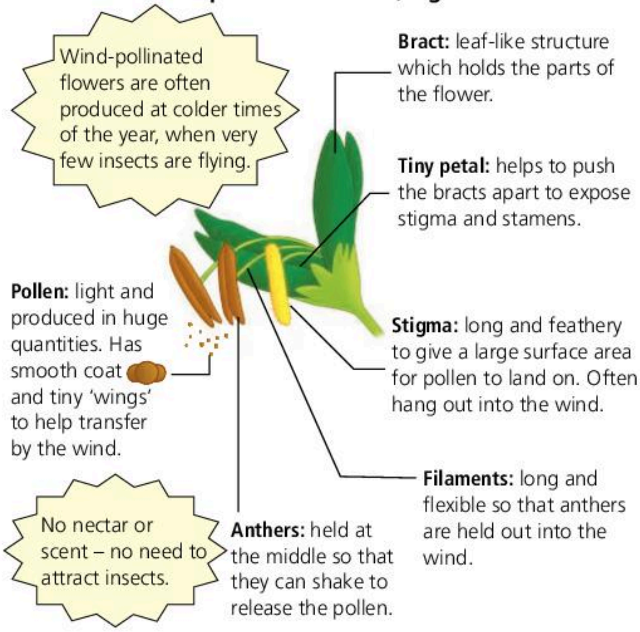
In **cross-pollination,** pollen is transferred from anther to stigma **of another plant of the same species**. This is risky (pollen may never reach the other plant) but offers a greater chance of genetic variation than self-pollination.



Cross-pollination is the only possibility for flowers that are not hermaphrodite. Sometimes a plant has only male or only female flowers. This is **very** risky, since plants of the opposite sex may not be nearby, but offers a very great chance of genetic variation (page 230).

▲ Wind-pollinated flowers such as this grass have small, inconspicuous petals. The anthers and stigmas hang outside the flower.

Wind-pollinated flower, e.g. maize



Part of flower	Insect-pollinated (e.g. convolvulus)	Wind-pollinated (e.g. grass)	Reason
Petals	Usually large, brightly coloured, scented, often with nectaries. Guide lines may be present.	Small, green or dull in colour, no scent or nectaries	Insects are attracted to colour and scent. Guide lines direct insects to nectaries, past anthers.
Anthers	Stiff, firmly attached and positioned where insects must brush against them	Hang loosely on long thin filaments	Wind is more likely to dislodge pollen from exposed, dangling anthers than from enclosed ones.
Pollen	Small amounts of large, sticky grains	Enormous quantities of light, smooth pollen grains	Sticky grains attach to hairs on insect's body. Larger amounts from wind-pollinated flowers mean pollination is more likely.
Stigma	Usually flat or lobe-shaped, and positioned where insect must brush against them	Long and feathery, and hanging outside flower	Feathery stigmas form a large network to catch pollen being blown past the flower.

EXPERIMENTAL DESIGN: USING MODELS

Scientists use **models** of living organisms to study one or two features of the organism. Living organisms may have features that other organisms can detect, but that humans cannot. These might affect the results of an experiment, so a model is easier to study.

Two students were interested in why honey bees visit wallflowers. One of them believed that the *colour* of the flower attracted the bees but the other was convinced that it was the *scent*.

Design an experiment to determine whether colour or scent is the more important stimulus to the honey bees.

In your design:

- devise suitable models for the wallflowers
- clearly state the independent (input) and the dependent (outcome) variables
- suggest any variables that should be fixed, and say how you would fix them
- consider whether there are any controls that you might use
- draw a table that would be suitable for the presentation of your data.

Q

1 State which of the following is unlikely to be involved with pollination in a Malaysian jungle.

A fruit bat **B** sunbird **C** jungle cat **D** great blue butterfly

16.4 Fertilisation and the formation of seed and fruit

OBJECTIVES

- To define the process of fertilisation
- To understand the role of the pollen tube
- To recall which parts of a flower form the fruit
- To understand that a seed contains a food store as well as an embryo

Fertilisation follows pollination

Pollination is complete once the pollen released from an anther has landed on the stigma of the same or another flower. The next step in the plant's reproductive process is **fertilisation**, the fusion of the male and female gametes. The diagram on the right shows how the nucleus from the pollen grain travels down a **pollen tube** to combine with the nucleus of the ovum.

The formation of fruit and seed

After the male nucleus has fused with the ovum, the resulting **zygote** divides many times to produce an **embryo**. The development of a seed and the structure of the embryo are described in the diagram on the opposite page.

Once fertilisation is complete, the developing seed sends hormone messages to the flower, and a number of changes take place:

- The sepals and petals wither away, and may fall off.
- The stamens, stigma and style wither away.

These structures have now completed their function, and would use up valuable food compounds if they remained.

- The wall of the ovary changes. It may become hardened and dry, or fleshy and succulent, and in the wallflower it forms a leathery pouch.

The ovary is now called a **fruit**. A fruit is a fertilised ovary, and has the function of dispersing the seeds away from the parent plant, which helps to reduce competition for light, water and minerals.

Note that only one fertilisation is shown here. Each ovule needs its own pollen grain and pollen tube to be fertilised. A plum has only one ovule in each ovary, a wallflower has a few tens and a poppy may have thousands of ovules in one ovary!

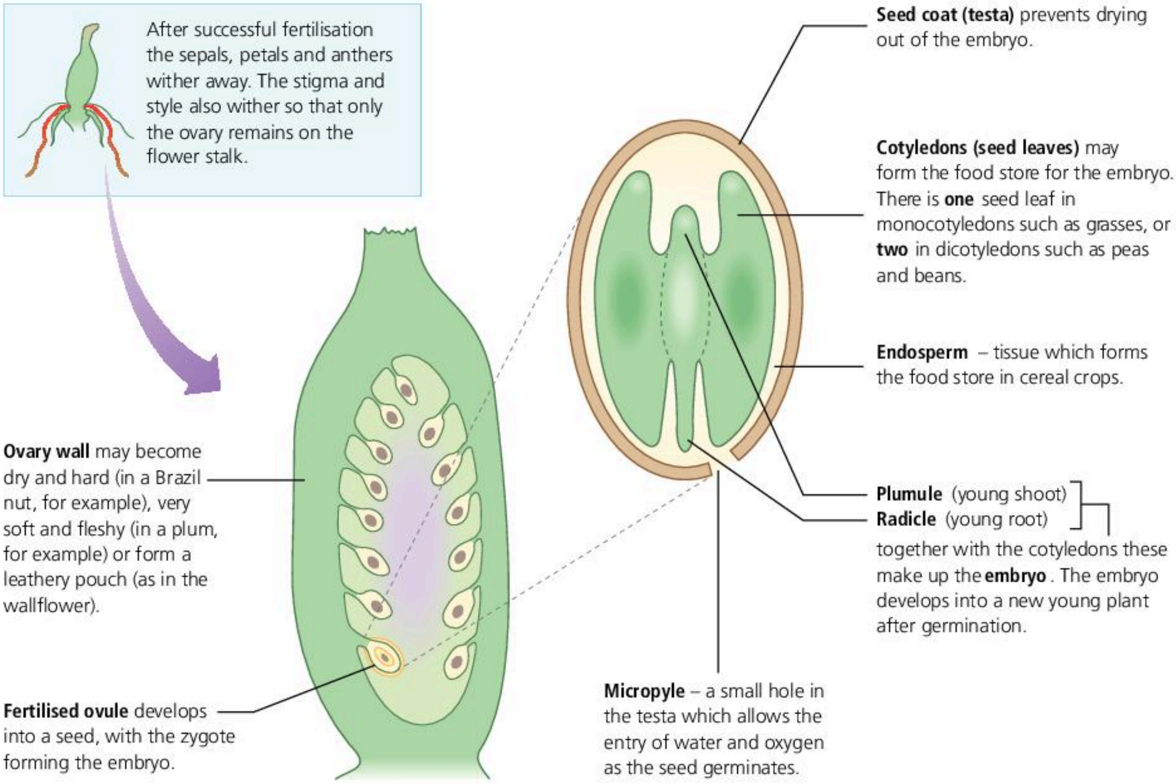
Stages in the development of a fruit


▲ Tomato flowers – the petals are still obvious


▲ After fertilisation, the petals have fallen off, the stigma and style have withered and the carpel is beginning to swell


▲ In the ripe fruit, the ovary wall is swollen and succulent. What do you think is the purpose of the bright red colour?

The formation of seed and fruit following fertilisation



Remember!

- The **carpel** becomes the **fruit**.
- The **ovule** becomes the **seed**.

Fruit or vegetable?

If it's been formed following **F**ertilisation it's a **F**ruit; if there's no sex in**V**olved it's a **V**egetable. Potatoes and carrots are vegetables but tomatoes are fruits.

Not all seeds are edible

Seeds contain stores of carbohydrate, fat, protein, minerals and other food compounds. These are used up by the embryo as it develops into a young plant, but also form an excellent food source for animals (including humans). But note …

- Uncooked castor oil seeds contain a deadly poison, **ricin**, which was used to kill the Romanian dissident Georgi Markov.
- Almonds contain **cyanide**. Don't eat too much marzipan since this is made from almond paste!

Q

1 In one sentence, explain the difference between pollination and fertilisation.

2 Draw a simple diagram of a typical hermaphrodite flower. On your diagram label:
  a the parts that fall off after fertilisation
  b the parts that develop into a fruit.

3 Define the word 'seed'.

4 Classify each of the following as:
  a fruit
  b seed or
  c neither fruit nor seed.
  Tomato, cucumber, Brussels sprout, baked bean, runner bean, celery, pea, grape

5 Two students suggested that the wallflower cannot produce fruit unless pollination has taken place. Their teacher showed them how to prevent bees reaching the flowers by covering the flowers in a fine mesh bag, and how to transfer pollen with a fine paintbrush.
  a Describe how the students could carry out an experiment to test their hypothesis.
  b Suggest how they could modify their experiment to test whether self- or cross-pollination produced more seeds in the wallflower.
In your answer, be sure to describe any controls which they could include, and any steps they could take to ensure that their results were valid.

16.5 Germination of seeds

OBJECTIVES

- To define the term germination
- To understand the conditions required for germination
- To describe the structural changes that accompany germination of the broad bean

Dispersal allows plants to spread their seeds so they can develop without competition from their parents. A seed is made up of an embryo and a food store, all enclosed within a seed coat. If environmental conditions are suitable, the embryo will begin to use the food store in the seed and grow into a new young plant. This development of a seed to a new young plant is called **germination**.

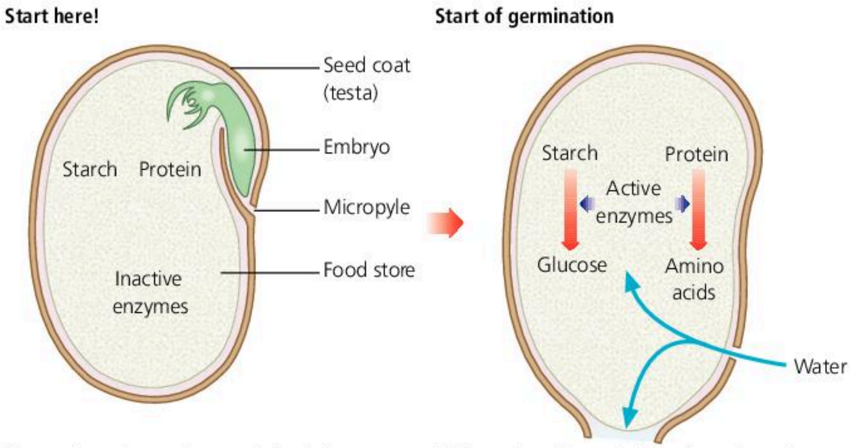
Conditions for germination

A seed needs the following to germinate:

- a **supply of water**
- **oxygen** for **aerobic respiration** (see page 122)
- a **temperature suitable** for the enzymes involved in germination (see page 40).

These requirements are explained more fully in the diagram below.

Some seeds have other requirements as well as the ones shown in the diagram. A few need particular conditions of light (for example, lettuce).



Dormant seed – embryo and food stores are surrounded by an impermeable seed coat. The micropyle is the only gap in the seed coat.

Water enters through the micropyle and:

- activates enzymes to convert insoluble stores to soluble foods
- makes tissues swell so that the testa is split open.

Enzymes work at their **optimum temperature**.

Water and oxygen enter through gaps in the testa. Oxygen and glucose enable aerobic respiration, which releases energy. The embryo is able to grow as it receives raw materials and energy.

Environmental factors that affect germination are very similar to those that affect enzyme activity. This indicates that **germination is a process controlled by enzymes** (page 40).

Dormancy will continue if the embryo in the seed does not experience the right conditions:

- if kept in anaerobic conditions
- if kept dry
- if kept cool.

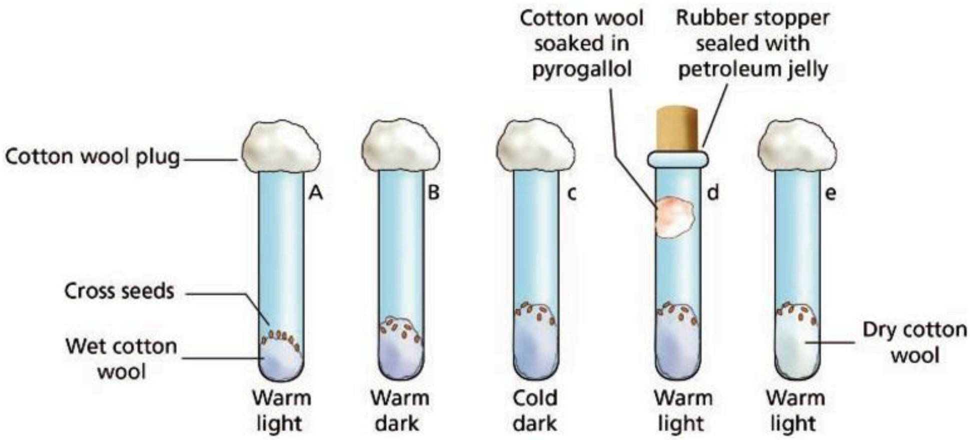
Oxygen and water cannot reach the embryo if the testa remains impermeable. Some seeds must pass through an animal's gut (where digestive juices are present) before the testa is weakened enough for the seeds to germinate.

Seeds kept dry in a vacuum, as in seed packets, can be stored for long periods.

Dormancy

If a seed does not experience ideal conditions for germination immediately, it will not die. Most seeds can survive long periods of poor conditions, only germinating when conditions improve. Seeds survive in a resting state called **dormancy** during which they use hardly any food. The very low water content of seeds allows them to remain dormant, and the availability of water is one of the conditions that allows a seed to escape dormancy and germinate.

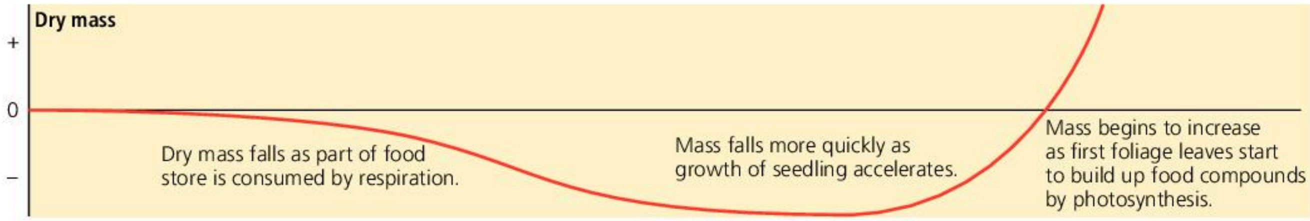
FACTORS AFFECTING THE GERMINATION OF SEED



Procedure

1. The five tubes are set up as shown in the diagram.
2. Tubes A, B, D and E are kept at room temperature (about 21°C). Tube B is wrapped in a lightproof cover.
3. Tube C is placed in a refrigerator.
4. After 48 hours, the number of germinated seeds is recorded.

Pyrogallol is very corrosive. The tube with pyrogallol will be prepared by your teacher.



▲ Germination of the broad bean. Dry mass is used as a measure of the food stores because wet mass would include water absorbed from the soil, and the amount of water absorbed and lost can vary greatly.

Q

1. Copy and complete the following paragraph.
Before germination, a seed must absorb _____ from the soil. The seed coat is impermeable to this substance, and it enters through a hole called the _____. This absorption causes the seed to _____ and split the _____. The gas _____ can now enter, which is necessary for _____. The energy from this process, together with soluble food compounds, allows the _____ to grow. The young root or _____ appears first and grows downwards by _____, providing _____ and absorbing water and minerals for the seedling. The young shoot or _____ appears next. This grows upwards and eventually bursts through the soil. The first _____ leaves develop and the seedling is able to produce its own food by _____.
2. How would you attempt to prove that germination is controlled by enzymes?

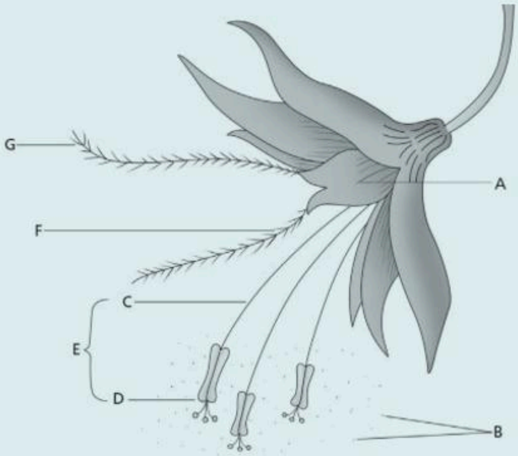
Questions on plant reproduction and growth

1 Which part of a flower produces pollen?
- **A** Ovary
- **B** Anther
- **C** Stigma
- **D** Petal [1]

2 Which part of the flower receives pollen?
- **A** Ovary
- **B** Anther
- **C** Stigma
- **D** Receptacle [1]

3 Which **one** of the following is not a condition necessary for the germination of a bean seed?
- **A** Water
- **B** Warmth
- **C** Oxygen
- **D** Light [1]

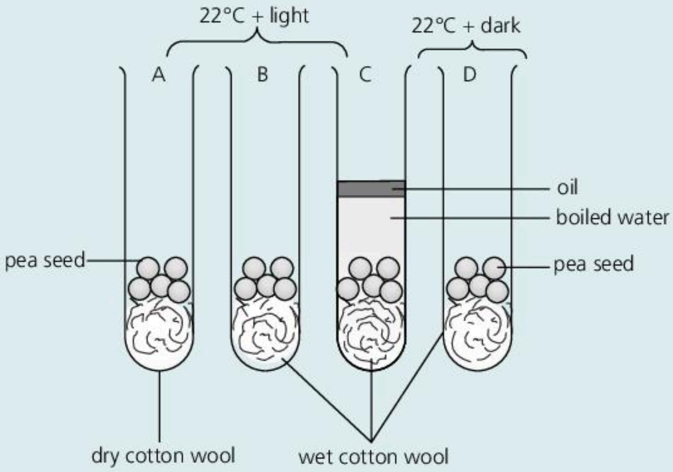
4 The diagram below shows a single grass flower.



a Label the structures **A–G** on the diagram. [7]

b State whether the flower is wind or insect pollinated. Explain your answer. [3]

5 a All seeds need oxygen, water and a suitable temperature to germinate. Pea seeds will germinate at a temperature of 22°C. Light and dark conditions have no effect on pea seed germination. The diagram shows an experiment on germination of pea seeds.



i Complete **Table 1** below. [4]

Tube	Would seeds germinate? (Write YES or NO)
A	
B	
C	
D	

▲ Table 1

ii Germination is quicker if the temperature is raised to 30°C. Explain why. [2]

b **Table 2** show how the dry mass of barley seedings changed over the first 35 days after sowing.

Time after sowing / days	0	7	14	21	28	35
Dry mass / g	4.0	2.8	2.8	4.4	9.6	17.8

▲ Table 2

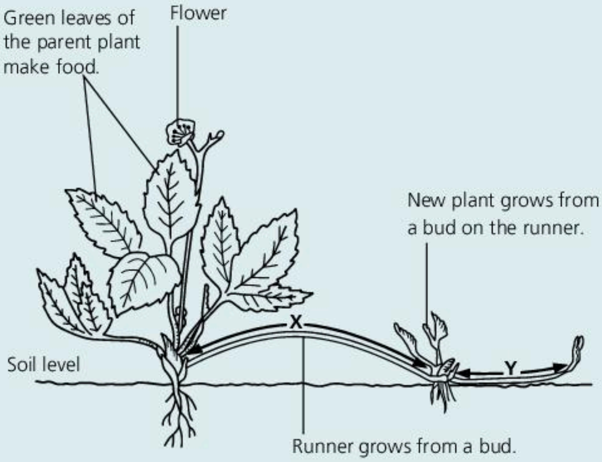
i Plot these results in a line graph. [4]

ii How many days after sowing did the barley seedings regain their original dry mass? [1]

iii How many days after sowing did the barley seedings TREBLE their original dry mass? [1]

iv Explain why dry mass falls in the early stages of germination. [2]

6 Strawberry plants are able to reproduce asexually by means of runners. A runner produced in early summer gives rise to a new plant, which in turn produces a runner to give rise to a second new plant and so on. This process is summarised in the diagram.



a Ten different strawberry plants were taken and the length of the runners **X** and **Y** (shown in the diagram) were measured. The results are shown in the table.

Plant number	Length of runner X / mm	Length of runner Y / mm
1	400	200
2	350	280
3	420	260
4	610	260
5	640	340
6	600	250
7	340	240
8	460	270
9	600	250
10	520	290

i Using the data in the table, calculate the average (mean) lengths for runner **X** and for runner **Y**.
Show your workings. [2]

ii Calculate the difference in mean length between runner **X** and runner **Y**.
Show your workings. [2]

iii The lengths of the runners **X** in the table vary considerably. Suggest **two** possible causes of this variation. [2]

iv Predict how the results would be different from those shown in the table if measurements were taken of the runners between the second and third new plants. Explain why there would be this difference. [2]

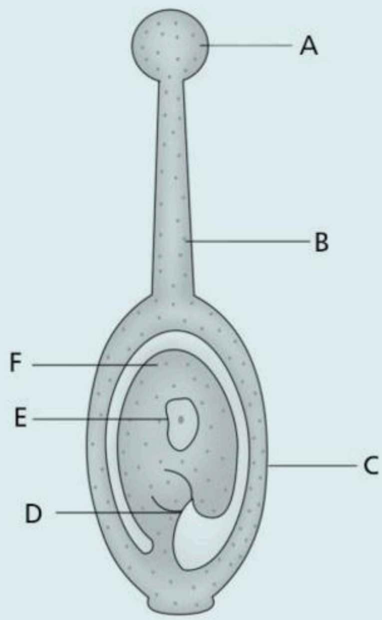
b What else has to happen to the plant shown in the diagram for the process of asexual reproduction to be completed? [1]

c A fruit grower found that one particular strawberry plant survived two weeks of heavy winter frosts. Suggest why the grower would be more likely to obtain frost resistant strawberry plants by the asexual method shown in the diagram than by using seeds produced by the flower. [2]

d **i** Describe briefly how the strawberry plant produces food to send to its developing strawberries. [2]

ii Name the plant tissue through which soluble food products are transported along the runner to the new plants. [1]

7 The diagram below shows a carpel – the female part of a flower.



a State which letter corresponds to:
i the stigma
ii the ovary
iii the micropyle. [3]

b Copy and complete the diagram to show how a pollen grain fertilises the ovule. [2]

8 **a** Define the term **cross pollination**. [2]

b Suggest the possible advantage to the species of this process. [2]

16.6 Reproduction in humans

OBJECTIVES

- To define the term 'sexual reproduction'
- To know the steps involved in sexual reproduction
- To describe the human reproductive systems

Reproduction may be sexual or asexual. In **sexual reproduction**, genetic information from two parents combines to produce a new individual. Humans, like all other mammals, only use sexual reproduction. Sexual reproduction produces individuals that are different from each other. The process involves a number of stages, as shown in the diagram below.

The female reproductive system

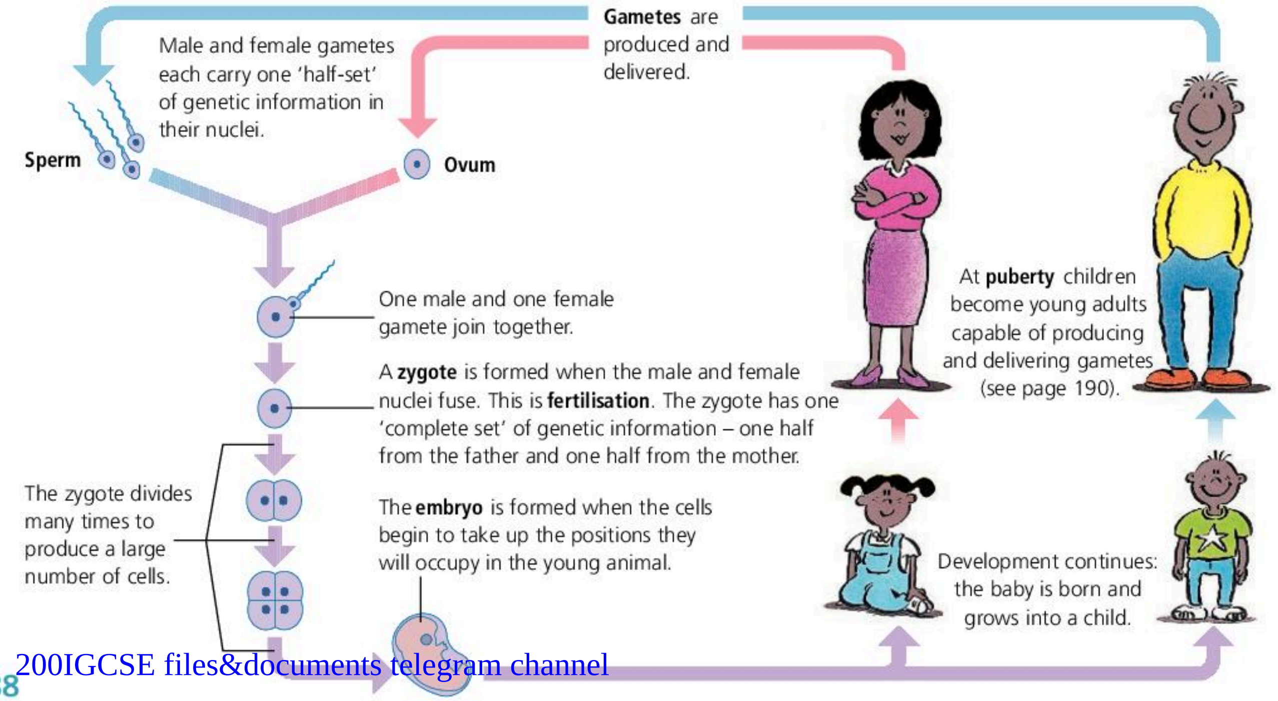
In addition to producing female gametes, the female reproductive system receives male gametes. It provides a site for fertilisation and for the development of the zygote. The female gametes, called **ova**, are produced one at a time by the two **ovaries**. The ovum travels along the **oviduct** or **Fallopian tube** towards the **uterus**. It may be fertilised while in the oviduct. The zygote grows and develops into a baby in the uterus. The female reproductive system is shown in the diagram on page 190.

The male reproductive system

The male reproductive system has two functions:

- to manufacture the male gametes
- to deliver them to the site of fertilisation.

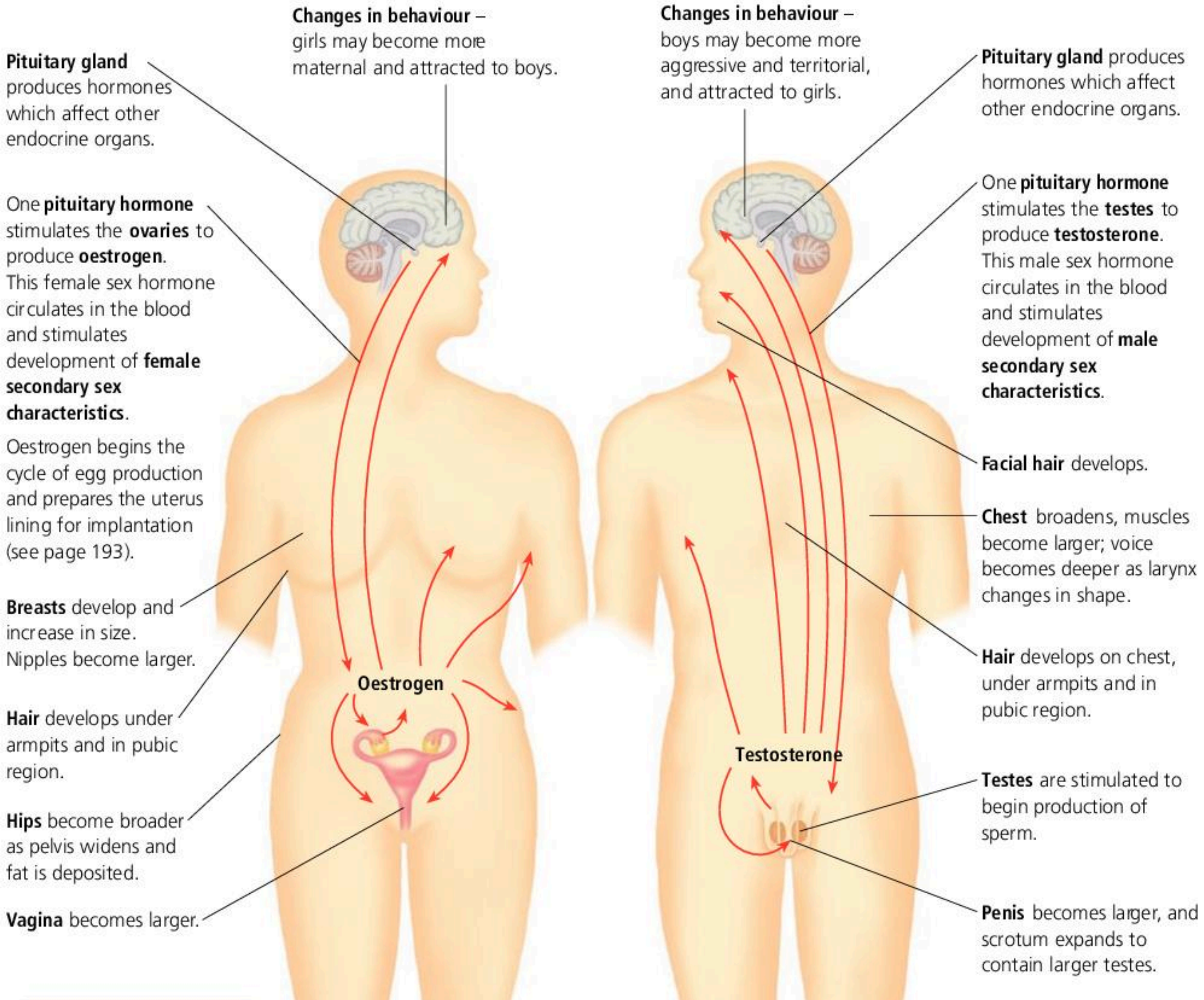
The male gametes, called **spermatozoa**, or **sperm** for short, are manufactured in the **testes**. These are enclosed in a sac of skin, the **scrotum**, which hangs outside the body between the legs. This position helps protect the testes from physical damage, and more importantly keeps them at a temperature 2–3°C lower than body temperature, ideal for development of the sperm. The sperm are delivered inside the female body through a series of tubes that eventually release the sperm from the tip of the **penis**. The male reproductive system lies very close to the part of the excretory system that removes urine from the body; indeed the urethra is a tube used to expel urine and seminal fluid from the body. A valve prevents this happening at the same time! The two systems together are called the **urinogenital system**. The male reproductive system is shown in the diagram on page 190.



Hormones control puberty in humans

Hormones control long-term processes, and often have widespread effects on the body. **At puberty** a person becomes physically able to reproduce. The development of sexual maturity is a good example of a hormone-controlled process.

As a young person develops physically, certain signals are processed by the brain, which then instructs the pituitary gland to stimulate the **primary sex organs** – the testes in males and the ovaries in females. Sex hormones – **oestrogen** (in females) and **testosterone** (in males) – are released into the bloodstream and circulate throughout the body. They only affect the target organs which have receptors that recognise them. These target organs then carry out responses, such as the growth of body hair, which may continue for many years. The effects of these hormones at puberty are explained further in the diagram below.

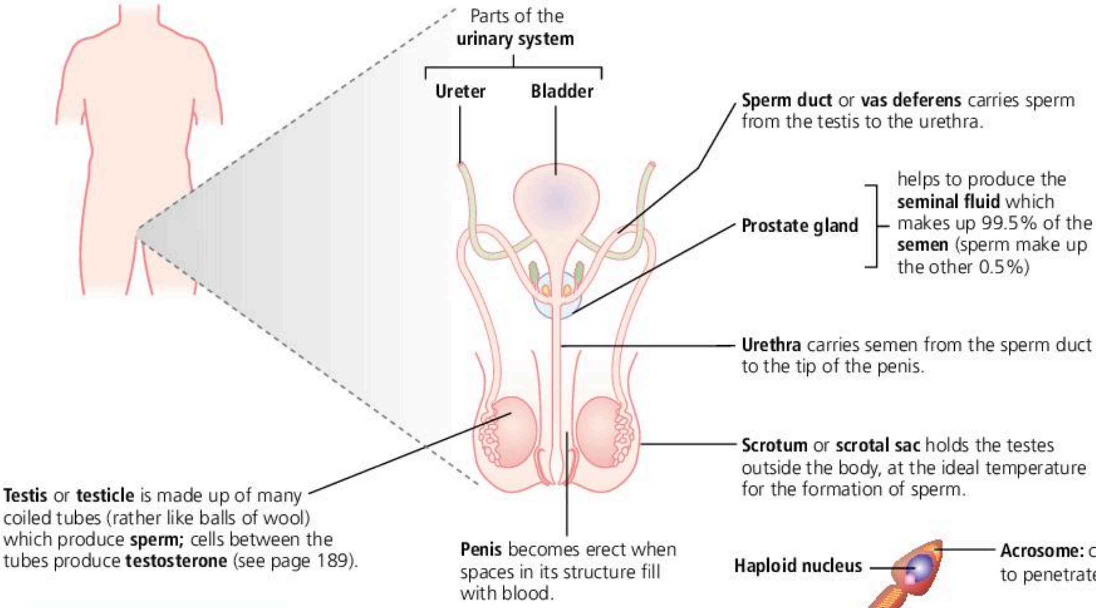


In girls, the proportion of fat may affect the onset of puberty. Puberty may be delayed in girls who are *extremely* muscular (such as gymnasts).

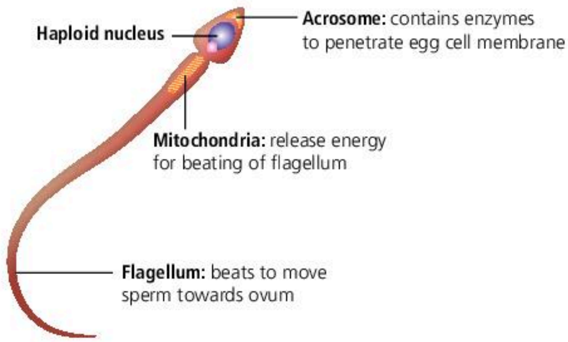
Not all of testosterone's effects seem beneficial! This hormone makes the skin more oily and acne can develop.

▲ Oestrogen and testosterone are hormones – they are chemical messengers secreted directly into the bloodstream and bring about widespread and long-lasting effects

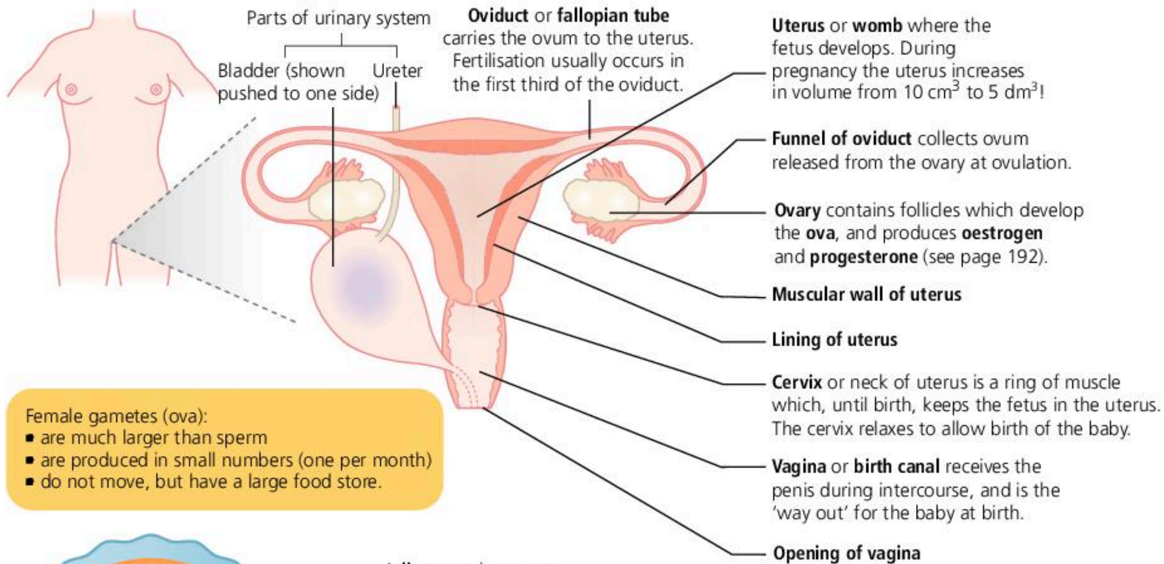
The male urinogenital system



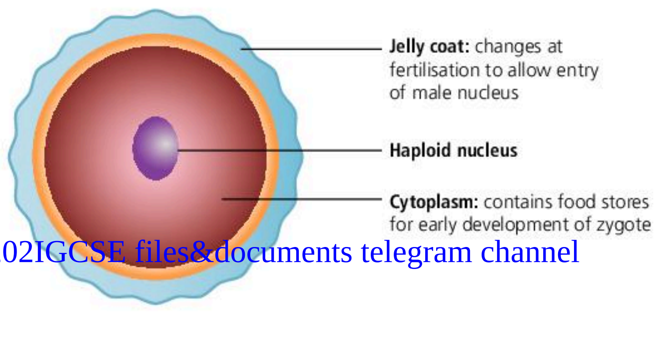
Male gametes (sperm):
- are smaller than ova
- are produced in huge numbers (300 000 000 per ejaculation)
- are motile – can swim by beating the flagellum (tail).



The female urinogenital system



Female gametes (ova):
- are much larger than sperm
- are produced in small numbers (one per month)
- do not move, but have a large food store.



1 Explain the importance of the following in the human life cycle:
   a fertilisation
   b puberty
   c gamete formation.

2 Describe the pathway followed by:
   a spermatozoa at ejaculation
   b an ovum at ovulation.

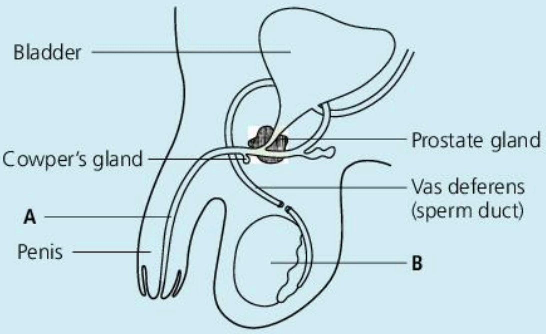
3 Where does fertilisation occur?

4 Why is reproduction necessary?

5 The table below lists the organs of the female reproductive system and their descriptions.
Match each organ with its description. Write the letter and number to show your answer, for example, **a–4**.

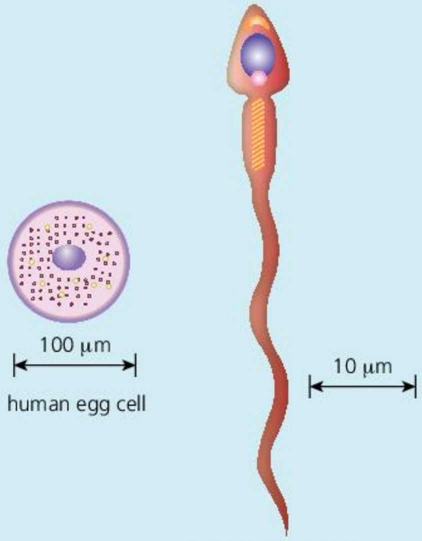
Structure	Description
a ovaries	**1** the neck of the uterus
b oviducts	**2** connects the uterus to the exterior
c cervix	**3** link the ovaries to the uterus
d vagina	**4** the site of implantation
e uterus	**5** ova are produced here

6 The figure below shows the reproductive organs of the human male after an operation called a 'vasectomy' has been performed. Following a vasectomy, the man can still ejaculate fluid produced by the prostate and Cowper's glands.



   a Name parts **A** and **B**.
   b Copy the diagram. Put an 'X' to show where sperm are made.
   c i In what way are the reproductive organs of the male with the vasectomy different from those of a normal, untreated male?
      ii Explain how this will act as a method of contraception.
   d A man infected with the human immuno-deficiency virus (HIV) may transmit AIDS (acquired immuno-deficiency syndrome) to another person. The virus is transmitted in body fluids. Following a vasectomy, is it still possible for an infected man to pass AIDS to another person? Explain your answer.

7 This figure shows a human egg cell and a human sperm cell.



   a i What is the name given to the release of eggs from the ovary?
      ii Sperm cells and egg cells are haploid. State the meaning of the term *haploid*.
   b Complete the table to compare egg cells with sperm cells.

feature	egg cells	sperm cells
site of production		
relative size		
numbers produced		
mobility		

16.7 The menstrual cycle

OBJECTIVES

- To understand the female monthly cycle of ovulation
- To know the role of hormones in the menstrual cycle
- To describe the sequence of events in follicle development and ovulation

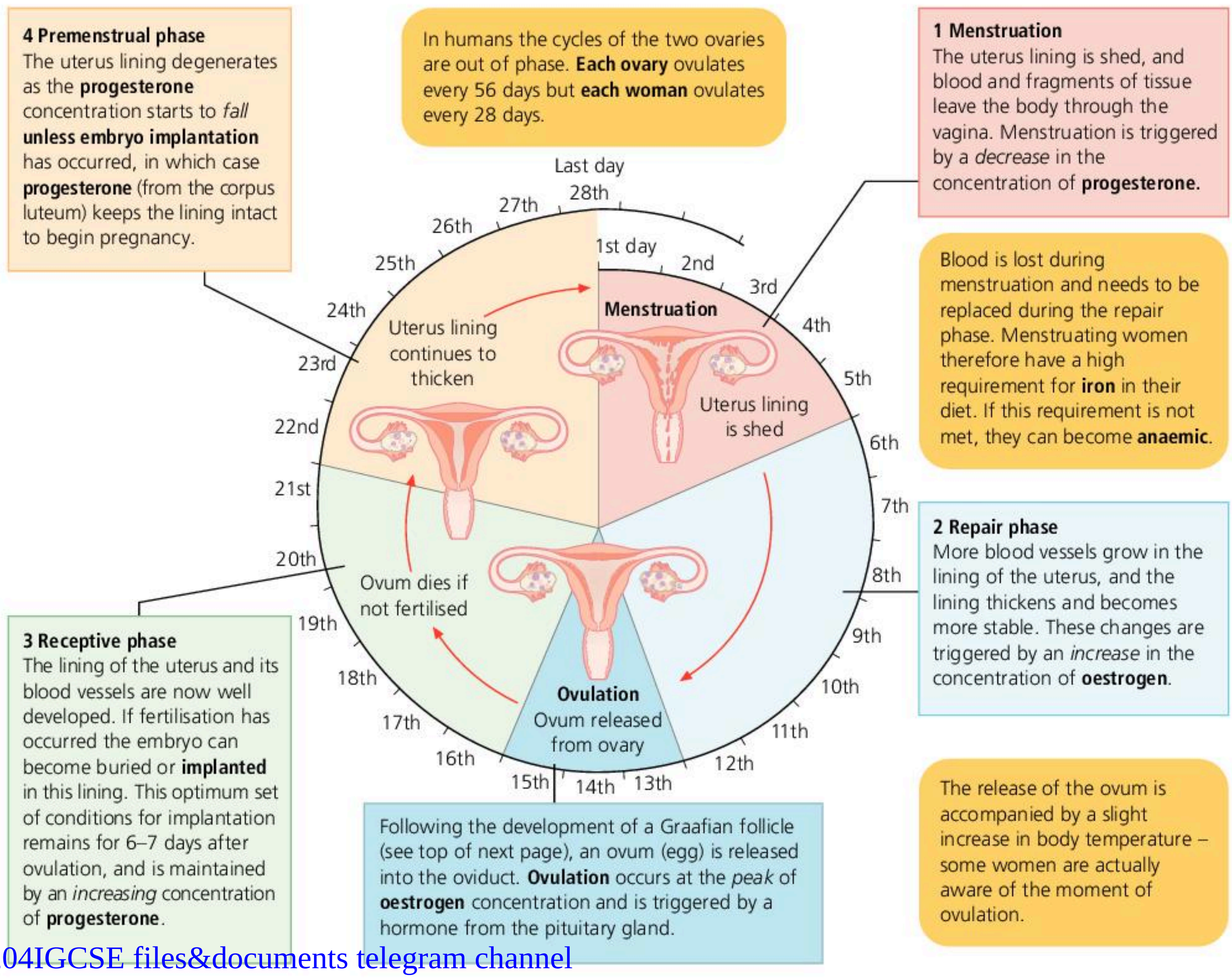
The testes produce sperm continually at a rate of about 100 000 000 per day from puberty to old age. Women produce only one ovum per month during their reproductive life, from puberty to middle age. The two ovaries take it in turns to produce an ovum, and one of them releases a mature female gamete every 28 days. The cycle of producing and releasing mature ova is called the **menstrual cycle** (from the Latin word *menstrua* meaning month).

The menstrual cycle is a long-term process controlled by a number of hormones, which:

- prepare the uterus to receive any fertilised ova
- control the development of mature ova.

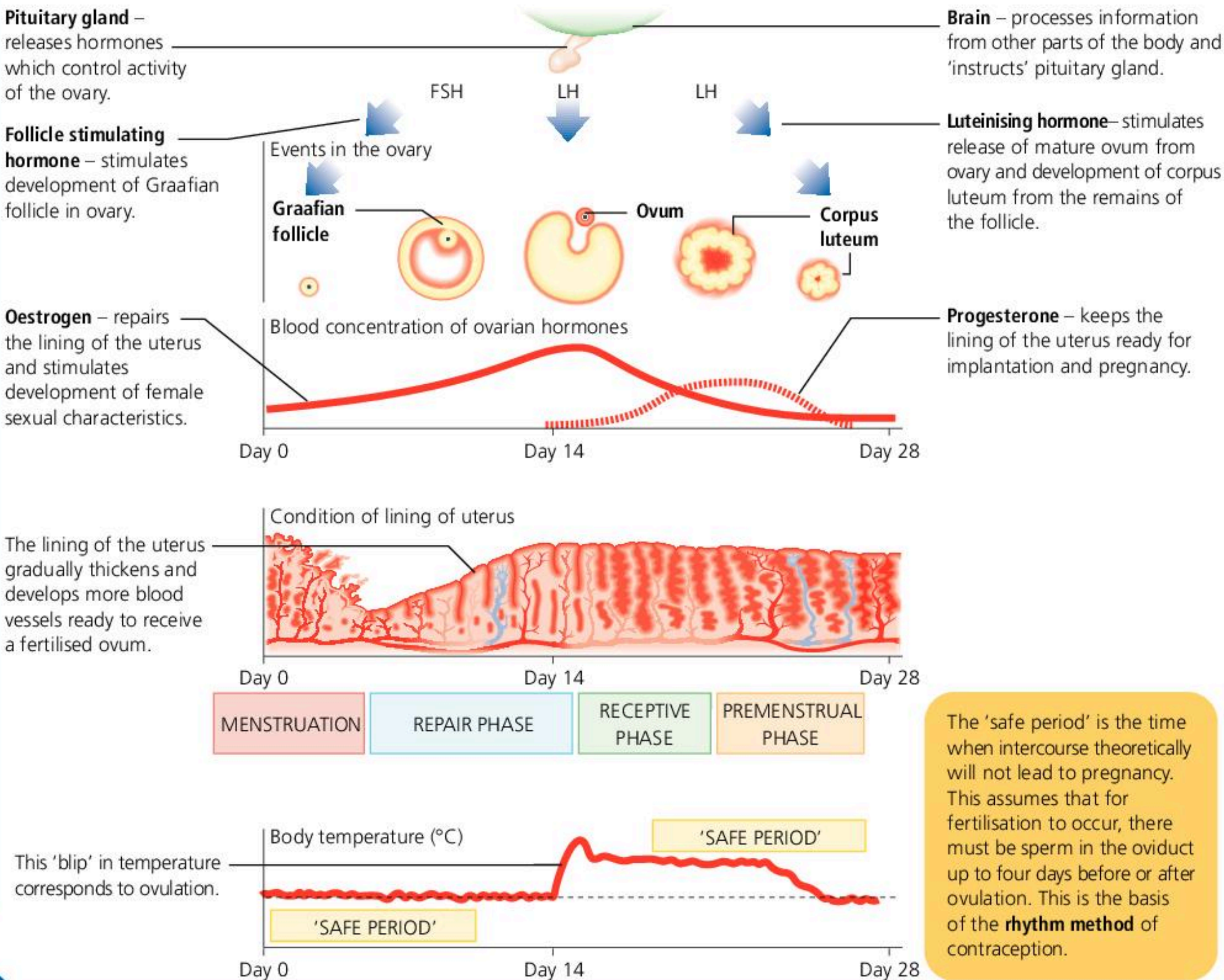
Hormones affect the wall of the uterus

During the menstrual cycle the wall of the uterus goes through four phases, under the influence of two hormones, **oestrogen** and **progesterone**. During the first phase, which lasts about five days, the lining of the uterus is shed, accompanied by a loss of blood. This time is a woman's **period**, or more correctly the **menstrual phase** or **menstruation**. The other phases of the cycle prepare the uterus to receive and protect a zygote, and are shown in the diagram below.



Hormones control the development of ova

The ova develop from cells lining the ovary. This is triggered by follicle stimulating hormone (**FSH**) released from the pituitary gland. **FSH** causes a special cell in the ovary to produce a sac around itself. The fluid-filled sac and the developing ovum inside it are together called a **Graafian follicle**. Once the follicle is mature, and there is a high concentration of oestrogen, it moves to the surface of the ovary and bursts, releasing the ovum into the funnel of the oviduct. This process is called **ovulation**. The remaining cells of the Graafian follicle become a structure known as the **corpus luteum**, which produces the hormone progesterone. This hormone keeps the wall of the uterus in good condition for the development of a zygote if implantation has occurred. It also prevents FSH secretion which prevents the release of any more mature ova by feedback inhibition. This ensures that only one fertilised ovum develops in the uterus at any one time. The processes taking place in the uterus and the ovary and their control by hormones are summarised in the diagram below.



The 'safe period' is the time when intercourse theoretically will not lead to pregnancy. This assumes that for fertilisation to occur, there must be sperm in the oviduct up to four days before or after ovulation. This is the basis of the **rhythm method** of contraception.

1. Define the terms **menstruation** and **ovulation**. What is the link between these processes?
2. Describe the role of the hormones FSH, LH, oestrogen and progesterone in the control of the menstrual cycle.
3. Use the term **feedback inhibition** to explain why contraceptive pills contain the hormone progesterone.
4. **a** List the phases of the menstrual cycle.
   b How long does the cycle last?
   c At what time in the cycle does ovulation occur?

16.8 Copulation and conception

OBJECTIVES

- To understand the difference between copulation and conception
- To describe the events of fertilisation
- To describe the processes of *in vitro* fertilisation and artificial insemination by donor
- To understand some of the moral and ethical questions posed by human intervention in reproductive processes

Ovulation provides a female gamete

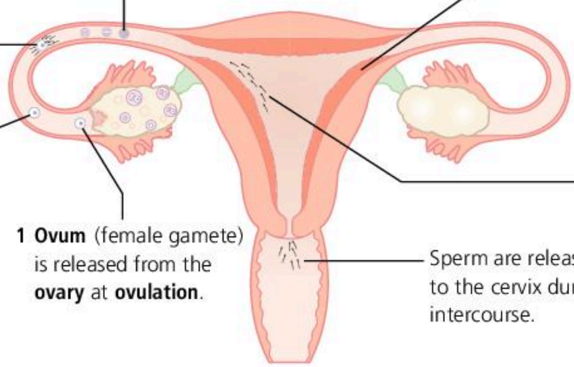
During ovulation each month, an ovum is released from one of the ovaries. The ovum moves slowly along the oviduct towards the uterus. This movement is brought about by:

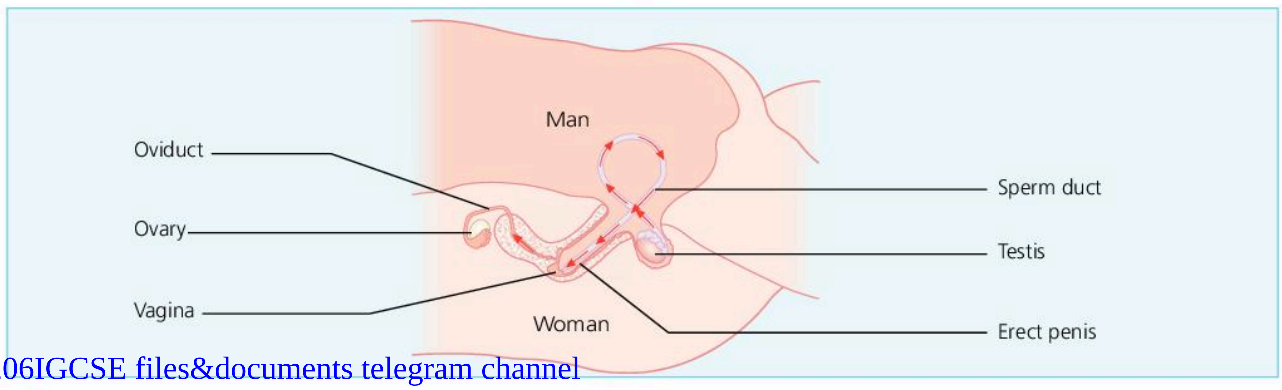
- **peristalsis** – rhythmic contractions of muscles in the wall of the oviduct
- **cilia** – fine hair-like structures on the lining of the oviduct which sweep the ovum along.

It takes 4–7 days for the ovum to reach the uterus, and during this time fertilisation may take place in the oviduct (see below).

Copulation delivers male gametes

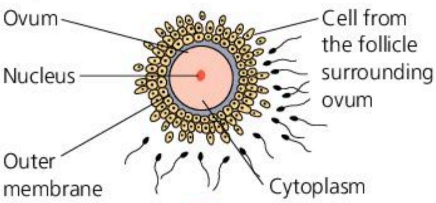
Before intercourse, sexual stimulation causes blood to flow into the man's penis. The penis becomes erect and hard enough to enter the woman's vagina (helped by lubricating fluids released by the walls of the vagina). This is called **copulation** or **sexual intercourse**. The rubbing of the tip of the penis (the **glans**) against the wall of the vagina sets off a reflex action that releases stored sperm from the testes, and squeezes them by peristalsis along the sperm ducts and the urethra. As the sperm pass along these tubes, seminal fluid is added to them and the complete **semen** is ejaculated in spurts from the tip of the penis. About 3 or 4 cm^3 of semen is ejaculated, and this contains about 300 000 000 sperm. The diagram below illustrates how the male and female gametes arrive at the same place.



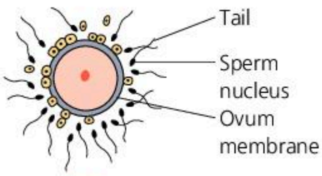


▲ Sexual intercourse or copulation delivers male gametes to the female reproductive system

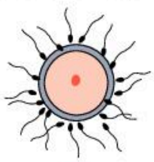
1 Sperm swim towards ovum.



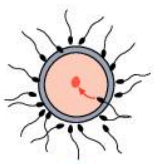
2 Remaining follicle cells are scattered by sperm.



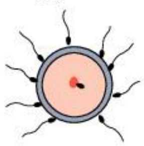
3 One sperm passes through the outer membrane. A barrier forms to prevent entry of more than one sperm.



4 Head of sperm crosses ovum cell membrane.



5 Sperm nucleus and ovum nucleus fuse at fertilisation. A zygote has been formed.



▼ Fertilisation is the fusion of ovum and sperm

Fertilisation is the fusion of ovum and sperm

Fertilisation is the joining together (fusion) of an ovum and a sperm. The new cell contains a set of genetic material from the mother and a set from the father. Fertilisation takes place in the oviduct, and although several hundred sperm may reach the ovum, only one of them will penetrate the membrane that surrounds it. Once this has happened a series of changes takes place:

- The ovum membrane alters to form a barrier to the entry of other sperm.
- The head of the sperm (the male nucleus) moves towards the nucleus of the ovum and the two fuse (join together).
- The fertilised ovum or **zygote** now starts to divide, first into two cells, then into four, and so on. It continues to move towards the uterus.

The events of fertilisation are summarised in the diagram on the left.

Conception is the implantation of the ball of cells

About six days after fertilisation, the ball of cells, now called an **embryo**, becomes embedded in the thickened lining of the uterus. **Conception**, the beginning of the development of a new individual, takes place when this embedding or **implantation** is complete. Once the embryo is attached to the lining of the uterus, some of its outer cells combine with some of the mother's cells and a **placenta** begins to develop.

Infertility treatment

In vitro fertilisation (IVF)

The term *in vitro* means 'in glass', and is used to describe a procedure that takes place outside the body in some form of laboratory glassware. In *in vitro* fertilisation, an ovum is fertilised outside a woman's body in a special kind of dish (not a test tube, although the technique is sometimes called 'test-tube fertilisation'). The fertilised ovum is placed in the woman's uterus to develop. This procedure is used to treat couples who are unable to conceive. For example, a woman's oviducts may be blocked, preventing sperm reaching the ovum, or making it difficult for a fertilised ovum to get to the uterus.

Artificial insemination by donor (AID)

If a couple is unable to conceive naturally due to a problem with the man's sperm, they may try AID. Sperm from a donor is obtained from a sperm bank (where it is stored) and is inserted into the woman's uterus close to her time of ovulation.

1. Define the terms conception, copulation and fertilisation. In what order do these events occur?
2. It is possible for humans to intervene in the process of reproduction. Suggest how IVF and AID raise ethical problems for the medical profession.

16.9 Pregnancy: the role of the placenta

OBJECTIVES

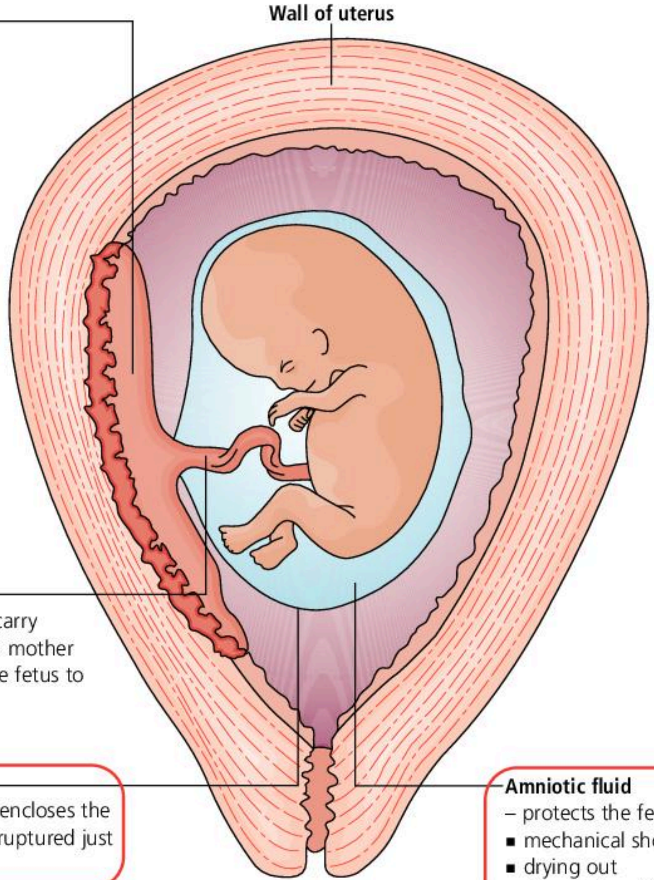
- To know the sequence of events in the development of a baby
- To understand the role of the placenta

Growth and development

From the time of conception it takes about nine months, or 40 weeks, for a fertilised ovum to become a fully formed baby. This progress involves two closely linked processes:

- **growth** – the repeated division of the zygote to provide the many cells that make up the baby
- **development** – the organisation of the cells into tissues and organs.

During growth, the zygote divides into many identical cells – one zygote at conception becomes 30 million million cells at birth! This type of cell division is called **mitosis** (see page 212). Each cell also takes up its correct position in the embryo. The cells become organised into tissues (see page 27) and start to take on special functions such as nerve cells and skin cells.



Amniocentesis is a test to check for abnormalities of the fetus. A sample of amniotic fluid is collected in a syringe through the abdominal wall of the mother. The fluid contains cells from the fetus, which are cultured and then analysed. There is a risk of miscarriage following the test.

- The procedure is usually offered to older women because fetal abnormalities are more common in older mothers.
- The test gives information about chromosome mutation (e.g. Down syndrome) and gene mutation (e.g. cystic fibrosis).
- Usually carried out at 16–18 weeks.

▲ The placenta protects and nourishes the developing fetus

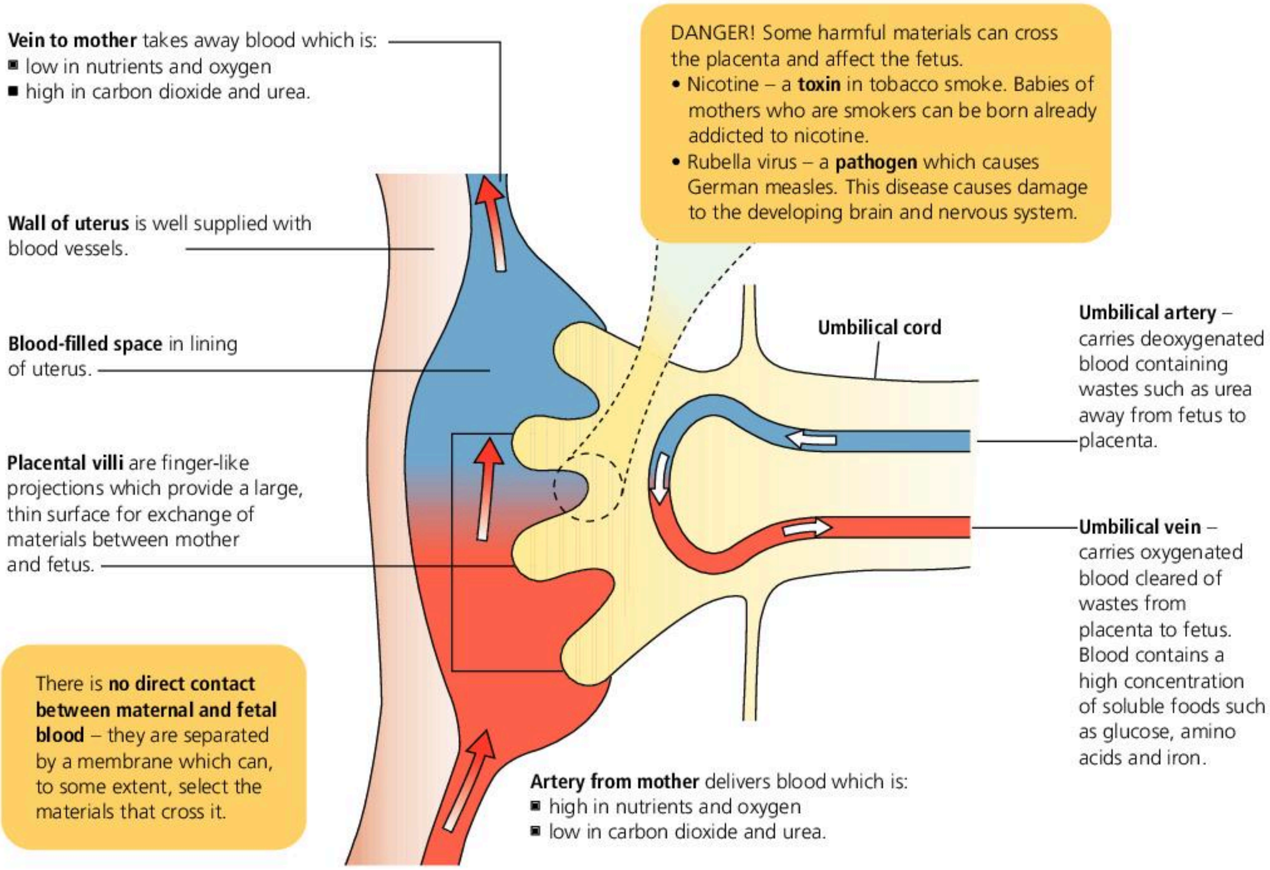
A controlled environment

The time taken for the development of a baby from an implanted zygote is called the **gestation period**. The developing fetus needs a stable environment which is provided by the **placenta**, a structure that is only found in mammals. The placenta forms early in pregnancy, partly from the lining of the uterus, and partly from the outside cells of the developing embryo. The fetus is attached to the placenta by the **umbilical cord** as shown below. It is surrounded by the **amniotic sac** which is filled with **amniotic fluid**; this protects the fetus from knocks and bumps.

The placenta begins to develop at implantation and after about 12 weeks it is a thick, disc-like structure with finger-like projections called **villi** that extend deep into the wall of the uterus. The placenta continues to grow to keep pace with the developing fetus and is about 15 cm across, weighing about 500 g, at the time of birth. After the baby has been born, the placenta, amniotic sac and umbilical cord are expelled from the uterus as the **afterbirth**. The structure of the placenta, and some of its functions, are illustrated in the diagram below.

Exchange of materials across the placenta

At the placenta, materials are exchanged quickly and selectively between the mother's blood and that of the fetus to keep a constant internal environment inside the fetus. The placenta has adaptations that make this process efficient, as outlined in the diagram below. Towards the end of pregnancy, protective antibodies also cross the placenta so that the baby has some immunity to certain diseases.



▲ The placenta is the site of exchange – useful substances such as glucose and oxygen pass from mother to fetus and wastes such as urea and carbon dioxide move in the opposite direction

1 Name two other parts of the body where villi give the benefit of an increased surface area.

16.10 Pregnancy: development and antenatal care*

OBJECTIVE

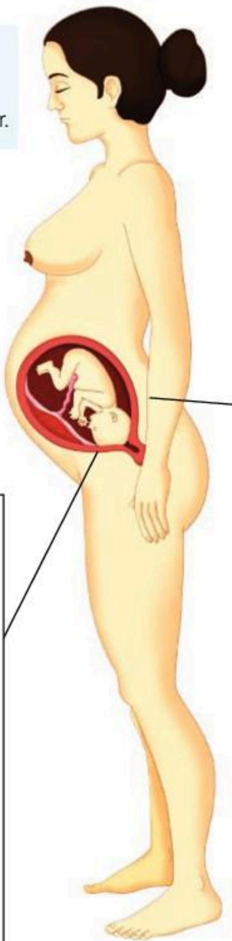
- To know about antenatal care

Antenatal care

Antenatal care includes
- advice on diet
- guidance on motherhood
- checks on fetus and mother.

Signs of pregnancy
- first sign – a missed period
- second sign – another missed period, perhaps with feelings of nausea, tender breasts and more frequent urination.

Testing for pregnancy
Measures the amount of HCG hormone in the urine, using monoclonal antibodies.



Checks on the fetus

Size and **position** can be felt by gentle pressure on the uterus. Towards the end of pregnancy the best position for the baby is head downwards and facing the mother's back.

Heartbeat can be measured, using a stethoscope, during the second half of pregnancy. The fetal heart rate is usually 120–160 bpm, about twice as high as its mother's!

Ultrasound scanning is used to produce a picture of the fetus in the uterus. It provides information on
- baby's age, size, sex and position
- position of the placenta
- whether there are twins!

Amniocentesis (see page 196) provides valuable early information about the developing fetus

Checks on the mother

Weight check: from about the 3rd month of pregnancy a woman gains about 1 lb (450 g) per week. During the whole pregnancy she will gain about 30 lb (12 kg). This includes the weight of the baby, the placenta and the amniotic fluid, as well as some fat under the skin. If she gains too much weight she will be advised to diet.

Diet should
- contain extra **calcium** (bone growth of fetus) and **iron** (haemoglobin)
- include **protein** (growth of fetus) and extra **carbohydrate** (mother may need 25% more kjoules)
- vitamin supplements.

Lifestyle
- Avoid **smoking** (carbon monoxide in smoke reduces oxygen transport to fetus, causing low birthweight).
- Reduce **alcohol intake** (alcohol can damage the nervous system of the developing fetus).

Blood pressure: checked at every visit as high b.p. may indicate **toxaemia of pregnancy** which can be very serious for both mother and baby.

Hormones: the level of **oestrogen** in the blood indicates how well the placenta is functioning to supply the fetus with food and oxygen.

Q

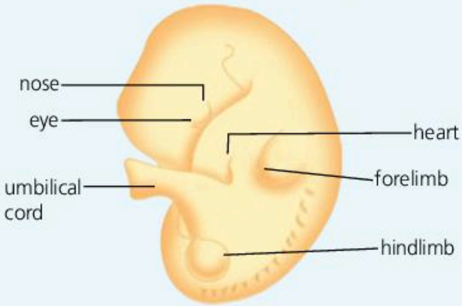
1 What name is given to the complete period from fertilisation to birth?

2 The growth of the fetus is due to an increase in the number of cells of which it is made. A newborn baby has about 30 million million cells. Remember that each cell divides into two, and each of those two into two more (a total of four), and so on. Calculate approximately how many divisions were necessary to produce the baby from the zygote.

3 Cell division is only part of the overall process of production of the baby. Which other process runs alongside cell division? Define this process.

From conception to birth: development of the human fetus

1 month actual length 7 mm

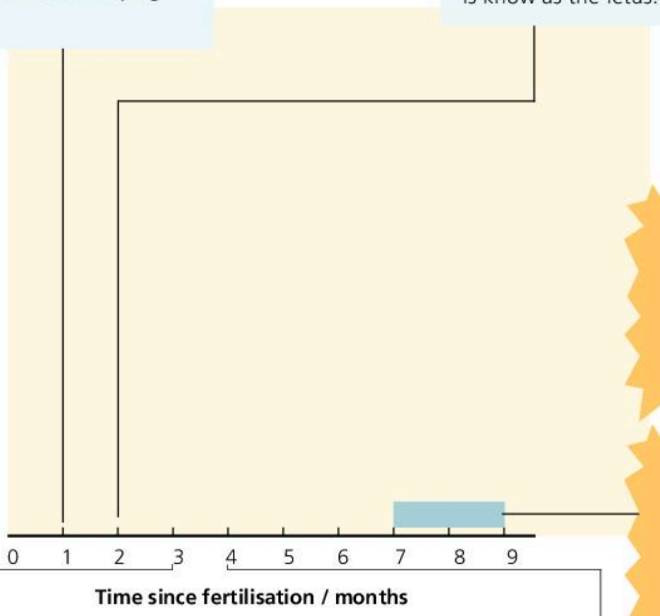


By this time the basic pattern of the body has been laid down – the nerve tube is forming, the heart begins to beat, the limb buds appear and the three regions of the brain are formed. The developing organism is an **embryo**.

2 months actual length (crown to rump) 16 mm

Drugs administered during this period may severely affect development, e.g. thalidomide leads to loss of or abnormal limbs.

All adult organs are present, though tiny and immature. Muscles begin to differentiate and embryo is capable of movement. Sex organ distinguishable as ovary or testis. Bones begin to harden. From now on, the developing organism is know as the fetus.



Birth is a compromise – the fetus has outgrown the placenta's supply systems but must adjust to a much more variable environment.

At this stage, **pre-term** babies have a good chance of survival with appropriate respiratory and thermoregulatory assistance.

3 months actual length (crown to heel) 70 mm

Fetus may kick, curl toes, squint and frown. Sex can be determined by external inspection. Lymph nodes develop.

4 months actual length (crown to heel) 120 mm

Face begins to look 'human'. Lobes of the forebrain develop. Eye, ear and nose begin to look 'normal'. Movements may begin to be vigorous, and may be detected by mother (the fetus 'kicks').

16.11 Birth and the newborn baby*

OBJECTIVES

- To describe the events leading to birth
- To describe the early care of a young baby
- To appreciate the benefits of breast feeding

Hormones are responsible for birth

The sequence of events that leads to the birth of a baby is called **labour**. Labour begins with the **contractions** of the uterus muscle. These contractions are:

- prevented by **progesterone** – the level of this hormone *falls* as birth approaches
- stimulated by **oxytocin**, a hormone released from the pituitary gland of the mother
- helped by **oestrogen** (which makes the uterus more sensitive to oxytocin) – the level of this hormone *rises* as birth approaches.

Labour

By the end of pregnancy the baby normally lies with its head against the cervix, ready to be born. At first the contractions come every 20 minutes or so and may be quite gentle, but as birth approaches they become more frequent and more powerful. The contractions cause the amniotic sac to break and release the amniotic fluid – known as breaking the waters – and the cervix to dilate (get wider). The first stage of labour is complete when the cervix is wide enough for the baby's head to pass through. Labour continues as the baby's head is pushed past the cervix into the vagina, which is now acting as a birth canal. From now on the process is quite rapid and may involve powerful and painful contractions by the mother, helped by the midwife or the obstetrician (doctor who specialises in birth). The birth process is quite traumatic for the baby, and it may become short of oxygen as the umbilical cord is compressed by the walls of the birth canal. The baby's heartbeat is monitored during birth, and the blood soon reoxygenates once the baby begins to breathe. When the baby is breathing properly, the umbilical cord is clamped (to prevent bleeding) and cut. During the third stage of labour, the placenta comes away from the wall of the uterus and leaves the vagina as the **afterbirth**.

Feeding the newborn baby

When a newborn baby is placed close to its mother's breast it sucks at the nipple. This is known as the **suckling reflex**. Suckling stimulates the mother's brain to release more oxytocin. The hormone causes tiny muscles in the **mammary glands** to squeeze out milk. This process is **lactation.**

S The mother's milk is an ideal food for the baby – it contains all the nutrients the baby needs in the correct proportions. It also contains some antibodies from the mother which help to protect the baby during its early months. Milk made in the first few days is called **colostrum.** It contains mainly antibodies and very little food. The mother continues to produce milk as long as the baby suckles. A newborn baby cannot eat solid food because it has no teeth and its digestive system is not developed enough to deal with solids. At around four to six months when the first teeth are starting to appear, the baby can begin to eat some solid food. The gradual changeover from milk to a solid food diet is called **weaning**.

Bottle feeding

The artificial or formula milks intended for use in bottle feeding are based on cows' milk. Various sugars and other substances are added to the dried powder to make it more like human milk. The differences between cow and human milk are shown below.

The main advantages of bottle feeding are that the exact quantity of the baby's food intake can be measured, and that people other than the baby's mother can help with feeding. The main disadvantages of bottle feeding are that formula milk is expensive and it is not as easily digested as breast milk. Also, unless the bottles are carefully cleaned and sterilised and unless the milk is made with boiled cooled water, microbes can be passed to the baby.

In some parts of the world, bottle feeding is a leading cause of gastrointestinal upset and deficiency disease in babies. There is an ongoing campaign to encourage breast feeding.

Human milk is low in bacteria and contains antimicrobial factors so that breast-fed infants suffer fewer infections, particularly the dangerously dehydrating gastroenteritis. Bottle-fed infants in developing countries may have a 10–15 times greater mortality than breast-fed babies.

Human milk is low cost, is delivered at body temperature, requires no preparation and breast feeding encourages a social bond between mother and infant. Suckling may have a contraceptive effect, although this is not certain.

Artificial milk ('formula') is based on cow's milk, but it must be modified since the gastrointestinal tract and kidneys of the human infant are immature and incapable of dealing with the 'richness' of cow's milk.

Cow's milk compared with human milk

Fat	High in long-chain, saturated fatty acids	Difficult to digest, inhibits calcium absorption
Protein	Three times higher	Infant kidneys cannot cope, excess amino acids may cause brain damage
	High casein:whey ratio	Causes hard curd in stomach – not easily digested
Minerals	Very high (particularly sodium)	Infant kidney cannot cope – severe (often fatal) dehydration
Lactose (milk sugar)	Very high	Lactose intolerance – may lead to severe disease, the symptoms of which may include brain damage

Q

1 Copy and complete the following paragraph about the birth of a human baby.
An expectant mother knows when she is about to give birth because her _____ begins to experience waves of contraction. These contractions are caused by an increased release of the hormone _____ from the pituitary gland, and become more and more powerful as the concentration of the hormone _____ falls. Eventually the contractions are so powerful that the _____ dilates, the _____ bursts and the 'waters' are released. Further powerful contractions push the baby through the _____ or birth canal (usually head first, but occasionally feet or bottom first in what is called a breech birth). Once the baby has been delivered, it is important that it takes deep breaths because it may have been deprived of _____ as the _____ cord is compressed during delivery. This cord is clamped and cut, and relatively mild contractions of the uterus cause the _____ to come away from the wall of the uterus and pass out of the vagina as the _____.

2 Breast milk contains all the nutrients a baby needs except for vitamin C and iron. However, the baby has sufficient iron stored in its liver for the first months of its life. The first milk a breast-fed baby receives is called colostrum. After a few days, normal breast milk is produced. Table 1 compares the composition of colostrum and normal breast milk.

	Nutrient / g per 100 cm^3		
	Fat	Protein	Sugar
Colostrum	2.5	8.0	3.5
Normal breast milk	4.0	2.0	8.0

▲ Table 1

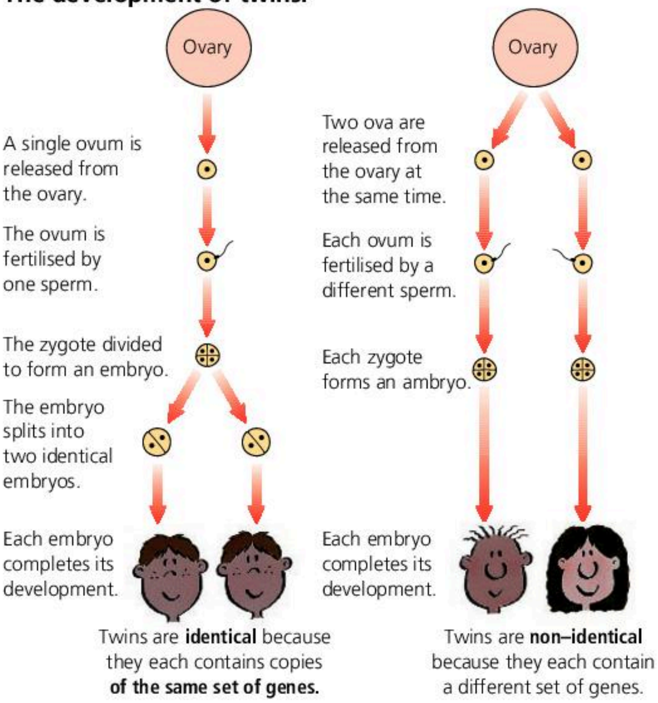
a Use data from Table 1 to describe how the amounts of fat, protein and sugar are different in colostrum and normal breast milk.
b A baby feeding on normal breast milk drinks one litre of milk per day. Calculate how much protein the baby receives per day. Show your working.
c Suggest a suitable fruit juice a mother could give her baby to provide vitamin C.

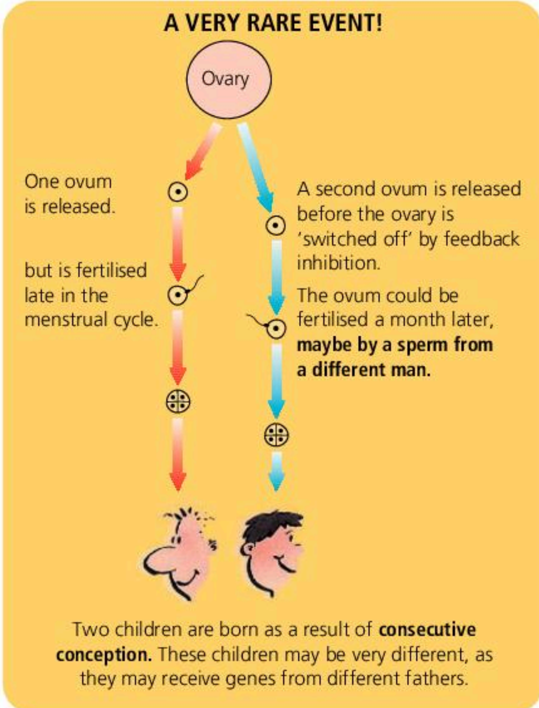
Twins

Humans usually give birth to a single baby. Occasionally two embryos develop together, each with its own placenta and umbilical cord, resulting in **twins**. There are two kinds of twins, and they arise in different ways, as shown in the diagram below.

Very occasionally three or more ova are released and fertilised at the same time, resulting in a multiple birth. This is quite common in women who have been treated with a **fertility drug.** The uterus cannot expand enough to contain several fetuses growing and developing at the same time, and the mother often gives birth early, usually around the seventh month of the pregnancy. Increasingly, medical care (including the use of incubators) means that the babies may survive.

The development of twins.





▲ Identical twins have the same genes

▲ Non-identical twins are no more alike than any other brothers and sisters

▲ Multiple births can happen naturally, or following treatment with fertility drugs

3 Describe the role of hormones in the birth and early growth of a human baby.

4 Consider this list of statements about identical twins, and say whether each is true or false.

- **a** They each have the same genes.
- **b** They are formed from two separate ova.
- **c** They each have their own placenta and umbilical cord.
- **d** They may be of the same sex or different sexes.
- **e** They are also known as fraternal twins.
- **f** They are formed from a single fertilised egg that splits in two.

16.12 Sexually transmitted infections

OBJECTIVES

- To understand that disease-causing organisms can be transmitted between partners during sexual activity
- To name some organisms responsible for sexually transmitted infections

The control of **sexually transmitted infections** (STIs) requires the interaction of individuals and communities. These diseases, some of which are listed below, are most likely to be transmitted by body fluids through sexual contact (the responsibility of the individual) but can only be controlled by a concerted effort both locally and worldwide.

Individuals must take care with sexual habits. An STI can be transmitted quickly through a population, so individuals should:

- know the sexual history of their partners
- use a condom for barrier protection
- have a medical check if any symptoms occur.

Communities must offer testing and treatment, e.g. by family doctors.

- Individuals at greatest risk, (e.g. drug users), can be offered testing for HIV.
- Sexual contacts can be traced to identify sources of infection.

Worldwide involvement can include, for example,

- education programmes to prevent infection
- provision of antibiotics
- development of vaccines and antiviral drugs.

STIs can be caused by bacteria, viruses or fungi.

Gonorrhea is a common STI caused by a bacterium.

Bacterial STIs are treated with antibiotics (e.g. penicillin) but resistant strains are developing.

Viral STIs are increasing in frequency. These include AIDS (acquired immune deficiency syndrome).

The causes, effects and treatment for gonorrhea and AIDS are summarised in the table below.

Name of STI and infective organism	Signs and symptoms	Transmission	Treatment
Gonorrhea (caused by bacterium)	1 Pain or burning when passing urine 2 A creamy discharge from the penis or vagina 3 Inflammation of the testicles	Usually by penetrative sex – i.e. when the penis enters the vagina, mouth or anus	Once diagnosed (an easy test in a clinic), treatment is straightforward, involving a course of **antibiotics**
AIDS (caused by virus, HIV–human immunodeficiency virus)	(S) A flu-like illness in the early stages. Many AIDS-related conditions may follow as the immune system begins to fail – e.g. fungal infection of the lungs. The virus reduces the number of lymphocytes and decreases the ability to produce antibodies.	1 Unprotected sex with an infected person 2 Contact with an infected person's blood 3 From mother to child, during pregnancy or childbirth 4 Sharing syringes while injecting drugs	**There is no cure.** Antiviral treatment slows down the progression from HIV+ status to full-blown AIDS. Modern treatments inhibit the enzymes which the virus uses to copy itself.

Q

1. Suggest two steps an individual can take to reduce the risk of named sexually transmitted infections.
2. What are the responsibilities of a community health service?
3. Name one viral and one bacterial sexually transmitted infection (STI).
4. For any one named STI, suggest how individuals, local communities and scientists worldwide might be involved in its control.

Questions on human reproduction

1 Many young women choose to take an oral contraceptive in order to avoid pregnancy. An oral contraceptive can prevent pregnancy by:

A destroying sperm before they can reach an ovum

B preventing a fertilised egg from becoming implanted in the lining of the uterus

C inhibiting the release of an ovum from the ovaries

D destroying ova that have been released from the ovaries [1]

2 In which organ are sperm made?

A Testes

B Prostate gland

C Penis

D Vas deferens [1]

3 Birth control is used in many countries to limit the size of families.

There are different methods of birth control available to people – some are used by men and some by women.

a Name the process which occurs when a sperm and an ovum fuse. [1]

b A common method of birth control, especially for men, involves the use of condoms. Some men believe that birth control affects their masculinity, and may stop using condoms.

i Explain how an increase in HIV infection may result from a reduction in the use of condoms. [2]

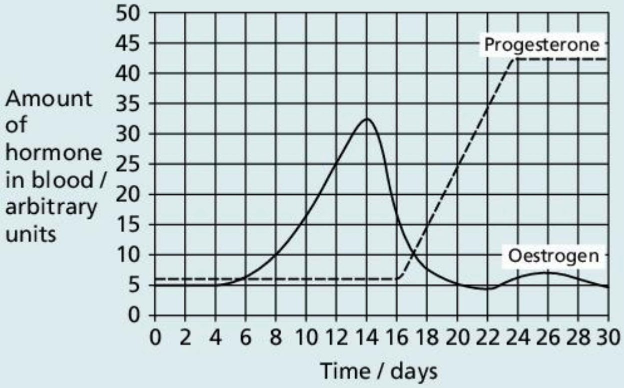
ii Explain why a person infected with HIV is more likely to suffer from other infections. [2]

c i Name **one** sexually transmitted infection caused by a bacterium. [1]

ii State **one** effect of this infection, and suggest **one** possible treatment. [2]

4 The graph that follows shows the levels of the hormones oestrogen and progesterone in a woman's blood during a month when she becomes pregnant.

Use the information in the graph and your own knowledge to answer the questions.



a When are the levels of oestrogen and progesterone equal? [1]

b Which process occurred between day 0 and day 5? [1]

c Give **one** function of each of these hormones:

i oestrogen [1]

ii progesterone. [1]

d What evidence from the graph shows that an ovum was fertilised? [1]

e Sketch a copy of the graph. Draw a line between day 16 and day 30 to show a probable level of progesterone which would be found in the woman's blood if she had **not** become pregnant. [1]

f How does the lining of the uterus help in the development of a fertilised ovum? [2]

5 Some women may be unable to become pregnant naturally. They may be treated with pills containing the hormone FSH.

a Explain how FSH could help a young woman to produce and release an ovum. [2]

b Reduction in fertility may also be the result of an infection, which leaves the fallopian tubes blocked. The woman may still be able to produce ova but they cannot pass down the fallopian tubes.

i Explain why this limits the possibility of woman becoming pregnant. [2]

ii Describe a method by which a woman with a blocked fallopian tube may still become pregnant. Include the role of FSH in your description. [4]

6 The temperature of the human fetus whilst in the uterus is about 0.5°C above that of its mother. At birth it emerges into a relatively cool, dry atmosphere and immediately encounters a problem of temperature control.

a Suggest why the temperature of the fetus is above that of its mother. [1]

b Explain how the following help the newborn baby to control its temperature:

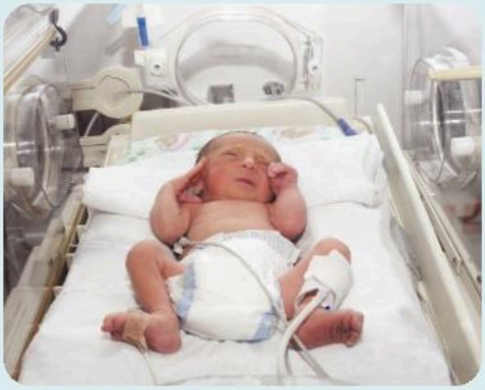
i from about the fifth month of pregnancy onwards a layer of subcutaneous fat is developed by the fetus [1]

ii at birth the blood vessels to the baby's skin constrict very quickly. [1]

c A baby born prematurely is less able to control its body temperature and must be kept in an incubator (see photograph).

i A constant temperature is maintained within the incubator, using a thermostat and an electric heater. Use this example to explain the meaning of the term negative feedback. [4]

ii Suggest two functions of the hood that covers the incubator. [2]



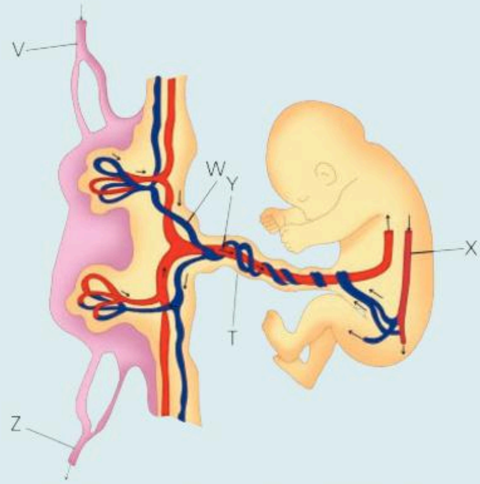
▲ An incubator provides a constant warm environment for a premature baby

d The premature baby must be fed through a plastic tube going through its nostril into its stomach.

i The food supplied to the baby contains substantial quantities of carbohydrate and protein. Suggest one function of each of these substances in the body of the newborn baby. [2]

ii Name one substance normally supplied across the placenta in the late stages of pregnancy which the artificial diet is unlikely to supply. What problem might this cause for the newborn baby? [2]

7 The diagram shows the structure of the placenta and parts of the fetal and maternal circulatory systems.



a **i** Copy and complete Table 1 by listing the blood vessels that carry oxygenated blood. Use the letters in the diagram to identify the blood vessels. [2]

Circulatory system	Blood vessels that carry oxygenated blood
maternal	
fetal	

▲ Table 1

ii Name structure **T** and describe what happens to it after birth. [1]

iii The placenta is adapted for the exchange of substances between the maternal blood and the fetal blood. Describe the exchanges that occur acrossthe placenta to keep the fetus alive and well. [3]

b The placenta secretes the hormones oestrogen and progesterone. Describe the roles of these hormones during pregnancy. [4]

17.1 Variation and inheritance

OBJECTIVES

- To know that there is variation between individuals of the same species
- To appreciate that some differences are inherited whereas others are acquired during the life of the individual
- To understand that genetics has a major impact on the lives of humans
- To understand that chromosomes, located in the nucleus, carry information about inherited characteristics

Inherited and acquired characteristics

Living organisms vary in many ways. For example, humans all have the same general shape and the same set of body organs, but some features differ from one person to the next, such as height, weight, eye and hair colour, shape of nose, language, knowledge and skills. These are examples of **individual variation**.

Some of these features that vary from person to person may be inherited from the parents. **Inheritance** is the transmission of genetic information from generation to generation. Examples of these **inherited** (or **hereditary**) **characteristics** include the tendency to develop some diseases, such as cystic fibrosis, and the permanent colour of the skin. Some, such as a temporary suntan or a scar, cannot be inherited – these are called **acquired characteristics**. Many acquired characteristics can be changed (for example, body mass can be changed by an adjustment to the diet). Inherited characteristics cannot usually be altered (except temporarily).

Genetics

The study of inherited characteristics, and the way they are passed on from one generation to another, is called **genetics**. Our knowledge of the subject of genetics is expanding extremely rapidly, and this knowledge depends upon our understanding of the molecule DNA (see page 208).

When we study inheritance we are looking for answers to several important questions:

- What is a characteristic? Why does a cell or organism develop a certain characteristic?
- How can characteristics be passed on accurately from one cell to another?
- How are the characteristics of two different organisms combined at fertilisation?
- How do characteristics vary from one organism to another and from one generation to another?

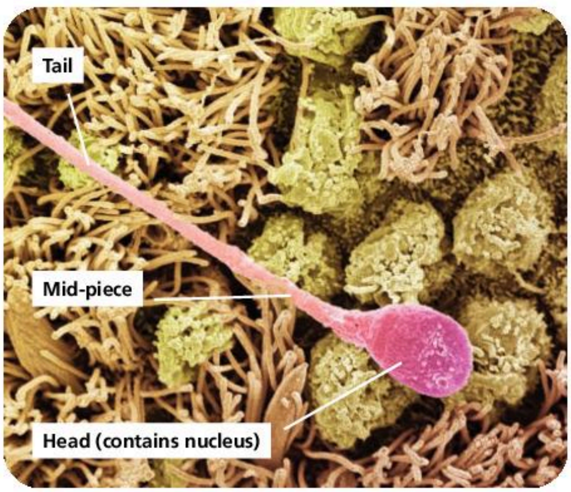
Answers to questions such as these help us in many ways, for example to increase our understanding about genetic diseases, and to develop techniques to 'add' desirable characteristics to our domestic animals and plants.

Sexual reproduction and inheritance

The production of offspring by sexual reproduction always involves the **production of gametes** and **fertilisation** (see page 176). In sexual reproduction:

- The only part of the male gamete (sperm in mammals) that goes to form the zygote is the **nucleus**.
- The gametes are formed by **cell division**.
- The young organism develops from a single fertilised egg by **cell division**.

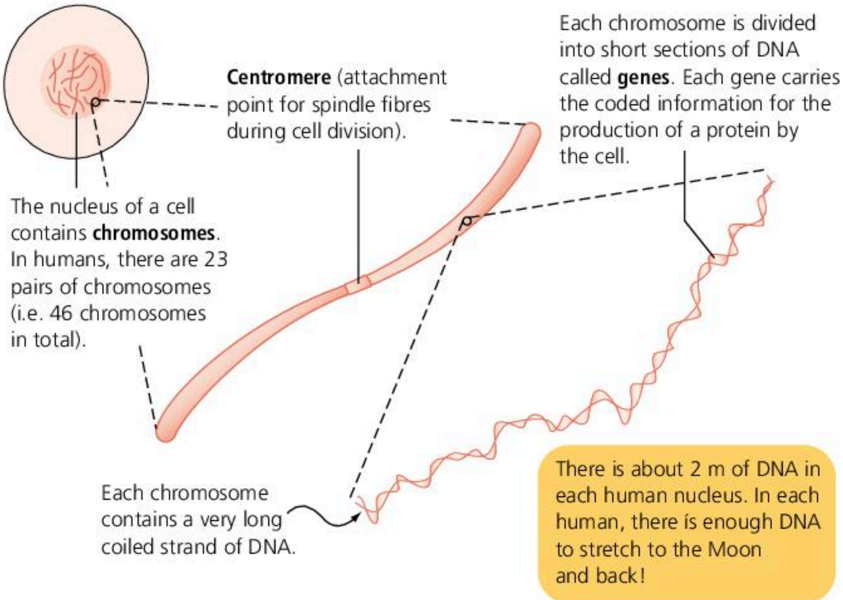
So, if we are to understand how characteristics are passed on during reproduction, we should look carefully at the structure of the nucleus, and how the nucleus behaves during cell division.



▲ Human sperm × 1000. Only the 'head' (containing the nucleus) enters the egg at the time of fertilisation.

The contents of the nucleus

Special stains can be used to show up the contents of the nucleus. If the cell is not actually dividing, these contents are rather unclear but, as the cell begins to divide, the contents show up as a series of thread-like structures. As the threads shorten, they take up the stain. For this reason, they were called **chromosomes** (literally 'coloured bodies'). The structure of a chromosome is outlined below.



▲ The structure of a chromosome

A great deal of evidence suggests that the chromosomes carry **genetic information** – the information that gives the particular characteristics to a cell:

- If sections of chromosome are transferred from one cell to another, the characteristics of the recipient cell change.
- If chromosomes are deliberately damaged, the characteristics of the cell change.
- In some cells, the chromosomes are seen to swell when proteins are being manufactured in the cell.
- The only difference between the nuclei of male and female cells is the presence of one particular chromosome (see page 224). (Males and females certainly have different characteristics!)

Remember these definitions!
Chromosome: a thread-like structure of DNA carrying genetic information in the form of genes.
Gene: a length of DNA that codes for a specific protein.

Q

1 Look around your class. This group of humans shows many variations between individuals. Suggest one variation that is inherited and one that is acquired.

2 Find three newspaper articles that include the words 'gene', 'genetic' or 'inheritance' in their headings. Summarise one of the articles in three or four sentences.

3 **a** What is a chromosome? What evidence is there that chromosomes carry genetic information?
b When can chromosomes be observed? Explain why this is possible.

17.2 DNA, proteins and the characteristics of organisms

S

OBJECTIVES

- To know that cell characteristics depend on proteins
- To understand the principle of the genetic code
- To be able to describe the replication of DNA

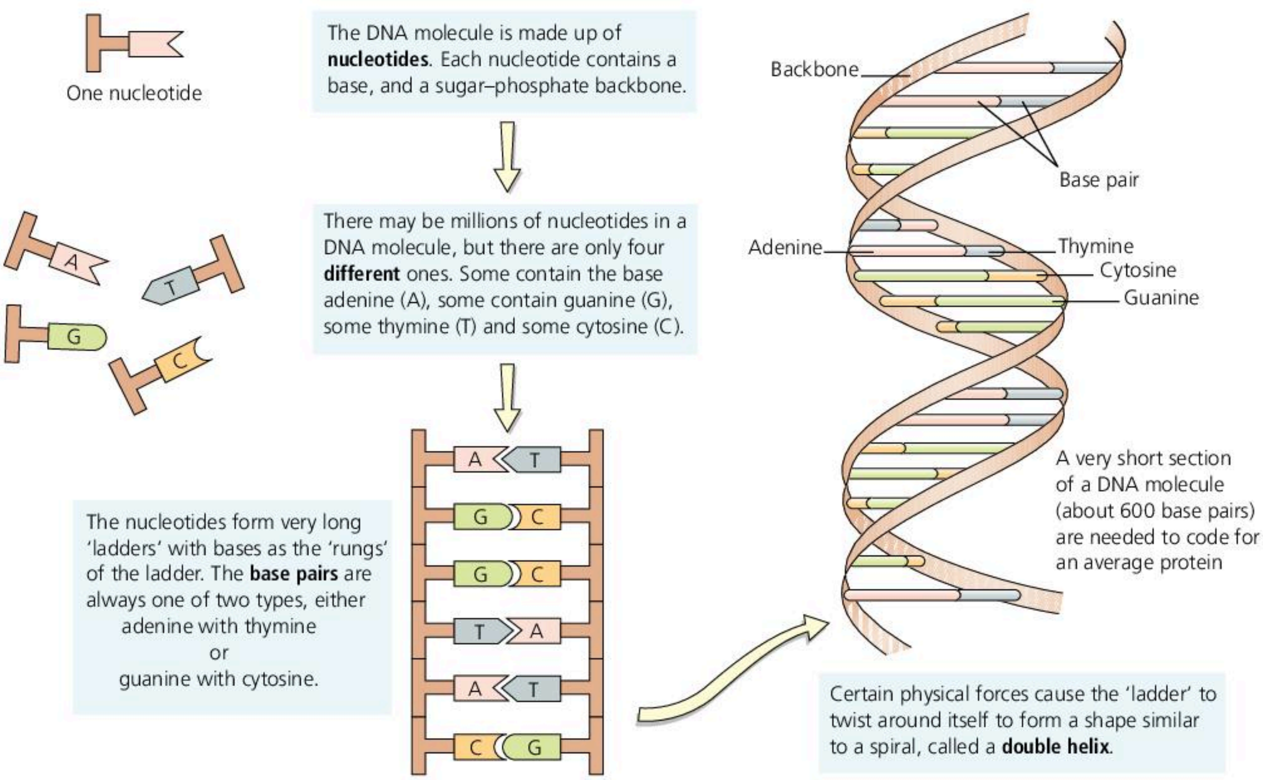
DNA as gene
↓ controls production of
protein
↓ responsible for
characteristic

Characteristics depend on proteins

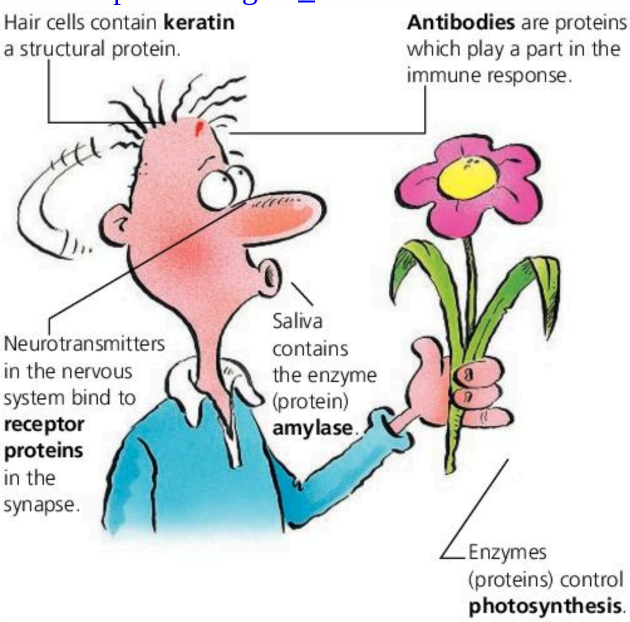
It has been discovered that the characteristics that a cell or organism possesses depend on the **proteins** that the cell can manufacture. For examples of this, look at the picture at the top of the opposite page.

For cells to specialise in the many different ways that they do, they must make different proteins. The instructions as to which proteins should be manufactured at any one time in a cell are carried as **genes** on the **chromosomes**. Chemical tests have shown that chromosomes are largely composed of the enormous molecule called **deoxyribonucleic acid** or **DNA** for short. In other words:

DNA carries its instructions as coded messages using just four different chemical compounds called **nucleotide bases** or organic bases (see page 37). The names of the bases are shown in the diagram below, but you only need to remember their initial letters (A, T, G and C) to understand how the code works.



▲ The structure of DNA. The exact length of the DNA molecule is not known, even for humans. It is very important to remember that: **adenine** always pairs with **thymine**, and **guanine** always pairs with **cytosine**.

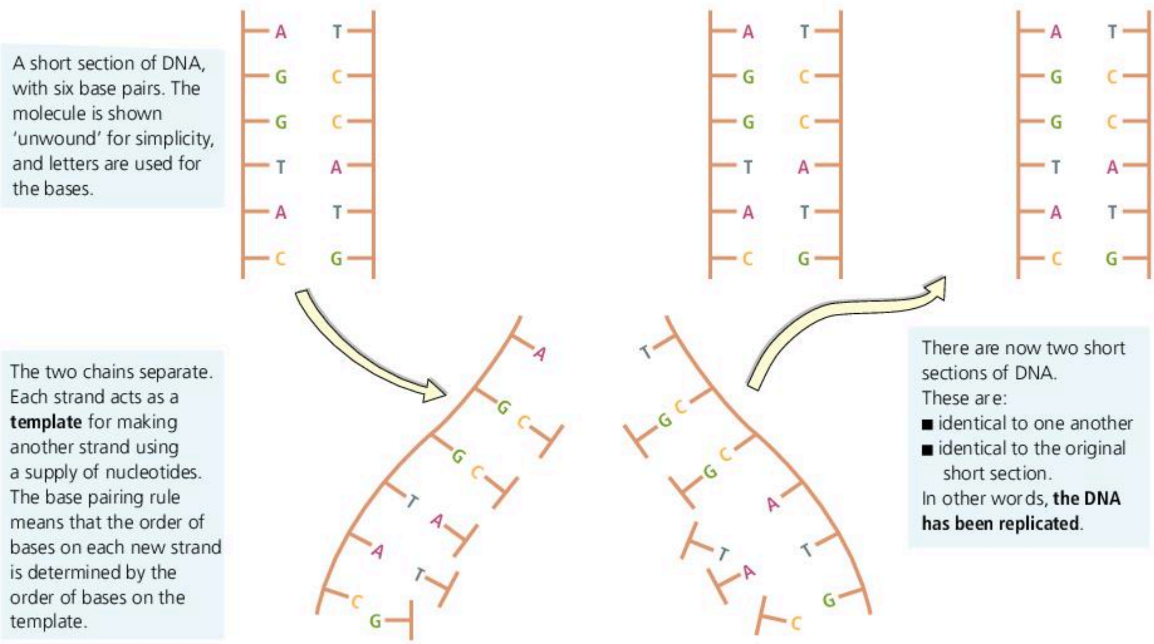


▲ Cell characteristics depend on proteins.

Base pairing can explain how DNA is replicated*

For one organism to pass on characteristics to its offspring, it must be able to copy the coded instructions for these characteristics and hand them on. In other words, DNA in the chromosomes must be copied or **replicated**. This replication must be carried out with great accuracy, since a change in characteristics might be harmful to the organism. The base pairing rule means that the coded sequence on one chain of the double helix automatically determines the coded sequence on the other chain, ensuring accurate replication. The principles of DNA replication are outlined below.

The replication of DNA is a vital part of cell division. It is particularly obvious in copying division (mitosis), as we shall see on page 212.



▲ Replication is essential for characteristics to be passed from one generation of cells to the next

The discovery of DNA

The discovery of DNA structure depended on the work of many scientists. These included

- **Rosalind Franklin:** she made many measurements on DNA, using patterns obtained by directing a beam of X-rays onto crystals of this molecule.
- **James Watson and Francis Crick:** used the measurements made by Franklin, and results of the chemical analysis of DNA which showed that the number of (adenine + guanine) bases was always equal to the number of (thymine + cytosine) bases, to produce a working model of the DNA molecule. This model was the double helix with which we are familiar.

Watson and Crick were awarded the Nobel prize (the highest scientific award) for their work of DNA. Sadly, Rosalind Franklin died before her part in the discovery of DNA structure was properly recognised.

1 Antibodies work by binding to another type of protein. Name this other type of protein.

2 DNA can be copied very quickly by a process called PCR. Look up what is meant by PCR, and explain how it has been useful in our fight against the COVID-19 pandemic.

17.3 How the code is carried

OBJECTIVES

- To understand that the genetic code is carried as a sequence of bases on the DNA molecule
- To understand the need for a messenger molecule in protein synthesis
- To define the terms transcription and translation

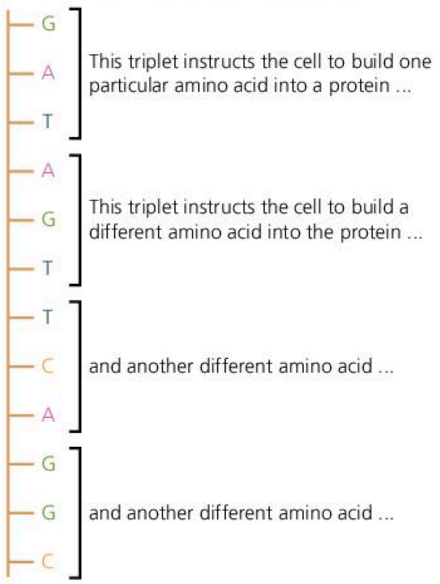
DNA 'code words' for amino acids

How does the DNA in the genes instruct the cell to make particular proteins? The following points are important in understanding this link:

- Each gene carries a series of coded instructions ('code words') for the synthesis of proteins.
- Each 'code word' on the DNA is made up of three bases (three 'letters') in a certain sequence.
- Each 'code word' – called a triplet – corresponds to a **single amino acid in a protein**.

The sequence of bases in DNA is therefore a series of coded instructions for the building up of amino acids into proteins. The proteins then give the cell or organism a particular characteristic. This relationship between DNA bases and amino acids is called the genetic code, and is outlined below.

A DNA strand carries instructions in the form of three-letter 'code words' called triplets.



▲ The four different bases in DNA can be arranged in enough different triplets to code for all 20 amino acids normally found in a cell

Passing the messages to the ribosomes

This coded information in the genes is located on the chromosomes, which are in the nucleus. You may remember that the protein-manufacturing stations, called **ribosomes**, are found outside the nucleus, in the cytoplasm. How does the code pass from the nucleus to the ribosomes in the cytoplasm? It is carried by another type of nucleic acid, called **messenger RNA** (mRNA).

Transcription and translation

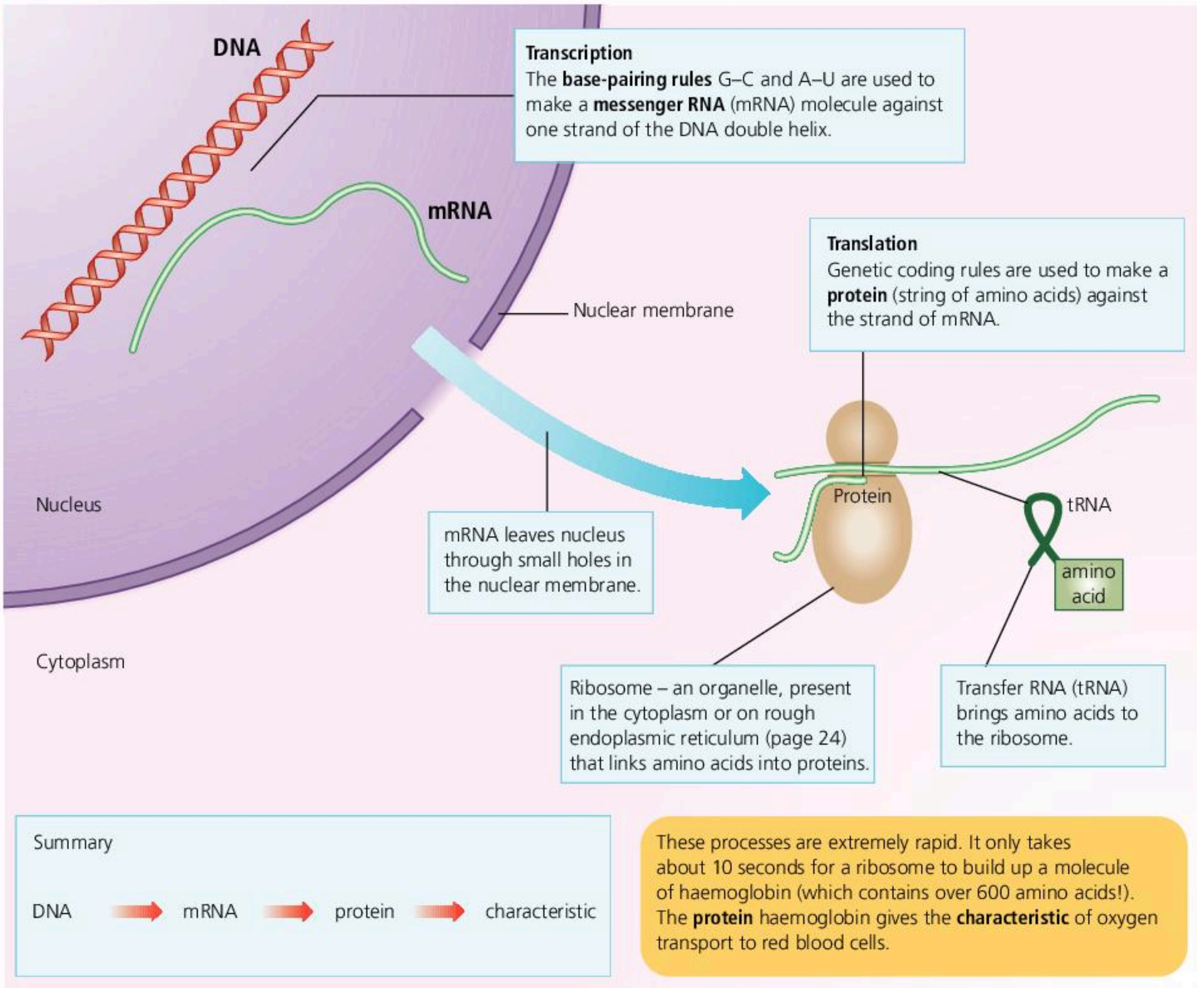
The mRNA is made by a process called **transcription**, which literally means 'cross writing'. The base sequence in the DNA is **transcribed** into another base sequence in the mRNA, using very similar base pairing rules to those used in the replication of DNA. There is one important difference – RNA never contains the base thymine (T). Thymine is replaced by a fifth base called **uracil** (U) so instead of the base pair A–T used in DNA replication, in transcription we have the base pair A–U.

Once it has been made, the mRNA leaves the nucleus and travels to the ribosomes. The sequence of bases in the mRNA is used to build up a sequence of amino acids into a protein in the ribosome. This process is called **translation** – it involves rewriting the language of bases into a language of amino acids. The processes of transcription and translation are outlined in the diagram on the next page.

Summary of replication, transcription and translation

It is quite easy to confuse the various processes involving nucleic acids. Remember:

- **Replication** makes a DNA copy, using DNA.
- **Transcription** makes mRNA, using DNA.
- **Translation** makes protein, using mRNA.

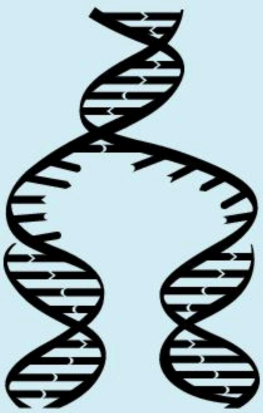


▲ How information in DNA codes for characteristics in cells

Cell specialisation depends on proteins.

- All body cells in an organism contain the same genes but many genes in a particular cell are not expressed.
- The cell only makes the specific proteins it needs to carry out its specialised function.

1 What are the subunits of a nucleic acid called?
2 Name the four bases in DNA.
3 DNA exists as a double helix. Name the base pairs that hold the double helix together. Why is base pairing important?
4 Define the term DNA replication.
5 Name four proteins that give particular characteristics to named cells.
6 Name one process of which DNA replication is a vital part.
7 The diagram on the right represents the behaviour of DNA strands during the early part of cell division. Use the information in the diagram to help you answer the following questions.
  a Identify the organic bases X and Y.
  b Name the process shown in the diagram.
  c What is the importance of the SEQUENCE of organic bases along a DNA strand?



Key:

Organic base	Symbol
Adenine (A)	▬
X	▬
Y	▬
Guanine (G)	▬

17.4 Cell division

OBJECTIVES

- To understand why it is necessary to copy genetic material accurately
- To know that copying division is called mitosis, and results in cells with an identical number and type of chromosomes as their parent cells
- To know how chromosomes behave during mitosis
- To know where mitosis takes place in the bodies of mammals and flowering plants
- To understand the need for a special cell division in the formation of haploid gametes

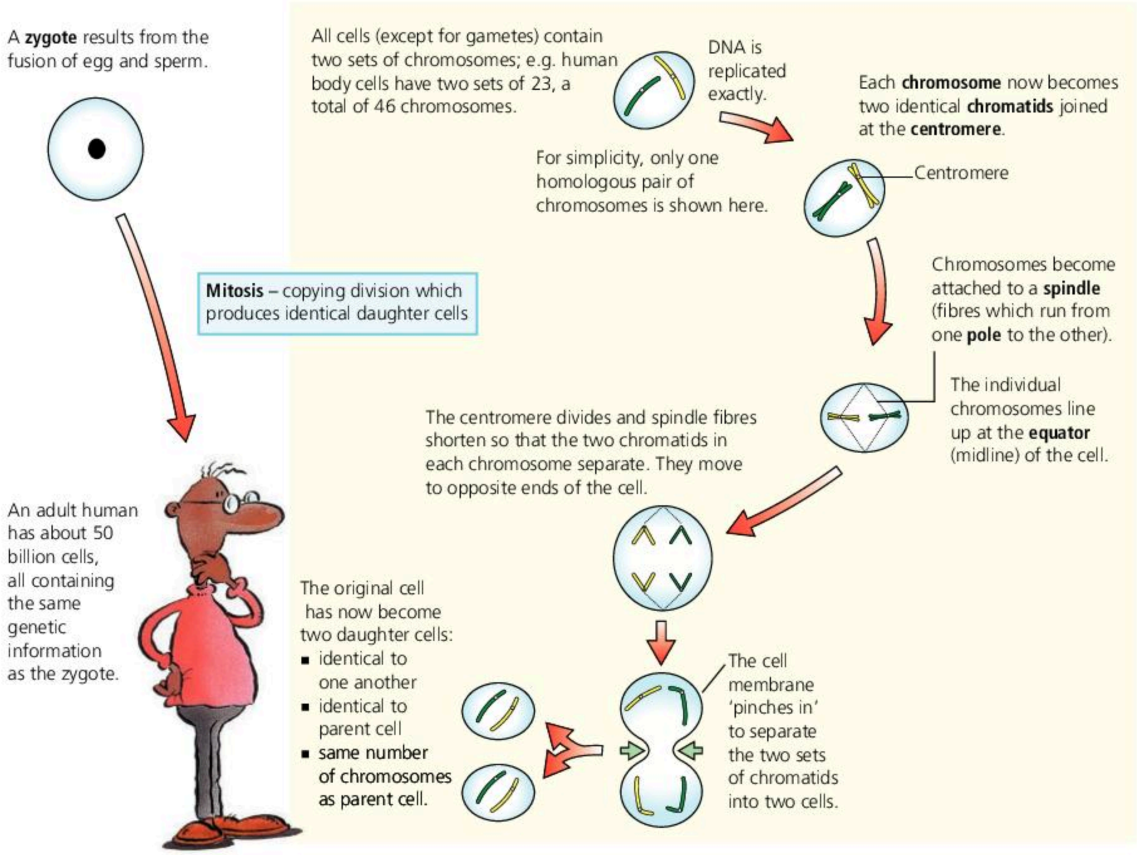
Mitosis is copying division

Characteristics are transmitted from one generation of cells to the next. For this to happen, the chromosomes must be accurately copied and passed on when cells divide. Each chromosome has a partner, forming **homologous pairs**. Both chromosomes in an homologous pair have the same genes in the same positions. The diagram below shows cell division in which the new cells are copies of the parent cell – **mitosis**.

Mitosis is for growth

Both plants and animals grow by mitosis.

- In animals each tissue provides its own new cells when they are needed, e.g. liver produces liver cells.
- **Stem** cells are unspecialised cells that divide by mitosis to produce daughter cells that can become specialised for specific functions.
- In plants, cell division in the **cambium** increases the plant girth (the plant gets thicker), and cell division in the **meristems** at the tips of the roots and shoots leads to an increase in length (see page 11).



▲ Mitosis – copying division. Note that cell division is a continuous process. Although the diagram shows mitosis in a series of stages, in reality each stage merges into the next one.

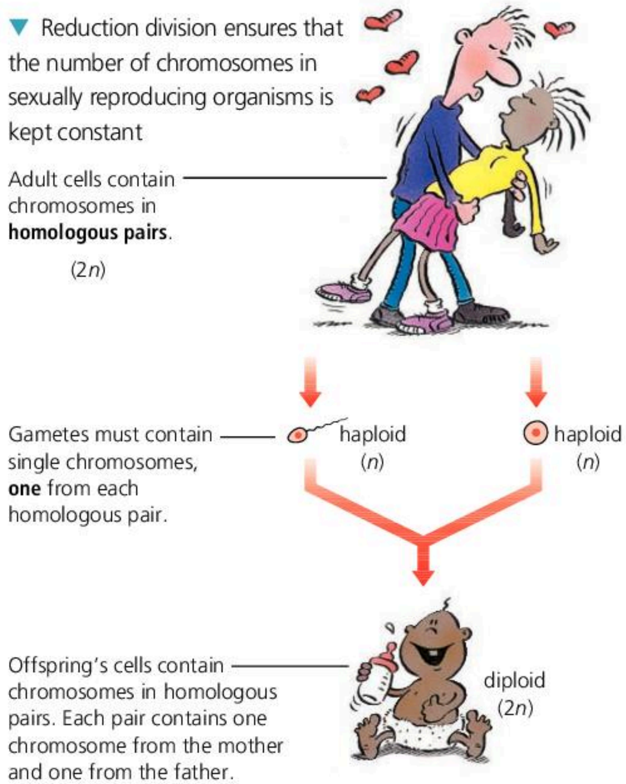
S Meiosis is reduction division

During sexual reproduction two gametes fuse to form the zygote. The gametes must contain only one set of chromosomes, otherwise the zygote would have twice as many chromosomes as it needed! This principle is outlined in the diagram on the right.

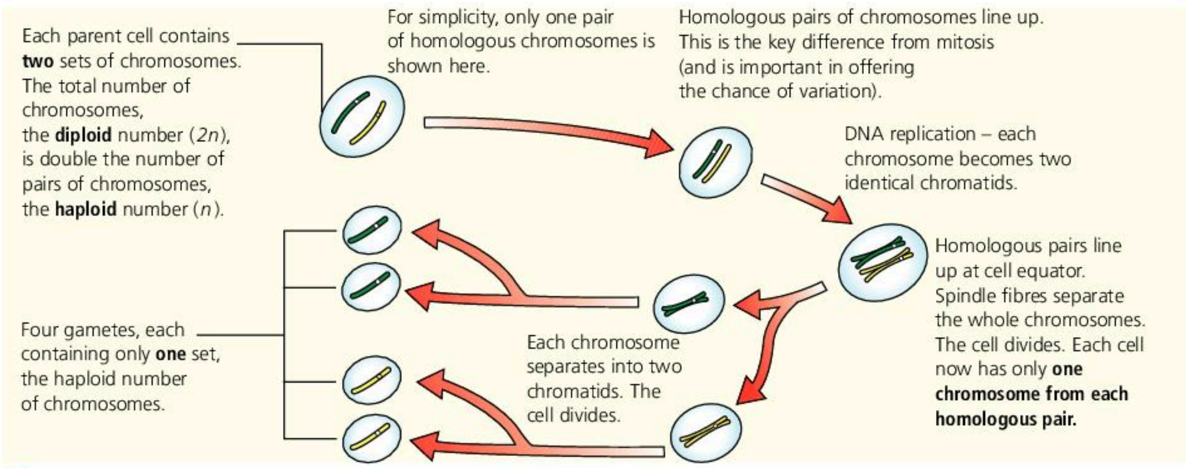
Each cell of an organism has a fixed number of chromosomes within the nucleus. The number of chromosomes in a normal body cell is the **diploid number** (or $2n$); the number of chromosomes in a gamete is the **haploid number** (or n). **Fertilisation** is the **fusion of haploid gametes to restore the diploid number in the zygote**. Gametes are formed by a type of cell division called **meiosis** or **reduction division**, shown in the diagram below.

Meiosis only happens in the gamete-producing organs: the testes and the ovaries in animals, and the pollen sacs of the stamens and the ovules in the ovary in plants.

▼ Reduction division ensures that the number of chromosomes in sexually reproducing organisms is kept constant



Meiosis is called reduction division because it halves the number of chromosomes in cells



Q

1 Cells in bone marrow undergo mitosis. Some of these cells become red blood cells, to replace those lost as they wear out. A typical red blood cell lasts for 120 days before it is removed from the circulation.

a Suggest why red blood cells last for a short time.

b Which organ removes red blood cells from blood?

c This organ stores the main metal ion that forms part of the red blood cell. Which ion is this, and what molecule is it a part of inside the red blood cell?

d The human circulation contains about 5 dm^3 of blood. Each mm^3 of blood contains 5 000 000 red blood cells. (1 dm^3 = 1 000 000 mm^3.)

i Calculate how many red blood cells there are in the human circulation.

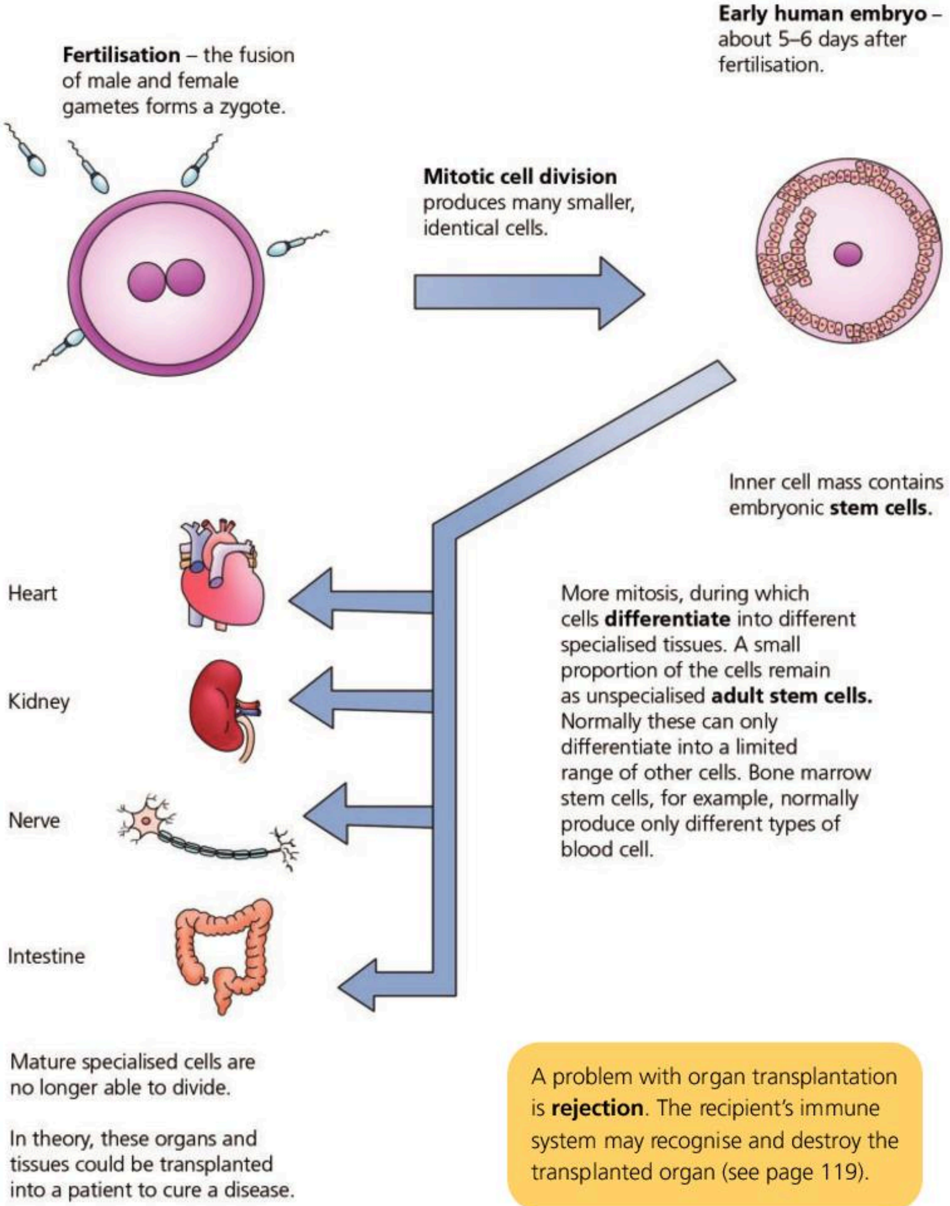
ii The total number of red blood cells is replaced every 120 days. Calculate how many cells are replaced each day. How many are replaced each second?

17.5 More about cell division*

Stem cells

Most of the cells in a multicellular organism are specialised (see page 26) – each cell or group of cells is adapted to perform a particular function with great efficiency. An organism begins its development as a single cell. This single cell then divides to produce many cells which undergo differentiation as they take on their specialised functions.

S



A problem with organ transplantation is **rejection**. The recipient's immune system may recognise and destroy the transplanted organ (see page 119).

▲ Division and differentiation of animal cells

Some cells, however, remain unspecialised and keep the ability to differentiate into many different types of cell when they are needed. These are called **stem cells** and they are among the most important cells in the body. Human stem cells are found in the embryo as well as in several adult tissues, including bone marrow, the liver, brain muscle and blood. These stem cells remain in this unspecialised form until the tissues become damaged or are affected by disease. They can then begin division and differentiation to replace the damaged cells.

Stem cell research

Stem cell research involves harvesting these primitive cells in laboratories and using them for producing large quantities of useful cells such as those of the blood, brain and spinal cord. This research has great potential in medical science for improving human quality of life and recovery from disease.

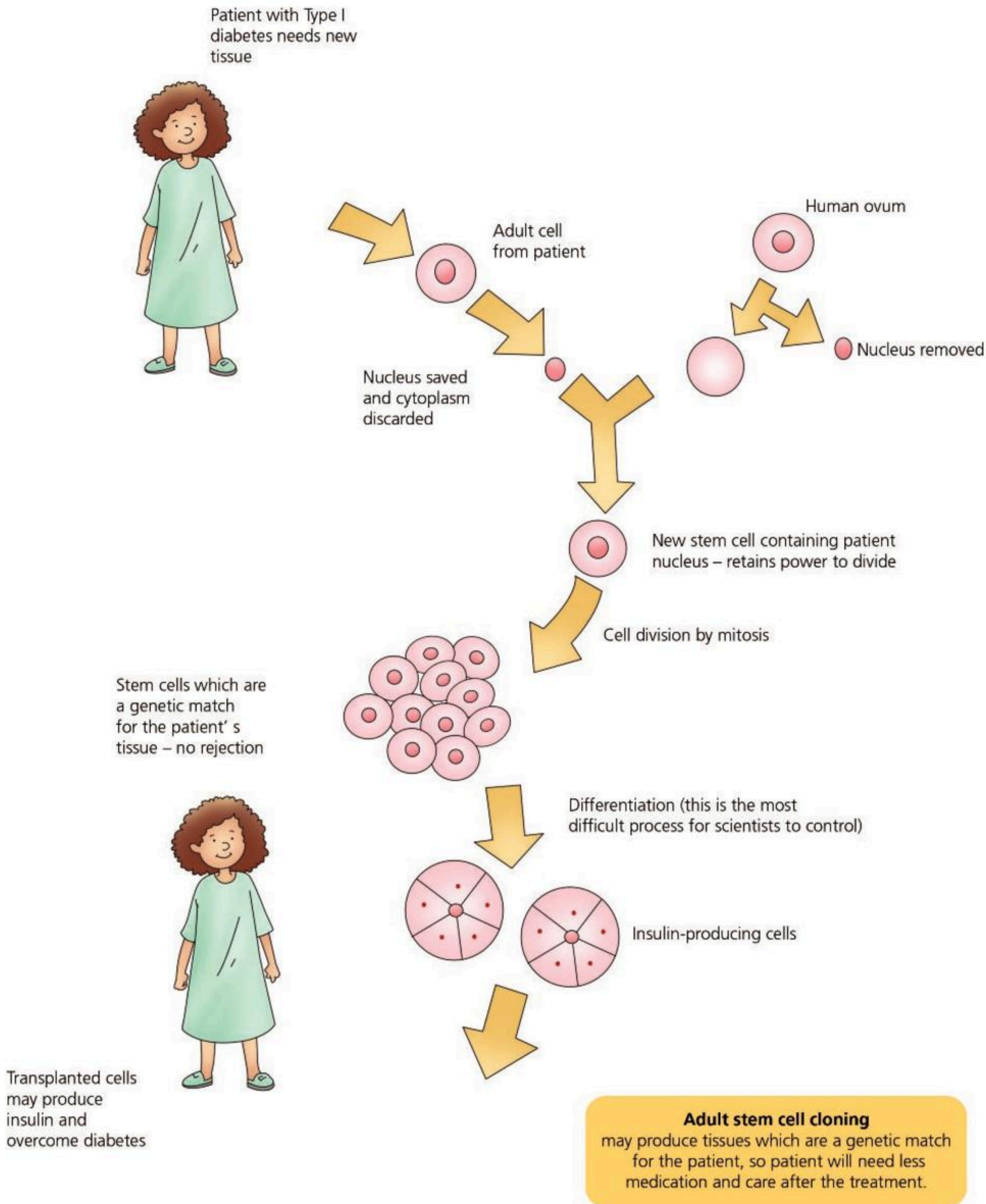
Stem cells are already being used to treat some human diseases – bone marrow cells in the treatment of leukaemia, for example. Research continues into other conditions, including spinal cord damage. It is hoped that replacement of damaged cells in the spinal cord by embryonic stem cells could help to reverse paralysis, for example. However, research into stem cell therapy is difficult and costly, and there are also arguments against this form of treatment.

For	Against
■ Stem cells are thought to hold the key that will one day help unlock the cure for Parkinson's disease, Alzheimer's disease, heart ailments, Type I diabetes, spinal cord injuries and some congenital disease conditions. ■ Stem cells can help in replacing and repairing organs and tissues within the body, for example those that have been damaged due to cancer, as a result of liver cirrhosis, or from deep burns. ■ They can be used in the study of human growth and cell development to test potential drugs and medicines, without the use of animals or human testers. This necessitates a process of simulating the effect the drug has on a specific population of cells, in this case stem cells.	■ The use of embryonic stem cells involves the destruction of unused embryos formed from laboratory-fertilised human eggs. Some people believe that life begins at conception, so these embryos represent human life and to destroy them is unethical. Researchers point out that many of the embryos are those left over after fertility treatment and would be destroyed anyway. ■ These cells are derived from embryos that are not a patient's own, and the patient's body may reject this 'non-self' tissue. ■ There may be unknown side effects. In some patients suffering from heart disease, for example, coronary arteries became narrower following stem cell therapy.

Q

1 True or false?

a Stem cells from one individual have the same genotype.
b Stem cells can be collected from bone marrow.
c All stem cells die once a person becomes adult.



▲ Treatment of Type I diabetes using stem cells

Embryonic or adult stem cells?

One other disadvantage of the use of **embryonic** stem cells is that a patient requires a great deal of medical care, including immunosuppression. **Adult** stem cells derived from the patient avoid the problems of tissue rejection. However, embryonic ones are easier to identify and isolate, and can be purified more easily than adult stem cells. Adult stem cells are not always a good alternative to embryonic stem cells – they could carry a genetic condition from a donor to a recipient, for example.

Embryonic stem cell research is now allowed in many countries – it is felt that the advantages, and the ease of culture, outweigh the disadvantages. Currently, efforts are being made to collect embryonic cells without damaging the embryos and to look for alternative means of harvesting stem cells without using embryos (from the umbilical cord, for example).

Q

1. Suggest two reasons why doctors and scientists are interested in stem cells.
2. State the two main sources from which stem cells originate.
3. Explain how a doctor or scientist could obtain embryonic stem cells.
4. Name two possible sources of adult stem cells.
5. Suggest two advantages of collecting umbilical cord stem cells.

17.6 Inheritance

OBJECTIVES

- To recall the features of sexual and asexual reproduction
- To be able to define the terms gene and allele, homozygous and heterozygous, dominant and recessive

Reproduction: a reminder

Living organisms can pass on their characteristics to the next generation (**reproduce**) in two ways (page 176).

Remember, for sexual reproduction:

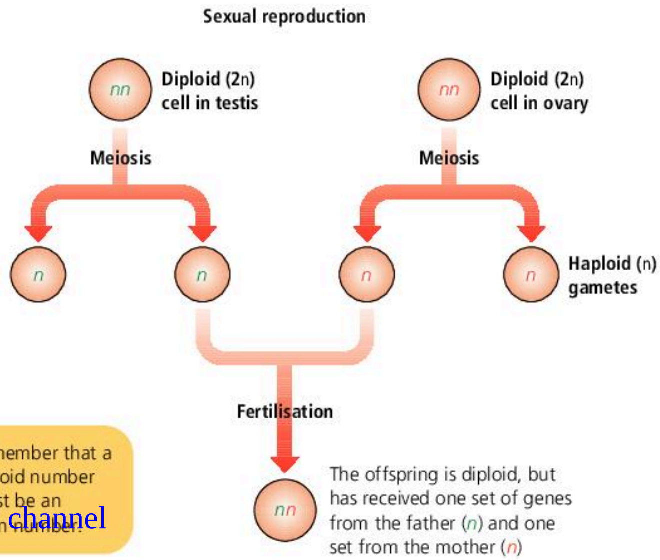
- two organisms of the same species, one male and one female are required
- each individual produces sex cells (**gametes**)
- sexual reproduction always involves **fertilisation** – the fusion of the gametes
- offspring receives some genes from each parent, so shows a mixture of parental characteristics.

In sexual reproduction, a mixture of genes is passed from parents to offspring. This handing down of genes is not random, and there are certain rules that govern how genes will be passed on and which ones will show up in the offspring.

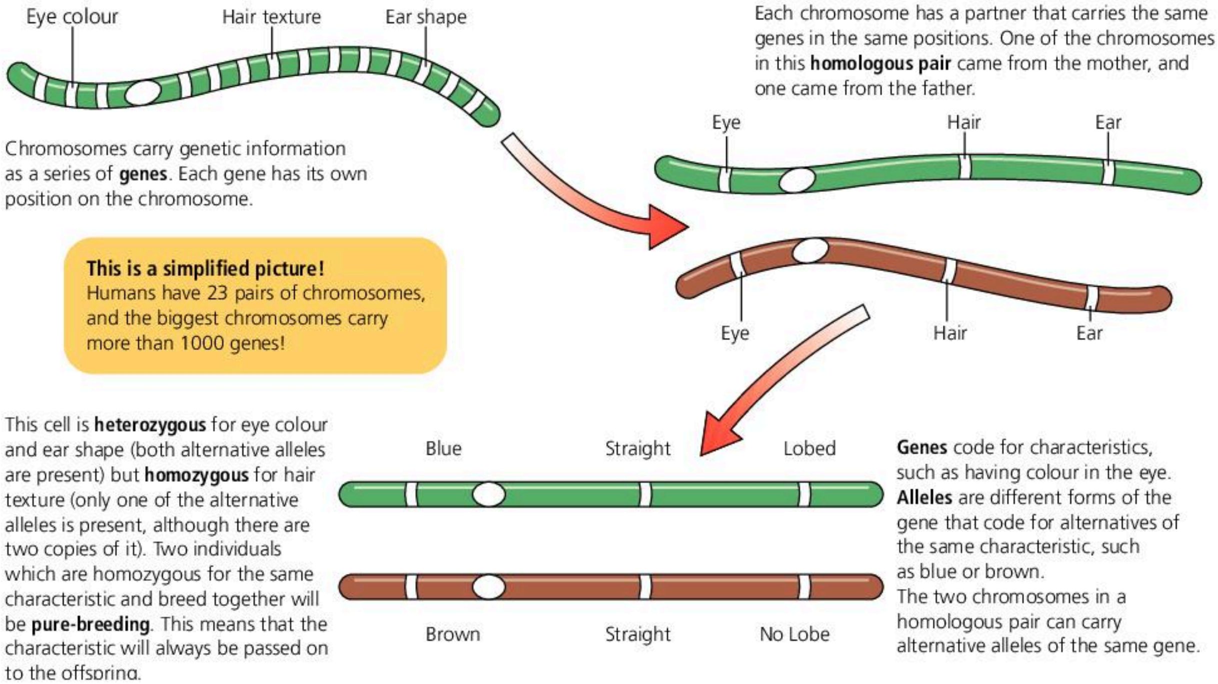
The inheritance of characteristics

Chromosomes carry genetic information as a series of **genes**, such as the gene for eye colour, the gene for earlobe shape and the gene for hair texture. Each chromosome in the nucleus of a diploid organism has a partner that carries the same genes. Such a pair of chromosomes is called an **homologous pair**.

Each chromosome in a pair may carry alternative forms of the same gene. These alternative forms are called **alleles**. For example, the gene for eye colour has alleles that code for blue or brown. If both alternative alleles are present in a particular cell nucleus, then the cell is **heterozygous** for that characteristic. On the other hand, if the nucleus carries the same allele on both members of the homologous pair, then the cell is **homozygous**. The meaning of these genetic terms is outlined in the diagram at the top of the next page.

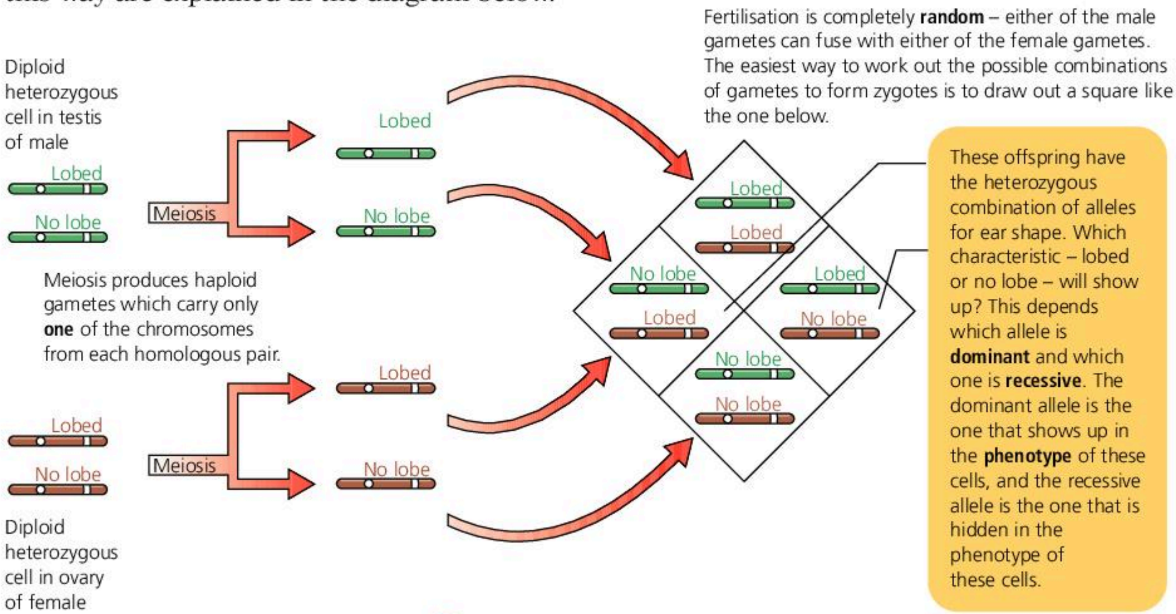


Remember that a diploid number must be an even number.



▲ Diploid organisms have homologous pairs of chromosomes in the nucleus

In a heterozygous cell, when the members of the homologous pair separate during meiosis the gametes will contain different alleles. This means that when gametes fuse at fertilisation, the resulting zygote may have a number of different possible allele combinations. The production of gametes and the formation of different zygotes in this way are explained in the diagram below.



▲ The recombination of alleles during sexual reproduction gives rise to a great variation among offspring. This leads to the evolution of new strains, races and, eventually, new species.

Q

1. Define the terms homologous pair, heterozygous and homozygous.
2. What is the difference between a gene and an allele?
3. What is a meant by a dominant allele?

17.7 Studying patterns of inheritance

OBJECTIVES

- To understand the method for describing genetic crosses
- To know the result of crosses involving two heterozygous parents
- To understand the principle of the test cross

Scientists called **geneticists** study the inheritance of characteristics by carrying out breeding experiments. There is a conventional pattern for describing the results of such experiments – a sort of genetic shorthand, shown in the example below.

At fertilisation, any male gamete can fuse with any female gamete

Drawing out chromosomes carrying alleles of genes is very time-consuming. Geneticists write out the stages of crosses using symbols to replace the chromosomes and genes. These symbols should always be identified at the start of a cross.

Let **B** = brown and **b** = blue

The **capital** letter is used for the **dominant** allele.

Brown (**B**) and blue (**b**) are **alleles** of the **gene** for eye colour.

Consider a cross between a homozygous brown-eyed man (**BB**) and a homozygous blue-eyed woman (**bb**):

Parents BB × bb

Gametes (B) and (B) (b) and (b)

Remember, gametes are **haploid** so receive only one allele from the two present in the parent cell.

At fertilisation (B) (b) → Bb

A male gamete fuses with a female gamete → Bb

First generation (called the F_1 **generation**) Bb

This **genotype** would give a brown-eyed **phenotype**, since brown is **dominant** to blue.

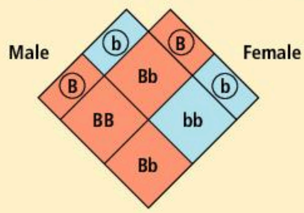
Now consider a cross between two heterozygous parents (**Bb**), i.e. with the same genotype as the F_1 above:

Parents Bb × Bb

Gametes (B) and (b) (B) and (b)

At fertilisation, any male gamete can fuse with any female gamete.

At fertilisation



F_1 generation

Genotype	BB	Bb	Bb	bb
Phenotype	brown	brown	brown	blue
	3 brown			1 blue

The inheritance of eye colour. There are two important points about this cross.

1. These results are **probabilities** (chances). The offspring *should* be in the 3:1 ratio shown, but each fertilisation is random so they may not be. This ratio is more likely to be seen in very large numbers of offspring. For human families, a 3:1 ratio is unlikely since very few mothers give birth to four children at one time.
2. Every cross between the same two parents is a different event. If two heterozygous parents produce a child with blue eyes (a 1/4 probability) there is still a 1/4 probability that their next child will have blue eyes.

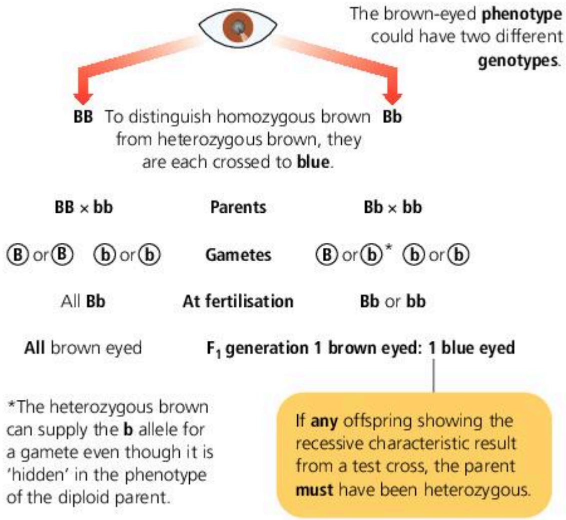
In theory, a cross between two heterozygous parents should produce offspring in the ratio of 3 showing dominant to 1 showing recessive. This can be restated as: 'The probability of any offspring showing dominant is 3/4 or 75%; the probability of it showing recessive is 1/4 or 25%'.

Test cross

In the eye colour example, both of the genotypes **BB** and **Bb** give the same phenotype – brown eyes. It might be important to know whether a particular organism is homozygous or heterozygous, particularly in the breeding of domestic animals. To do this, geneticists use a **test cross** (often called a **back cross to the recessive**). The principle is outlined on the right.

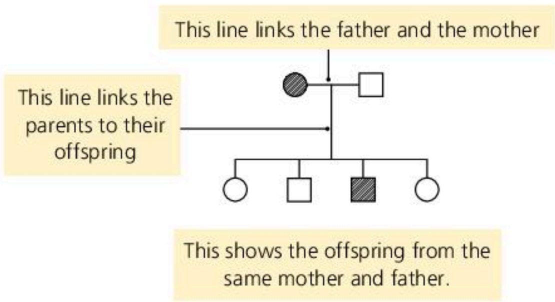
Reminder!	
Ratio: dominant to recessive	**Phenotypes of parents**
3:1	Both heterozygous
1:1	One heterozygous, one homozygous recessive

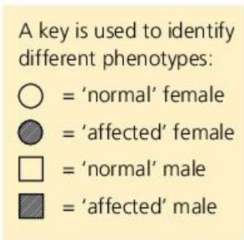
The results of genetic crosses are sometimes shown as a **pedigree**.



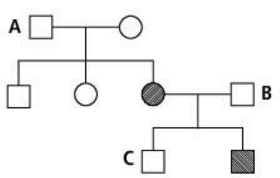
▲ A test cross can distinguish different genotypes with the same phenotype

Rules for showing a pedigree ('family tree')





SOLVING PEDIGREES – AN EXAMPLE



◀ This family tree ('pedigree') refers to the inheritance of fur colour in rabbits. Brown fur is dominant to white fur. What can you deduce about the genotype of individuals A, B and C?

- Let B = brown and b = white
- ● and ■ must be bb, this is the starting point since the only certainly is that animals with the 'recessive' phenotype must have the homozygous recessive genotype.
- A must be Bb because he has brown fur but can pass on the b allele to one of his daughters (his partner must be Bb too!).
- B must be Bb for the same reason as A is.
- C must be Bb because he has brown fur but must have received the b allele from his mother.

Q

1. Draw a diagram to explain how two brown-eyed parents can have a blue-eyed child.
2. Gregor Mendel suggested that a cross between two heterozygous individuals produces offspring in a ratio of 3 showing the dominant characteristic to 1 showing the recessive characteristic. Explain why such crosses rarely give an exact 3:1 ratio.
3. Use a suitable example to explain the value of a test cross.

17.8 Inherited medical conditions and codominance

OBJECTIVES

- To know some examples of inherited conditions
- To understand inheritance when neither allele is dominant

Inherited medical conditions

There are several important medical examples of monohybrid inheritance, including albinism and sickle cell anaemia.

Albinism

Albinism is caused by a recessive allele. Heterozygous individuals are not affected by the condition, but they are **carriers** of the mutant, recessive allele.

People with albinism do not produce the pigment **melanin**. This pigment normally makes skin, the iris of the eye and hair a dark colour. These people have pale skin, light hair and pink eyes (the pink is actually the blood in the retina showing up). They are very sensitive to bright light and the skin burns very easily in sunlight.

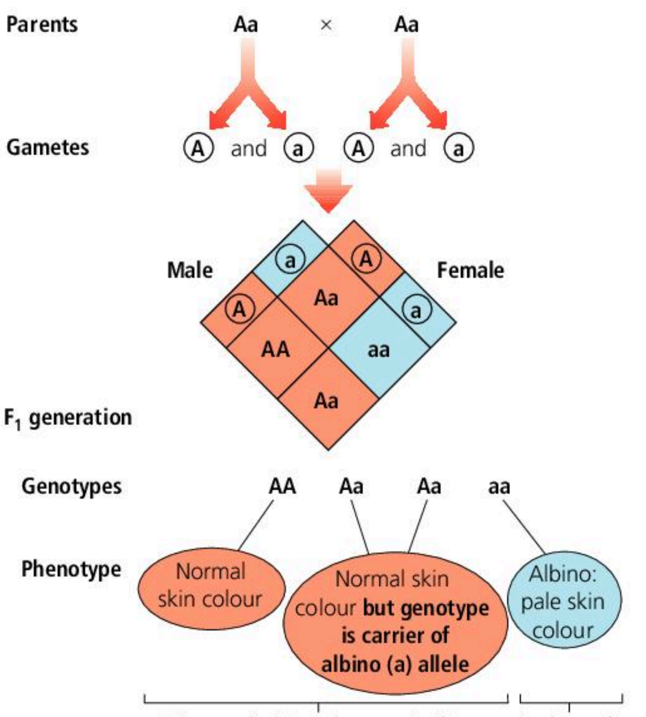
Because the allele for 'albino' is recessive, we can be certain that an albino human is homozygous recessive (**aa** in this case).

▲ A girl with albinism

Albinism is caused by a recessive allele.

Let **A** = normal allele and **a** = mutant (albino) allele.

If both parents are heterozygous (i.e. Aa)



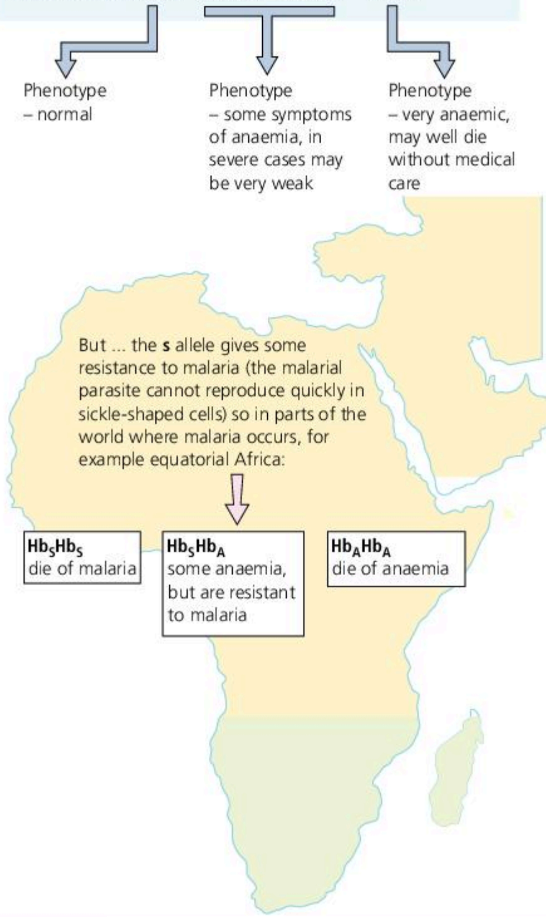
Sickle cell anaemia

Sickle cell anaemia is a condition in which a homozygote has the disease, but a heterozygous individual may gain some benefit in certain environments. A change in the base sequence of the gene for haemoglobin results in abnormal haemoglobin and sickle-shaped red blood cells.

Sickle cell anaemia – carriers are anaemic but are resistant to malaria

Sickle cell anaemia is caused by a recessive allele.
Let Hb_S = normal allele and Hb_A = sickle cell allele.
Consider a cross between two heterozygous parents:

Parents	Hb_SHb_A	Hb_SHb_A
Gametes	Hb_S or Hb_A	Hb_S or Hb_A
F_1 generation	Hb_SHb_S Hb_SHb_A Hb_SHb_A Hb_AHb_A	



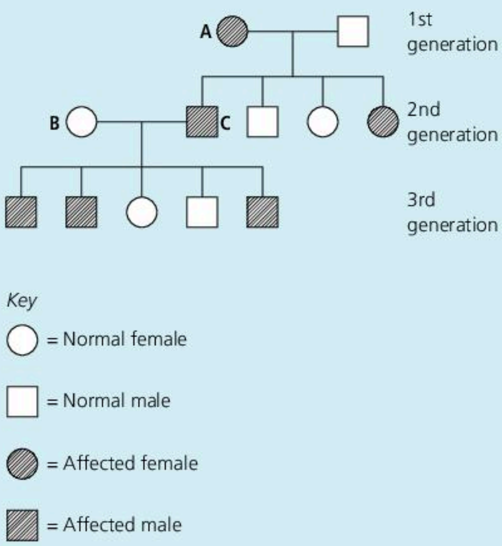
Codominance

Some genes have more than two alleles. For example, the gene controlling the human ABO blood groups has three alleles, given the symbols I^A, I^B and I^O. Neither of the I^A and I^B alleles is dominant to the other, although they are both dominant to I^o. This is called **codominance**. It results in an extra phenotype when both alleles are present together. The genotypes and phenotypes are shown in the table.

Genotype	Phenotype
I^AI^A or I^AI^O	Blood group A
I^BI^B or I^BI^O	Blood group B
I^AI^B	Blood group AB
I^OI^O	Blood group O

The human blood groups are easily detected by a simple test on a blood sample.

1 Huntington's disease (HD) is caused by a dominant allele (**H**) – the other allele (**h**) results in normal working of the central nervous system. This diagram shows how one family is affected by HD.



a What was the genotype of the grandmother, **A**? Explain your reasoning.

b Draw a genetic diagram to show how parents **B** and **C** passed on HD to their children.

c If parents **B** and **C** have a sixth child, what are the chances that it will have HD?

d Most serious genetic diseases are caused by recessive alleles. Explain why a dominant allele that causes a serious disease may quickly disappear from a population.

2 **a** Draw a genetic diagram to explain the inheritance of blood group in the Wilson family. Mr Wilson has the genotype I^AI^B and Mrs Wilson has the genotype I^OI^O.

b What is the probability of the Wilsons' first child being female?

c What is the probability of this child being female (see page 224) and having blood group A?

d A person with alleles I^A and I^B shows the effect of both alleles in the phenotype. What term is used to describe this?

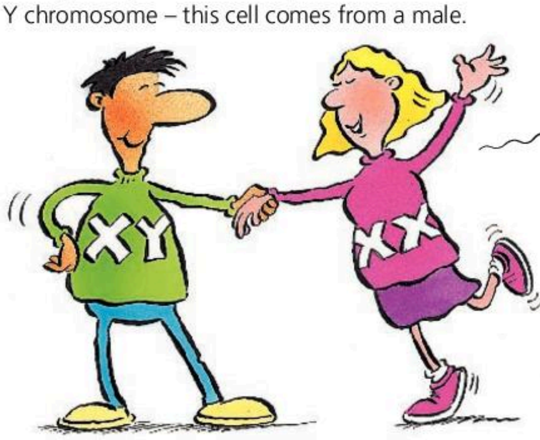
17.9 Sex is determined by X and Y chromosomes

OBJECTIVES

- To understand how sex is determined and inherited in humans
- To know that some genes are sex linked
- To understand the pattern of inheritance of sex-linked genes

The photograph below shows a complete set of human chromosomes (a karyotype). When all of the chromosomes are arranged in pairs, there may be two left over which differ in size and do not form an homologous pair. These are the **sex chromosomes**. The importance of these sex chromosomes is outlined below.

▲ A **karyotype** – a photograph of human chromosomes arranged in pairs. The 23rd pair is an X and a Y chromosome – this cell comes from a male.



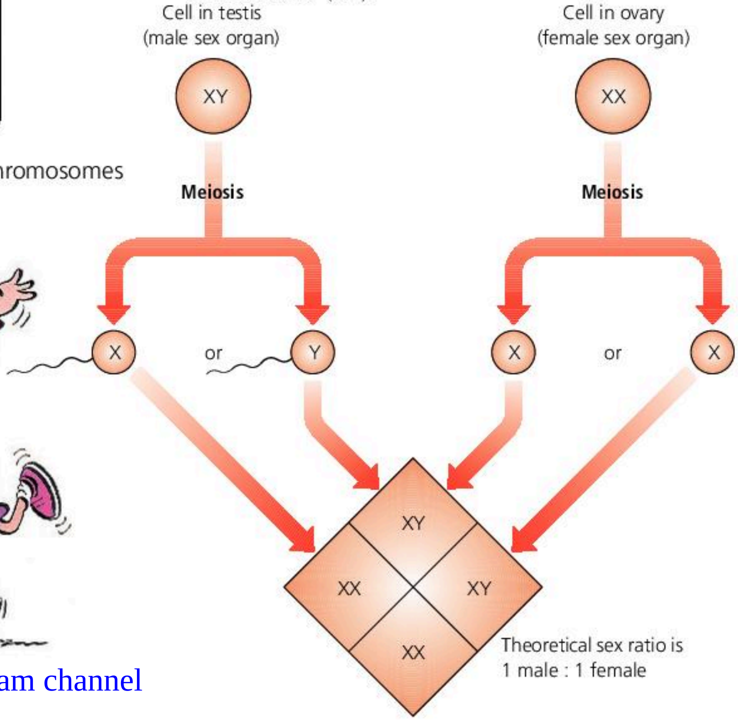
Note that:

- The man's sperm determines the sex of his children since the woman can only produce gametes with an X chromosome.
- The sex chromosomes carry genes concerned with sexual development, such as development of the sex organs and position of fat stores.
- The sex chromosomes also carry a few genes that code for characteristics that are not concerned with sex. Since these genes are carried on the sex chromosomes, they may show their characteristics only in one sex.

For example, the gene for **colour blindness** is carried on the X chromosome. We say that colour blindness is **sex linked**.

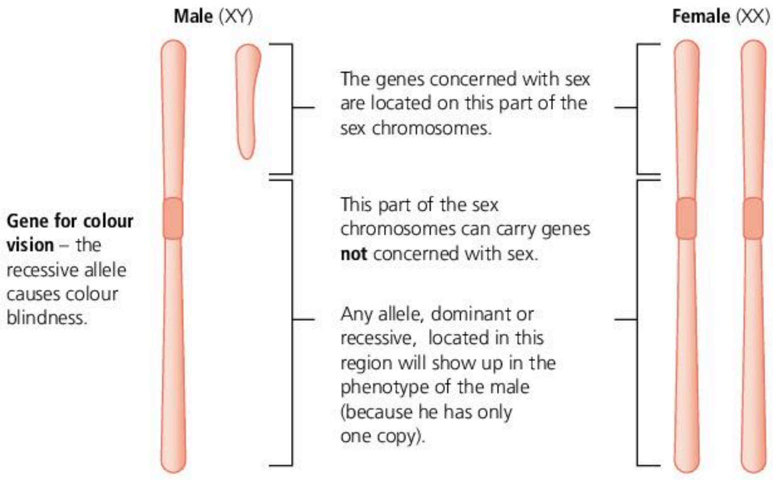
▼ The inheritance of sex

Each human body cell has 46 chromosomes. There are 22 **pairs** of chromosomes plus another two chromosomes which may not look alike. These are the **sex chromosomes**. Female cells have two sex chromosomes that are alike (called XX) and male cells have two sex chromosomes that are not alike (XY).



The inheritance of sex-linked characteristics

One well-known sex-linked characteristic is red–green colour blindness. This is a disease in which the person cannot tell the difference between red and green. It is an X-linked condition. The inheritance of this disease is shown below. Haemophilia (a failure in blood clotting) is inherited in a similar way – there are many more males than females who cannot clot their blood efficiently.

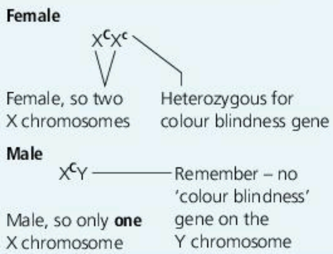


▲ Any gene carried on the sex chromosomes is sex-linked

The inheritance of colour blindness

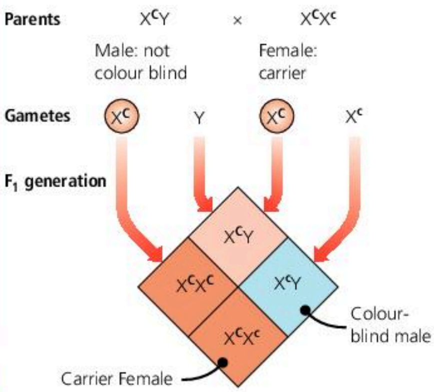
Let **C** = normal allele and
c = mutant allele.

Because these alleles are carried on the X chromosome, it is necessary to show the sex chromosomes in the pattern of inheritance. For example:

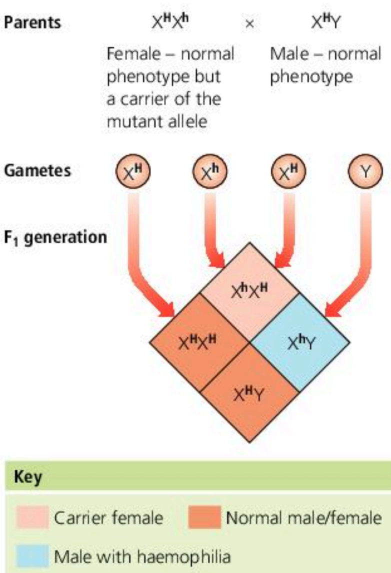


Airline and military pilots must be tested for colour blindness, red and green signals mean very different things!

Consider a cross between a carrier woman and a normal man:



For haemophilia



Q

1 Use a simple genetic diagram to explain why there are approximately equal numbers of male and female babies.

2 Why are males more likely to have red–green colour blindness than females? How could you explain, genetically, a colour-blind female?

3 Haemophilia is a sex-linked characteristic. The diagram above shows how the allele for haemophilia is inherited.

a Explain why the mother is described as a carrier of this condition.

b If she has one child, what is the probability of her having a haemophiliac son?

Questions on inheritance

1 The table below lists some terms for inheritance and their definitions.
Match each term with its definition. Write the letter and number to show your answer, for example, **a–4**.

Term	Definition
a allele	**1** the sum of the alleles on the chromosomes in the nucleus
d phenotype	**2** a form of a gene that codes for one of a pair of contrasting characters
c heterozygote	**3** an allele which, if present, always has an effect
d genotype	**4** an organism with two different alleles for a particular characteristic
e dominant	**5** the sum of the measurable characteristics of an organism

[4]

2 Copy the following paragraphs and complete them by filling in the missing words.
Use words from the list below. Each word may be used once, more than once or not at all.
allele, diploid, dominant, gene, haploid, heterozygous, homozygous, meiosis, mitosis, recessive, sex-linkage
Polydactyly is an inherited condition in humans. The condition is controlled by a single ________________ which has two alternative forms. One form causes polydactyly while the other does not.
In preparation for sexual reproduction, gametes are formed by ________________ – the gametes fuse at fertilisation to form a ________________ zygote. Neither parent has polydactyly, but one of their three children does. This suggests that polydactyly results from a ________________ allele and that each of the parents is ________________ . [5]

3 The gene for the ABO blood group has three alleles, I^A, I^B and I^o.

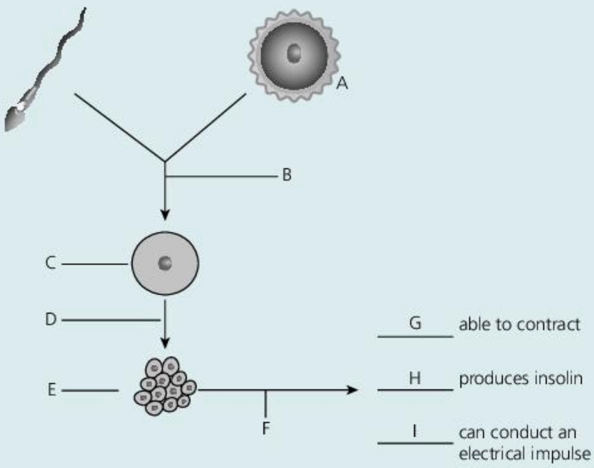
a A person with blood group O has parents who have blood groups A and B. Copy and complete the genetic diagram to show how this is possible.
Use the symbols, I^A, I^B and I^o, for the blood group alleles. [3]

parental phenotypes	blood group A	×	blood group B
parental genotypes	______	×	______
gametes	______ ______	+	______ ______
offspring genotype		______	
offspring phenotype		blood group O	

b Use your answer to **a** to give examples of the following. The first one has been completed for you. [3]

Term	Example
a dominant allele	I^A
Heterozygous genotype	______________
codominant alleles	______________
phenotype	______________

4 The diagram below shows a set of processes involved in the formation of a human body.



a Name the cells labelled A, C and E. [3]
b Name the processes labelled B, D and F. [3]
c Suggest the names of the organs or tissues labelled G, H and I. [3]

5 Cystic fibrosis is a common inherited disease caused by a recessive allele. A blood test can detect this allele. A man and his wife were both found to be carriers of the cystic fibrosis allele.

a What is meant by a carrier of the allele? [1]
b Draw a genetic diagram to show the inheritance of cystic fibrosis in any children of this couple. What is the chance that a child will have cystic fibrosis? [5]

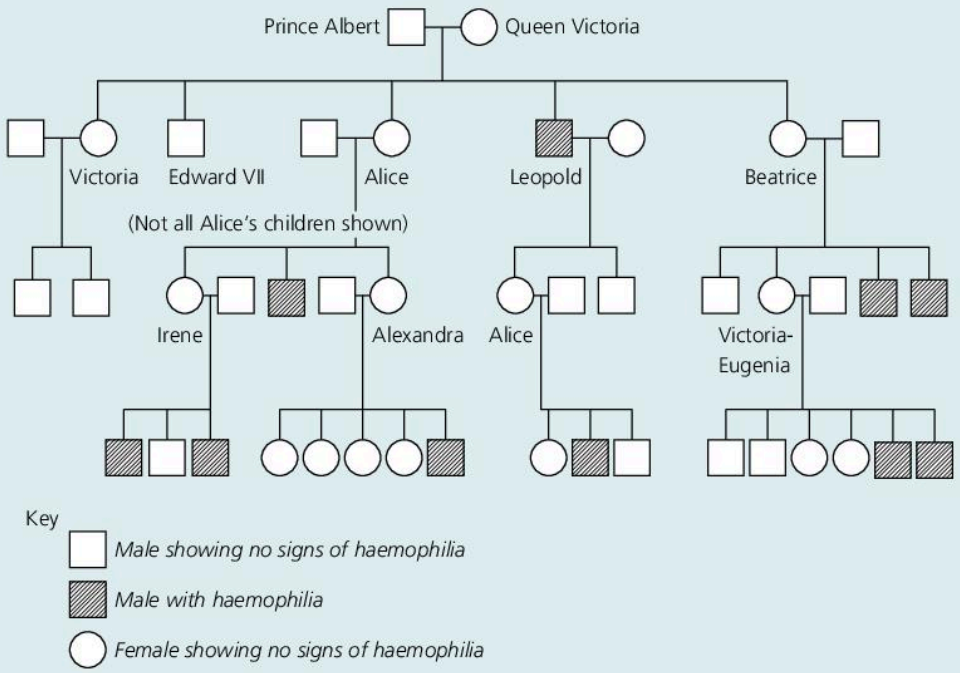
6 The diagram below shows part of Queen Victoria's family tree. The diagram shows the inheritance of the condition haemophilia. The gene causing haemophilia is carried on the X chromosome.

a If X = normal chromosome, X^h = chromosome carrying the haemophilia gene, a normal male has genotype XY, and a normal female has genotype XX, what are the genotypes of:

i a haemophiliac male? [1]

ii a haemophiliac female? [1]

iii a female who appears normal but carries the gene for haemophilia? [1]



Use information from the family tree to answer the following questions.

b State which parent passed on the haemophilia allele to Prince Leopold. Explain your answer. [3]

c Haemophilia did not appear in any of the ancestors of Queen Victoria or Prince Albert. Suggest how this condition appeared in their children. [2]

d State whether the allele for haemophilia is dominant or recessive. Explain your answer. [3]

18.1 Variation

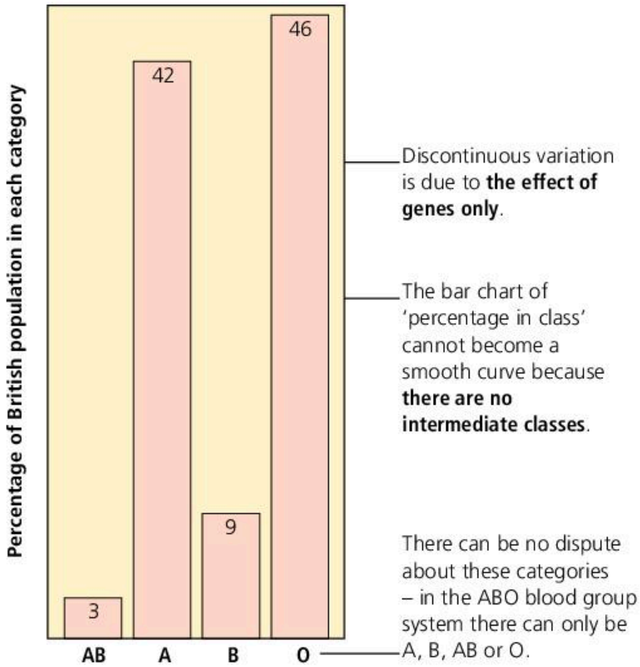
OBJECTIVES

- To recall that living organisms differ from one another
- To distinguish between continuous and discontinuous variation

Living organisms differ from one another. Even members of the same species have slightly different sets of characteristics. Some of these differences are inherited from their parents, and others are the result of the environment. The differences between individuals of the same species are called **variations**. Scientists who study variation are interested in questions such as:

- Are all the variations of the same type?
- How do the variations come about?
- How are the variations in characteristics passed on from parents to offspring?
- What is the importance of these variations?

There are two types of variation – **discontinuous variation** and **continuous variation**.



▲ Human blood groups are an example of discontinuous variation. Another example is gender – you are born as either male or female.

Discontinuous variation

Characteristics that show discontinuous variation have several features:

- An organism either has the characteristic or it doesn't have it. There is no range of these characteristics between extremes. An organism can easily be placed into definite categories, and there is no disagreement about the categories.
- These characteristics are usually **qualitative** – they cannot be measured.
- They are the result of genes only – they are not affected by the environment.

An example of discontinuous variation is shown in the diagram above right.

Continuous variation

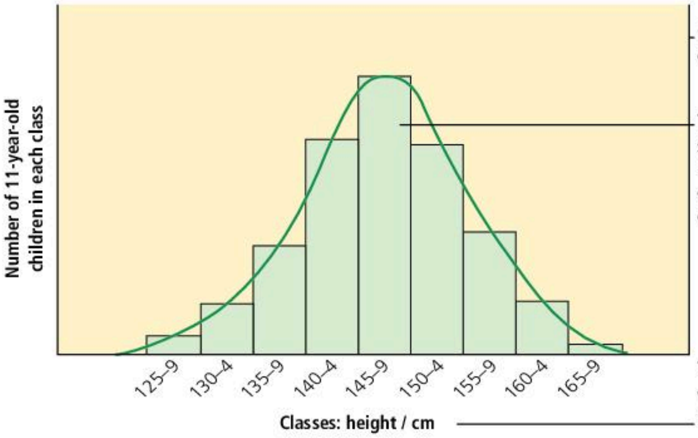
Characteristics that show continuous variation have different features:

- Every organism within one species shows the characteristic, but to a different extent. The characteristic can have any value within a range. Different scientists might well disagree about which category any single organism falls into.
- These characteristics are usually **quantitative** – they can be measured.
- They result from several genes acting together, or from both genes and the environment.

An example of continuous variation is shown in the diagram at the top of the opposite page.

Characteristics can be both discontinuous and continuous

Some characteristics are difficult to classify as either discontinuous or continuous variation. Human hair colour, for example, appears in a range from black to blond with many intermediate colours (it shows continuous variation as a result of the involvement of many genes). However, the gene for red hair is masked by every other hair colour gene (which gives a discontinuous situation – hair is either red or not red). Eye colour can be identified as brown or not brown, which would classify it as a discontinuous variation, or it can be put into a range of many intermediate classes, which would make it a continuous variation. A simple guideline is: 'if it can be measured and given a numerical value, it is a continuous variation'.



▲ Human height is an example of continuous variation. Other examples include quantitative characteristics such as chest circumference, body mass and hand span.

Francis Galton was a cousin of Charles Darwin. He investigated intelligence as an example of phenotype, and believed that 'nature' (genotype) was much more important than 'nurture' (environment). He suggested that:

a children from families where the parents were uneducated would always have low intelligence

b females were less intelligent than males – he suggested the 'ideal' child would be born to 'a man of genius and a woman of wealth'.

His ideas have rightly been discredited, but he does deserve some credit – his studies showed that identical twins were genetically the same.

Phenotype and genotype

Variations in characteristics allow us to recognise different organisms, and to place them in different categories. The overall appearance of an organism is a result of the characteristics that it has inherited from its parents and the characteristics that result from the effects of the environment. The following equation summarises this:

phenotype	=	**genotype**	+	**effects of the environment**
the observable characteristics of an organism		the full set of genes it possesses		

S Some characteristics result from both genes and environment. For example, a bean seedling has the genes to develop chlorophyll (and turn green) but it won't do so unless it receives enough light. A young mammal has the genes to develop a rigid bony skeleton, but it won't do so unless it receives calcium in its diet.

Q

1 Copy and complete the following paragraph.
Variation occurs in two forms, ______, which shows clear-cut separation between groups showing this variation, and ______, in which there are many intermediate forms between the extremes of the characteristic. The first of these is the result of ______ alone, whilst the second is also affected by ______ factors. The sum of the genes that an organism contains is called its ______ and the total of all its observable characteristics is called the ______.
The two are related in a simple equation: ______ equals ______ plus ______.

2 Which of the following is an example of discontinuous variation?
Body mass, chest circumference, blood group, hairstyle, height
Explain:
a why you chose one of these characteristics
b why you rejected the others.

3 Two students in the first year of secondary school were carrying out a mathematical investigation. They decided to measure the heights of all of the other students in their class. The results are shown in the table below.
a Plot these results as a bar chart.
b Does this illustrate continuous or discontinuous variation? Explain your answer.
c Suggest one characteristic that the students could have recorded to illustrate the other kind of variation.

Height category / cm	Number in category
121–125	2
126–130	4
131–135	9
136–140	6
141–145	4

18.2 Causes of variation

OBJECTIVES

- To identify mutation and sexual reproduction as sources of variation
- To understand that mutations may involve whole chromosomes or genes within them
- To recognise that environmental factors may increase the likelihood of mutation

Permanent changes to the phenotype

Permanent characteristics that can be inherited are due to the genetic make-up of an organism. This may be altered, thereby increasing variation, as a result of **mutation** or of **sexual reproduction**.

Mutation

A **mutation** is a change in a gene or chromosome and can arise because of:

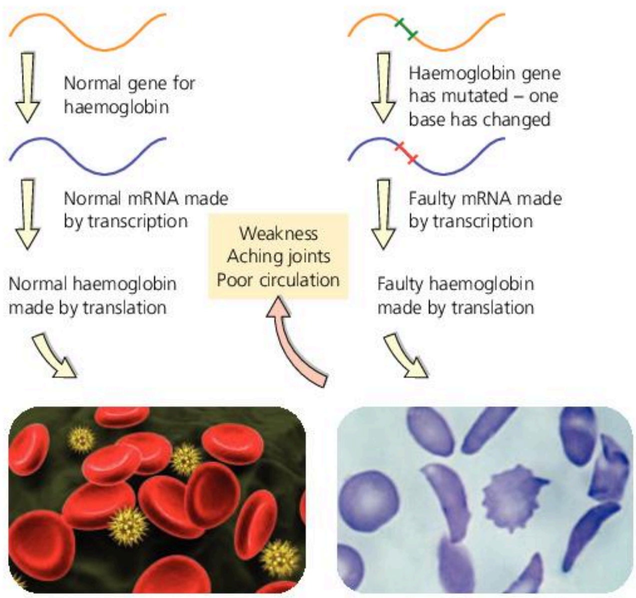
- mistakes in the copying of DNA as cells get ready to divide – pairing with the 'incorrect' base
- damage to the DNA – some environmental factor might alter the bases present in the DNA
- uneven distribution of chromosomes during the division of cells.

Chromosome mutations occur when cell division fails to work with complete accuracy. For example, when human gametes are formed each gamete should receive 23 chromosomes. Occasionally an error occurs. The consequences of chromosome mutations are often serious.

Gene mutations occur when part of the base sequence of the DNA on a single chromosome is changed. As a result, a defective protein may be produced, or no protein at all. This can lead to a considerable change in a characteristic. There are many examples, including **sickle cell anaemia**, shown below.

Beneficial mutations

Not all mutations are harmful. Many of them give benefits to the organisms that have them, and aid adaptation to the environment



◀ Sickle cell anaemia. (A sickle has a curved blade for cutting hay.)

S (see page 232). Some may cause harm in one environment but be a benefit in another! Sickle cell anaemia is an example of this (see page 223) people who are heterozygous for sickle cell anaemia are resistant to malaria.

Radiation can increase mutation rates

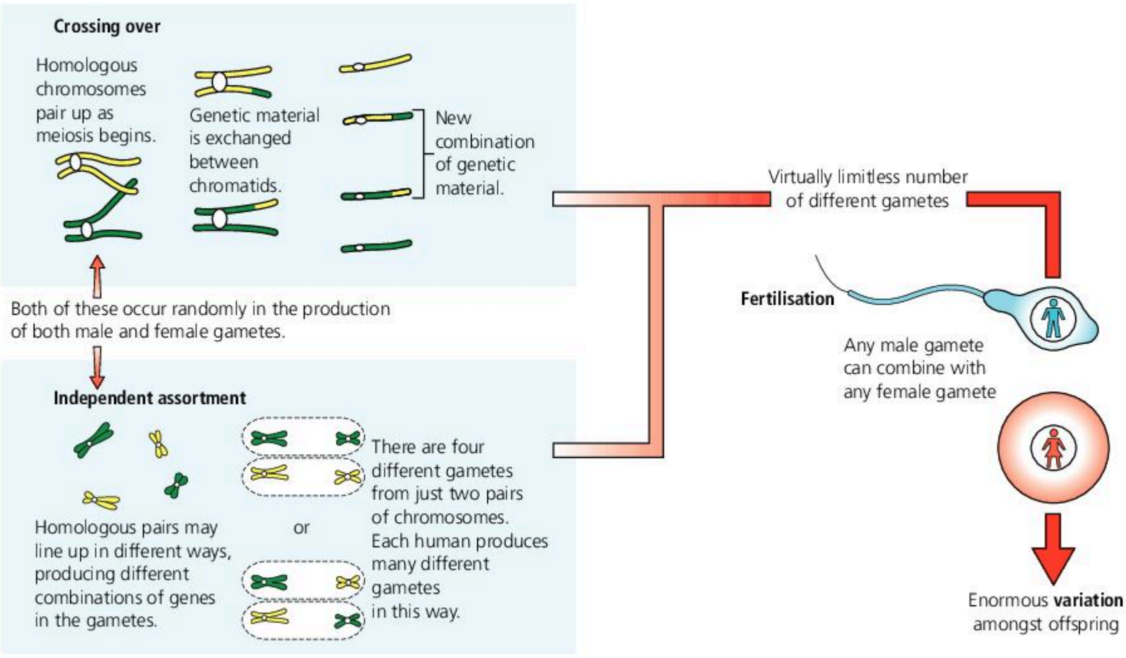
Mutations occur spontaneously (for no apparent reason), though they are very rare events. However, a number of factors (called **mutagens**) can increase the rate of mutation. Important mutagens are:

- **radiation** – gamma, ultraviolet and X-radiation can all damage DNA and so cause mutations
- **chemicals** – tars in tobacco smoke, high concentrations of some preservatives and some plant control hormones can cause mutation.

Mutations may be linked with cancer. A mutagen that causes uncontrolled cell division is called a **carcinogen** ('cancer maker').

S Sexual reproduction leads to variation

Sexual reproduction mixes up genetic material in three ways, as shown below, producing new genotypes and so variations in phenotype.



▲ **Crossing over**, **independent assortment** and **fertilisation** all lead to variation. There is very little chance that any two gametes from one individual will be identical. The combined effects of mutation and sexual reproduction lead to enormous variation between individuals.

Q

1 What is a gene mutation? Give an example of a gene mutation that is:
  a harmful
  b beneficial.

2 What is a carcinogen? Give two examples of carcinogens.

3 How does sexual reproduction lead to variation amongst members of a population?

18.3 Variation and natural selection: the evolution of species

OBJECTIVES

- To understand the meaning of adaptation, and to provide examples of this
- To realise that Darwin's theory benefited from the ideas of other scientists

Adaptation

As we have seen, living organisms differ from one another. Some of these variations make an organism well suited to its environment, some make no difference, and others make the organism *less* well suited to its environment. An organism that is well suited to make the most of the limited resources within its environment is said to show **adaptation** to its environment, as shown opposite. The cactus (a xerophyte) and the water lily (a hydrophyte) (see page 93) are both well adapted to their environments.

Other species similar to the large ground finch had **adapted** to take advantage of the feeding opportunities on the different islands. Darwin suspected that they had **evolved** from the large ground finch.

As a result of many observations made during his voyage on HMS *Beagle*, Charles Darwin began to think that living organisms could change in structure. Darwin suggested that species became adapted to meet the challenges of their environment.

The work of Charles Darwin*

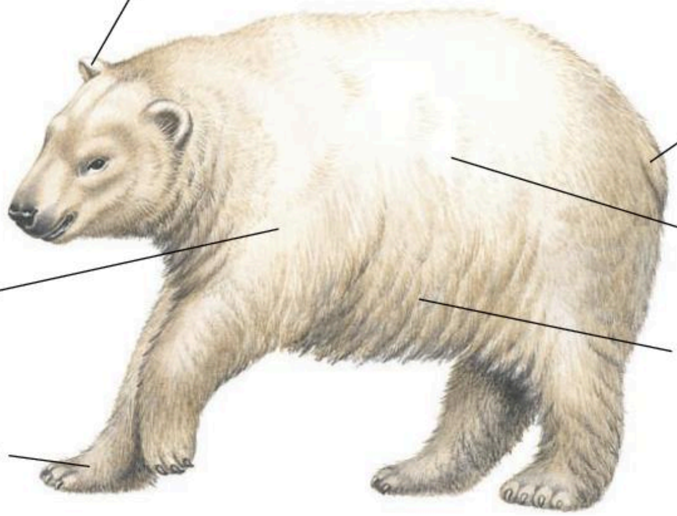
Charles Darwin (1809–82) was a British naturalist who took part in a world voyage on a ship called HMS *Beagle*. The voyage, which began in 1831 and lasted for five years, allowed Darwin to see many examples of adaptations. His most famous observations were made on the Galapagos Islands off the west coast of South America. Some species seemed to have adaptations to life on particular islands, but had similarities, and Darwin suspected that they all originated from a single species.

Evolution by natural selection

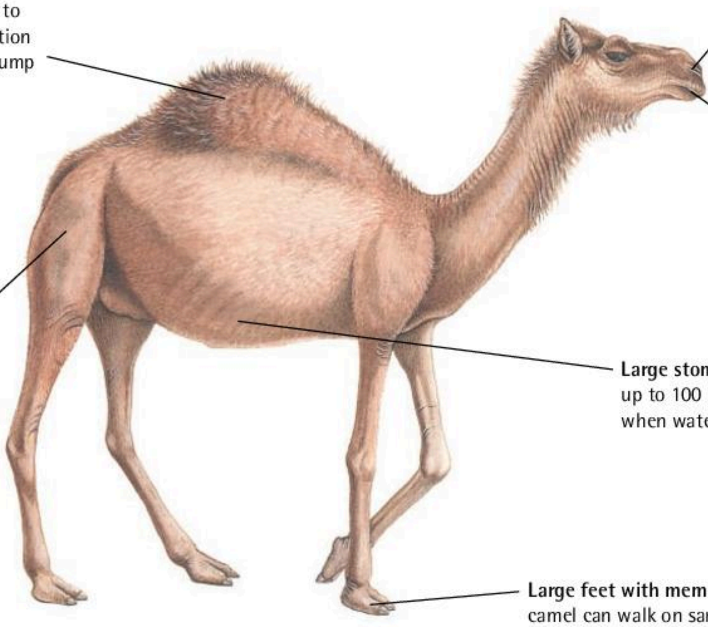
At the time that Darwin lived, most people believed that each species was fixed, and had been put on Earth in its current form by a creator – God. Darwin thought that species were not fixed, and that they changed through time to produce new species. He called this changing through time **evolution**. At first he was unable to convince other scientists because he could not suggest a **mechanism for evolution**. However, he eventually published his ideas in a famous book, *The Origin of Species by Means of Natural Selection*.

Organisms that are well adapted show high **fitness** - the probability that an organism will survive and reproduce in the environment in which it is found.

An **adaptive feature** (adaptation) is an inherited functional feature of an organism that increases its fitness.



▲ The polar bear is adapted to cold, arctic conditions



▲ The camel is adapted to dry, desert conditions

Update! We can now define natural selection as the greater chance of passing on genes by the best adapted organisms.

Q

1. What is meant by the term adaptation?
2. Name one animal and one plant with which you are familiar, and describe how each is adapted to its environment.

18.4 Natural selection

OBJECTIVE

- To understand how adaptation leads to natural selection

Darwin's ideas about natural selection can be summarised under a number of headings, as shown in the diagram below.

Natural selection may lead to new species

Some organisms are better suited to their environment than others. These organisms will be more likely to survive and breed than some of their competitors. Because of this, the characteristics they possess will become more common in the species over successive generations. If we consider one such characteristic, for example neck length in antelopes, we should be able to draw a graph showing how this characteristic is distributed in the population. If the environment applies a **selection pressure** such as a limited availability of leaves for food, one part of the population may be favoured. In a few generations' time, the graph may look rather different, as shown on the opposite page. If two populations of this antelope were separated from one another, natural selection might favour different adaptations in the two environments. Eventually the two different populations of antelope could have so many different adaptations that they can no longer interbreed – they are said to be different **species**.

The development of antibiotic-resistant strains of bacteria (see page 175) is a well-known example of natural selection.

Alternative theories of evolution

Early scientists and religious leaders believed that a creator had placed all living organisms on the Earth in their present-day forms. Even once the evidence for evolution had been accepted, not everyone agreed with Darwin's idea of natural selection. Jean Baptiste Lamarck was a Frenchman who lived about 70 years before Darwin. He believed that organisms adapted to their environment by 'use and disuse', that is, a giraffe might gain a long neck by stretching up for food in a tall tree. However, Lamarck was never able to show how these acquired characteristics could be passed on from one generation to another. The major difference between the theories of Darwin and Lamarck was that:

- **Lamarck** suggested that the environment *caused* the variations
- **Darwin** suggested that the environment *selected* the variations, which had arisen purely by chance.

Over-production – all organisms produce more offspring than can possibly survive, and yet populations remain relatively stable.
e.g. a female peppered moth may lay 500 eggs, but the moth population does not increase by the same proportion!

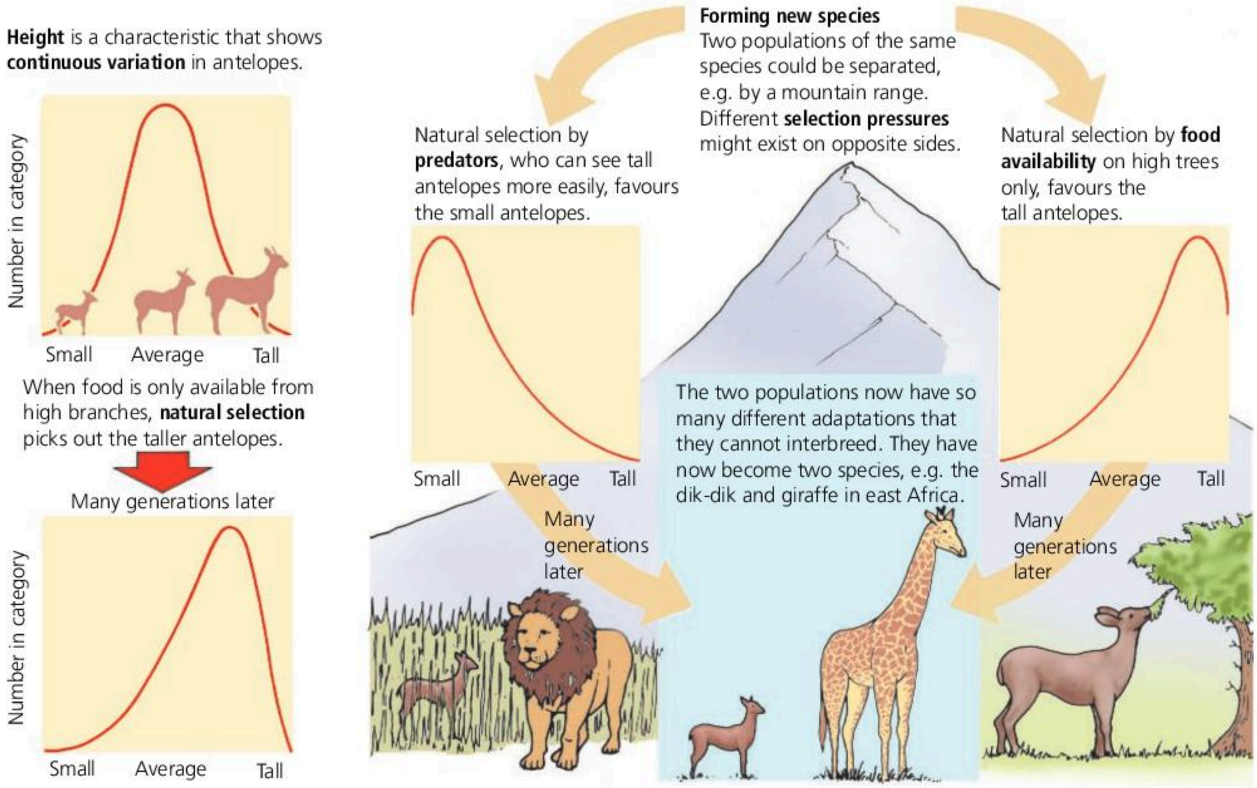
Struggle for existence – organisms experience environmental resistance, i.e. they compete for the limited resources within the environment.
e.g. several moths may try to feed on the same nectar-producing flower.

Variation – within the population there may be some characteristics that make the organisms that have them more suited for this severe competition.
e.g. some moths might be stronger fliers, have better feeding mouthparts, be better camouflaged while resting or be less affected by rain.

Survival of the fittest – individuals that are most successful in the struggle for existence (i.e. that are the best suited/adapted to their environment) are more likely to survive than those without these advantages.
e.g. peppered moths: dark-coloured moths resting on soot-covered tree trunks will be less likely to be captured by predators than light-coloured moths.

Advantageous characteristics are passed on to offspring – the well-adapted individuals are more likely to breed than those that are less well-adapted – they pass on their genes to the next generation. This process is called **natural selection.**
e.g. dark-coloured moth parents will produce dark-coloured offspring.

▲ Evolution by means of natural selection



▲ The formation of new species

1 Using only the following information, answer questions **a** to **d**.

Cepaea is a type of snail which shows considerable variation in its shell colour. The basic colour can be yellow, brown, fawn, pink, orange or red. Over the top of this basic colour up to five bands of a darker colour may occur, around the shell. Colour of shell provides camouflage for the snail because some colours are more difficult to see than others against the background.

Cepaea is an important part of the diet of thrushes. These birds collect snails and break open their shells by banging them on a stone. Thrushes tend to use the same stone, called an 'anvil', whenever feeding in a particular area.

It is possible to collect the remains of the shells and count the number of each shell type. It is also possible to collect the live snails in the same area and count the numbers of each shell type.

Collections of both live snails and broken shells were made in an area where the ground layer plants gave a fairly evenly coloured background. The results are shown in the table.

	Number of snails			
	Banded	**Unbanded**	**Total**	**% Banded**
Live snails	264	296	560	47.0
Shell remains from 'anvils' in the area	486	377	863	56.0

a How many more live, unbanded *Cepaea* were collected than banded?

b Suggest an explanation for thrushes taking more banded snails even where there appear to be more unbanded snails in the live populations.

c Which type of shell, banded or unbanded, would you expect to occur most frequently in a live snail population

i amongst dead leaves in a wood?

ii amongst grasses growing on a sand dune?

d The main points of the theory of evolution by natural selection are listed below.

A The number of offspring is far greater than the number surviving to adult stage.

B Variation exists among the offspring.

C Some variations are useful and help the organisms to survive.

D Competition occurs between the offspring.

E Only those surviving can breed.

Natural selection can change the proportions of the different colours in a snail population. Use the five points A to E above to describe how this change might come about.

18.5 Artificial selection

OBJECTIVE

- To understand the process of artificial selection

Making organisms useful to humans

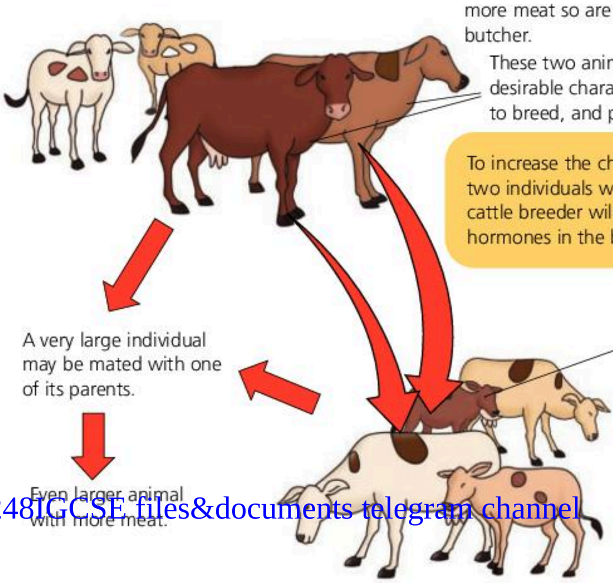
Variation occurs naturally and randomly in all living organisms, but the natural environment is not the only agent of selection. Ever since early humans began to domesticate animals and plants, they have been trying to improve them. This improvement is brought about by selecting those individuals that have the most useful characteristics and allowing only these individuals to breed. This process is called **artificial selection**. Humans have replaced the environment as the agents of selection. There are many important examples of selective breeding:

- **Jersey cattle** have been bred to produce milk with a very high cream content.
- All domestic **dogs** are the same species, but some have been bred for appearance (e.g. Pekinese), some for hunting (springer spaniels) and some as aggressive guards (rottweilers).
- **Wheat** has been bred so that all the stems are the same height (making harvesting easier) and the ears separate easily from the stalk (making collection of the grain easier).

Some examples of artificial selection are shown below and opposite. The same species can be bred in different ways for different purposes. Early horses have become specialised as carthorses or for racing, for example.

Maintaining variation

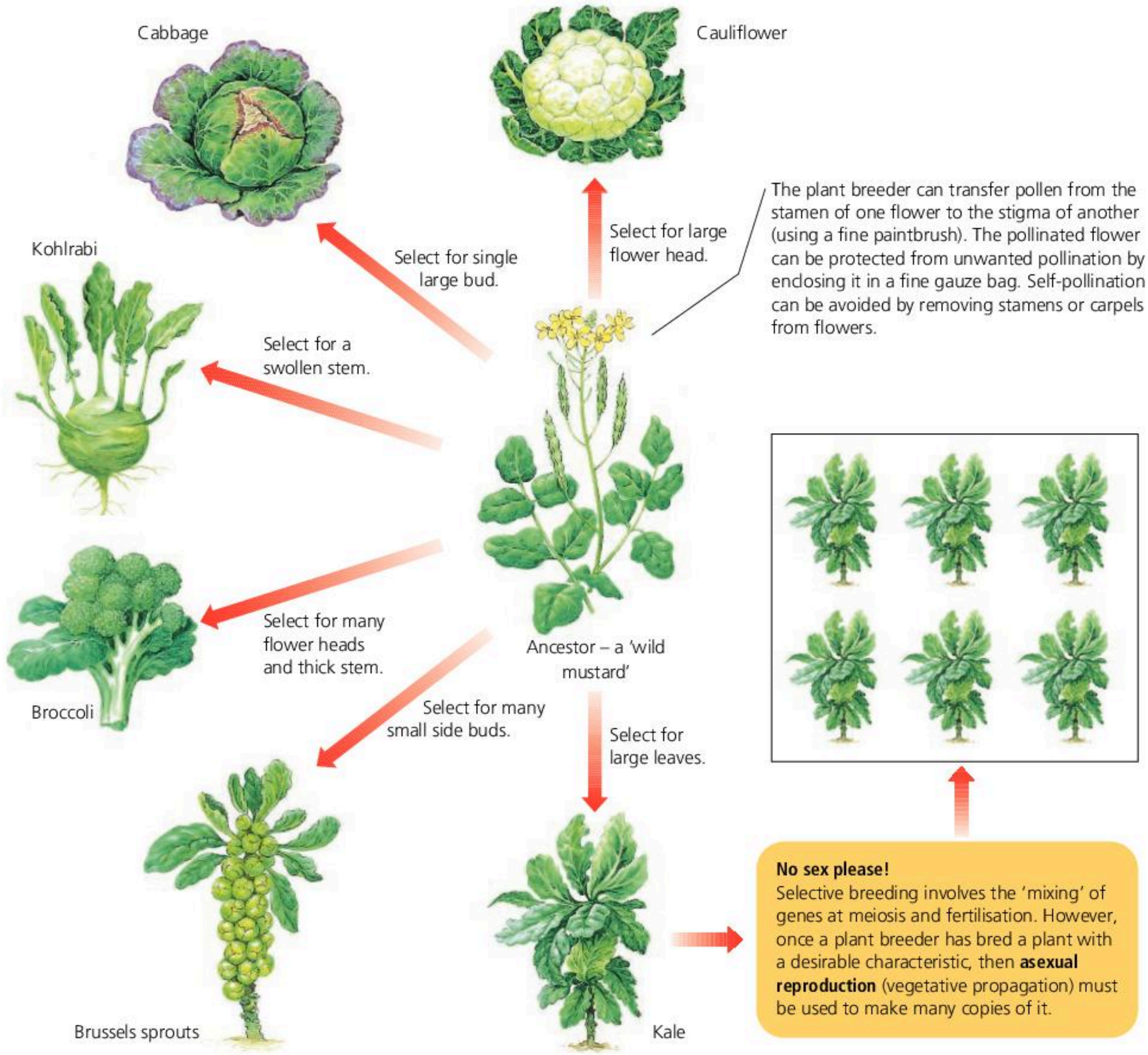
What appears to humans as a valuable characteristic might not always be valuable in a natural situation. For example, a Chihuahua dog would probably not survive in the wild because its hunting instincts have been bred out to make it more suitable as a pet. It is very important that humans preserve animal and plant genes for characteristics that do not offer any advantage to us at the moment. A cow with a limited milk yield may carry a gene that makes it resistant to a disease which is not yet a problem in domestic herds, for example. This resistance gene might be extremely valuable if such a disease ever did become established. For this reason many varieties of animals and plants are kept in small numbers in rare-breed centres up and down the country. Plant genes may be conserved as seeds, which are easy to store, and some animal genes may be kept as frozen eggs, sperm or embryos.



Artificial insemination

Male animals, no matter how many useful characteristics they have, **cannot give birth to young animals!** So:

- Most male offspring will be fattened up for selling as meat.
- 'Desirable' males may be electrically stimulated to ejaculate – the sperm is collected and frozen. One male can easily produce several hundred samples.
- The sperm can be taken to a cattle breeding farm and used to inseminate many females.



▲ Artificial selection has produced many vegetables from one ancestor species

Three major differences between artificial and natural selection

- In artificial selection, humans are the agents of selection, while natural selection depends upon the natural environment.
- Artificial selection is much quicker than natural selection.
- Artificial selection offers no advantage to the animal or plant in its natural environment.

It is likely that selective breeding will be replaced by genetic engineering in the future. This technique, explained on page 300, is much more predictable than selective breeding and produces useful results more quickly.

1 A potato grower wanted to produce a new variety of potato which grows quickly and makes good chips. She has one variety which grows quickly but makes poor chips, and another which grows more slowly but makes good chips.
When plants of these two varieties produce flowers she crosses the two varieties. Later she collects the seeds and plants them.

a To cross the two varieties, the grower pollinates a flower of one variety with pollen from the other. Describe how the grower should do this.

b From the seeds she collects, she finds that one of the new plants grows very quickly and produces potatoes which make good chips. How would she produce a crop of potatoes which are exactly the same?

Questions on variation and evolution

1 Merino sheep have much thicker wool than wild sheep. Merino sheep are the result of:

A mutation of a gene
B natural selection
C phenotypic variation
D selective breeding [1]

2 An island was invaded by a species of bird that preyed on butterflies. In the population of butterflies, only those individuals that produced a toxic substance as a protection against predation survived. This is an example of:

A artificial selection
B competition
C immunity
D natural selection [1]

3 Mutation and natural selection are processes which occur at all times.

a Define the term **natural selection**. [2]

b Suggest why

i bacterial infections which were controlled by antibiotics 50 years ago are now a problem in hospitals. [2]

ii malaria-carrying mosquitoes in East Africa were almost wiped out by the insecticide DDT in the 1950s, but today cases of malaria are increasing in this area. [2]

4 Haemoglobin is a protein carried in red blood cells.

a **i** State the function of this protein. [1]

ii Name the mineral required for the production of this protein. [1]

b The allele for the production of normal haemoglobin is Hb^N. A mutant form of this allele Hb^S results in the production of an abnormal haemoglobin which results in the condition sickle cell anaemia.

Two parents who are heterozygous for this gene have a child. Use a genetic diagram to predict the possibility that this child will be heterozygous. [4]

c Under some circumstances people who are heterozygous for this condition have a greater chance of survival than homozygous individuals. Suggest why this is the case. [3]

5 **a** In western Europe, 45% of the population have blood group O, 43% have blood group A, 10% have blood group B and 2% have blood group AB.

i Plot the data as a bar chart. [4]

ii Explain the form of your bar chart. [2]

b The characteristics of organisms may be altered by mutation.

i Define the term **mutation**. [2]

ii Suggest **two** factors which could affect the rate of mutation. [2]

6 Students collected small nuts from a group of trees of the same species growing close to their school grounds. The nuts were collected at random, and 50 of them were weighed.

a Explain why it is important that
  i the trees were all of the same species. [1]
  ii the nuts were collected at random. [1]

b They presented their results in the table below.

Mass of nut / g				
0.5	1.3	1.2	0.6	1.2
0.6	0.4	1.1	1.3	1.6
1.4	1.4	1.2	1.2	0.4
1.1	1.3	1.1	1.3	0.6
0.3	1.5	1.2	1.3	1.1
1.1	1.3	0.5	0.5	0.5
1.0	1.2	1.4	1.0	1.0
1.3	0.6	1.3	0.9	1.4
1.0	1.2	1.2	1.3	1.2
1.3	0.7	1.4	0.6	1.3

  i Copy and complete the table below for the mass of nuts.

Mass of nut / g	Number of individual nuts
0.3	
0.4	
0.5	
0.6	
0.7	
0.8	
0.9	
1.0	
1.1	
1.2	
1.3	
1.4	
1.5	
1.6	

[2]

  ii Plot the data in the second table as a histogram. [4]

c State which type of variation is shown in the histogram. [1]

7 One of the early chapters in Charles Darwin's book, *The Origin of Species*, describes the variation of living organisms under domestication.

a State the name of the type of selection used by humans to breed crops and animals for their own use. [1]

b Varieties of cereal crops with a lower than normal requirement for water have been produced for use in some less economically developed countries.
Suggest how a plant breeder might produce a variety of wheat with this important property. [3]

c **i** Describe how recombinant DNA technology might be used to produce a useful crop variety. [4]
  ii Suggest **two** reasons why scientists are concerned about the use of this technique. [2]

8 Warfarin is used as a rat poison. It prevents blood clotting and so small wounds bleed and the animal dies.
Some rats are not affected by this substance. Their numbers are increasing.
Explain why this is happening. [3]

19.1 Ecology and ecosystems

OBJECTIVES

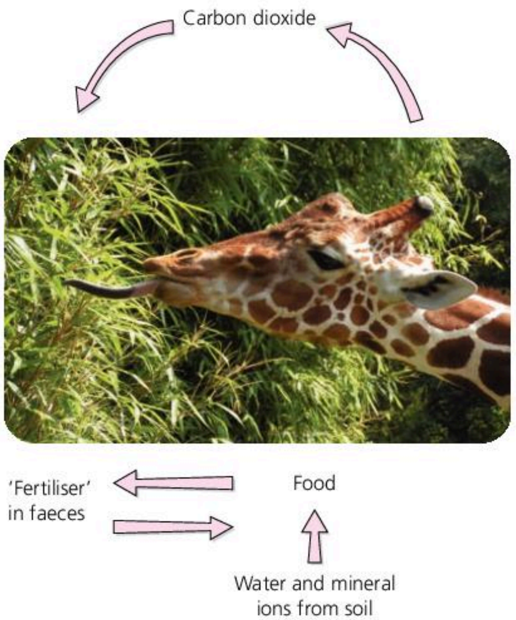
- To understand that living organisms require certain conditions for their survival
- To understand that living organisms interact with one another, and with their non-living environment
- To define population, community and ecosystem
- To realise that available resources change through the year

Environmental survival kit

All living organisms depend upon their environment for three 'survival essentials'. These are a **supply of food**, **shelter** from undesirable physical conditions and a **breeding site**. The living organism **interacts** with its environment – for example, a living plant:

- removes carbon dioxide, water and light energy from its habitat
- may be eaten by an animal or a parasite
- depends upon soil for support.

Factors in the environment affect the growth of the plant. Some of these factors are **biotic** – other living organisms – and some are **abiotic** – the non-living components of the habitat. **Ecology** is the study of living organisms in relation to their environment. The interactions between the organism and its environment are summarised below.



A giraffe feeds on a thorn tree. The tree requires water, mineral ions, carbon dioxide and light to grow. The giraffe may provide carbon dioxide from respiration, and ions from decomposition of its faeces.

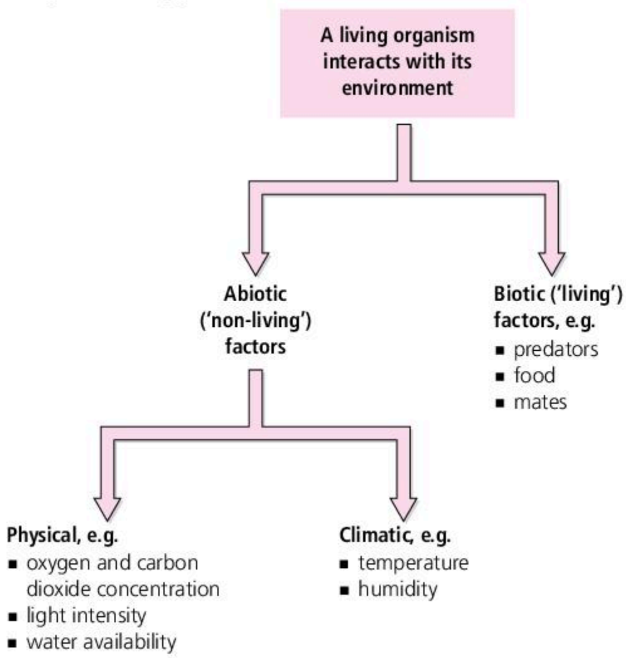
Changing with the seasons

The ability of the habitat to supply living organisms with their requirements may vary at different times of year. The ecosystem in the photograph opposite will only exist for a certain period of time – as food or water becomes exhausted some animals may leave. These will then be followed by the predators which feed on them. The great animal **migrations** seen in East Africa result from the changing conditions in the animals' environment, for example:

- poor rain means little growth of grass
- herbivores leave for areas of fresh growth
- carnivores follow herbivores
- (then scavengers follow carnivores!).

Living together

Living organisms normally exist in groups. The names given to these groups, and the way they interact with the abiotic environment, are explained opposite.



A **population** is all of the members of the same species (e.g. wildebeest) in the same area at the same time.

A **community** is all of the populations of living organisms in one area (e.g. acacia trees, zebra, wildebeest and grass). The community is the **biotic environment**.

Air, water and soil make up the **abiotic environment**.

▶ Organisms exist in groups within an ecosystem

An **ecosystem** is a unit containing the community of organisms and their environment interacting together.

A **habitat** is a part of the environment that can provide food, shelter and a breeding site for a living organism (e.g. a patch of grassland).

Q

1 Define the terms population, community and ecosystem.

2 Name two abiotic factors that might determine whether or not a habitat is suitable for a living organism.

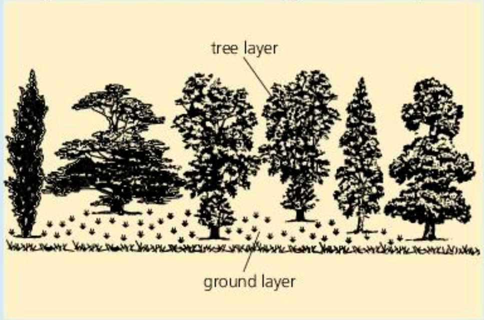
3 Suggest two ways in which a plant and an animal in the same habitat may interact.

4 What must a habitat provide?

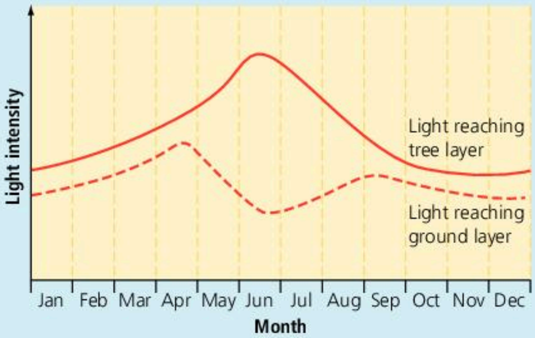
5 How are the following observations related?
- Very few flying insects are found in Britain during the winter.
- Swallows migrate to Africa when it is winter in the UK.
- Hobbies (small bird-eating falcons) leave Britain in late autumn.

6 What is meant by the term ecology?

7 **a** A group of students were studying a forest. They noticed that the plants grew in two main layers. They called these the tree layer and the ground layer.



The students measured the amount of sunlight reaching each layer at different times in the year. Their results are shown on the graph.



i During which month did most light reach the tree layer?

ii During which month did most light reach the ground layer?

iii Suggest why the amount of sunlight reaching the ground layer is lower in mid-summer than in the spring.

b The pupils found bluebells growing in the ground layer. Bluebells grow rapidly from bulbs. They flower in April and by June their leaves have died.

i Suggest why bluebells grow rapidly in April.

ii Suggest why the bluebell leaves have died by June.

19.2 Flow of energy: food chains and food webs

OBJECTIVES

- To know that the feeding relationships in an ecosystem can be expressed as food chains
- To understand why energy transfer through an ecosystem is inefficient
- To understand why complex food webs are the most stable

Food chains

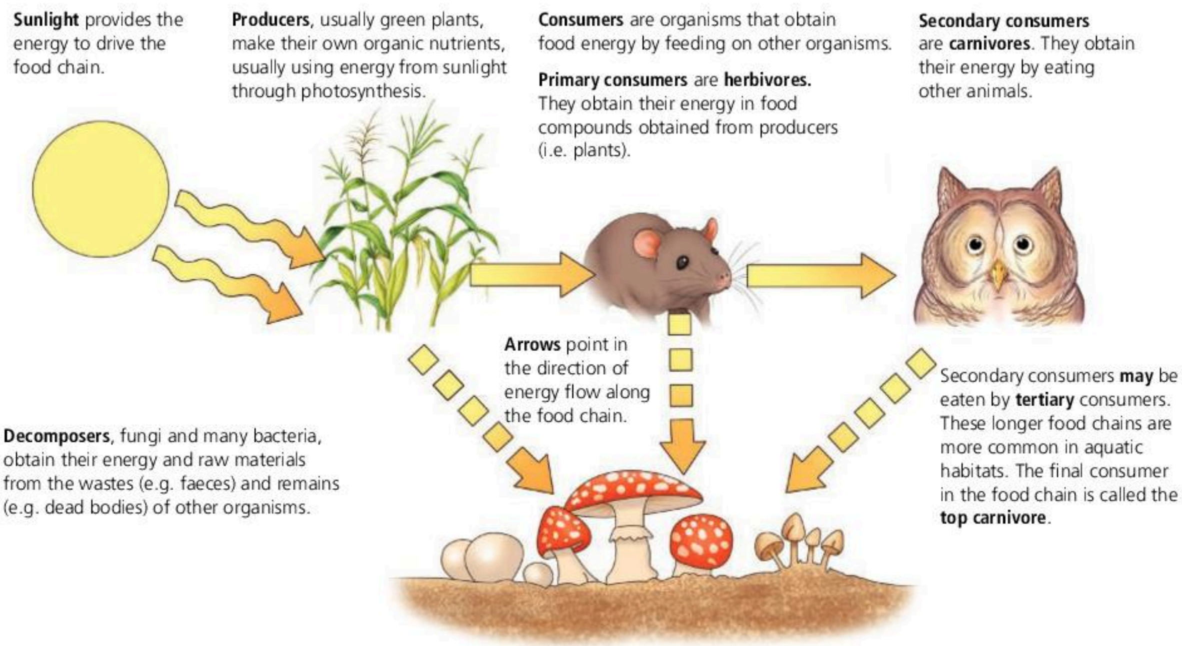
The most obvious interaction between different organisms in an ecosystem is feeding. During feeding, one organism is obtaining food – energy and raw materials – from another one. Usually one organism eats another, but then may itself be food for a third species. The flow of energy between different organisms in the ecosystem can be shown in a **food chain**, as in the diagram below.

Energy transfer is inefficient

The amount of energy that is passed on in a food chain is reduced at every step. Energy can be neither created nor destroyed, so it is not lost but is converted into some other form. During respiration, some energy is transferred to the environment as heat. The flow of energy through a food chain, and the heat losses to the environment, are illustrated in the diagram opposite.

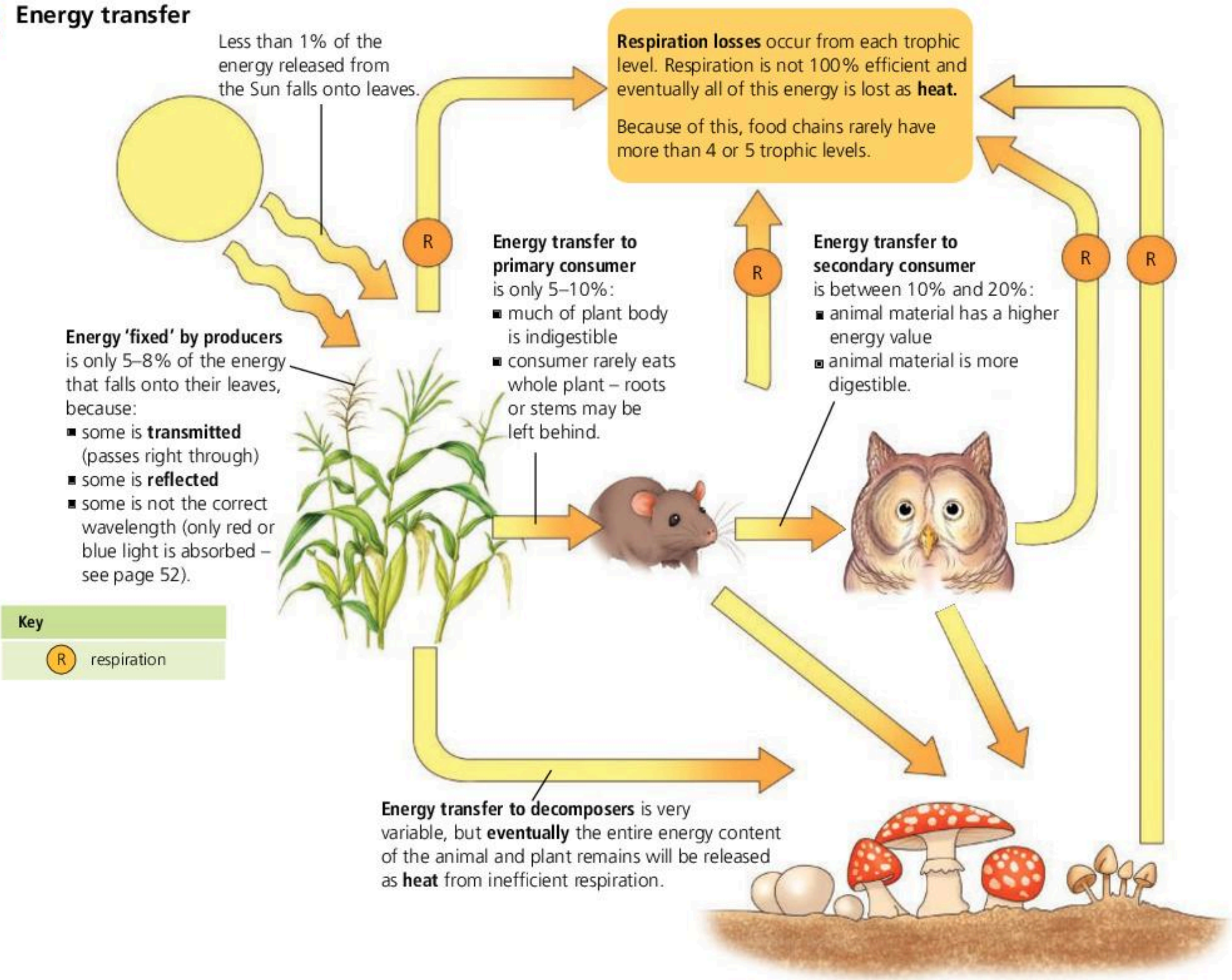
Food webs

Little energy is transferred from the base to the top of a food chain, so a top carnivore must eat many herbivores. These herbivores are probably not all of the same species. In turn, each herbivore is likely to feed on many different plant species. All these interconnected food chains in one part of an ecosystem can be shown in a **food web**. The more complicated a food web, the more stable the community is. For example, in the forest food web shown opposite, if the number of squirrels fell, the owls could eat more worms, mice and rats. The mice and rats would have less competition for food from squirrels, and so might reproduce more successfully.

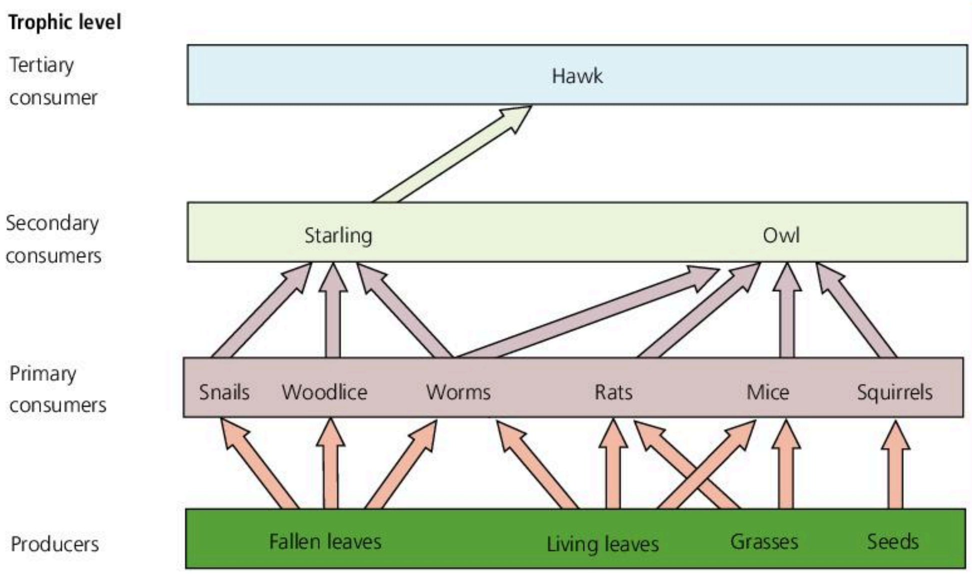


▲ Food chains show energy flow through an ecosystem. The position of each organism in the food chain or food web represents a different **trophic** (feeding) **level**.

Energy transfer



A simple forest food web: a series of interconnected food chains



Q

1. Define the terms producer, consumer and decomposer. Which of these could be omitted from an ecosystem? Explain your answer.
2. Write out a food chain from a named ecosystem which you have studied.
3. Why are food chains usually restricted to three or four trophic levels?

Humans and food webs

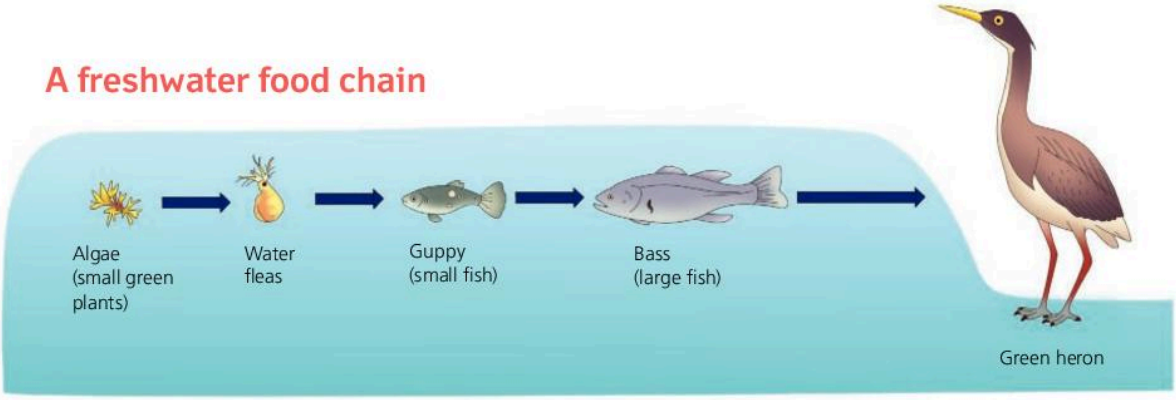
Humans can have negative effects on food chains and food webs:

- by over-harvesting food species such as cod (so species eaten by cod increase in numbers, and species which eat cod may switch to eating other foods).
- by introducing foreign species to a habitat. Rabbits, for example, were introduced to Australia for hunting but bred very quickly. This reduced grass available for native Australian species.

More examples of feeding relationships

Food chains and food webs in aquatic (watery) environments can be longer than those on the land. This is because this type of environment has space and ideal growth conditions for many producers. Even with energy losses at every stage there is enough 'trapped' energy for more steps in the chain. Many of these food chains begin with phytoplankton (tiny green plants) or algae.

A freshwater food chain



Note that energy flow is not cyclic!

sunlight → chemical bond energy → heat

As a result there must be a continuous input of light energy to 'drive' life in an ecosystem.

It is more efficient for humans to eat plants than to feed plants to animals, and then to eat the animals. Every step in the chain loses 80–90% of the available energy as heat, so THE FEWER 'STEPS' THE BETTER!

Q

1 Look at the three aquatic feeding relationships shown on this page and the next. Make and fill in a table like this one:

Producers	Herbivores	Carnivores	Top carnivores

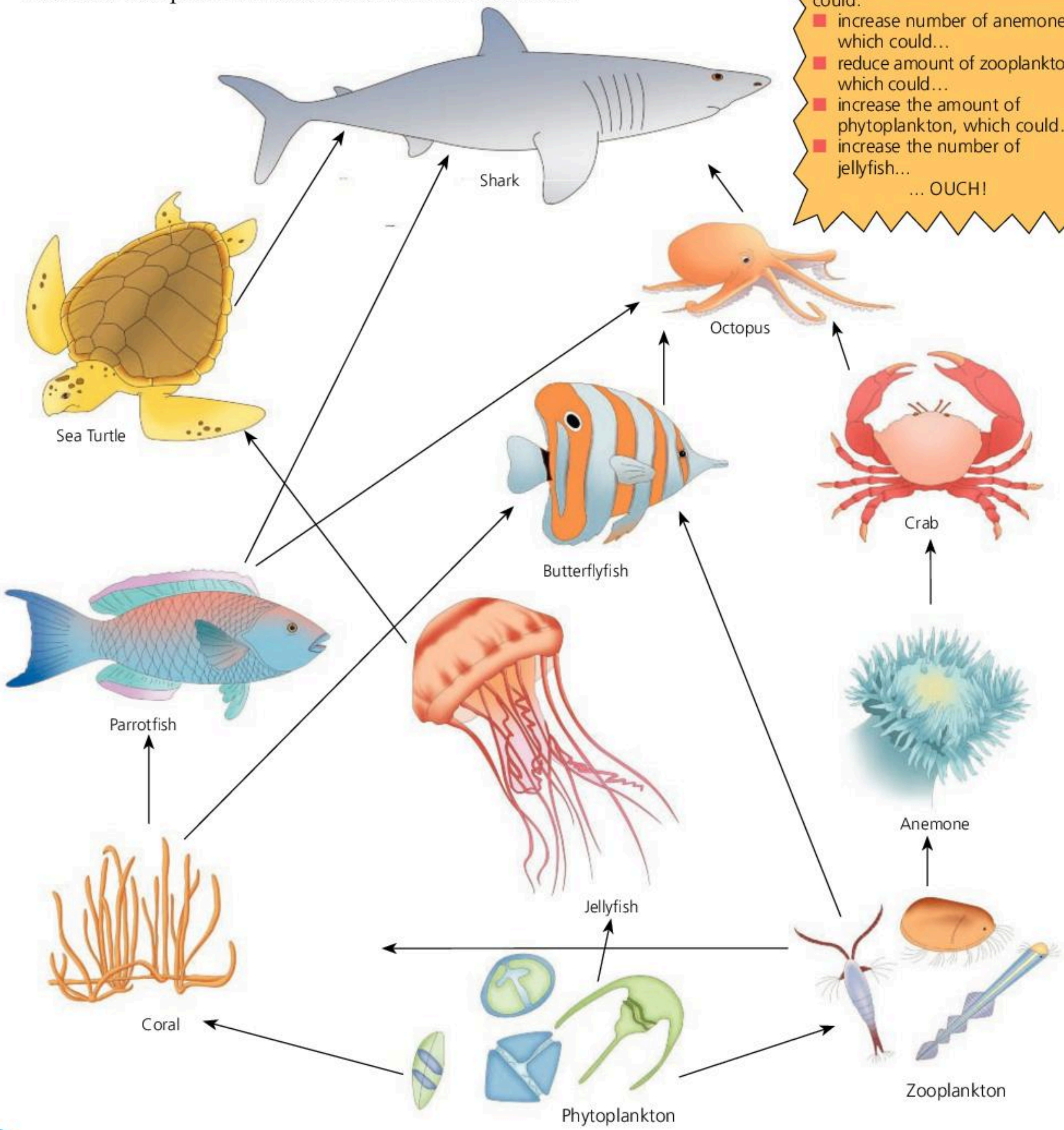
2 Shark fishing is a popular sport. Explain what might happen if all of the sharks living around a section of reef were captured by fishermen.

Coral reef food web

The most complex food webs are found in the ocean.

Catching crabs for human food could:
- increase number of anemones, which could…
- reduce amount of zooplankton, which could…
- increase the amount of phytoplankton, which could…
- increase the number of jellyfish…

… OUCH!



Q

3 Use words from the following list to complete the paragraph about ecosystems. You may use each word once, more than once or not at all.

decomposition, producer, chemical, carnivore, consumer, photosynthesis, energy, light, elements, decomposers, herbivore.

In each ecosystem there are many feeding relationships. A food chain represents a flow of ____ through an ecosystem, and always begins with an organism called a ____ which is able to trap ____ energy and convert it to ____ energy. An organism of this type is eaten by a ____, which is a kind of ____ that feeds only on plant material. This type of organism is, in turn, eaten by a ____ (an organism that consumes other animals).

19.3 Feeding relationships: pyramids of numbers, biomass and energy

OBJECTIVES

- To be able to describe pyramids of numbers, biomass and energy
- To understand how data can be gathered to make ecological pyramids

Pyramids of numbers

Look at the food chain on page 242. Two things should be clear:

- The organisms tend to get bigger moving along the food chain. Predators, such as the owl, need to be large enough to overcome their prey, such as the mouse.
- Energy is 'lost' as heat on moving from one trophic level to the next, so an animal to the right of a food chain needs to eat several organisms 'below' it in order to obtain enough energy. For example, a rabbit eats many blades of grass.

S Food chains and food webs provide **qualitative** information about an ecosystem – they show which organism feeds on which other organism. How do we show **quantitative** information, for example how many predators can be supported by a certain number of plants at the start of the chain? We can use a **pyramid of numbers** or a **pyramid of biomass**, as shown in the diagram below.

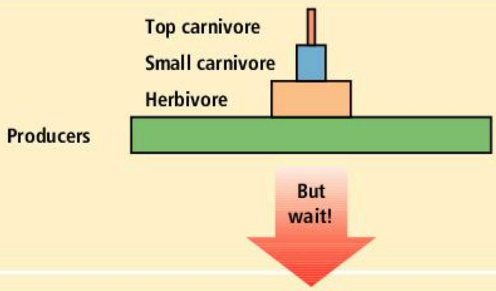
Pyramids of energy

A pyramid of biomass describes how much biomass is present in a habitat *at the time the sample is taken*. This can be misleading, because different feeding levels may contain organisms that reproduce, and so replace themselves, at different rates. For example, grass in a field would replace itself more quickly than cattle feeding on the grass, so when the pyramid of biomass is constructed there would be more 'cattle biomass' than 'grass

Pyramid of numbers – a diagrammatic representation of the number of different organisms at each trophic level in an ecosystem **at any one time**

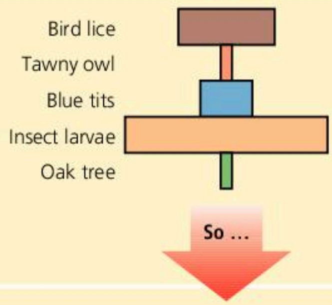
Note

1. The number of organisms at any trophic level is represented by the length (or the area) of a rectangle.
2. Moving up the pyramid, the **number** of organisms generally **decreases**, but the **size** of each individual **increases**.



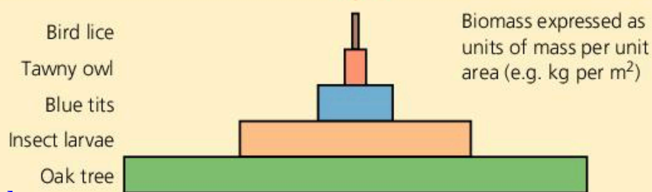
S **Problems**

a. The range of numbers may be enormous – 500 000 grass plants may only support a single top carnivore – so that drawing the pyramid to scale may be very difficult.
b. Pyramids may be **inverted**, particularly if the **producer is very large** (e.g. an oak tree) or **parasites feed on the consumers** (e.g. bird lice on an owl).

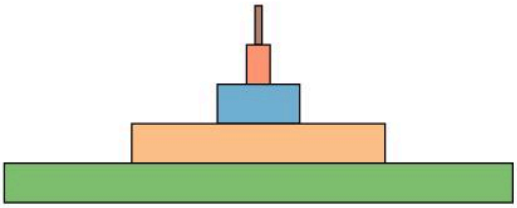


The pyramid of biomass is useful because the biomass gives a good idea of how much energy is passed on to the next trophic level.

Pyramid of biomass – which represents the **biomass** (number of individuals × mass of each individual) at each trophic level **at any one time**. This should solve the scale and inversion problems of the pyramid of numbers.



▲ Ecological pyramids represent numerical relationships between successive trophic levels biomass' and the pyramid would be inverted. To overcome this difficulty a **pyramid of energy** can be constructed. This measures the amount of energy flowing through an ecosystem *over a period of time*. The time period is usually a year, because this takes into account the changing rates of growth and reproduction in different seasons. It is even possible to add an extra base layer to the pyramid of energy representing the solar energy entering that particular ecosystem.



▲ **Pyramid of energy:** energy values are expressed as units of energy per unit area per unit time (e.g. kJ per m^2 per year)

GATHERING DATA FOR ECOLOGICAL PYRAMIDS

To construct a pyramid of numbers or of biomass, organisms must be captured, counted and (perhaps) weighed. This is done on a **sample** (a small number) of the organisms in an ecosystem. Counting every individual organism in a habitat would be extremely time-consuming and could considerably damage the environment.

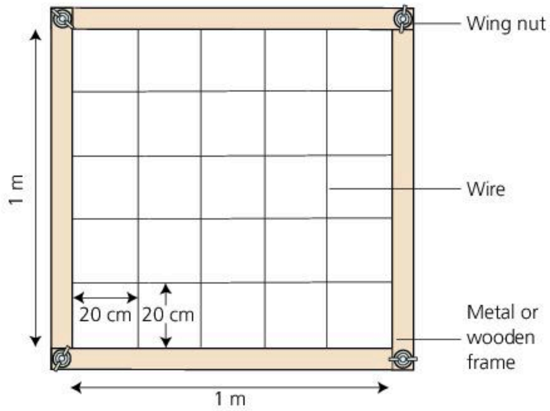
The sample should give an accurate estimate of the total population size. To do this:

- The sampling must be **random** to avoid any bias. For example, it is tempting to collect a large number of organisms, by looking for the areas where they are most common. To avoid this, the possible sampling sites can each be given a number and then chosen using random number generators on a computer.
- The sample must be the **right size** so that any 'rogue' results can be eliminated. For example, a single sample might be taken from a bare patch of earth, whereas all other sites are covered with vegetation. The single sample from the bare patch should not be ignored, but its effects on the results will be lessened if another nine samples are taken. A **mean value** can then be used.

Sampling plants and sessile animals

Once the organisms in a sample have been identified and counted, the population size can be estimated. For example, if 10 quadrats gave a mean of 8 plants per quadrat, and each quadrat is one-hundredth of the area of the total site, then the total plant population in that area is $8 \times 100 = 800$.

There are other ways of collecting data on populations. Some of these are described on the following pages.

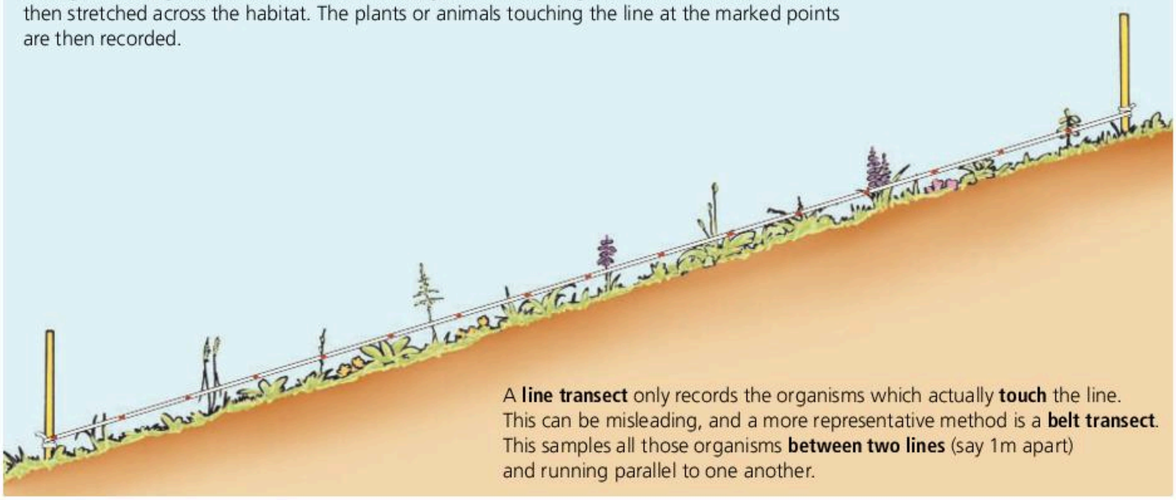


▲ **A quadrat** is a square frame made of wood or metal. It is simply laid on the ground and the number of organisms inside it is counted.

▼A quadrat is used most commonly for estimating the size of plant populations, but may also be valuable for the study of populations of sessile or slow-moving animals (e.g. limpets).

*

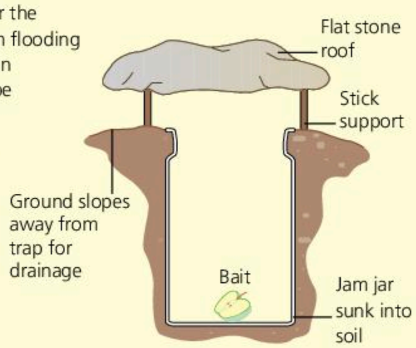
A transect is used to sample the distribution of organisms in a straight line across a habitat. A length of string or plastic line is marked at regular intervals (e.g. with an indelible pen) and then stretched across the habitat. The plants or animals touching the line at the marked points are then recorded.

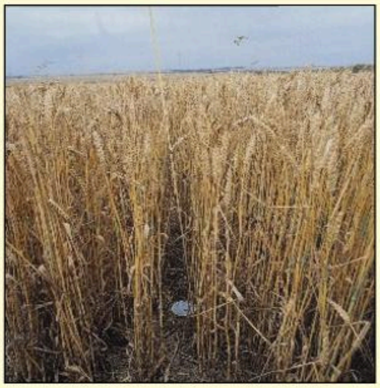


A **line transect** only records the organisms which actually **touch** the line. This can be misleading, and a more representative method is a **belt transect**. This samples all those organisms **between two lines** (say 1m apart) and running parallel to one another.

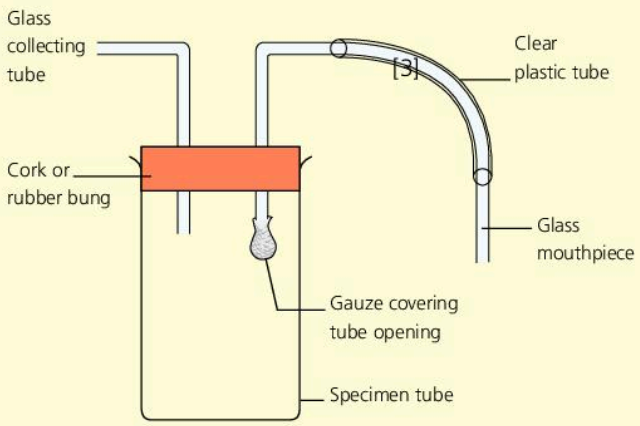
▲ Quadrats and transects sample populations of non-motile organisms

Pitfall traps – used to sample arthropods moving over the soil surface. The roof prevents rain from flooding the trap, and also limits access to certain predators. Any trapped predators can be prevented from eating other trapped animals if a small quantity of methanol is added to the trap. Bait of meat or ripe fruit can be placed in the trap. Pitfall traps are often set up on a grid system to investigate the movements of ground animals more systematically.





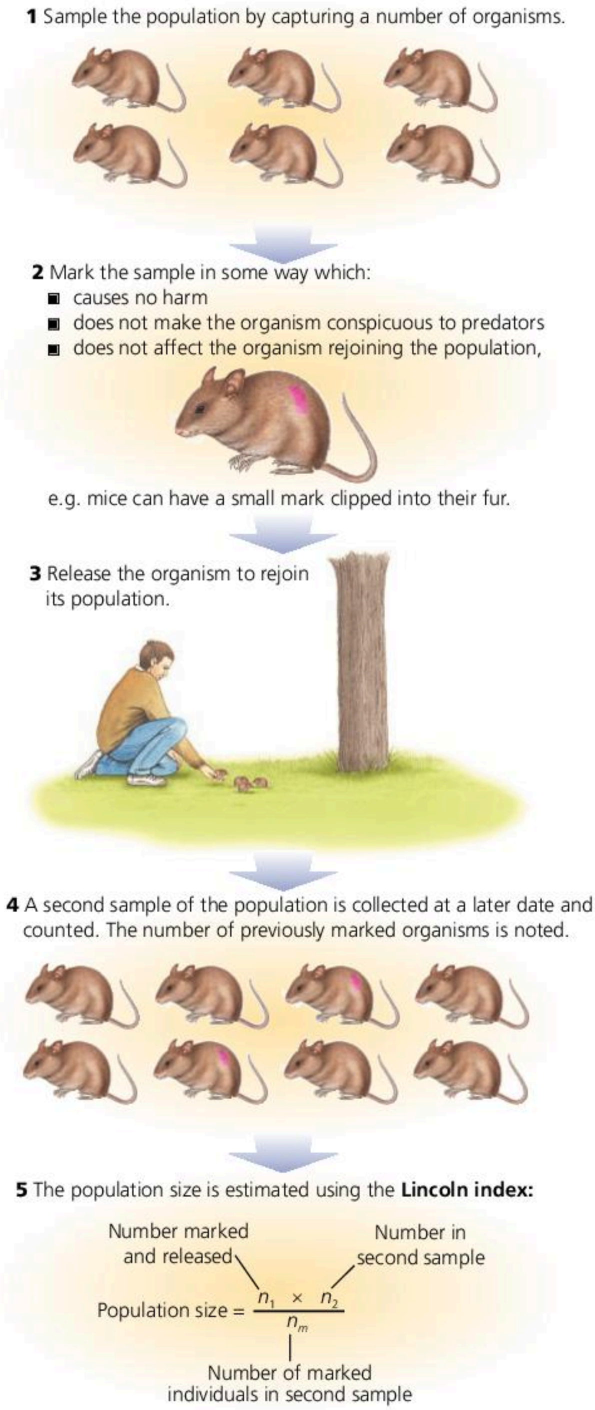
Pooter – used to collect specimens of insects and other arthropods. Trees or bushes are beaten and the animals fall on a sheet or tray underneath. They are then collected in the pooter. Sucking on the mouthpiece pulls the organism along the collecting tube and into the specimen tube. This does not harm the organism, and it can then be returned to its natural habitat.



Other methods of collection are numerous. Many are based on some form of netting – for example, large **mist nets** may be used to collect migrating birds for identification and ringing, and **sweep nets** may be used to capture flying or aquatic arthropods.

The mark–recapture method

The diagram below shows one useful technique for estimating populations of motile animals.



This method might be used, for example, when comparing populations **before** and **after** a conservation management plan.

▲ The mark–recapture method

RECORDING AND ANALYSIS

Two students wished to investigate the invertebrate populations present in an area of woodland. They set out pitfall traps in the evening, with rotting meat as a bait. They returned to count the collected animals next morning. The table shows their results.

Animal type	Number recorded by students	Total
Beetles	\III/ \III/ \III/ \III/ \III/ \III/ \III/ \III/ \III/ II	
Centipedes	\III/ \III/ \I	
Millipedes	II	
Spiders	\I/I \III/ I/	
Earthworms	/II	
Woodlice	I/I \I/I	
Snails	I	

1 **a** Copy the table and complete it to show the total number of each animal collected.

b Plot a bar chart of your results from part **a**.

c Suggest a function of the trap lid, apart from preventing entry of rain.

d The students used rotting meat in their traps. Suggest how the types and numbers of animals collected might be different if they had used rotting leaves.

The teacher suggested that a mark–recapture method might give a more accurate estimate of the beetle population. The students set up the pitfall traps with meat as bait and then marked the beetles they collected with a small spot of brown water-soluble paint. They released the beetles into the area they had been collected from, and that evening reset the traps. On the following day the numbers of marked and unmarked beetles in the traps were recorded, as shown below.

Number of		
beetles in first sample – marked then released	marked beetles in second sample	unmarked beetles in second sample
30	12	40

e Use the Lincoln index to calculate the total beetle population in the area.

f Why did the students use brown paint, not yellow or red paint?

g Why did the students use a water-soluble paint rather than an oil-based paint?

19.4 Decay is a natural process

OBJECTIVES

- To understand that nutrients in dead organisms are recycled
- To know that the process of decay often begins with the activities of scavengers
- To know how saprotrophic nutrition is responsible for decomposition

Recycling nutrients

Humans have an unusual skill – they can modify their environment to suit themselves. For example, we cut down forests and plant crops, and we build houses. Many building materials are natural, such as wood and straw, and the environment treats these materials as the dead remains of once-living organisms – the environment reclaims the nutrients and returns them to the ecosystem.

Starting with scavengers

When an organism dies, the nutrients in its body are returned to the environment to be reused. The nutrients are recycled by a series of processes carried out by other living organisms. The first ones to appear are usually the **scavengers** which break up the dead bodies into more manageable pieces. Scavengers eat some of the dead body, but leave behind blood or small pieces of tissue.

▲ Scavengers such as the vulture feed on dead bodies

Decomposition by microorganisms

The remains that are left are **decomposed** by the feeding activities of microorganisms. These fungi and bacteria feed by secreting enzymes onto the remains and absorbing the digested products. This form of nutrition is called saprotrophic feeding.

The diagram on the opposite page illustrates some of the features of the decomposition process. The decay process provides energy and raw materials for the decomposers. It also releases nutrients from the bodies of dead animals and plants, which can then be reused by other organisms, for example:

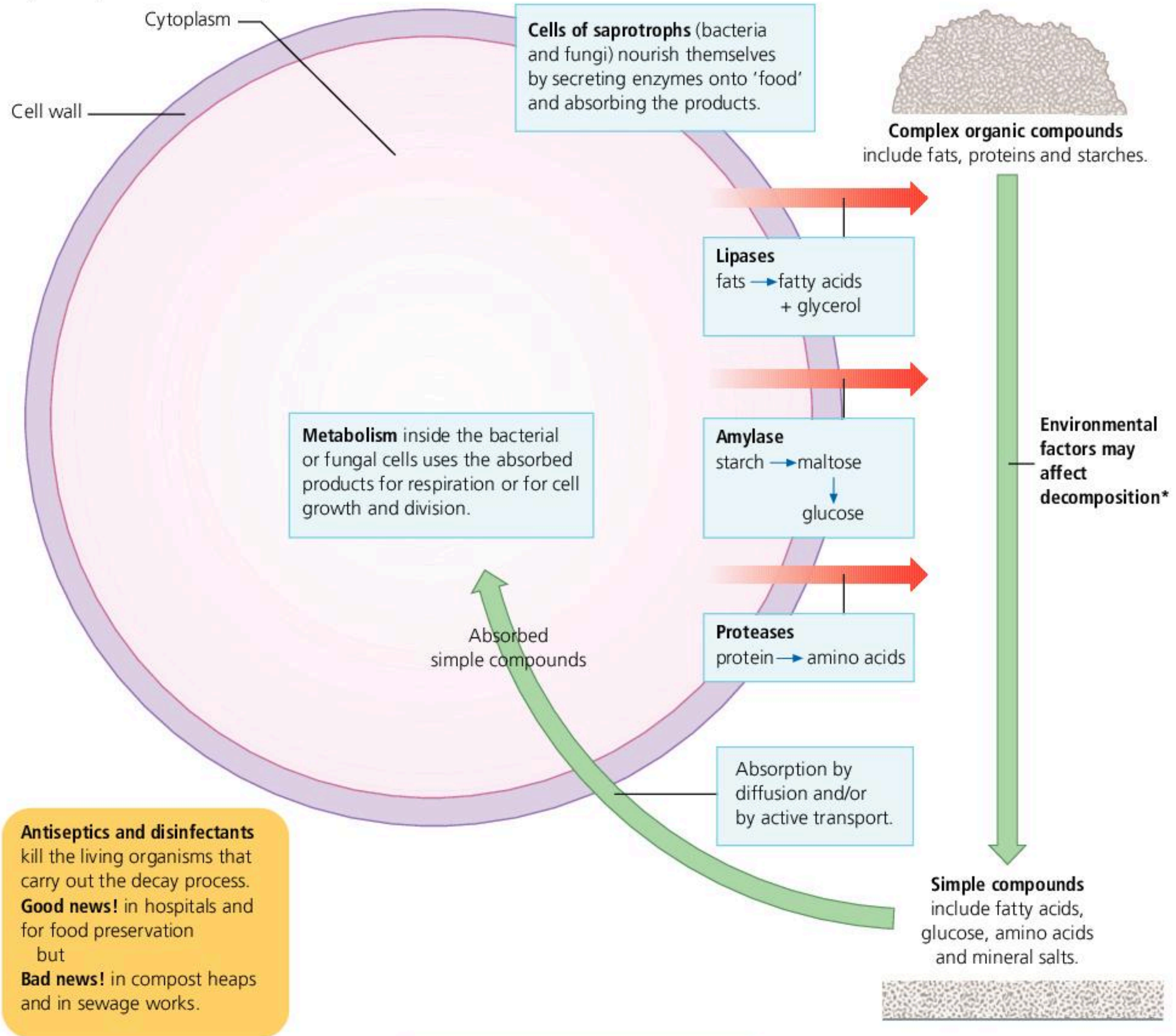
sugar in dead rabbit
↓ respiration by microorganisms
carbon dioxide
↓ photosynthesis in plant
sugar in plant

In this way substances pass through **nutrient cycles** as microbes convert them from large, complex molecules in animal and plant remains to simpler compounds in the soil and the atmosphere. The next sections describe the recycling of the elements carbon and nitrogen.

Importance of decomposition processes to humans

- Organic waste in sewage is decomposed and made 'safe' in water treatment plants (see page 282).
- Organic pollutants such as spilled oil may be removed from the environment by decomposing bacteria (see page 252).
- Food is spoiled due to decomposition by fungi and bacteria. Many food treatments alter physical conditions to inhibit enzyme activity.
- Wounds may become infected by saprotrophs, leading to tissue loss or even to death. Many medical treatments inhibit the multiplication or metabolism of saprotrophs.

Saprotrophs cause decay



***Heat** – for rapid decomposition, need to maintain an **optimum temperature** for the activity of **enzymes**. Heat is generated by the respiration that occurs during the decomposition process.

***Oxygen** is required for **aerobic respiration**, which releases energy in bacteria and fungi to drive their metabolism. In the **absence of oxygen**, decomposition is **slow** and **very smelly**, because methane and hydrogen sulfide may be produced.

***Water** – many decomposition reactions are **hydrolysis reactions**, i.e. they use water to split chemical bonds. Water is also necessary to dissolve the breakdown products before they can be absorbed by the saprotrophs or other organisms.

Q

1 Copy and complete the following paragraph.
During the process of decay, ____ and ____ convert complex chemicals into ____ ones. For example, proteins are converted to ____ , and ____ to fatty acids and glycerol. These decay processes involve the biological catalysts called ____ , and so the processes are affected by changes in ____ and ____ . Humans exploit decay, for example in the treatment of ____ to provide drinking water, and may deliberately limit decay, for example in the preservation of ____.

2 Gardeners often place vegetable waste on a compost heap. Over the course of time the waste will be decomposed.
- **a** What do gardeners gain from the decomposed waste?
- **b** Why do gardeners sometimes spray water over the heap in warm summer weather?
- **c** Why do gardeners often build compost heaps on a pile of loose-fitting sticks or bricks?

19.5 The carbon cycle

OBJECTIVES

- To recall why living organisms need carbon-containing compounds
- To appreciate that carbon is cycled between complex and simple forms by the biochemical processes of photosynthesis and respiration
- To understand that formation and combustion of fossil fuels may distort the pattern of the carbon cycle

Carbon-containing nutrients – a reminder

The Sun keeps supplying *energy* to food chains. However, the supply of *chemical elements* to living organisms is limited, and these elements must be recycled. The nutrient elements are cycled between simple forms in the non-living (abiotic) environment and more complex forms in the bodies of living organisms (the biotic component of an ecosystem). Living organisms require carbon-containing compounds as:

- **a source of energy**, released when carbon-containing compounds are oxidised during respiration (particularly carbohydrates and fats)
- **raw materials** for the growth of cells (particularly fats and proteins).

Recycling carbon compounds

Plants, and some bacteria, manufacture these compounds from carbon dioxide during the process of photosynthesis (see page 46). Animals obtain them in a ready-made form by feeding on other living organisms (see page 62), and decomposers obtain them as they break down the dead bodies or wastes of other living organisms. These processes of feeding, respiration, photosynthesis and decomposition **recycle** the carbon over and over again. Theoretically, the amount of carbon dioxide fixed by photosynthesis should equal the amount released by respiration. As a result, the most accessible form of carbon in the non-living environment, that is **carbon dioxide**, remains at about the same concentration year after year after year (about 0.03% of the atmosphere). Other processes may affect this regular cycling of carbon.

- Sometimes conditions are not suitable for respiration by decomposers, and carbon dioxide remains 'locked up' in complex carbon compounds in the bodies of organisms. For example, anaerobic, low pH or extreme temperature conditions will inhibit decomposition – this is how fossil fuels have been laid down in environments where decomposition is not favoured.
- Over millions of years the formation of fossil fuels has removed carbon dioxide from the environment. Humans have exploited fossil fuels as a source of energy over a relatively short time, and the **combustion** of oil, gas, coal and peat has returned enormous volumes of carbon dioxide to the atmosphere. As a result, carbon dioxide concentrations are increasing (see page 292).
- S The burning of biomass fuels such as wood and alcohol uses up oxygen, returns carbon dioxide to the atmosphere, and can have a very severe local effect although worldwide it is less significant than the combustion of fossil fuels.

The way in which these different processes contribute to the cycling of carbon is illustrated opposite.

Q

1 Refer to the carbon cycle opposite.

a Name the simple carbon compound present in the abiotic part of the ecosystem.

b Name two compounds present in the biotic part of the ecosystem.

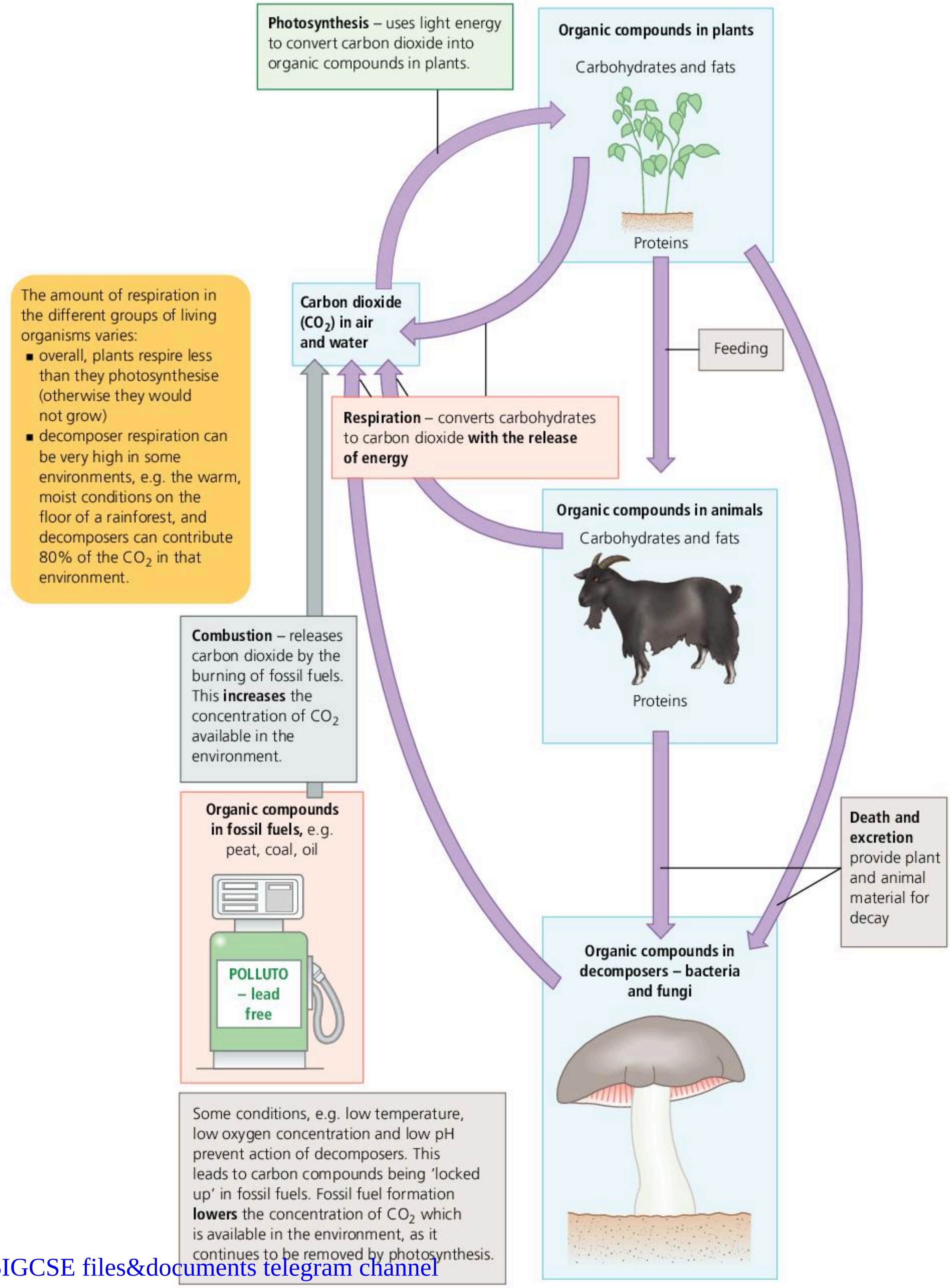
c Which processes raise the concentration of carbon dioxide in the atmosphere?

d Which process reduces carbon dioxide concentration in the atmosphere?

e Name the process that distributes carbon dioxide throughout the atmosphere from places where it is released.

f Suggest a reason why some fossil fuels were formed as sediments at the bottom of ancient seas.

The processes of photosynthesis, feeding, death, excretion and respiration lead to the cycling of carbon between living organisms and their environment. Fossil fuel formation and combustion affect the concentration of carbon dioxide in the atmosphere.



▲ The carbon cycle

19.6 The nitrogen cycle

S

OBJECTIVES

- To recall why nitrate is an essential mineral for plant growth
- To know how nitrate is made available in the soil
- To understand that a series of biochemical processes results in the cycling of nitrogen between living organisms and the environment
- To appreciate the part played by microorganisms in the cycling of nitrogen

Plants need nitrate

Plants need nitrogen for the synthesis of proteins and other compounds, including DNA and vitamins. Nitrogen gas makes up about 80% of the Earth's atmosphere, but plants do not have the enzymes necessary to use the nitrogen directly – instead they must absorb it as **nitrate**. Nitrate is formed by two sets of processes carried out by microorganisms – **nitrogen fixation** and **nitrification**.

Nitrogen fixation

In **nitrogen fixation**, nitrogen and hydrogen are combined to form ammonium ions and then nitrate. The process depends upon enzymes that are only possessed by certain bacteria called **nitrogen-fixing bacteria**. Some of these bacteria live free in the soil, but one important species lives in swellings called **nodules** on the roots of leguminous plants such as peas, beans and clover. Nitrogen fixation only happens if oxygen is present. It also occurs naturally in the atmosphere when the energy from lightning combines nitrogen directly with oxygen. Farmers can plant legumes in a crop rotation scheme to avoid having to use so much nitrogen-containing fertiliser. This saves money, and also limits pollution of water (see page 274).

Nitrification

In **nitrification**, ammonium ions produced by the decomposition of amino acids and proteins are oxidised, first to **nitrite** and then to nitrate. The process is carried out by **nitrifying bacteria** which live in the soil. Nitrification only happens if oxygen is present. In the absence of oxygen the process is reversed, and **denitrifying bacteria** obtain their energy by converting nitrate to nitrogen gas. This is why waterlogged soils, for example, tend to lose nitrate as nitrogen gas.

Recycling nitrogen

Once nitrate has been formed by either nitrogen fixation or nitrification, it can be absorbed by plants through their roots. Eventually the plant dies, and its body is added to the animal wastes and remains in the soil. Decomposers break down the nitrogen compounds in these wastes and remains and the formation of nitrate can begin again.

In a typical ecosystem, the processes shown opposite recycle nitrogen between living organisms and the environment. However, some processes cause the loss of nitrate from the environment. This happens naturally as a result of **denitrification** (see above), and less naturally when crops are **harvested** and removed from the site where they have grown. These losses of nitrate can be made up either by nitrogen fixation or by adding nitrate in the form of fertilisers.

Q

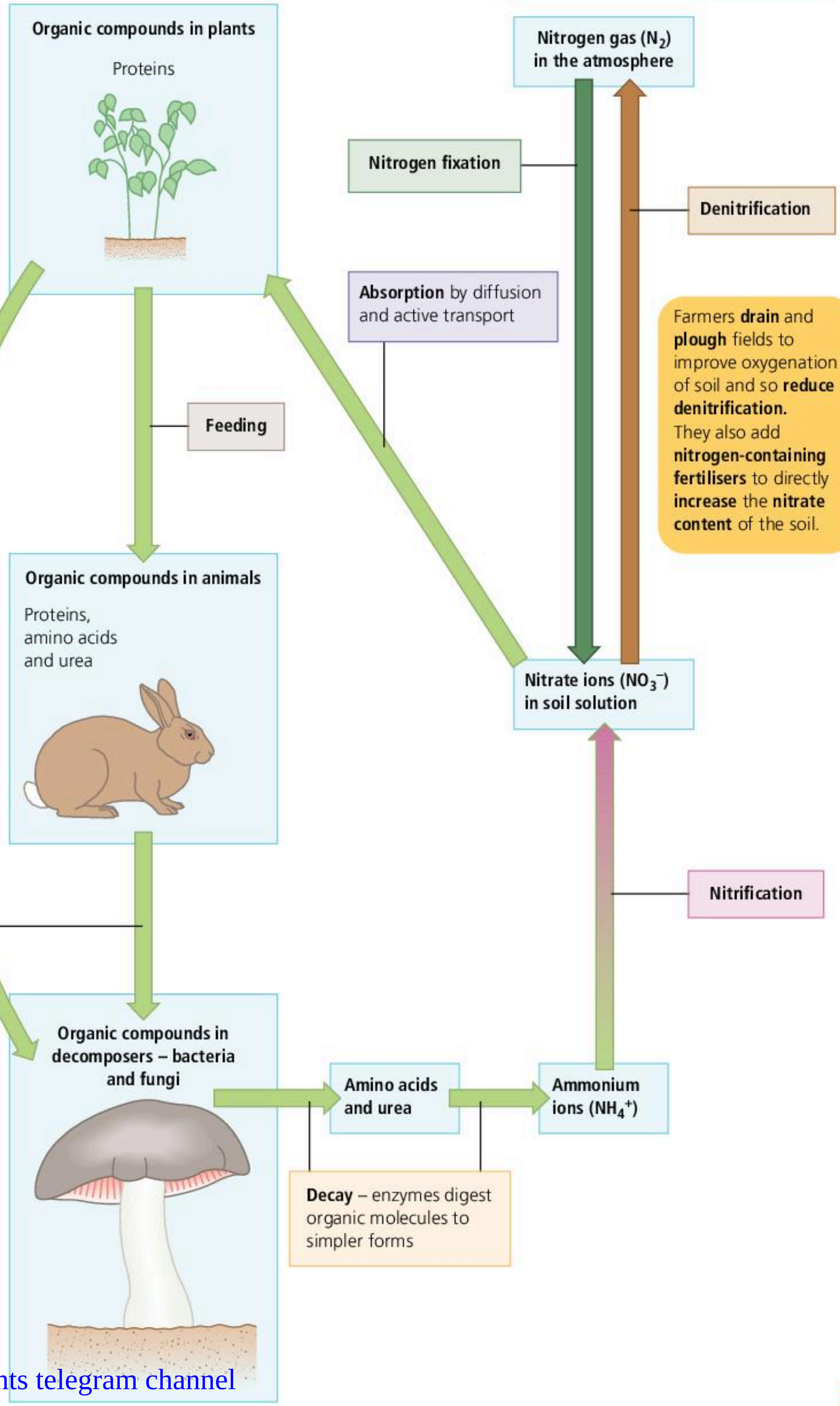
1 Use your knowledge of the nitrogen cycle to explain how the following farming practices might improve soil fertility.
   a ploughing in stubble rather than burning it
   b draining waterlogged fields
   c planting peas or beans every third year
   d adding NPK fertiliser
   e adding well-rotted compost.

2 Explain why farmers drain waterlogged fields.

The nitrogen cycle

The processes of nitrification, absorption, feeding, death, excretion and decay lead to the cycling of nitrogen between living organisms and their environment. In a natural ecosystem, nitrogen fixation can 'top up' the cycle and make up for losses by denitrification.

Some plants, called **legumes** (beans and peanuts are examples), have swellings on their roots. These **root nodules** contain bacteria, which can convert nitrogen gas to nitrate ions. These plants reduce the need for artificial fertilisers.



Farmers **drain** and **plough** fields to improve oxygenation of soil and so **reduce denitrification.** They also add **nitrogen-containing fertilisers** to directly **increase** the **nitrate content** of the soil.

Farmers are encouraged to plough roots and stalks of harvested crops back into the soil. This provides raw material for the action of decomposers.

19.7 Water is recycled too!

OBJECTIVES

- To know that all living organisms are largely water, and that biological reactions always take place in an aqueous (watery) environment
- To understand that the biological properties of water result from the structure of the water molecule
- To list some of the biological functions of water

Water and life

Life first evolved in water for a number of reasons:

- The molecules that were used by living organisms, and that made up their structure, were dissolved in the first seas.
- In the muddy estuaries and shallow seas of the primitive Earth, the molecules could become concentrated enough to react together.
- Water acted as a protective shield for the first living organisms against the damaging ultraviolet rays from the Sun.

Recycling water

Life continues on this planet because water has special properties. In particular, all three states of water – solid ice, liquid water and gaseous water vapour – exist at the temperatures found on the Earth's surface. The temperature varies at different times and at different places on the planet, but the average temperature over the Earth's surface is about 16.5 °C. This means that ice, liquid water and water vapour are all present and are continually interchanging. Water is recycled between different parts of the environment, as shown in the water cycle diagram opposite.

The water cycle

All of the elements that make up living organisms, not just carbon and nitrogen, are recycled. The water cycle is different to the cycles of carbon and nitrogen because:

- only a tiny proportion of the water which is recycled passes through living organisms
- the most important factor in water recycling is heat energy from the Sun. This evaporates water, and also creates the temperature gradients which lead to winds.

The steps involved in the water cycle are shown in the diagram opposite.

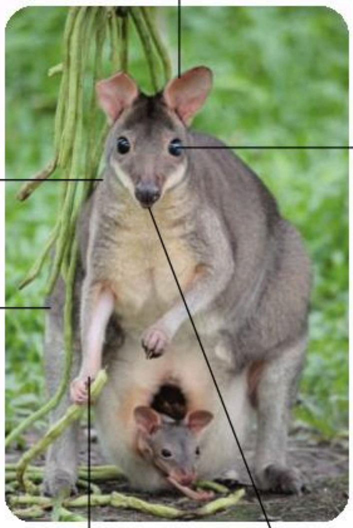
The special properties of water

The picture of the kangaroo shows the importance of the properties of water to living things.

The **high specific heat capacity** of water means that cells or bodies with a high water content tend to resist heating up or cooling down, even when the temperature of their environment changes.

Evaporation of water from a surface allows loss of heat. Water has a **high latent heat of vaporisation**.

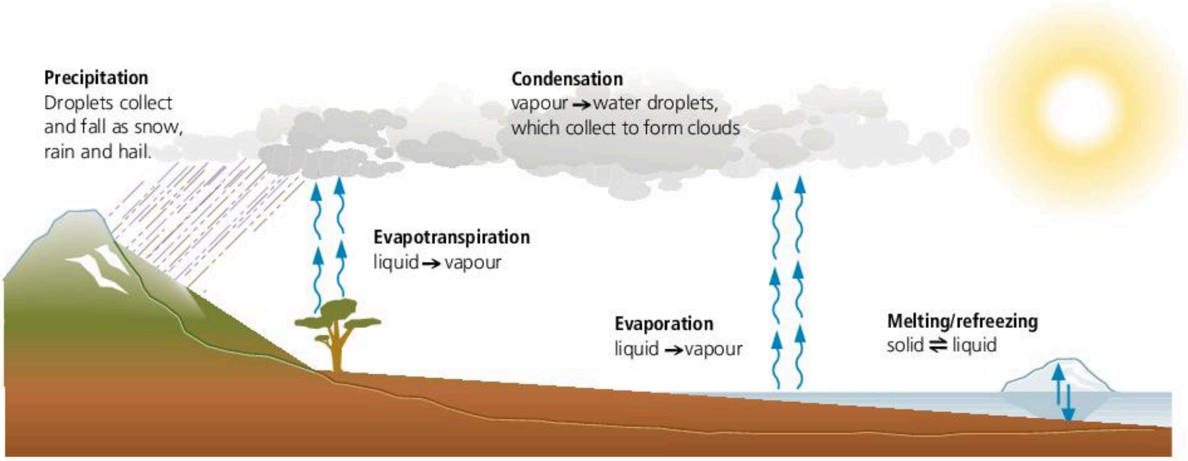
Because water is **incompressible**, it provides excellent support. Water helps support a whole organism (e.g. a fish), or part of an organism (e.g. the eyeball, or the erect penis of a mammal).



Water is an excellent **lubricant**, for example in saliva or in the synovial fluid of movable joints.

Water can be a **biological reagent**, for example in the processes of photosynthesis and digestion.

Water is an excellent **transport medium** for many biological molecules, such as oxygen, glucose, amino acids, sodium ions and urea.



▲ The water cycle is maintained by heat energy from the Sun

Q

1 **a** Amino acids in the muscle protein of a cow may be found in the muscle protein of a rabbit after several years. Explain how this is possible.

b Explain how fungi and bacteria play a part in the nitrogen cycle.

2 Use words from the following list to complete the paragraphs about ecosystems. You may use each word once, more than once or not at all.

respiration, decomposition, producer, chemical, carnivore, consumer, photosynthesis, energy, light, elements, decomposers, herbivore

In each ecosystem there are many feeding relationships. A food chain represents a flow of ____ through an ecosystem, and always begins with an organism called a ____ which is able to trap ____ energy and convert it to ____ energy. An organism of this type is eaten by a ____, which is a kind of ____ that feeds only on plant material. This type of organism is, in turn, eaten by a ____ (an organism that consumes other animals).

The process in which light energy is transferred into a chemical form is called ____ – eventually the energy is released from its chemical form during the process of ____ This process provides energy for all living organisms, including ____ which are microbes that feed on the remains of animals and plants.

3 Many people are concerned about the effects on the environment of rearing cattle for food.

a Explain why growing vegetables for human consumption instead of raising beef cattle results in fewer energy losses.

b Suggest **one** way in which rearing cattle can result in a loss of biodiversity.

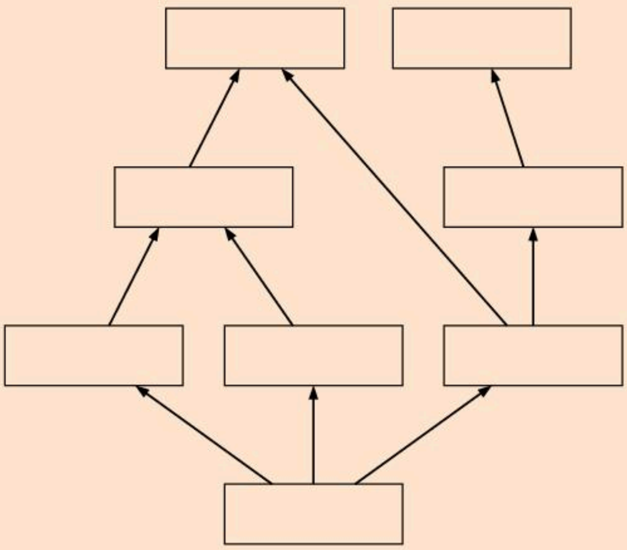
c Explain how eating less meat in the USA and Western Europe could help to feed the world's growing population.

Questions on ecosystems, decay and cycles

1 The following organisms were found living in the same habitat.

caterpillar, fox, greenfly (aphid), green plant, hawk, ladybird beetle, rabbit, small bird

a Copy and complete the diagram below by filling in the names of the organisms to show their feeding relationships.



[4]

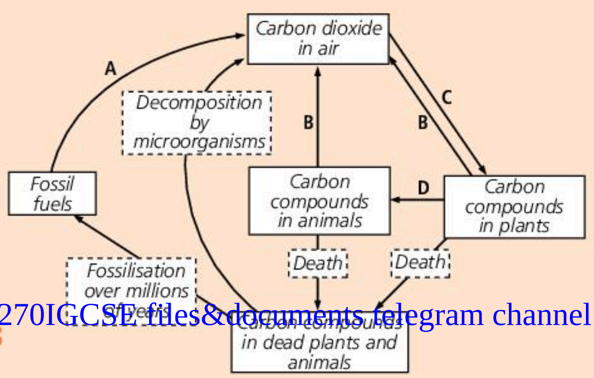
b This type of diagram is called a food web. Explain the meaning of the arrows in the food web. [1]

c **i** Name **two** organisms which are primary consumers. [2]

ii Name the organism which is the producer. [1]

d Myxomatosis is a disease which kills rabbits. Suggest **two** possible consequences of a reduction in the number of rabbits. [2]

2 The diagram below shows the carbon cycle in nature.

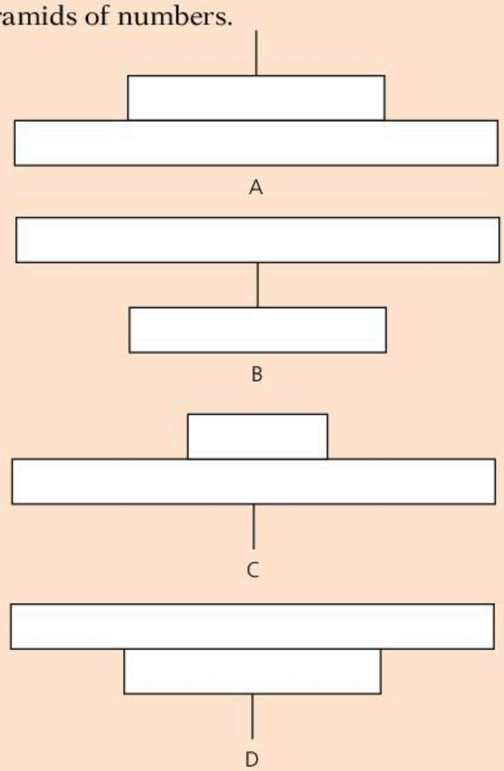


a **i** Name the processes represented by the letters **A**, **B**, **C** and **D**. [4]

ii Name the most abundant carbohydrate in a plant cell. [1]

b Measurements suggest that the carbon dioxide concentration in the atmosphere is rising. Suggest how this is happening. [2]

3 The following diagrams represent different pyramids of numbers.



A food chain can be represented by a pyramid of numbers. Match each of these food chains with the correct pyramid.

grass seed ⟶ mouse ⟶ weasel

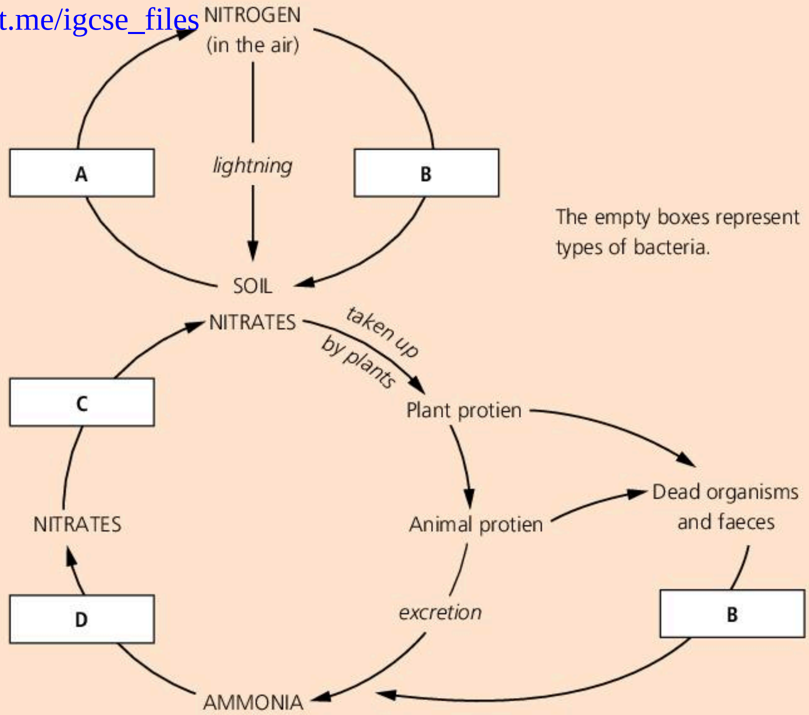
oak tree ⟶ aphid ⟶ ladybird

cabbage ⟶ caterpillar ⟶ wasp parasite

oats ⟶ rabbit ⟶ flea [4]

4 Several types of bacteria involved in the nitrogen cycle are listed below.

decay bacteria, denitrifying bacteria, nitrifying bacteria, nitrogen-fixing bacteria



a The diagram above summarises the nitrogen cycle. Match the letters in the boxes with the names of the bacteria active at each stage. [5]

b Soil nitrates are taken up by plants. They can be produced by the two methods shown in the diagram.
Suggest another way in which soil nitrates may be increased. [1]

5 The diagram below represents the water cycle.

a Name the processes represented by the letters **P** and **R**. [2]

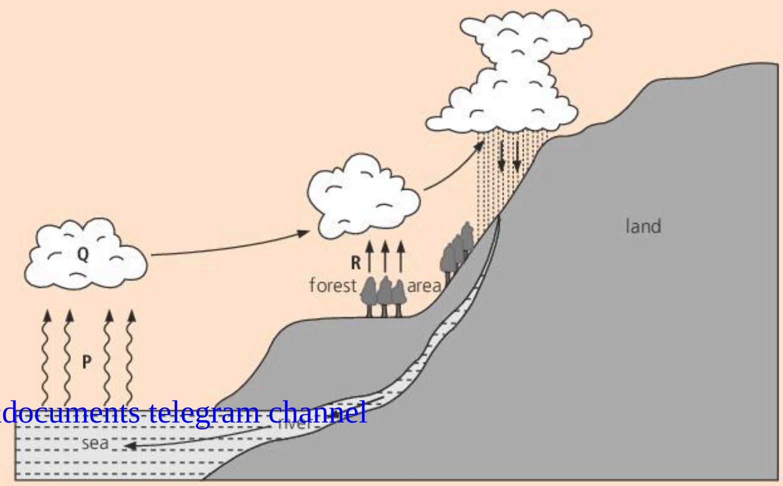
b Name **two** factors that could affect the rate of process **R**. Explain your answers. [4]

c State **two** reasons why water is essential for green plants. [2]

6 The table below lists some terms used in ecology and their definitions.
Match each term with its definition. Write the letter and number to show your answer, for example, **a–4**.

Term	Definition
a ecology	**1** an area that can supply food, shelter and a breeding site
b community	**2** the study of living things in relation to their environment
c habitat	**3** the physical and biological conditions that are present in the place where an organism lives
d population	**4** the living organisms of different species which live in a particular habitat
e environment	**5** the number of individuals of a particular species present in a particular habitat

[4]



19.8 Factors affecting population size

OBJECTIVES

- To understand what is meant by environmental resistance
- To list examples of biotic and abiotic factors which limit population growth
- To explain the form of a typical growth curve

A **population** is a group of organisms of one species, living in the same area at the same time (see page 241).

Environmental resistance

By taking samples and counting the numbers of organisms in a particular habitat, an ecologist can study how any factor affects the size of the population. For example, a woodland manager might wish to know whether thinning the trees in the wood affects the population of low-growing plants, or a farmer might wish to know whether the time of grass-cutting affects the population of bank voles. These factors may be **living** (**biotic**) or **non-living** (**abiotic**). Together they affect the rate at which a population grows, and also its final size. All the factors that affect population growth and size together make up the **environmental resistance**.

Some significant **biotic** factors that affect population growth include:

- **Food** – both the quantity and the quality of food are important. Snails, for example, cannot reproduce successfully in an environment low in calcium, no matter how much food there is, because they need this mineral for shell growth.
- **Predators** – as a prey population becomes larger, it becomes easier for predators to find the prey. If the number of predators suddenly falls, the prey species might increase in number extremely quickly.
- **Competitors** – other organisms may require the same resources, such as food, from the environment, and so reduce the growth of a population.
- **Disease** – often caused by parasites, and may slow down the growth and reproductive rate of organisms within a population.

Important **abiotic** factors affecting population growth include:

- **Temperature** – higher temperatures speed up enzyme-catalysed reactions and increase growth.
- **Oxygen availability** – affects the rate of energy production by respiration.
- **Light availability** – for photosynthesis. Light may also control breeding cycles in animals and plants.
- **Toxins and pollutants** – tissue growth can be reduced by the presence of, for example, sulfur dioxide, and reproductive success may be affected by pollutants such as oestrogen-like substances.

Growth curves and carrying capacity

When a small population begins to grow in a particular environment, the environmental resistance is almost non-existent – there may be plenty of food and no accumulation of poisonous wastes. The diagram opposite shows how environmental resistance eventually limits population growth, and the environment reaches its **carrying capacity**. Unless the environmental resistance is changed, perhaps by a new disease organism, the size of the population will only fluctuate slightly. Organisms that are able to maintain their population, or even increase it, must be well adapted to their particular environment.

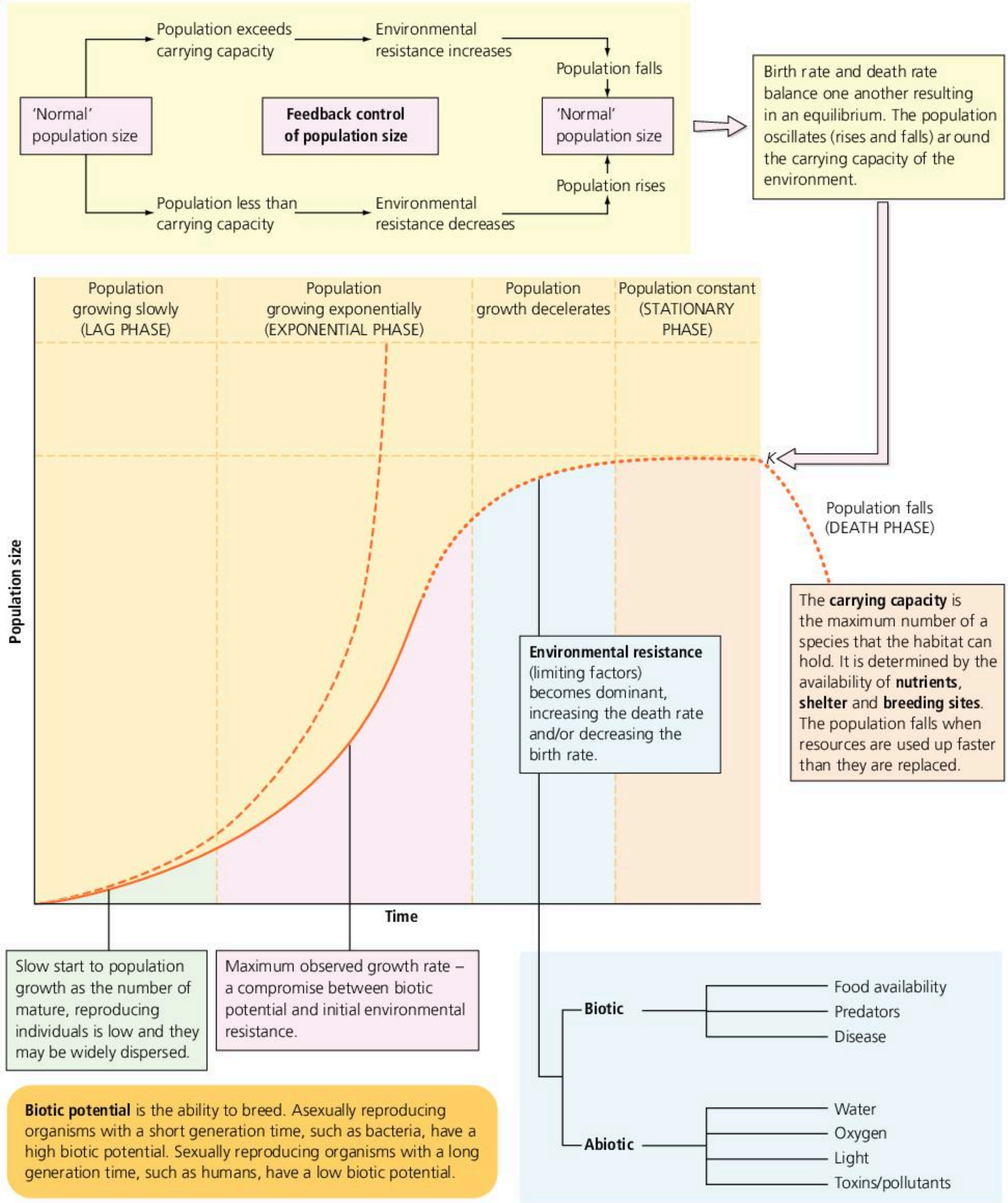
Humans exploit environmental resistance

People use their understanding of environmental resistance to manage populations. For example:

- Predators are eliminated from farm situations.
- More food is made available to domestic animals.
- Nitrogen fertilisers and artificial light are used to boost plant growth.
- Predators may be used to control pests.
- Anaerobic conditions or low temperatures are used to prevent populations of microbes from consuming our food.
- Competitors are eliminated from crops using pesticides.

An example can be found on page 174.

Factors affecting population growth



1 What is meant by the term environmental resistance? Give an example.

2 Define the terms biotic and abiotic factors, and give examples of each.

3 Give examples of the ways in which humans exploit their knowledge of the factors affecting population growth.

19.9 Human population growth

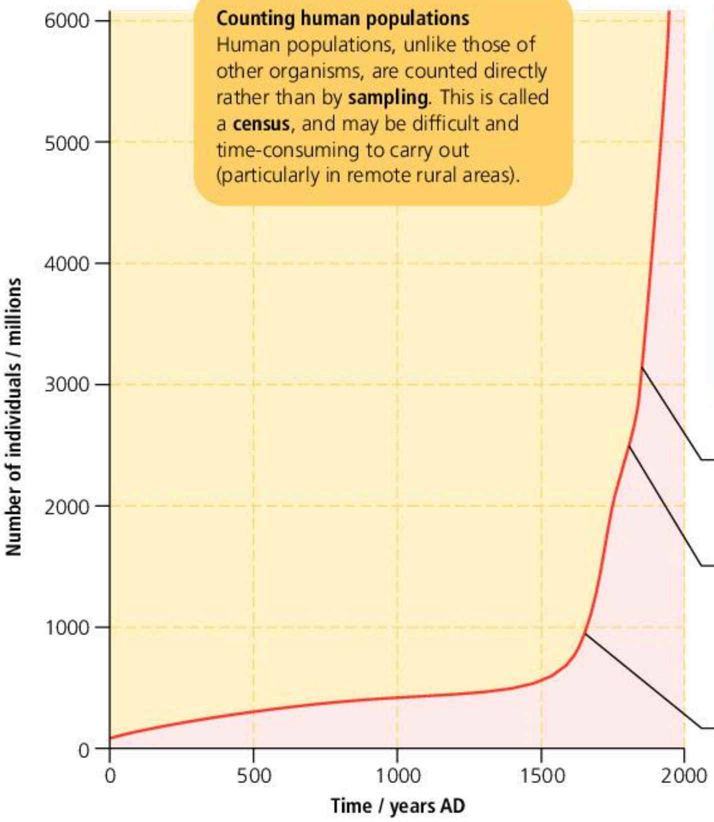
OBJECTIVES

- To know that the evolution of humans from hunter-gatherers to permanent settlers caused changes in the environment
- To understand the form of a human population growth curve

Humans, like other organisms, must find **food**, **shelter** and a **place to breed**. The first humans were hunter-gatherers who moved from place to place, taking what they needed to satisfy these requirements (but allowing the environment to recover once they moved on). After the most recent Ice Age this method of living became more difficult and humans began to settle in the most suitable areas. This meant that the environment did not have time to recover.

Growth of the human population

As with other organisms, the growth of the human population can be presented as a population growth curve. The number of humans increases, by reproduction, until the carrying capacity of the environment has been reached. Humans have the ability to alter their environment to raise the carrying capacity. Three major changes in human activities led to significant surges in the world population over the past 300 years, as shown below.



Counting human populations
Human populations, unlike those of other organisms, are counted directly rather than by **sampling**. This is called a **census**, and may be difficult and time-consuming to carry out (particularly in remote rural areas).

The UK population is almost static as socio-economic factors limit family size ...
... but
- greater affluence leads to greater demand for leisure and recreation space
- smaller families increase the demand for housing
- greater expectations of population lead to greater demand for a variety of foods at all times of the year
- more cars per household increases demand for roads

⇩

great competition for available land
and
greater effects on the environment

Medical revolution – improvements in sanitation and the control of infectious diseases reduced the number of deaths.

Industrial revolution – the development of machinery increased agricultural efficiency and improved housing conditions. More people earned enough money to be able to afford larger families, and the number of births increased.

Agricultural revolution – human settlers became more efficient in their farming. More food became available, and this part of environmental resistance to the human population was reduced.

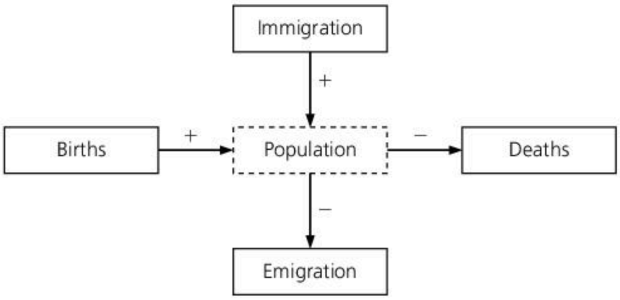
▲ Human population of the world

Human success may be measured as:
- worldwide distribution
- large number of individuals
- dominance over other species.

This is largely due to behavioural skills which:
- allow solution of complex problems
- allow control/modification of environment leading to **changes in carrying capacity** of the environment.

The shapes of populations

A population grows if the number of births plus the number of immigrants is greater than the number of deaths plus the number of emigrants. This relationship is shown in the figure below.



▲ Factors affecting population size

If immigration and emigration remain stable, the population size will depend on the relative numbers of births and deaths. If the population size is measured, and then the data is broken down into different age groups, a **population pyramid** can be drawn. A population pyramid shows the **age structure** of a population – the percentage of males and females in each age group in a country.

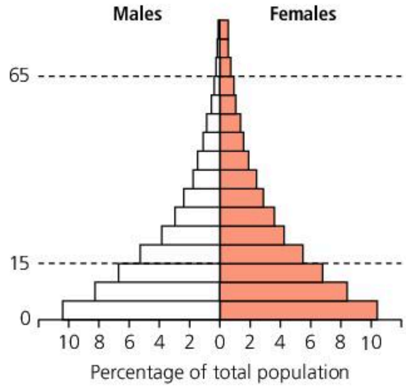
This age structure is affected by:

- **Food availability:** this is particularly significant in those countries where a balanced diet might be difficult to obtain. Deficiencies in protein and vitamins can lead to a very high death rate amongst infants.
- **Hygiene:** food poisoning and water-borne infections can cause an increased death rate from diarrhoea and dehydration. Provision of a 'safe' water supply has a huge impact on the stability of a population.
- **Medical provision:** vaccination programmes can prevent many deaths, and care during childbirth can dramatically reduce deaths among young women. The availability of combination therapy for HIV infections has significantly reduced death rates in the 25–40 age groups in sub-Saharan Africa.
- **Working conditions:** unsafe work, for example mining, can increase death rates amongst young people (usually men), particularly if medical care is poor.
- **Political instability:** this can sometimes lead to civil war, with serious effects on death rates.

Less economically developed nations (LEDNs) typically have a high birth rate but a high mortality rate amongst young people. The population pyramid tends to have a wide base (lots of births) but sloping sides (high death rate in younger age groups). The population pyramids for more economically developed nations (MEDNs) have a narrower base but almost vertical sides, reflecting a lower birth rate and few deaths amongst young people. All population pyramids show a higher proportion of females in the older age groups (the two X chromosomes offer genetic benefits against sex-linked conditions, see page 225). Population pyramids for two contrasting nations are shown here.

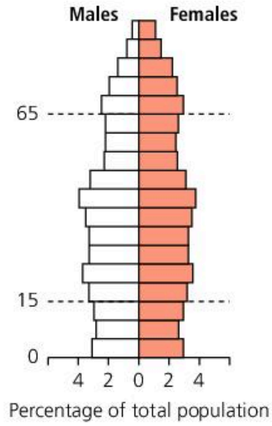
LEDN

- wide base
- low height
- sloping sides



MEDN

- narrow base
- considerable height
- vertical sides



Age (population) pyramids show the age structure of a population.

They can be compared with respect to:

- width of base (proportion of young people in population)
- height (number of individuals surviving to old age)
- angle of sides (death rate affects slope).

20.1 Food supply: humans and agriculture

OBJECTIVES

- To understand why agriculture is a threat to conservation
- To understand how careful management can help to conserve biodiversity

The human population is increasing and may reach 9 billion (9 000 000 000) by the end of the century. More people means a demand for more food. This food is mainly provided by agriculture – the management of land for food production.

Around the world, agriculture presents a serious threat to conservation of existing habitats. Although 75% of England is designated as farmland, only 2% of the UK population is involved in farming. In 1850, one farm worker produced enough food for about 4 people; now in advanced agricultural countries the same worker produces enough for 60 people. The enormous rise in productivity of land is due to many factors. These include:

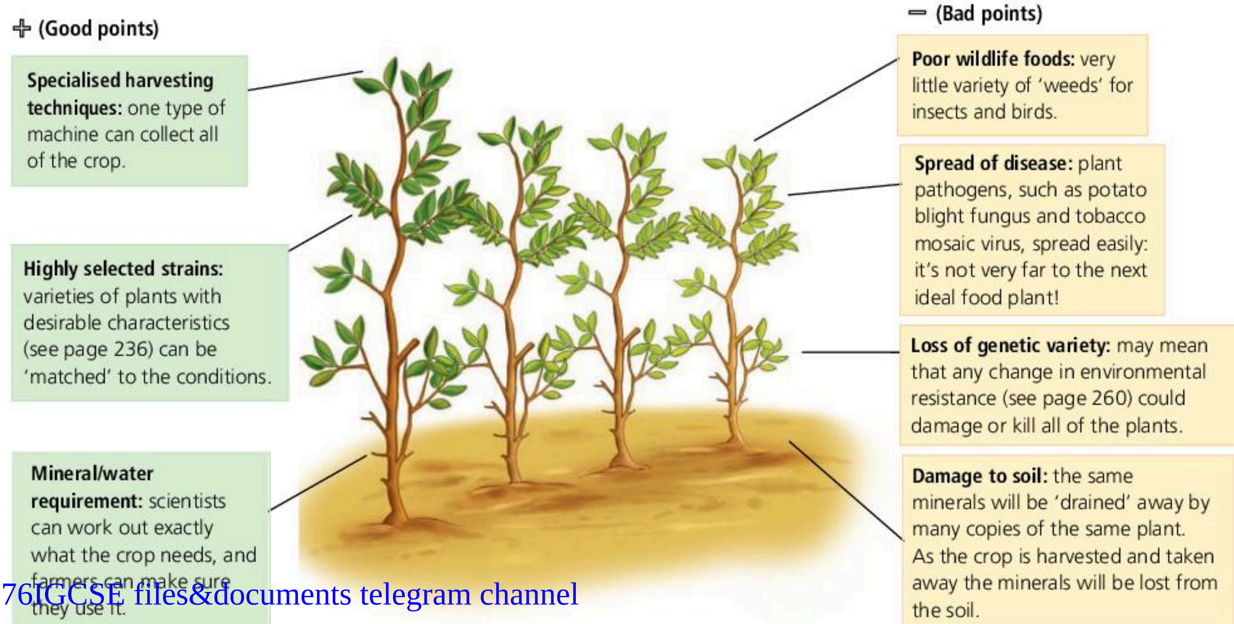
- **increased and more efficient use of machinery** has resulted in increased field sizes and the removal of hedges (see page 266)
- **increased use of inorganic fertilisers** affects plant diversity dramatically and can result in excessive nitrate levels in rivers, leading to eutrophication (page 274)
- **use of pesticides** to eliminate competitors for crop species has caused the reduction in population of many native wildflowers and some non-target insects and birds by direct toxicity or, more often, by removal of their food sources. Pesticides include **insecticides** to improve the quality and yield of crops by killing insects, and **herbicides** which reduce competition with weeds
- the tendency towards **monoculture**
- **selective breeding** of both crops and livestock.

All of these can have negative effects on the environment.

It all boils down to monoculture!

Farms used to be small and mixed, supplying enough food for just a few families throughout the year, but now tend to be large and specialised. Growing a single crop in this way is called **monoculture** and, as ever, there are pluses and minuses.

Monoculture



Intensive farming: livestock

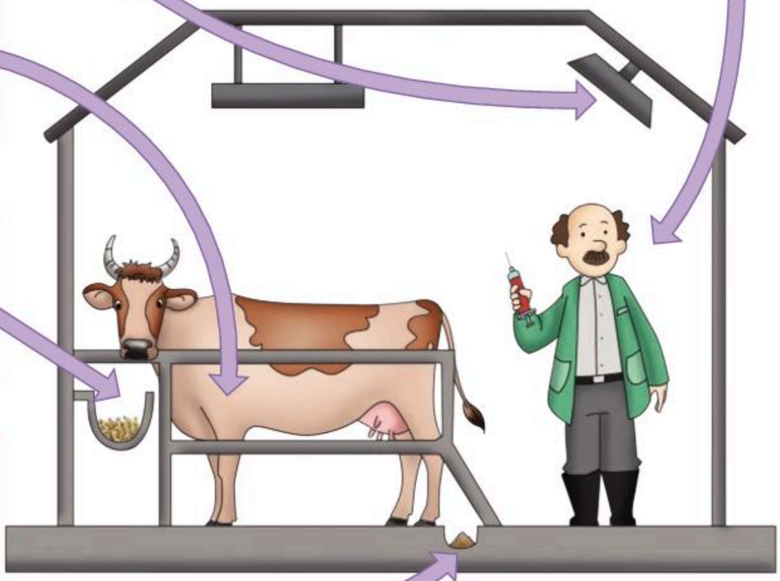
This means many animals can be kept in a very limited area, and is possible because of …

Both cows and sheep release **methane** – a very potent greenhouse gas (see page 270).

Temperature control: essential so that costly heat energy is not wasted.
- If **too high**, animals are uncomfortble and will not feed.
- If **too low**, food intake is 'wasted' on heat production to maintain body temperature.

Veterinary care:
- Antibiotics to reduce bacterial infection. Vaccination to minimise viral infection. Hormone/vitamin supplements can be administered more accurtely than in the diet.
- Artificial insemination techniques can reduce costs (no need to keep bulls in dairy farms).

- **Strain of animal:** selective breeding for animals with high **conversion ratio**, i.e. most efficient transfer of food intake to body mass.
- **Minimise movement:** less energy consumption and thus more efficient 'conversion'.



Food input: control content
- High protein for growth
- Minimal fat to suit customer demand for lean meat
- Include growth hormone to increase growth rate.

Hygienic conditions: most animals are free of gut parasites and debilitating bacteria – healthy animals grow more quickly and meat is more saleable.

Intensive farming can provide more food but there are **disadvantages**:
- Waste (faeces and urine) can pollute nearby rivers and lakes.
- Animals may suffer as they are not in normal social groups.
- Disease can spread easily from animal to animal.
- Use of antibiotics can select resistant strains of bacteria (see page 175).
- Heating and lighting are expensive – and cause more environmental damage.

The problem for the world is how to balance **productivity** (more food for humans) and **biodiversity** (keeping the wide range of wildlife).

Q

1 Intensive farming of cattle has reduced the cost of meat, but has some disadvantages. Explain why

a the use of antibiotics to reduce infections in cattle, and

b the addition of growth hormone to animal diets might be harmful to humans who consume the meat.

20.2 Land use for agriculture

OBJECTIVES

- To understand that chemical discharges may pollute land as well as air and water
- To understand that many human effects on the land involve loss of wildlife habitat
- To know that there are ways to reverse loss of wildlife habitat

Many of the pollutants described on pages 270–5 have an effect on land, as well as on the air or water.

Pollution also includes the loss of wildlife habitat that results from human competition for land.

Removal of hedges

Farmers remove hedges to increase the area where they can grow crops. The benefits of hedgerows as habitats, and the reasons why farmers feel justified in removing them, are outlined below.

Deforestation

The removal of woodland provides firewood, building materials, cleared land for crops such as palm oil or for grazing of cattle. For our first settler ancestors, it also removed the habitat of predators of domestic animals.

Deforestation is also a result of clearing land so that natural resources (e.g. oil in the Amazon basin and copper in Zaire) can be extracted.

The technique used to clear forest today is often called **slash and burn**. The largest trees may be removed for sale as timber for furnishings but the less valuable woods are simply chopped down (slashed) and then burned. The humans using the land gain a short-term benefit, but the damage to

▲ The removal of hedgerows in Britain averaged 8000 km per year in the twentieth century. This represents a disaster for wildlife.

wildlife habitats is immediate and humans also suffer in the long term. Newspaper and television headlines emphasise the loss of forest in tropical areas of the world, but it should be remembered that most of the UK was once forested! Some of the penalties of large-scale deforestation are illustrated below.

Q

1. It has been estimated that more than 150 000 km of hedgerow have been removed from around Britain's fields since the Second World War. Why has this been done? What are the possible effects on wildlife?
2. What is deforestation? Give reasons why humans should be anxious about this process.

Deforestation – the rapid destruction of woodland

Reduction in soil fertility

- Deciduous trees may contain 90% of the nutrients in a forest ecosystem. These nutrients are removed if the trees are cut down and taken away.
- Soil erosion may be rapid in the absence of trees because wind and direct rain may remove the soil, and soil structure is no longer stabilised by tree root systems.

Flooding and landslips

Normally in a woodland, 25% of rainfall is absorbed by foliage or evaporates and 50% is absorbed by root systems. After deforestation, water may accumulate rapidly in river valleys, often causing landslips from steep hillsides.

Changes in recycling of materials – fewer trees means:

- atmospheric CO_2 concentration may rise as less CO_2 is removed for photosynthesis
- atmospheric O_2 – vital for aerobic respiration – is diminished as less is produced by photosynthesis
- the atmosphere may become drier and the soil wetter as evaporation (from soil) is slower than transpiration (from trees).

Climatic changes

- Reduced transpiration rates and drier atmosphere affect the water cycle and reduce rainfall.
- Rapid heat absorption by bare soil raises the temperature of the lower atmosphere in some areas, causing thermal gradients which result in more frequent and intense winds.

Species extinction

Many species are dependent on forest conditions. For example, orang utans depend on rainforest in Indonesia.

A loss of one species can disrupt several food chains and food webs.

It is estimated that one plant and one animal species become extinct every 30 minutes due to deforestation.

Many plant species may have medicinal properties, e.g. as tranquillisers, reproductive hormones, anticoagulants, painkillers and antibiotics.
The Madagascan periwinkle, for example, yields a potent drug used to treat leukaemia.

20.3 Damage to ecosystems: malnutrition and famine

OBJECTIVES

- To recall that malnutrition is a condition resulting from a defective diet where certain important food nutrients (such as proteins, vitamins, or carbohydrates) may be absent
- To remember that malnutrition can lead to deficiency diseases
- To understand some of the reasons why famines occur including over-use of land for agriculture.

A high global death rate linked to malnutrition has arisen from famine situations caused by a number of natural problems as well as by socio-political factors, such as alcohol and drug abuse, poverty, and war.

As well as suffering from a deficiency disease, a malnourished person is usually more at risk from other diseases (as the immune system may be very much reduced in efficiency) and a society with many malnourished individuals experiences mounting problems:

- Adults become ill and cannot work, so little money is available to buy food.
- Children become ill, and so adults must attempt to care for them (often going without food themselves).
- Older, weaker people will die and the society is deprived of their experience and knowledge.

15% of the world's population receive fewer than 10 000 kJ per day

Famine

Increasing population
Improved medical services may mean that populations increase (see page 262). As the number of people increases, the need for food increases too. At the same time, greater numbers of domestic animals may reduce the amount of land available for food production.

Drought
Water is essential for plant growth and for the health of domestic animals. Global warming (see page 271) may upset rainfall patterns and so make less water available. This can dramatically reduce crop yield.

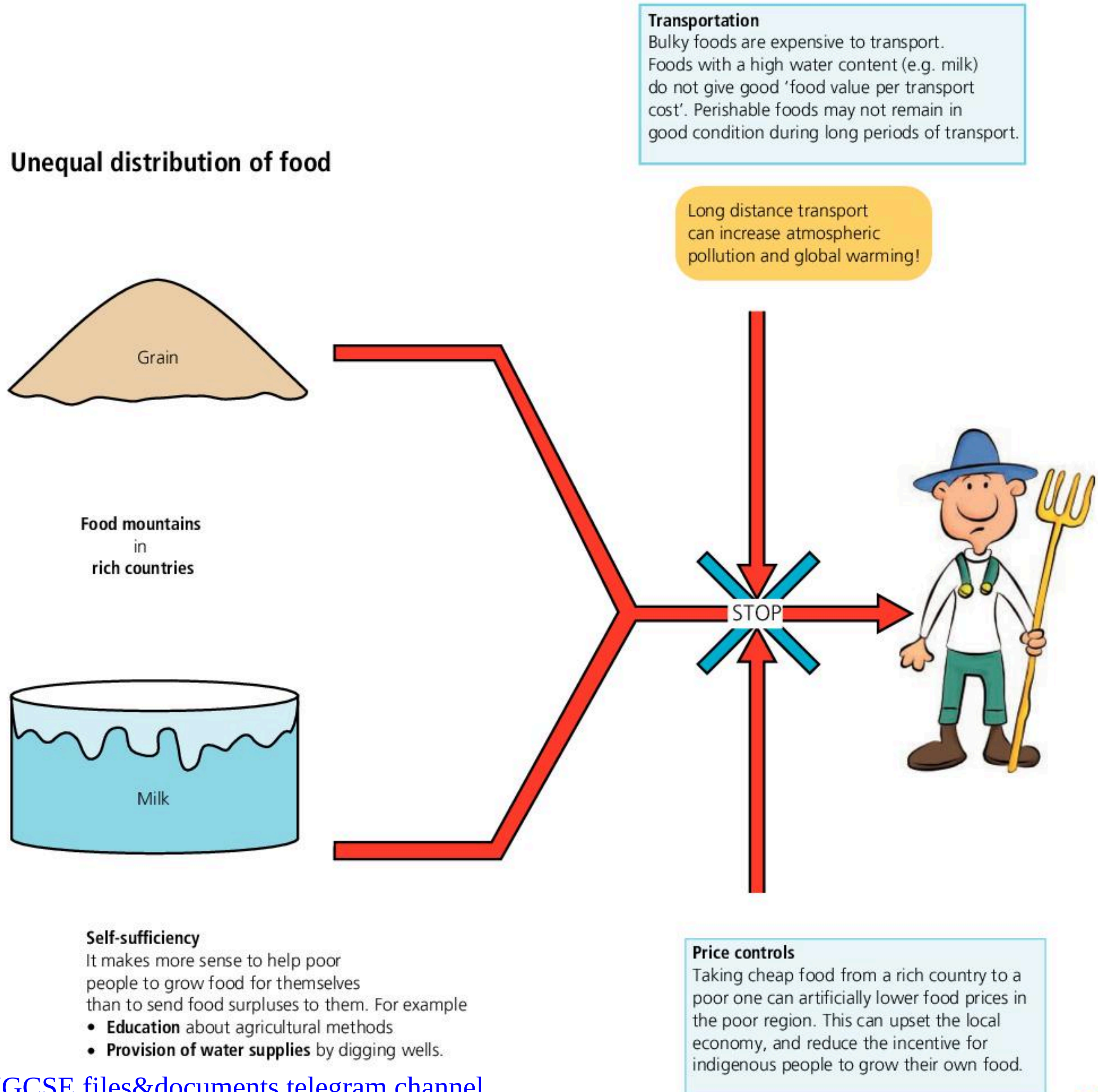
Flooding
Although plants such as rice grow in flooded conditions, **unpredictable** flooding can reduce crop yield severely. Plants (e.g. maize) can be damaged and fertile soil can be washed away.

Unequal distribution of food
Some areas produce more food, either because of a more suitable environment (e.g. water availability) or more advanced agriculture (e.g. use of fertilisers). Food surpluses in one area cannot always be moved to areas where food supplies are limited.

Cost of fuel and fertiliser
Crop yield may be low in developing countries because poor farmers cannot afford fertiliser, or fuel to run machinery.

Can famine be stopped?

The world probably produces enough food to feed all of its inhabitants. Agriculture in developed parts of the world is extremely efficient (see page 264). Even so, as many as 15% of the world's inhabitants suffer from malnutrition because the available food is not evenly distributed among the world's population. Some people believe that all surplus food from developed countries should be made available to poorer countries, but many others (including EU agricultural ministers) argue that aid to poorer people should be mainly in the form of education and farming equipment. Direct food aid should only be reserved for disaster situations, such as the earthquake in Nepal and flooding in Bangladesh, where many individuals would quickly die if food were not made available. The problem of unequal food distribution is outlined in the diagram below.



20.4 Human impacts on the environment: pollution

OBJECTIVES

- To understand that humans can alter their environment
- To understand how changes in human population have altered our impact on the environment
- To consider human impacts in terms of cause, effect and possible remedies

Humans already are, or could easily become, the most significant biotic factor in every environment. Primitive humans had a *temporary* effect on the environment – hunting, fishing and burning wood – because they were **nomadic** and allowed the environment periods of time to recover. After humans became **cultivators** and **settlers** (thousands of years ago) the following 'effects' on the environment gradually became noticeable:

- The use of tools and the domestication of animals meant a more efficient **agriculture**.
- The greater need for shelter, agricultural land and fuel meant a greater rate of **deforestation** and **desertification**.
- The careless use of pesticides and fertilisers, together with increasing consumption of fossil fuels, produced problems of **pollution**. These have been added to by the development of nuclear energy sources.

Humans may also have positive effects – we are able to use our skills and knowledge in **conservation**.

Our demands on the environment

Human success, measured as an increase in population size, is largely due to our ability to solve complex problems and modify the environment for our benefit. This places great demands on the environment, causing changes in **the atmosphere**, **the aquatic environment** and **the land.**

Humans have also, intentionally or otherwise, seriously upset the balance of populations of other living organisms. (see effects on food webs, page 242).

Causes, effects and remedies for pollution

Pollution is any effect of human activities upon the environment, and a **pollutant** is any product of human activities that has a harmful effect on the environment. When looking at pollution, we shall consider three key points:

- What is the **cause**?
- What are the **effects**?
- What are the **solutions**?

Pollution of the atmosphere

Two big problems with the Earth's atmosphere are:

- the **greenhouse effect**
- production of **acid rain**.

Burning of fossil fuels has a major effect on the atmosphere. The combustion process oxidises elements and compounds in the fuel, as shown in the equations below.

carbon + oxygen	⟶	carbon monoxide (CO) and carbon dioxide (CO_2)
sulfur + oxygen	⟶	sulfur dioxide (SO_2)
nitrogen + oxygen	⟶	nitrogen monoxide (NO) and nitrogen dioxide (NO_2)

These oxides affect the atmosphere – carbon dioxide is a greenhouse gas and sulfur dioxide and oxides of nitrogen contribute to acid rain. The other major pollutant of the atmosphere is methane, produced by livestock (especially during intensive farming, see page 265).

There are also localised problems with lead compounds, and with smoke. The causes and effects of, and possible solutions to, each of these problems are outlined in the diagrams opposite.

S

Causes of the increased greenhouse effect

Greenhouse gases trap infrared radiation ('heat') close to the Earth's surface. Solar radiation is allowed to enter the lower atmosphere but is not allowed to escape. The greenhouse effect is increasing because of raised levels of these greenhouse gases:

- **carbon dioxide** released by combustion of fossil fuels in power stations and internal combustion engines (in cars and lorries, for example)
- **methane** produced in the guts of ruminants such as cows, and in the waterlogged conditions of swamps and rice fields.

More methane is produced by **termites** than by all the ruminant mammals on the Earth!

Effects

Global warming (raised temperatures close to the Earth's surface) causes:

- greater climatic extremes – strong winds, heavier rainfall and unseasonal weather
- melting of polar ice and changes in density of sea water – rising sea levels and flooding
- evaporation of water from fertile areas – deserts form
- pests may spread to new areas

(all may cause loss of crops)

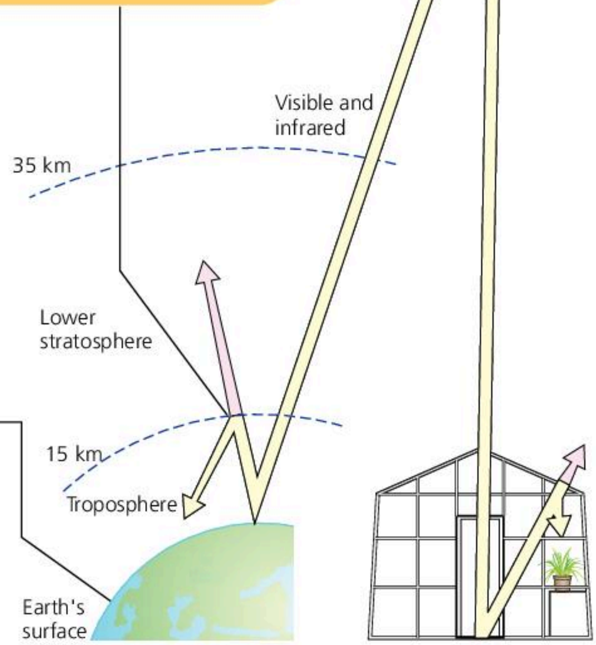
But

- higher temperatures and more carbon dioxide mean **more photosynthesis** and **more food production**.

Solutions

To limit the effects of greenhouse gases, humans should:

- reduce burning of fossil fuels – explore alternative energy sources
- reduce cutting of forests for cattle ranching or rice growing
- replant forests.



▲ Some gases added to the atmosphere act like the panes of glass in a greenhouse and raise the temperature close to the Earth's surface

Causes of acid rain

Human activities release acidic gases

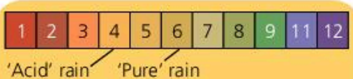
- Sulfur and nitrogen in fossil fuels are converted to oxides during combustion.
- More oxidation occurs in the clouds. Oxidation is catalysed by ozone and by unburnt hydrocarbon fuels.
- The oxides dissolve in water, and fall as **acid rain**.

sulfur dioxide and nitrogen oxides $\xrightarrow{H_2O}$ sulfuric and nitric acids

Effects

Acid rain causes problems

- **Soils** become very acidic. This causes **leaching of minerals** and **inhibition of decomposition**.
- **Water in lakes and rivers** collects excess minerals. This causes **death of fish and invertebrates** so that food chains are disrupted.
- **Forest trees** suffer **starvation** because of leaching of ions and destruction of photosynthetic tissue.



Rain of pH 4 is 100 times more acidic than rain of pH 6.

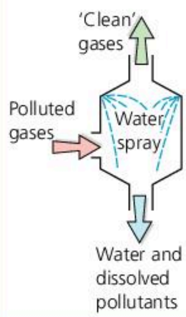
'Acid' lakes and fields can be improved by the addition of crushed limestone ($CaCO_3$) – this is very expensive and time consuming.

Solutions

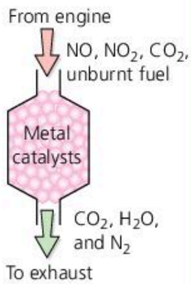
Acid rain can be reduced

- Clean up emissions from power stations with **scrubbers**.
- Clean up emissions from car exhausts with **catalytic converters**.

Scrubber



Catalytic converters clean up exhaust emissions by encouraging several pollutants to react together to give less harmful products:



▲ Acid rain damages both living organisms and buildings made by humans. Acid rain also causes pollution of water. Some lakes are almost empty of life as a result of pH levels as low as 4 or 5.

Radioactive pollution

The Earth's environment is naturally radioactive due to cosmic radiation emitted from space, and terrestrial radiation emitted from the Earth's crust. However, this background level of radiation is exceeded in many parts of the world by contamination from human-made sources of radioactivity.

'Radiation' here means ionising radiation (as opposed to other non-ionising radiation, e.g. UV, infra-red, microwave). Radiation is emitted from radioactive substances as they spontaneously decay and takes several forms. The types of most concern are:

- alpha particles (α)
- beta particles (β)
- gamma rays (γ).

Each type of radiation has different properties and different penetrating power; e.g. alpha particles can be stopped by a few centimetres of air or a sheet of paper, however they are intensely ionising in the matter they pass through and can cause more damage to living tissue than particles with a longer path. Like alpha particles, beta particles lose their energy within a short distance and their biological significance is greatest if a beta emitter is taken into the body. Gamma radiation particles are similar to X-rays – they are deeply penetrating and strongly ionising; gamma rays can only be stopped by thick layers of concrete, lead or steel.

The decay of radioactive wastes takes a very long time. Some radioactive substances have a half-life of more than 10000 years, which means they are dangerous for a very long time. (The half-life is the 'period of time required for the disintegration of half of the atoms in a sample of a radioactive substance'.)

There are two major ways in which the atmosphere can become polluted by radiation:

▲ Chernobyl disaster

Nuclear power plants

Nuclear power plant accidents can endanger life and the surrounding environment if the radioactive core is exposed and meltdown occurs and releases large amounts of radioactivity. This happened at Chernobyl, a nuclear power station in the Ukraine: an accident here destroyed the Chernobyl-4 reactor and killed 30 people, including 28 from radiation exposure. Large areas of Belarus, Ukraine, Russia and beyond were contaminated in varying degrees, and an increased number of birth defects was noted in the years following the disaster.

In 2011 a tsunami severely damaged the nuclear power station at Fukushima, Japan. There are fears that marine life will be contaminated, and a large area near the reactors has very restricted access.

Nuclear weapons

Nuclear weapon tests that are conducted above ground or under water can release radiation into the atmosphere. A nuclear test is the explosive test of a complete nuclear warhead – some tests in the twentieth century were conducted in areas occupied by soldiers. Most of the troops ordered to take part in the testing programme were not equipped with any specialised protective clothing. They were simply ordered to turn their backs or cover their eyes to avoid being blinded by the flash of the explosion. One former soldier remembers having his hands over his eyes but the flash was so bright that it acted like an X-ray and he could see all the bones in his hands.

Exposure to radioactivity frequently leads to various forms of cancer, including leukaemia. The troops involved have suffered much higher cancer rates than normal. However, because cancer may take years to develop, it is difficult to prove that a particular case is linked to a particular cause.

Non-biodegradable plastics

Plastics are widely used as packaging and transporting materials. They are useful because they can be shaped to form different products, they are light and they protect products (especially foods) from fungi and bacteria.

Many plastics are made from large hydrocarbon molecules and cannot be decomposed by normal microbial methods. Because they are so widespread and they are non-biodegradable, they can have severe environmental effects.


▲ Non-biodegradable plastics cause marine pollution

They can pollute both aquatic and terrestrial habitats.

- They can block the passage of water through drainage channels, leading to waterlogging of soils. This reduces oxygenation and so affects soil fertility.
- They can be mistakenly consumed by animals, on both land and in water. They block the animal's digestive system and cause many deaths.
- They do not allow the passage of oxygen, so when they are present in landfill sites they inhibit natural decomposition of other wastes.
- If they are burned in an attempt to remove them they release toxic 'smoky' particles, which can affect breathing and have a long-term effect on health.

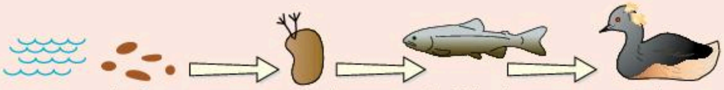
These plastics are very light, and so when discarded they easily blow from place to place. They make the environment less attractive (they lower the amenity value of the environment) and often become lined up against natural windbreaks such as hedgerows and stands of trees.

Pesticides

Causes

Over-use of pesticides on agricultural land (e.g. to protect a crop from insects) or directly on water (e.g. to kill an aquatic stage of an insect) can raise pesticide levels in water. The pesticide levels are then **amplified** as they pass through food chains. For example, one stickleback may consume 500 *Daphnia*. The living matter in the *Daphnia* will be used for raw materials or lost as heat but the pesticide remains **concentrated in the tissues** of the stickleback.

DDT concentration in parts per million:



Effects

High concentrations of pesticides may accumulate in the tissues of top carnivores. The pesticide may be toxic (and kill the carnivore) or may affect its metabolism. DDT, used to control mosquitoes in malarial zones, severely reduced breeding success in birds of prey.

Solutions

- Use degradable pesticides – DDT, for example, lasts for a long time and so its use is banned in many countries.
- Explore alternative methods, such as biological pest control.
- Crops that are **genetically modified** to resist attack by insects may reduce the need to use insecticides.

Q

1 Scientists in Japan recently discovered a bacterium which can digest plastic.
Explain
  a how this bacterium might have evolved
  b how scientists might be able to increase the amount of this organism so that it could be used to degrade plastics.

Female contraceptive hormones are washed into water when excreted in urine. They:

- reduce sperm count in men
- lead to feminisation of aquatic organisms (causing imbalance of gender in fish populations, for example).

20.5 Pollution of water: eutrophication

OBJECTIVES

- To recall why water is important to living organisms
- To understand that water supplies oxygen to living organisms
- To know how excess nutrients in water lead to depletion of oxygen levels
- To recall other aspects of water pollution

The causes of oxygen depletion

All living organisms depend on a supply of water, as we saw on page 256. Many organisms actually live in water. Most of these **aquatic** organisms respire aerobically and so require oxygen from their environment. Any change that alters the amount of oxygen in the water can seriously affect the suitability of the water as a habitat. The two pollutants that most often reduce oxygen in water are:

- **Fertilisers** – nitrates and phosphates are added to soil by farmers (see page 266). Some of the fertiliser is washed from the soil by rain into the nearest pond, lake or river. This process is called **leaching**.
- **Sewage** – this contains an excellent source of organic food for bacteria, and also contains phosphates from detergents (see page 58).

Sea water can also be polluted!
Marine environments are affected by human activities:
- spillages of oil which can seriously reduce oxygen levels on the seabed as well as reducing waterproofing properties of seabirds' feathers
- radioactive compounds from cooling of nuclear power stations
- temperature changes caused by global warming.

How fertilisers and sewage affect the oxygen concentration

Water that contains few nutrients is rich in oxygen and supports a wide variety of living organisms. The oxygen enters the water from the atmosphere by diffusion and from photosynthesising aquatic plants. Simpler forms of life, such as algae and bacteria, are controlled because the low concentration of nutrients such as nitrate is a limiting factor for their growth. If more nutrients are made available, from fertiliser runoff or from sewage, then:

- Algae and other surface plants grow very rapidly, and block out light to plants rooted on the bottom of the river or pond.
- The rooted plants die, and their bodies provide even more nutrients.
- The population of bacteria increases rapidly. As they multiply, the bacteria consume oxygen for aerobic respiration. There is now a **biological oxygen demand** (or **BOD**) in the water because of oxygen consumed by these microbes.
- Other living creatures cannot obtain enough oxygen. They must leave the area, if they can, or they will die. Their bodies provide even more food for bacteria, and the situation becomes even worse. This is an example of **positive feedback** – the change from ideal conditions causes an even greater change from ideal conditions.

The lower diagram opposite shows what happens if a pond or river receives too many nutrients. The process is called **eutrophication**. The pond or river soon becomes depleted of living organisms. Only a few animals, such as *Tubifex* (sewage worms), can respire at the very low oxygen concentrations that are available. The solution to this problem is straightforward – **do not allow excess nutrients into the water**.

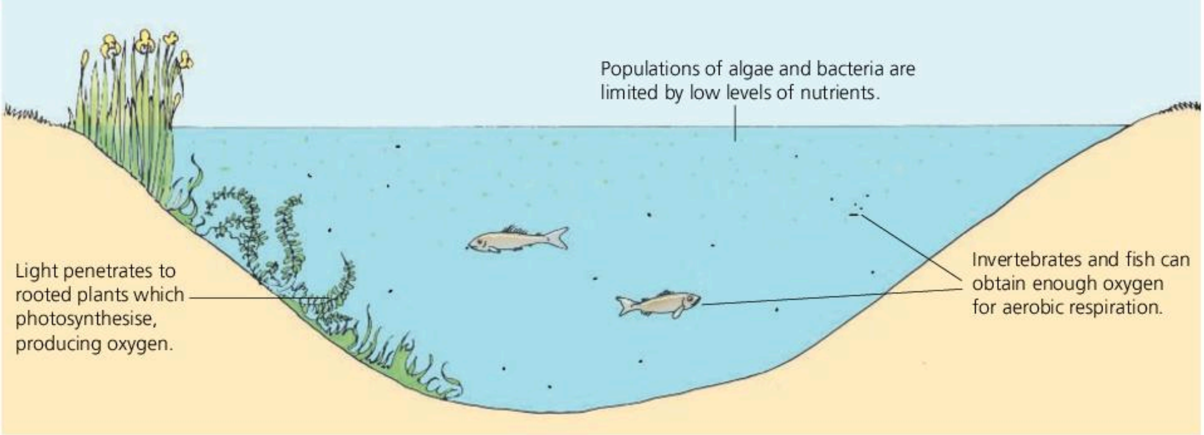
Q

1 Detergents often contain phospholipid, which can be broken down to release phosphate. Use this information to explain why we should not use too much detergent and soap when washing clothes, cooking vessels and ourselves!

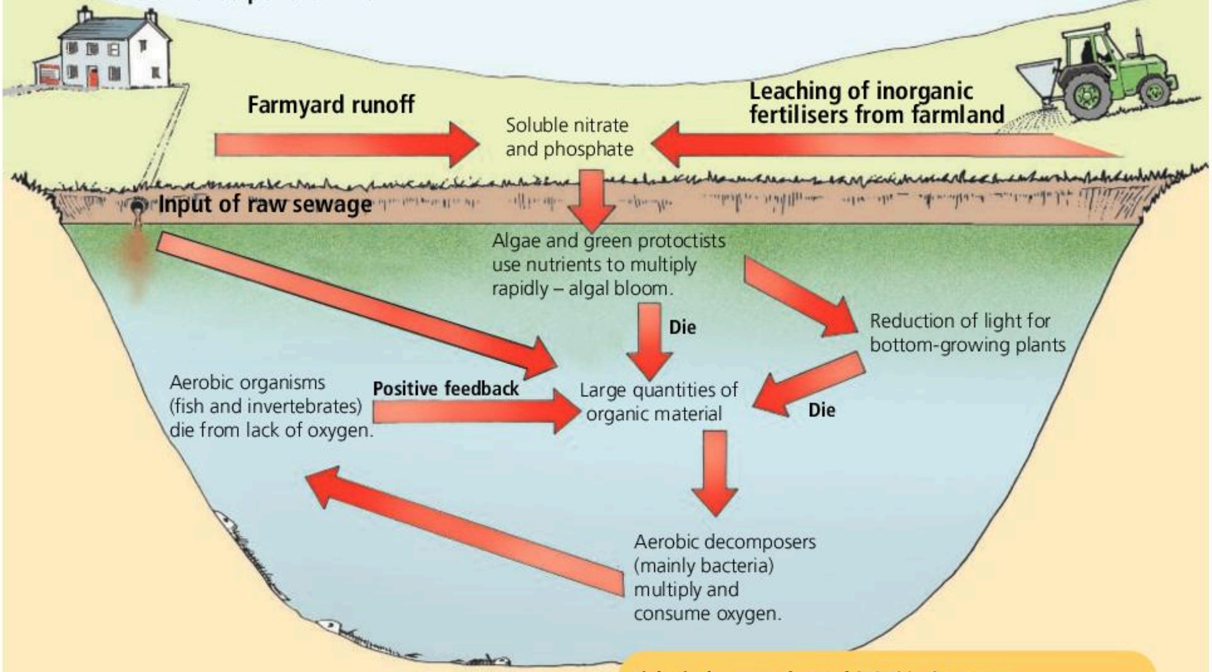
2 Explain the difference between negative and positive feedback.

S

A well-balanced natural pond or river



A nutrient-enriched pond or river



Many garden ponds become eutrophic because of leaves falling into them in autumn. To improve conditions for fish, ponds should be sited well away from overhanging trees.

Biological oxygen demand (BOD) is the mass of oxygen consumed by microorganisms in a sample of water. It is determined by measuring oxygen concentration with an oxygen electrode **before and after** a period of microbial respiration. It shows the oxygen that is **not available** to more advanced organisms.

Causes of eutrophication

Unnaturally high levels of nutrients:
- from leaching of fertilisers
- from input of raw sewage
- from liquid manure (slurry) washed out of farmyards.

Effects

Depleted oxygen levels in water cause death of fish and most invertebrates. High nitrate levels can be dangerous to human babies.

Solutions

- Treat sewage before it enters rivers (see page 282).
- Prevent farmyard drainage entering rivers and ponds.
- Control use of fertilisers:
  - apply only when crops are growing
  - never apply to bare fields
  - do not apply when rain is forecast
  - do not dispose of waste fertiliser into rivers and ponds.
- Bubble a stream of air through badly polluted ponds.

20.6 Humans can have a positive effect on the environment: conservation of species

OBJECTIVES

- To understand that humans may have a beneficial effect on the environment
- To realise that conservation often involves compromise
- To understand a conservation strategy
- To know some examples of successful conservation

Humans do not always damage the environment – growing numbers of **conservationists** try to balance the human demands on the environment with the need to maintain wildlife habitat. They will try to assess the likely effects of any human activity by producing an **Environmental Impact Statement**.

Forest management

Humans have been responsible for deforestation of much of the Earth's surface. Humans have also set up schemes for the large-scale planting of trees – in areas that have been cleared (**reforestation**) or in a new site (**afforestation**). There are a number of reasons for planting trees:

- as a cash crop, providing timber for building (coniferous plantations in the UK) or for fuel (fast-growing eucalyptus trees are widely planted in central Africa)
- to reverse soil erosion, particularly valuable in areas that have become deserts
- to provide valuable wildlife habitats – for example, Scots pine plantations are important habitats for red squirrels
- as recreational areas, providing leisure activities such as camping and mountain-biking.

A well-managed forest can combine all of these functions and maintain this valuable resource.

A **sustainable resource** is one which is produced as rapidly as it is removed from the environment, so that it does not run out.

We must aim for sustainable development.
This means that we should not alter our environment so much that we take things away and harm the environment for future generations. We should still provide for the needs of an increasing population.

Endangered species

Competition between humans and other living organisms means that many species have disappeared or declined in number. The reasons for this are not always understood, but the following may be to blame:

- **Pest control** – the term pest includes any species that causes inconvenience to humans. Many species have been hunted ruthlessly, such as red deer (which damage trees), and also predators such as cheetahs, and scavengers such as vultures.
- **Commercial exploitation** – species of value to humans have been exploited, such as the tiger which has been hunted and trapped for fur and medicinal compounds.
- **Loss of habitat** – more land is being used for agriculture, including previously unusable land that has been drained. This removes habitats for many species, such as wading birds and amphibians.
- **Climate change** – loss of ice from the Arctic reduces hunting sites for polar bears.
- **Pollution** – ponds and rivers may be polluted by fertilisers and sewage. Many oxygen-requiring species can be lost (see page 275).
- **Introduced species** – predators such as stoats and weasels introduced to offshore islands can eliminate ground-nesting birds.

Conservationists work to slow down or stop the decline in **biodiversity** (the number of different species), and also to raise public awareness of the need to maintain species and their habitats. The number of different species in a community of living organisms can be described by a formula called the **Species Diversity Index**.

Conservation programmes

Conservation involves management of an area, and may include a number of strategies:

- **Preservation** – keeping some part of the environment unchanged. This might be possible in Antarctica, but is less significant in a densely populated area like Britain than …
- **Reclamation** – the restoration of damaged habitats such as replacing hedgerows or recovering former industrial sites, and …
- **Creation** – producing new habitats, for example by digging a garden pond, or planting a forest.

A **conservation plan** involves several stages:

- **sampling** to assess the number of organisms
- **devising a management plan** – for example, trying to increase a species' population based on knowledge of its breeding requirements
- **carrying out the plan**
- **re-sampling** to assess the number of the 'conserved' species once more, and find out whether the conservation plan has worked.

As populations decrease in size, genetic variation (see page 228) is reduced and a species may become more vulnerable to environmental change.

Conservation programmes are needed:

- to reduce the risk of extinction
- to protect vulnerable environments
- to provide valuable resources, such as food, drugs, fuel and genes.

Captive breeding and the role of zoos

Many animal species are threatened by habitat degradation, fragmentation and destruction. The International Union for Conservation of Nature (IUCN) estimates that only 3% of the planet is designated as a protected reserve and that, on average, one mammal, bird or reptile species has been lost each year for the last hundred years. Certain groups of species are particularly at risk – those with a restricted distribution, those of high economic value, those at the top of food chains and those which breed very slowly.

Zoos are areas of confinement keeping samples of species alive under varying degrees of captivity. The role of zoos in captive breeding is becoming more and more important. For example, the Arabian oryx had been hunted to extinction in the wild but zoos in London, San Diego and Phoenix have provided animals to release in Oman and Jordan.

Education can help.

- Local people can be taught about the tourist value of conserving species.
- Students can be taught about keeping complex food webs and about the management of habitats.

Plants need help too: the value of seed banks.

- Seeds can survive for long periods in a dormant state (see page 184).
- Seeds of threatened plant species can be collected and stored – usually in cool, dry conditions.
- Conditions can be manipulated to stimulate germination of seeds when more plants are required.

Sustainable development is a compromise.

- Requirements for wildlife must be balanced by human demands for **resources** (e.g. mining for uranium), **recreation** (e.g. diving around coral reefs) and **agricultural land**.
- Different organisations – local, national and international – must cooperate (see page 280).

1 Many plants contain chemical compounds not normally found in animals.
Explain why it is important that scientists try to conserve individual plant species before development of roads, housing and agriculture might eliminate them. Include an example in your explanation.

20.7 Managing fish stocks: science and the fishing industry

OBJECTIVES

- To understand the value of fish as a food source
- To know how fishing methods increase yield
- To understand how overfishing has reduced fish stocks
- To appreciate that the management of fish stocks depends on scientific research

Fish as a source of food

Fish have been a valuable food source for humans for thousands of years. Fish are an excellent source of protein and, depending on species, of oils. Scientists are becoming more aware of the value of fish oils in preventing some of the 'diseases of affluence', such as coronary heart disease (see page 106). It is very important that humans include certain oily compounds (especially unsaturated fatty acids) in their diet, and these oily compounds are extremely abundant in some fish species.

Steps taken to conserve fish stocks

Education

Through knowledge of the growth pattern of individual fish, it is possible to study small groups of fish to work out how long they take to reach breeding age, what their maximum size will be and which diseases they might be susceptible to. This allows scientists to advise on net mesh sizes which should be used to catch adult fish, and to suggest fishing methods which will limit the catch of 'trash' fish (fish which are not used for human food). Fishing methods and mesh sizes used in herring fishing are shown opposite.

Q

1 *Tilapia* is a fish which can be 'grown' in fish farms. Suggest
   a why this is more financially sensible in tropical countries
   b three benefits of having *Tilapia* in the diet

Setting of quotas

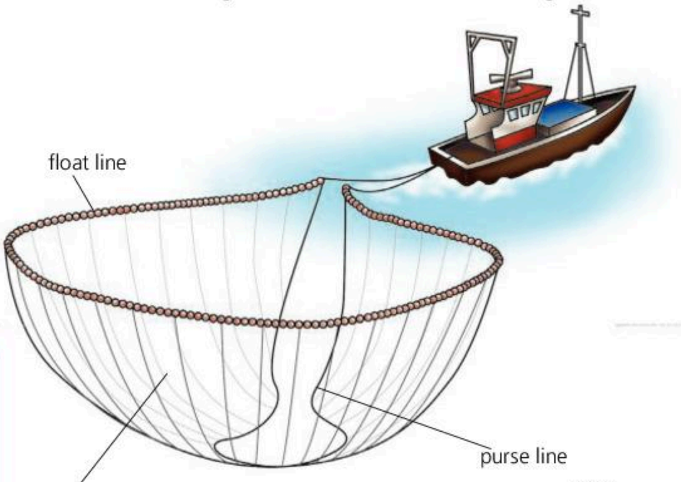
Governments set quotas in an attempt to limit the size of catches. Unfortunately, scientists now believe that initial quotas for some species were too high, and even the reduced quotas now in force have not allowed fish populations to recover. The fishermen are tempted to catch more than their quota but to throw back the smaller, less marketable fish. These fish are often damaged by capture and do not survive to reproduce.

As with many situations, there are no clear-cut answers. Fishermen understand that fish stocks must be allowed to recover but are naturally anxious about making a living. The scientists can only advise, the governments must act on this advice!

Restocking

Fish can be bred in very large numbers in enclosures, either in the sea or in lakes. These fish can be grown to a size at which they can be successfully released to replenish wild populations.

Seine ('purse-seine') netting – the net is towed to the school of herring by two boats. The fish are surrounded by the net and the bottom of the 'purse' is sealed by pulling on the rope. The net is slowly tightened so that the fish are concentrated in a small volume of water - the immature fish have time to escape. The captured fish are lifted from the water using hand nets - this limits the damage to the fish and so reduces wastage.

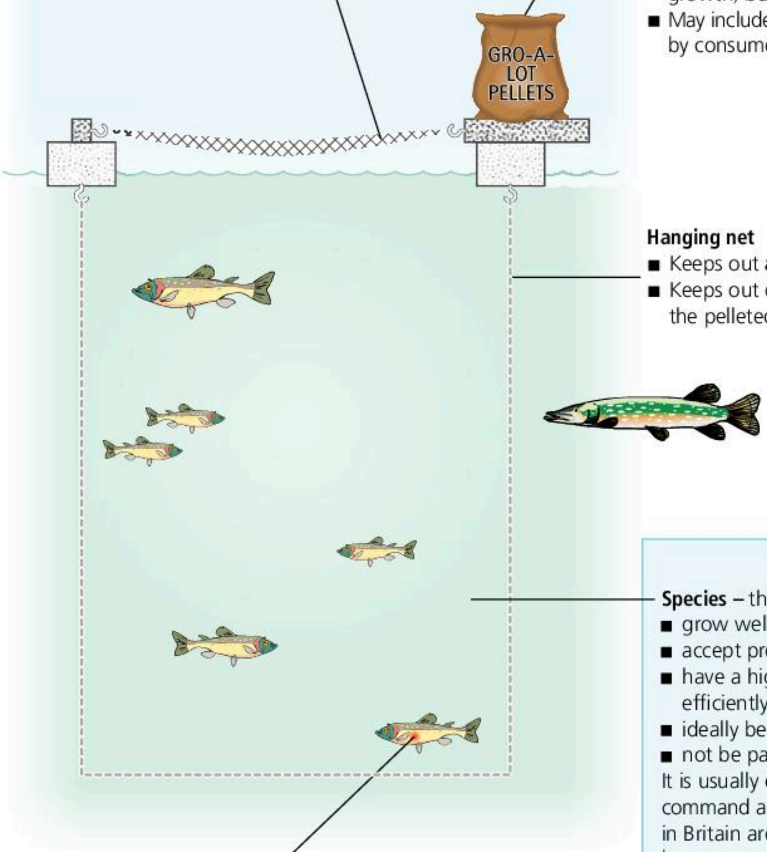


Mesh – square mesh does not close up to trap small fish whereas older diamond mesh did.

120 mm mesh size catches mature herring but allows small cod and haddock to escape.

▲ Mesh and methods used in herring fishing

Fish farming can provide food or may be used for restocking the wild.



Suspended net keeps out aerial predators such as cormorant, heron and osprey.

Prepared food fed to the fish
- Pellets are easily transported and easily measured out.
- Usually made from fish caught in nets but not used for human consumption – **very high in protein** (gives rapid growth) but very expensive.
- May include **colouring agent** (turns fish pink – favoured by consumers) and **antibiotic** (disease control).

Hanging net
- Keeps out **aquatic predators** such as otter and pike.
- Keeps out other fish and so **reduces competition** for the pelleted food.

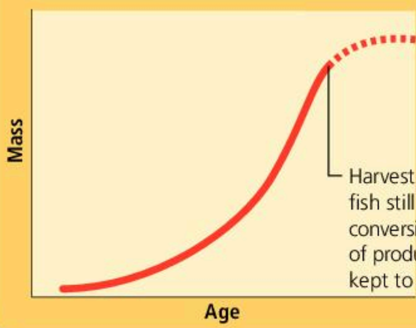
Species – the 'farmed' species must:
- grow well under captive conditions
- accept prepared (non-living) food
- have a high **conversion ratio**, i.e. convert food ⟶ flesh efficiently
- ideally be able to breed under captive conditions
- not be particularly susceptible to disease.

It is usually **expensive** to farm fish so the product should command a **high price**. For this reason, the main farmed species in Britain are members of the salmon family, with tilapia or sea bream more common in tropical countries.

Disease control – close confinement makes diseases more likely to spread. Pesticides are added to water to control fish lice and fungal infections, and antibiotics are added to food.

Fry production
- Fish are often spawned in aquaria using added reproductive hormones.
- Temperature is controlled while fry are 'grown on' (higher temperature gives rapid growth). Oxygen levels are kept high with aerators. Growth hormones may be added to water.
- Fry of **uniform size** are released into the farming pens, before 'growing on' for release into the wild. This reduces the chance of the fish eating each other!

Age for harvesting



Problems
- Very high food costs.
- Poor control of temperature and oxygen availability in large outdoor farming pens.
- Much more research necessary to obtain highest yields – **selective breeding** programmes to develop new fish varieties with improved growth rates and conversion ratios.

Environmental concerns
- Pollution by pesticides which may kill organisms that are foods for wild species.
- Excess food and fish faeces create nutrient-rich environment below netted area ⟶ growth of bacterial population ⟶ increased **biological oxygen demand.**

20.8 Conservation efforts worldwide

Although the demands on land – for agriculture, mining and building – are increasing in almost every country around the world, many scientists are trying to maintain biodiversity by managing the populations of endangered species. This management is always a compromise, because humans usually place their own requirements above those of wildlife. As a result, the conservation managers must be prepared to plan to balance the needs of local people with the scientists' long-term plans to conserve individual species.

CITES	Convention for Trade in Endangered Species: controls the transfer of wildlife and wildlife products between member countries.
IUCN	International Union for the Conservation of Nature.
Red Data Book	Lists all species at risk: includes categories such as 'vulnerable', 'endangered' and 'critically endangered'. Updated twice each year.
WWF	Worldwide Fund for Nature: organisation which attracts public funding for conservation projects.
rare	A species limited to a few areas but in no immediate danger.
vulnerable	A species which is likely to become endangered if the causes of its decline continue.
endangered	A species which is unlikely to survive if the causes of its decline continue.
extinct	A species for which there have been no confirmed sightings for 50 years.

▲ Egrets have suffered for many years as they were shot for their feathers. Conservation measures mean that the cattle egret is beginning to breed successfully, even in the UK.

Some examples of species conservation are outlined on the map on the opposite page. In each case, note that there is a reason why the species is endangered. There is also a suggested management plan to try to maintain a breeding population of the species under threat. Also see the importance of scientific research into the biology of species, particularly into the breeding requirements of endangered species.

SUSTAINABLE DEVELOPMENT REQUIRES MANAGEMENT OF CONFLICTING DEMANDS

HUMANS **and** **WILDLIFE**

HUMANS:
- Require sufficient land area to grow crops.
- Livestock must be protected from predators.

WILDLIFE:
- Reduce risk of extinction by over-hunting.
- Maintain population size high enough to maintain genetic variation.
- Protect suitable habitat, which must provide food, shelter and breeding sites.

PLANNING AND COOPERATION AT DIFFERENT LEVELS

local: farmers, for example
national: government regulations
international: conservation bodies such as WWF

Poison dart frogs in Central America

a Loss of habitat, due to deforestation and drainage of wetlands.
b A series of viral and fungal diseases.

Setting up protected areas, with buffer zones to prevent the spread of contagious diseases. Education programmes which emphasise that amphibians are often a good indicator of the 'health' of our planet. Research into disease, and into the breeding success of these animals.

Tigers in Sumatra, Siberia and India

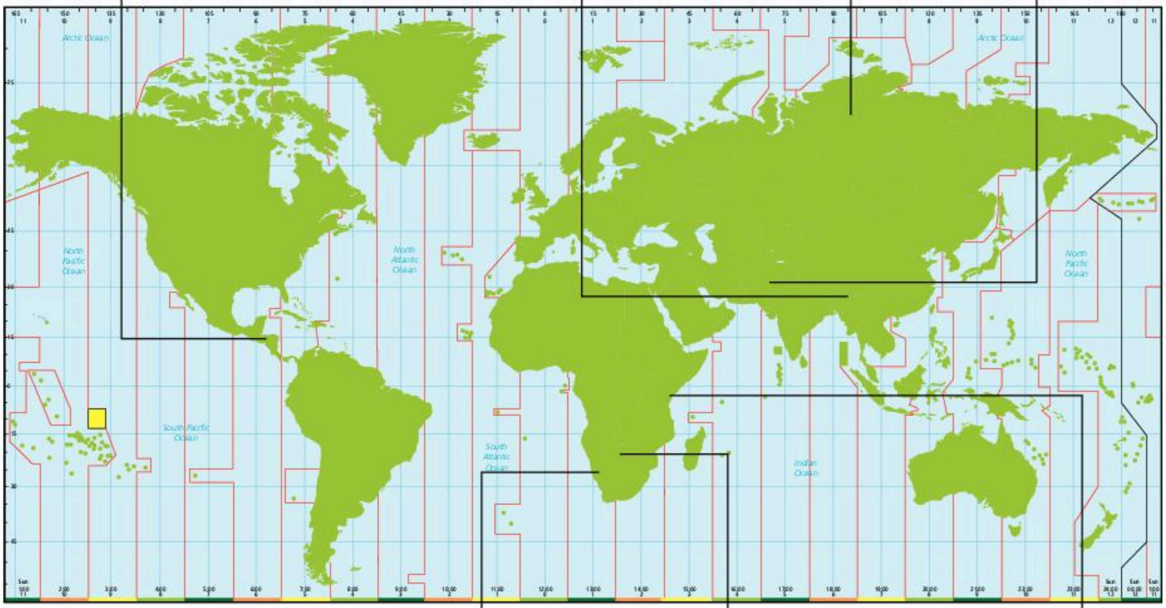
a Hunting for fur, bones, teeth and blood which are used in Chinese traditional medicines.
b Competition for land with villagers, who cannot afford to lose livestock to predation by the tigers. In some areas, tigers can pose a direct threat to humans as they are such powerful predators.

Setting up protected areas such as fenced sanctuaries, conservation areas and intensive protection zones, especially in National Parks. Trade in tiger products is banned by CITES. Tiger populations in the wild have fallen so dramatically that captive breeding (see page 277) is now responsible for keeping up numbers of most subspecies.

Snow leopard in Pakistan and Nepal

a Hunting for fur, bones, teeth and blood which are used in some traditional medicines.
b Conflict with villagers, who cannot afford to lose livestock to predation by the leopards.

Snow leopard populations are carefully monitored by cameras set on established trails. Some animal movements can also be tracked using radio collars. Government bodies provide financial compensation to villagers, and set up education programmes which show local people the possible benefits of eco-tourism.



THINK LOCAL!
Answer questions on conservation programmes with examples from where **you** live.
Remember:
- say **why** the species is endangered
- explain **how** the species may be conserved.

▲ Worldwide conservation programmes

Cheetahs in Namibia

a Loss of habitat causes competition with local people, who believe that cheetahs kill domestic livestock.
b Hunting for fur.
c The cheetahs' own breeding habits, and low genetic variability.

Trusts have been set up to look after and rehabilitate cheetahs trapped on farmland. CITES has banned trade in fur of spotted cats. Breeding studies have learned more about the unusual breeding requirements of cheetah (several males must 'court' a female for her to become receptive) so captive breeding has become more reliable.

Elephants in Botswana

a Poaching of adults for ivory: apart from death of individuals this upsets family relationships so that younger elephants do not learn survival skills and whole populations are put at risk.
b Animals may be shot if they trample crops or damage fences in villages.

Game wardens can be paid for by the tourist industry. Some people argue that controlled 'trophy' hunting can provide funds to warden the populations more effectively. Trade in ivory is banned by CITES, or very closely controlled by government organisations.

Rhinoceros in Africa

a Loss of habitat as agricultural development increases.
b Hunting for horn, which is mistakenly believed to have medicinal properties.

Setting up protected areas such as fenced sanctuaries and intensive protection zones especially in National Parks. Surplus animals have been translocated to set up new populations within and outside the species' former range. Controlled sport hunting of surplus males, for example, attracts investment in rhino conservation. Trade in rhino products is banned by CITES.

20.9 Conservation of resources: recycling water by the treatment of sewage

OBJECTIVES

- To recall that pathogens cause disease only when they gain access to body tissues
- To recognise that food and water are possible means of entry to body tissues
- To understand the processes involved in the provision of a safe water supply

Limiting the spread of diseases

Pathogenic microbes can only cause disease if they are able to enter the body and invade the tissues. The body has defences against disease, but there are a number of weaknesses (see page 110). For example, food and water may contain pathogenic microbes. *Salmonella* and *Escherichia coli* (*E. coli*), which cause food poisoning, enter the body in this way, and so do *Cholera vibrio* and *Amoeba* which are waterborne organisms causing cholera and dysentery, respectively. We try to protect ourselves from these diseases by making sure our drinking water, milk and foods are pathogen-free.

Safe water: sanitation and water treatment

Living organisms need water for a number of reasons (see page 256). Water can be lost very rapidly from the human body and we need access to a supply of drinking water. Water supplies are kept **potable** (pathogen-free and drinkable) by both **sanitation** and by **sewage treatment**.

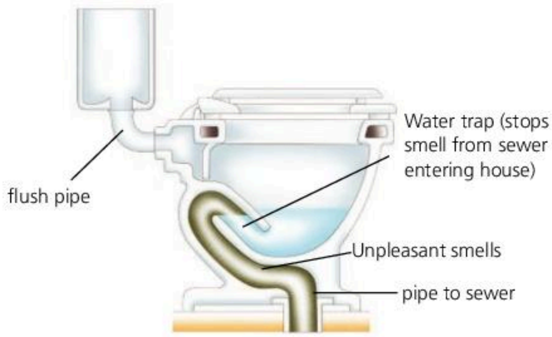
Sanitation is the removal of faeces from waste water so that any pathogens they contain cannot infect drinking water.

Pit latrine

In camps and in isolated houses sewage can be disposed of in a hole. The hole is dug deep enough to accept a large quantity of sewage (ideally several metres deep), and then filled in with soil to keep away flies and rats. This type of disposal system – called a 'long drop' or **pit latrine** – is cheap to produce and does not depend on running water, but has several disadvantages:

- The smell can be extremely unpleasant, especially in tropical areas.
- The sewage can overflow, especially during rainy periods. This allows faeces, perhaps contaminated with human pathogens, to reach water supplies and agricultural land. The sewage (and pathogens) can be washed down through the soil and contaminate nearby water supplies.

Where a good water supply is available, a flush WC is connected to the water carriage system and a flow of water carries the waste away.



▲ **Diagram of a lavatory pan or water closet (W.C.)**
Water is flushed around the rim, down the sides, and through the U-bend. Water retained in the U-bend seals off smells from the sewer.

The waste is then treated at a **sewage treatment plant** so that the valuable water can be recycled.

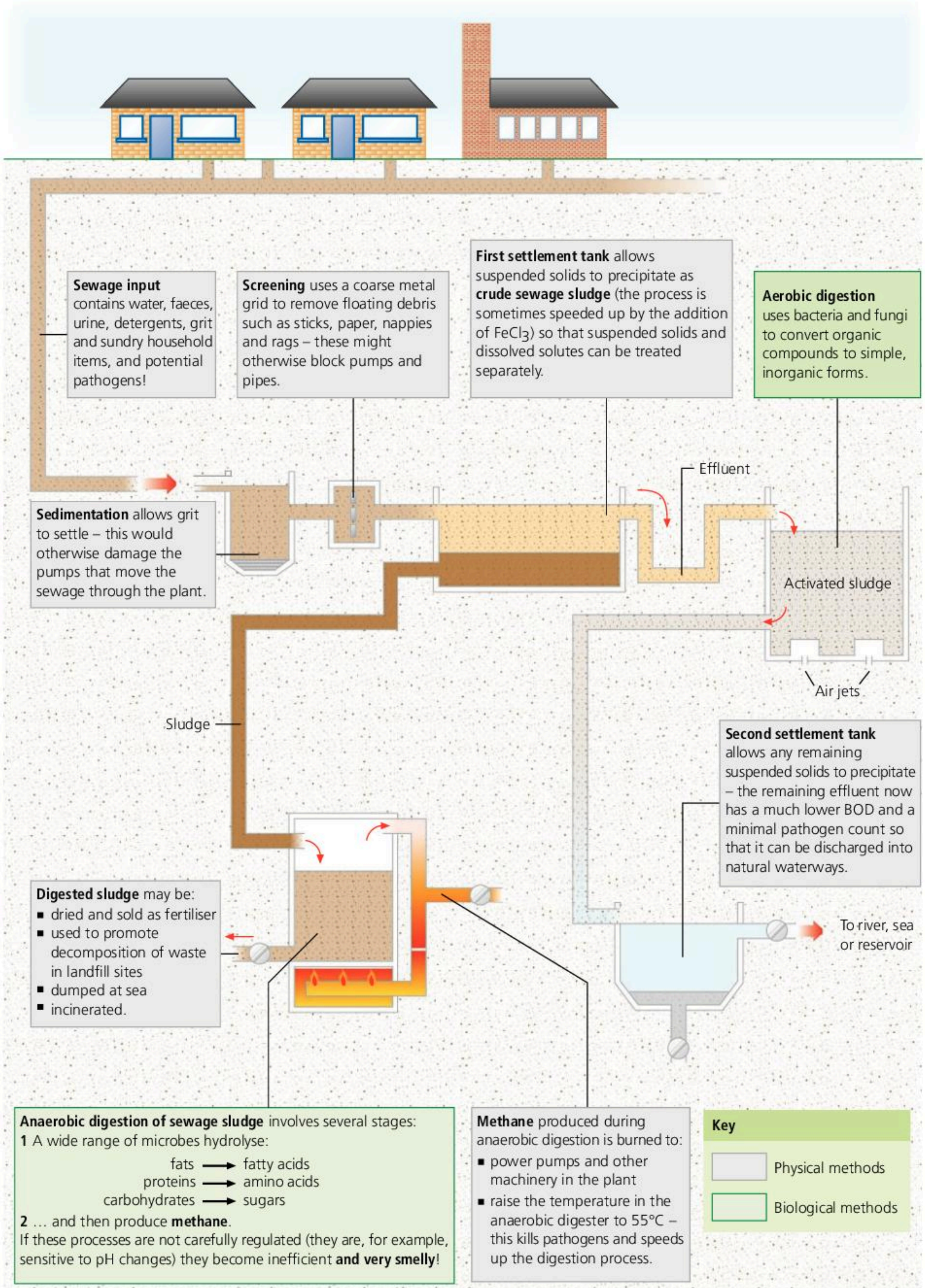
The page opposite shows one type of sewage treatment plant called the **activated sludge** system.

The treatment of the sewage has two functions:

- to destroy or eliminate potential pathogens – either by the high temperature in the anaerobic digestion tank, or by chlorination of the water before it is discharged
- to remove organic compounds (mainly in faeces and urine). These might otherwise contribute to the **biological oxygen demand** (**BOD** – see page 274) of the water into which the treated sewage is discharged. Organic compounds are digested by fungi and bacteria.

In the activated sludge chamber, powerful jets of air keep the sludge aerated so that the processes of decomposition and nitrification (see page 254) can be completed in 8–12 hours. This means that large quantities of sewage can be processed very quickly.

Sewage treatment provides clean water by a combination of physical and biological methods



20.10 Saving fossil fuels: fuel from fermentation

OBJECTIVES

- To recall that microbes carry out fermentation reactions
- To appreciate that fermentation products may be used as fuel rather than as food
- To list examples of fuels generated by microbial fermentation reactions

Fermentations make products which can be used as **fuel**. **Biomass fuels** use raw materials produced by photosynthesis. These materials are from plants and can therefore be regenerated. Biomass fuels include:

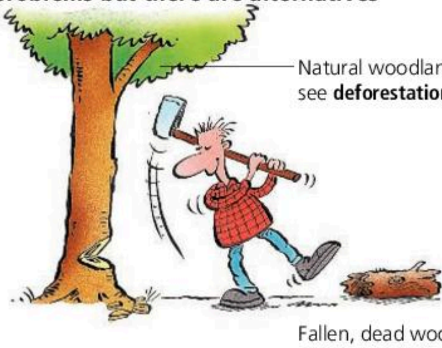
- **solid fuels** – wood, charcoal and vegetable waste
- **liquid fuels** – alcohol and vegetable oil
- **gaseous fuel** – biogas (a methane/carbon dioxide mixture).

The production of these biomass fuels is described in the diagrams on the right: this can help to reduce our use of fossil fuels, which are **non-renewable**.

Q

1 What is a biomass fuel? What advantages might the use of biomass fuels offer?
2 What are the environmental benefits of fast-growing tree species?
3 Look at the diagram opposite.
   a Suggest three products which could be sold, apart from the alcohol produced.
   b Both amylase and cellulase are involved in the preparation of the glucose feedstock for a gasohol generator. Suggest the exact function of these enzymes.
   c How has genetic engineering helped the gasohol industry?
   d A typical American car travels 10 000 miles a year at 15 m.p.g. This consumes the alcohol generated by the fermentation of 5000 kg of grain. A human on a subsistence diet consumes about 200 kg of grain per year. Comment on these figures.
4 Give two benefits that biogas generators offer to rural communities in poor countries.
5 Why are biogas generators built underground?
6 Why would it be inefficient to add disinfected household waste to the biogas generator?

Solid fuel using natural woodland causes environmental problems but there are alternatives



Natural woodland – live cutting: see **deforestation** (page 270).

Fallen, dead wood: lesser environmental problem, but still loss of habitat and nutrients.

Fast-growing tree species may provide renewable fuel

e.g. eucalyptus in the Democratic Republic of the Congo …

Erect, regular growth habit means easy cutting and storing.
Rapid growth – 8 m in 3 years.
High resin/oil content means it is clean-burning, giving out much heat.

… and **sweet chestnut** from coppices in Kent may fuel local power stations.

Sustainable forests

Using wood as fuel contributes to deforestation (see page 270), but:

- **selective felling** (only a small proportion of trees are cut down) is better than **clear felling** – less erosion and more wildlife habitats
- **replanting** can replace clear-felled trees, but tends to be a monoculture (see page 284) and is a poor wildlife habitat
- **education** can explain the benefits of forests, particularly in terms of tourism. Local people can be introduced to alternative fuels (see biogas opposite).

S

Liquid fuel - ethanol

The raw material is called feedstock

USA uses Corn

- **Soak** (then use the liquid as **cattle feed**) → **Seed**
- **Grind** – separates germ, producing **corn oil** → **Starch**
- **Enzymatic hydrolysis** uses amylase →

Brazil uses Sugar cane

- Wash and crush → **Cane pulp**
- **Enzymes** amylases and cellulases; **Separation** – waste is **bagasse**. This is burned, giving energy for distillation → **Syrup**
- **Purification** – impure sucrose solution (molasses) → **cattle feed**

NB

- Raw material is cheap and readily available.
- Enzymes are involved at several stages.
- Waste products may be sold.
- Less reliance on expensive petrochemicals, a diminishing resource.

$$\underset{\text{(glucose)}}{C_6H_{12}O_6} \xrightarrow{\text{fermentation}} \underset{\text{(alcohol)}}{2C_2H_5OH} + 2CO_2$$

Fermentation agent

the yeast *Saccharomyces*.

Useful mutants/engineered strains can:

- cope with high temperatures generated during fermentation
- survive at higher alcohol concentrations (up to 15%, compared with 8–9% for 'normal' strains)
- respire anaerobically even when O_2 is present.

Fuel value of gasohol

- start engine on high petrol/alcohol mixture
- once warm, engine runs well on alcohol alone.

Environmental impact

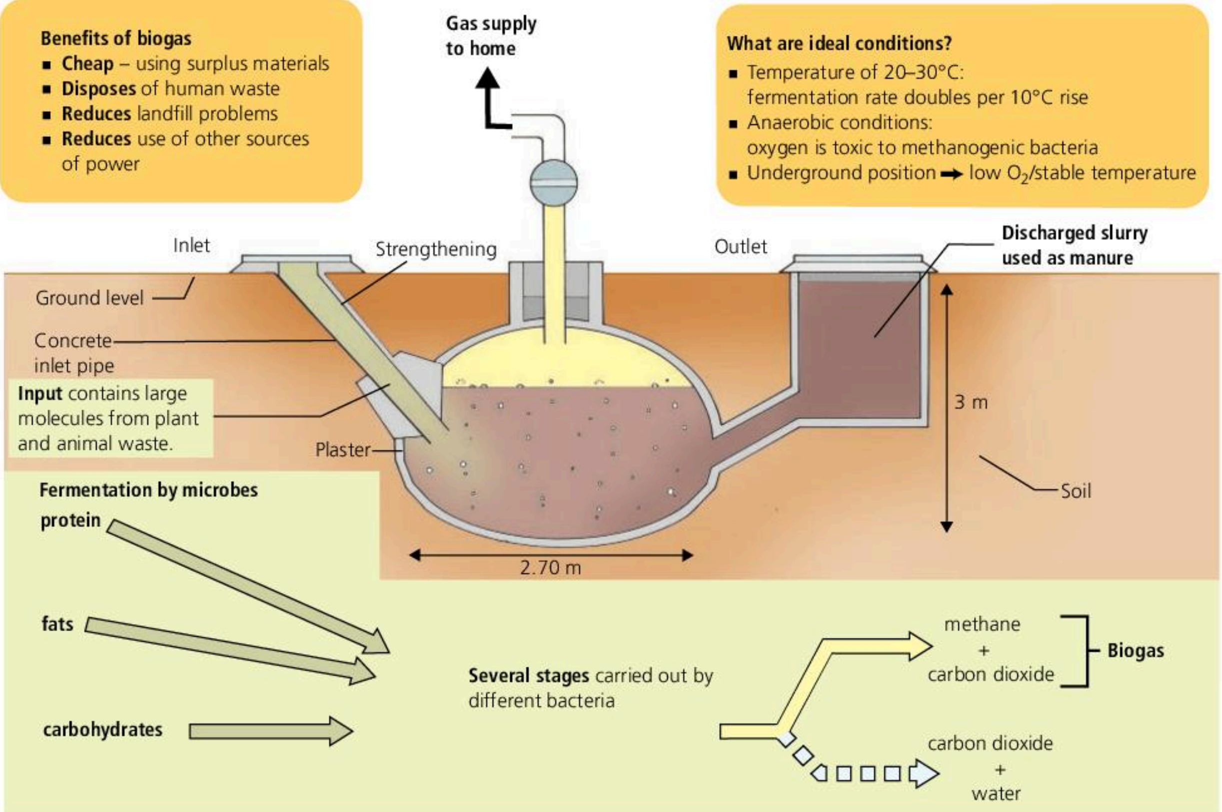
- alcohol fuels do not require 'anti-knock' additives
- alcohol fuels produce fewer emissions such as CO, SO_2 and NO
- process does not increase CO_2 in atmosphere (photosynthesis of feedstock removes the CO_2 which is generated by combustion).

Benefits of biogas

- **Cheap** – using surplus materials
- **Disposes** of human waste
- **Reduces** landfill problems
- **Reduces** use of other sources of power

What are ideal conditions?

- Temperature of 20–30°C: fermentation rate doubles per 10°C rise
- Anaerobic conditions: oxygen is toxic to methanogenic bacteria
- Underground position → low O_2/stable temperature



20.11 Recycling: management of solid waste

OBJECTIVES

- To recall that humans produce many waste materials
- To understand that human wastes may become food for disease vectors
- To appreciate that there are different ways of disposal of human refuse
- To understand the benefits of recycling

Human refuse contains such items as metals, plastic bags, glass, remains of food and ash. This refuse must not be allowed to accumulate because:

- It is inconvenient, and gets in the way of people, their vehicles and their animals.
- It is unpleasant to look at.
- It could act as a breeding ground for organisms which transmit disease.

To prevent refuse (rubbish) from building up it can be delivered to refuse tips, landfill sites or incinerators. The refuse disposal sites are normally sited away from residential areas, and surrounded by fences to stop rubbish blowing away and prevent children from playing in them. Two alternative ways of disposing of the refuse – **incineration** and **landfill** – are described on page 114. Each of these methods has the advantage that it can provide energy, and so reduce our use of fossil fuels.

Recycling

Recycling involves reusing waste products or materials which would otherwise be thrown away. This includes reusing items in their original form and sending materials away to special centres where they can be melted down or pulped to act as raw materials in industry.

Items that can be reused include:

- glass milk or soft drink bottles
- plastic shopping bags
- paper that has only been written on one side
- clothes

… and materials that can be pulped or melted down include:

- glass bottles
- aluminium cans
- plastic bottles
- paper and card
- scrap metal.

Plastic bottles can be melted and reused in clothing, for example!

S Non-biodegradable plastics cannot be broken down by natural biological processes. They may accumulate and are a danger to fish, birds and mammals (see page 273). If they can be collected they may be recycled.

Recycling can make scarce resources last for longer, and can reduce the energy requirements of industry. It takes only 5% of the energy to make an aluminium can from recycled aluminium than from aluminium ore. People and companies will only recycle, however, if:

- their products are cheaper than if they don't use recycling
- governments give subsidies for manufacturing products from recycled materials.

Recycling of paper

Paper is one of the easiest materials to recycle. It is collected from our kerbside or recycling banks by local authorities and waste management companies.

After the paper is collected there are several steps in the recycling process.

- First it is sorted, graded and delivered to a paper mill. As it is sorted, contaminants such as plastic, metal, and other rubbish that may have been collected with the paper are removed.
- Once at the paper mill, it is added to water and then turned into pulp.
- The paper is then screened, cleaned and de-inked through a number of processes until it is suitable for papermaking. Cleaning and de-inking may use hazardous chemicals: hydrogen peroxide is often used to help bleach the paper when dark inks are present.
- Once the pulp has been rinsed, it is spread onto large flat racks, and rollers press the water out of the pulp. As it dries, new paper forms.
- It is then ready to be made into new paper products such as newsprint, cardboard, packaging, tissue and office items.

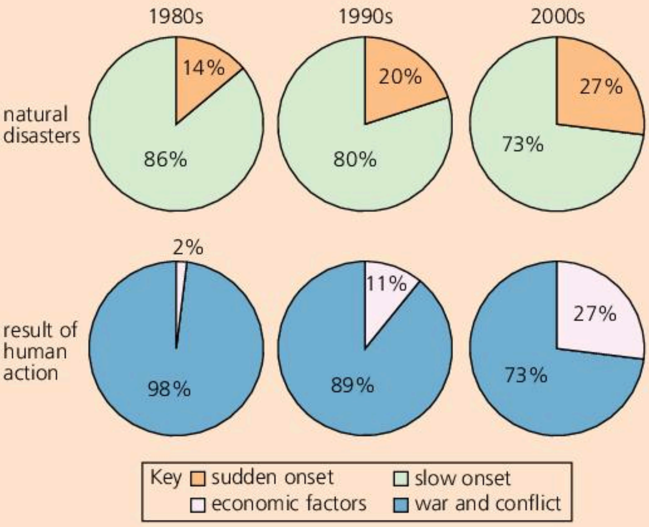
It can take just seven days for a newspaper to go through the recycling process and be transformed into recycled newsprint which is used to make the majority of national daily newspapers.

Both paper and plastic can be recycled.

1 Suggest why it is important to recycle
   a paper
   b plastic.
2 Suggest how bacteria and fungi might be important in the recycling of these materials.

Questions on human impacts on ecosystems

1 This figure shows the causes of severe food shortages in the 1980s, 1990s and 2000s.



a i State **two** types of natural disaster that occur suddenly and may lead to severe food shortages. [2]

ii State **one** type of natural disaster that may take several years to develop. [1]

b Explain how the increase in the human population may contribute to severe food shortages. [2]

The quality and quantity of food available worldwide has been improved by artificial selection (selective breeding) and genetic engineering.

c Use a **named** example to outline how artificial selection is used to improve the quantity or quality of food. [2]

d Define the term *genetic engineering*. [1]

2 The peppered moth (*Biston betularia*) lives in woodlands. It rests on the lichen-covered bark of trees during the daytime. The moth is usually lightly covered in speckles, so that it appears grey (the 'light' form). A few are so heavily speckled that they appear black (the 'dark' form).

Several small species of birds feed on the moths during the daytime.

A group of scientists released some moths into two different areas. After 72 hours, the moths were recaptured and counted.

The results of this investigation are shown in the table below.

	Industrial area		Agricultural area	
	Light form	Dark form	Light form	Dark form
Number released	250	450	500	480
Number recaptured	34	125	108	25
Percentage recaptured	13.6		21.6	

a Calculate the percentage of recaptured 'dark' moths in the two different areas. [2]

b Explain the results for the survival of the two forms of the moth. [4]

c A government decision has been taken to reduce the release of smoke from industrial sites. Suggest and explain the possible effect on the population of peppered moths in these industrial areas. [2]

d State the genus of the peppered moth. [1]

3 Read the following paragraph carefully and then answer questions (a) to (d).

Between 1947 and 1963 hedges in the United Kingdom were being removed at an average rate of over 5000 km per year. This increased to more than 8000 km per year by 1968.

A report by a government conservation body claimed that between 1980 and 1985, 8000 km of hedgerow were removed and 4000 km were planted in England and Wales.

Older hedges usually provide a richer range of habitats, with greater diversity of plants and animals.

Both during and after the Second World War, farmers were encouraged to grow more food, with greater efficiency and at lower cost.
On one farm with small fields, removing 2 km of hedgerow provided another 1.5 hectares of arable land and reduced by 35% the amount of time needed to harvest a field of wheat.
Towards the end of the 20th century, the European Union was paying large subsidies to farmers to store excess agricultural produce.
Farmers are now encouraged by the European Union to grow less food.

a State the highest average removal of hedges in the UK before 1969. [1]

b If that rate of removal continued, suggest
- **i** the likely effect on the variety of wild animals and plants in the countryside [1]
- **ii** the effect on the amount of arable land available for farming. [1]

c Suggest why it is less important to gain additional arable land now than during and immediately after the Second World War. [1]

d More efficient farming often involves **monoculture**.
Suggest **two** advantages and **two** disadvantages of monoculture. [4]

Read the following and then answer questions (e) and (f).

- **A** *Hedges provide an important habitat for animals which can help with pollination and biological control.*
- **B** *Hedges shade part of the crop which can reduce yields.*
- **C** *Hedges can provide a home for insect pests and rabbits.*
- **D** *Hedges are an attractive feature in the countryside.*
- **E** *Hedges make it more difficult to use modern farm machinery.*
- **F** *Hedges can compete with crop plants for minerals and water.*
- **G** *Many farmworkers are needed to maintain hedges properly.*
- **H** *Hedges provide a windbreak and shelter and shade for farm animals.*
- **I** *Hedges help to prevent topsoil blowing away.*
- **J** *Hedges provide cover for gamebirds such as pheasants and partridges.*

e Choose **five** statements from this list to support a case for retaining hedges. [5]

f Suggest **two** important minerals required by crop plants. State why each of them is important. [4]

4 A scientist noticed that some plants were never bothered by insects. He was interested in whether the plants contained their own natural insecticide. He ground up the plants so that he could collect the natural insecticide which he thought was soluble in water.

a Describe a technique the scientist might use to separate the dissolved insecticide from the crushed-up remains of the plant. [2]
He thought that the juice would be able to kill insects and decided to try to find out whether spraying a greater volume of pesticide juice would kill larger numbers of insects.

b Suggest what his **hypothesis** would be, and what **prediction** he might make. [2]

To carry out this investigation, the scientist and his team of workers made up a number of different concentrations of the natural pesticide and then sprayed the insecticide solutions onto a series of plants. Each plant was of the same species and each plant had 100 aphids (small insects which feed on the phloem contents) feeding on it. The team kept all of the plants in the same room and later counted how many aphids were alive after 24 hours.

c Name the independent variable in this investigation. [1]

d Name the dependent variable. [1]

e Explain why the team of scientists believed that the results were valid. [2]

The table below shows the results obtained.

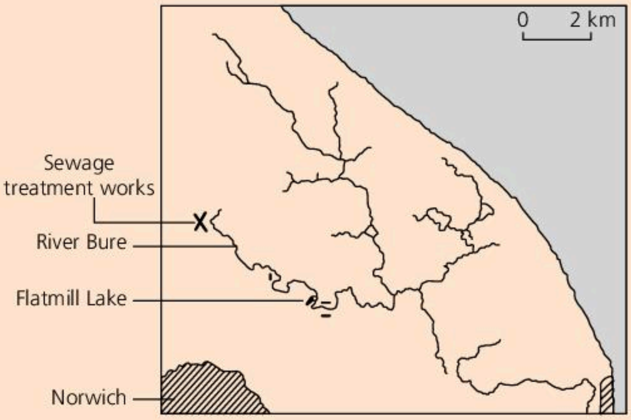
Concentration of insecticide / g per 1000 dm^3	0	5	10	15	20	25	30	40	50	100
Number of aphids alive after 24 h	99	97	96	95	55	40	25	20	21	20

f Draw a line graph of these results. [4]

g State the concentration of insecticide needed to kill 50% of the aphids. [2]

h Explain whether the results support the original prediction made by the scientist. [2]

5 Flatmill Lake is a lake in East Anglia in the UK. Water flows into the lake from the River Bure, and the lake is surrounded by farmland which slopes down towards it.



In recent years there has been a large increase in the concentration of nitrates and phosphate in the waters of the lake.

a Suggest how these chemicals reached the lake. [2]

b High levels of nitrate and phosphate can have unwelcome effects on the lake. Some of these changes are described in the following statements.
State the correct order of these changes.
A Nitrates and phosphates are minerals essential for the growth of algae.
B Fish die due to lack of dissolved oxygen.
C Large amounts of oxygen are consumed as populations of bacteria increase.
D Nitrates and phosphates pollute the water.
E Water becomes green and cloudy as populations of algae increase.
F Dissolved oxygen concentrations fall rapidly.
G Many algae die and provide nutrients for decay bacteria. [6]

6 The red squirrel is a small rodent which feeds largely on pine cones. Two ecologists were interested in the conservation of the red squirrel, and particularly in the reasons for its decline in number. They studied the number of deaths of red squirrels in a large sampling area. The data in the table refer to the number of deaths in one year.

Month	Number of deaths
Jan	22
Feb	29
Mar	32
Apr	20
May	14
Jun	17

Month	Number of deaths
Jul	10
Aug	12
Sep	10
Oct	22
Nov	26
Dec	36

a Plot this data as a bar chart. [4]

b Calculate the total number of deaths in this year. [1]

c In which two months did most deaths occur? Suggest why. [2]

d The scientists believed that the maximum population existed in August (the young are born in April–May). They sampled the population, using the mark–recapture method, and obtained the following data.

Number in first sample, marked and released	Number in second sample	Number of marked animals in second sample
100	80	25

Calculate the total population size at the time of the sample. [2]

e The population of red squirrels in Britain has fallen rapidly over the last century. They are protected under the Wildlife and Countryside Act, so cannot legally be killed by humans. Grey squirrels do not enjoy the same protection. Suggest two measures which could be taken to increase the number of red squirrels. [2]

7 The table below shows estimates of the total amounts of various pollutants released into the atmosphere during a single year in the USA.

Pollutant	Mass / million tonnes	Percentage
carbon monoxide	190	
nitrogen oxides	40	
sulfur oxides	50	
hydrocarbons	50	
particles e.g. carbon	30	

a Calculate the percentage contribution of each of the pollutants. [2]

b Draw a bar chart to show the data. [4]

c Choose **one** pollutant from the table. State **one** effect on human health and **one** effect on the environment of this pollutant. [2]

8 Sea otters eat fish, and fish eat small crustaceans such as shrimps. The shrimps feed by filtering algae from the water.

a Write out a food chain that links these organisms.

b Pesticides are washed from nearby farmland into rivers and then into the sea. Farmers say that the concentration of the pesticides is too low to directly affect the otters. Explain how the pesticides might still cause the death of the otters.

9 Untreated human sewage should not enter river water, but occasionally an overflow from a water treatment plant occurs. The tables below and to the right contain information on the changes that occurred in river water downstream from a sewage overflow.

Distance downstream / m	Concentration of dissolved oxygen / percentage of maximum
0 (point of sewage entry)	95
100	30
200	20
300	28
400	42
500	58
600	70
700	80
800	89
900	95
1000	100

a Plot these data in the form of a line graph. Choose axes to display the information in the way that best relates the abiotic factor to the biotic factors.

b Suggest why the number of bacteria was high at 0 m.

c Explain the shape of the curve for algae.

d How is it possible for fish numbers to fall to zero and then recover?

e Describe the changes in the concentration of oxygen dissolved in the water downstream from the point of sewage entry.

f Explain what might have caused these changes in oxygen concentration.

	Number / arbitrary units of		
Distance downstream / m	Bacteria	Algae	Fish
0 (point of sewage entry)	88	20	20
100	79	8	6
200	74	7	1
300	60	21	0
400	51	40	0
500	48	70	0
600	44	83	0
700	42	90	0
800	39	84	0
900	36	68	4
1000	35	55	20

21.1 Bacteria are useful in biotechnology and genetic engineering

OBJECTIVES

- To know the structure of a typical bacterial cell
- To know the requirements for bacterial growth
- To know how bacteria reproduce
- To understand some of the ways in which bacteria can be used in human activities

Requirements of bacteria

Bacteria have certain requirements that their environment must provide. An understanding of these requirements has been important in biotechnology and in the control of disease. If the environment supplies these needs, the bacteria can multiply rapidly by **binary fission** (see below). In this process, each bacterium divides into two, then each of the two divides again and so on, until very large populations are built up. A bacterial colony can quickly dominate its environment, making great demands on food and oxygen, and perhaps producing large quantities of 'waste' materials. Some of these waste materials can be useful to humans. For example, bacterial enzymes are used in a number of industrial processes.

Microorganisms that produce those valuable enzymes are grown under carefully controlled conditions in a fermenter (bioreactor), like the one shown on the opposite page.

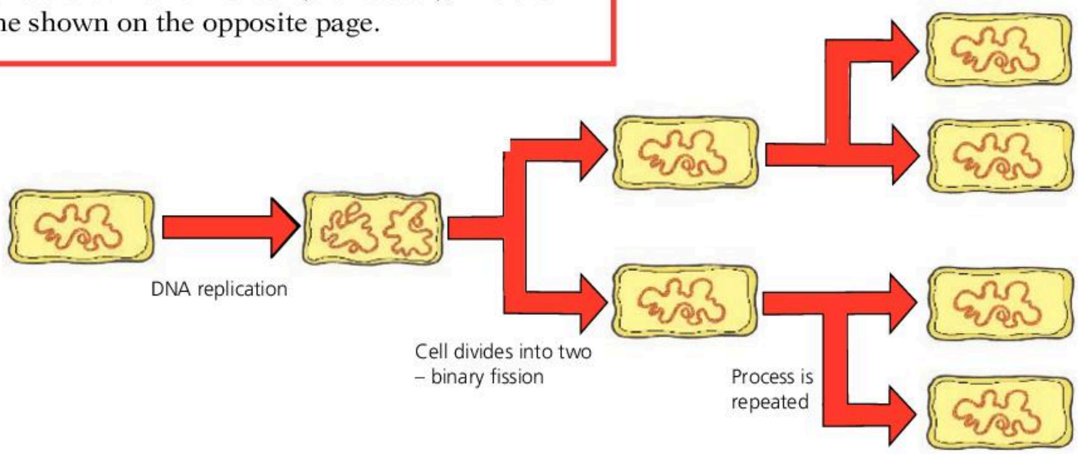
S

Bacteria are particularly useful in biotechnology and genetic engineering because:
- they reproduce very rapidly so scientists can build up large populations very quickly
- they can produce complex molecules, such as enzymes and the hormone insulin
- their genetic code is the same as that in more complex organisms (even humans!)
- they have extra pieces of DNA – plasmids – which scientists can use to carry genes from one cell to another
- people are less worried about experiments on bacteria than on more familiar, larger, organisms such as mice, rabbits and dogs.

Understanding what bacteria need to reproduce can be useful in:
- preventing food spoilage – see page 113
- controlling infections
- providing the best conditions for growth of useful bacteria.

The **generation time** (time taken for each cell to divide into two) can be as little as 20 minutes under ideal conditions. One *E. coli* cell in the human gut could **theoretically** become 2^{72} cells in 24 hours – this number of cells weighs about 8000 kg!

The number of cells in a population, starting from just one cell, is 2^n (where n = number of generations)



This can be so rapid that a bacterial population can grow very quickly

A fermenter (or bioreactor)

Paddle stirrers continuously mix the contents of the bioreactor:

- ensures microorganisms are always in contact with nutrients
- ensures an even temperature throughout the fermentation mixture
- for aerobic (oxygen-requiring) fermentations the mixing may be carried out by an **airstream**.

Fermenters are also used in fuel production (see page 284) and the manufacture of the antibiotic penicillin (see page 174), the hormone insulin and the food product mycoprotein.

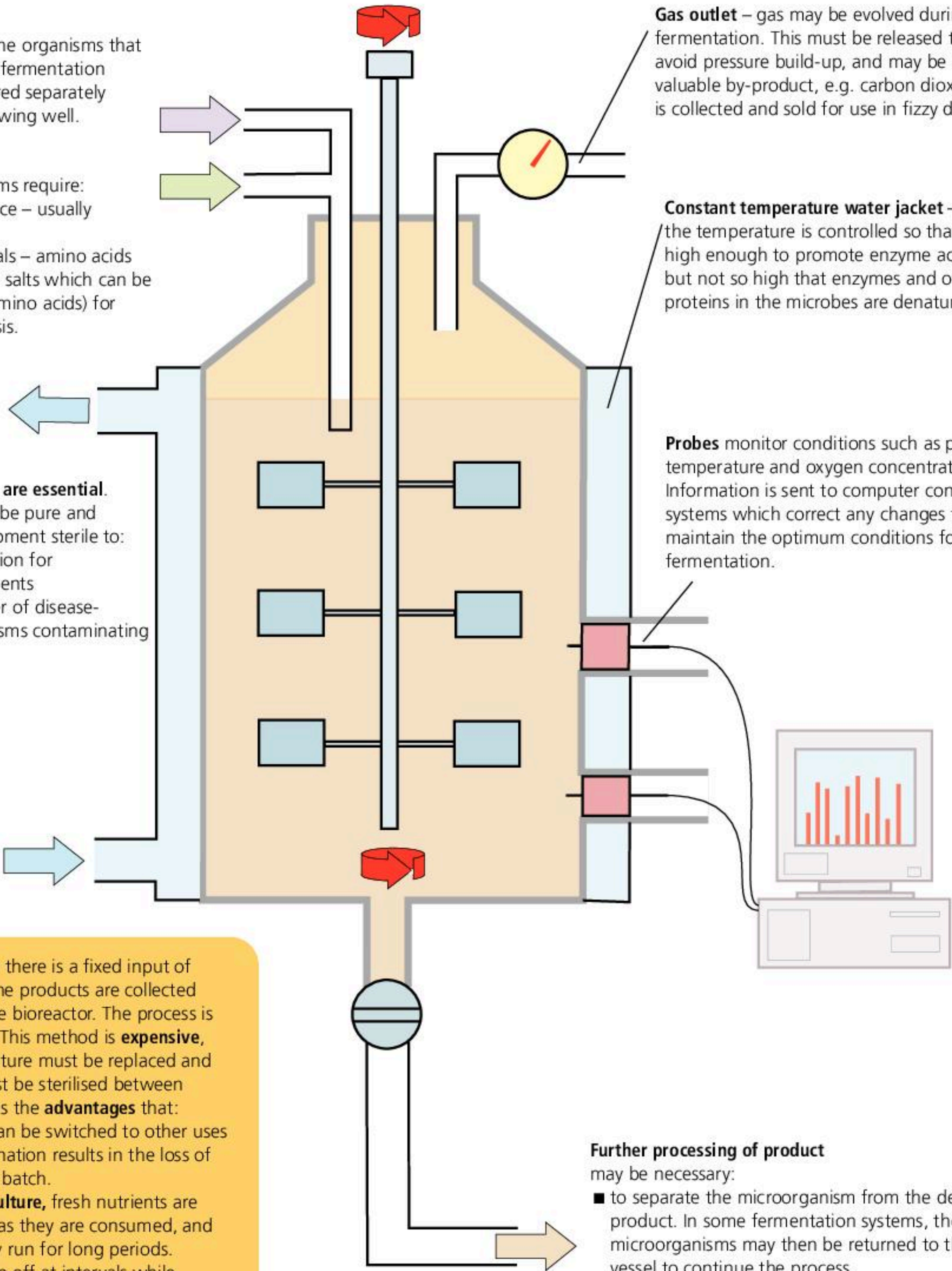
Microbe input – the organisms that will carry out the fermentation process are cultured separately until they are growing well.

Gas outlet – gas may be evolved during fermentation. This must be released to avoid pressure build-up, and may be a valuable by-product, e.g. carbon dioxide is collected and sold for use in fizzy drinks.

Nutrient input – the microorganisms require:

- an energy source – usually carbohydrate
- growth materials – amino acids (or ammonium salts which can be converted to amino acids) for protein synthesis.

Constant temperature water jacket – the temperature is controlled so that it is high enough to promote enzyme activity but not so high that enzymes and other proteins in the microbes are denatured.



Heating/cooling water out

Probes monitor conditions such as pH, temperature and oxygen concentration. Information is sent to computer control systems which correct any changes to maintain the optimum conditions for fermentation.

Sterile conditions are essential. The culture must be pure and all nutrients/equipment sterile to:

- avoid competition for expensive nutrients
- limit the danger of disease-causing organisms contaminating the product.

Heating/cooling water in

In **batch culture** there is a fixed input of nutrients and the products are collected by emptying the bioreactor. The process is then repeated. This method is **expensive**, because the culture must be replaced and the reactor must be sterilised between batches, but has the **advantages** that:

- the vessels can be switched to other uses
- any contamination results in the loss of only a single batch.

In **continuous culture**, fresh nutrients are added as soon as they are consumed, and the reactor may run for long periods. Products are run off at intervals while the process continues. This is **more economical** but has the **disadvantages** that:

- contamination causes greater losses
- the culture may block inlet or outlet pipes.

Further processing of product may be necessary:

- to separate the microorganism from the desired product. In some fermentation systems, these microorganisms may then be returned to the vessel to continue the process.
- to prepare the product for sale or distribution – this often involves **drying** or **crystallisation**.

21.2 Humans use enzymes from microorganisms

OBJECTIVES

- To understand that enzymes have many roles which benefit humans
- To know examples of a range of uses of enzymes
- To understand the benefits of enzyme immobilisation

Enzymes in industry

Enzymes are biological catalysts that operate at the temperatures, pressures and moderate pH values found in living organisms (see page 40). Using enzymes for industrial processes therefore does not require extreme (and expensive) conditions. For example, the Haber process for producing ammonia requires a temperature of 750°C and a pressure of 30 times atmospheric pressure whereas nitrogen-fixing bacteria can perform this process at 25°C and at atmospheric pressure.

In industry, the enzymes are often extracted from the living organisms before they are used. This has several advantages:

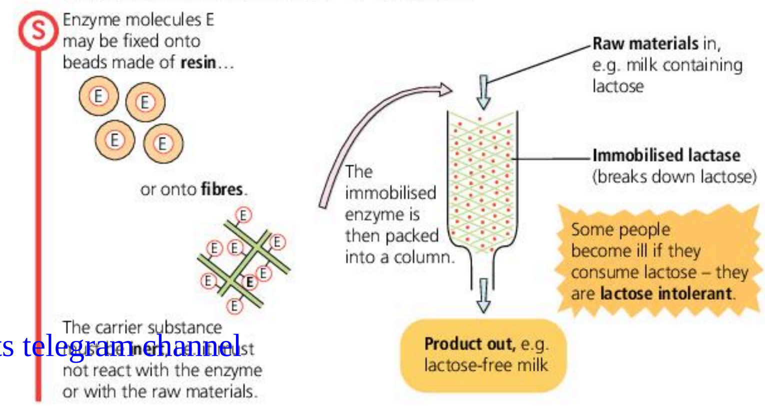
- there is no loss of raw materials for growth of the organism
- optimum conditions for a particular enzyme can be used, which may not be the same as optimum conditions for the whole organism
- wasteful side-reactions within the organism are eliminated
- purification of the product is easier – the remains of the whole cells need not be removed.

The majority of enzymes used commercially are obtained from microbial sources, usually fungi or bacteria. Sometimes the organism naturally secretes the enzymes onto its substrate; sometimes the microbial cells must be broken open to release the enzymes. Using genetic engineering (see page 300), genes for desirable enzymes such as chymosin can be inserted into organisms that do not use this enzyme, and so they secrete it into their environment.

Immobilised enzymes

Enzymes are unstable – they can break down very quickly when used to catalyse industrial processes. Enzymes can now be protected and stabilised by immobilisation, a technique which fixes the enzyme to a non-reactive support material, as shown below. When using immobilised enzymes, the product of the reaction does not contain enzyme molecules, so purification is simple and inexpensive. Immobilised enzymes also allow continuous production rather than batch production, again reducing costs.

Commercial applications of enzymes



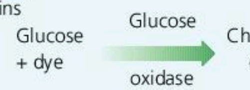
Pharmaceuticals

The enzyme **catalase** is used in wound dressings. Catalase converts hydrogen peroxide in the dressing to oxygen and water. Oxygen speeds up healing and inhibits dangerous, anaerobic bacteria such as the species which causes gas gangrene.

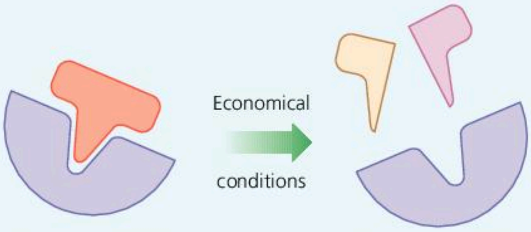
Analysis

Dip-sticks such as Clinistix® and Albustix® use enzymes to detect biological compounds in mixtures. The biological compound is oxidised to a product which causes a colour change in a dye.

Pad at the end of stick contains enzyme + dye



This is used by people with diabetes to test blood or urine for the presence of glucose (see page 149).



FUNGI CAN BE USEFUL TOO! A **lipase** from fungi helps to make chocolate flow to cover biscuits and sweets!

Food production

- A **protease** from bacteria softens gluten, making the rolling of biscuits easier.
- **Pectinase** breaks down clumps of plant cells: this changes fruit juices from cloudy to clear.

Biological washing powders

The most difficult stains to remove from clothes often include **lipids** (e.g. from fatty foods or greasy fingerprints) or **proteins** (e.g. from blood). These can be washed out using biological washing powders that contain **lipase** and **protease**. These powders have the added advantage of working at lower temperatures (less water heating needed, and clothes don't shrink).

Q

1 Read the following passage.

An enzyme implant has successfully reduced the level of particles of the fatty substance, cholesterol, in the blood of rabbits by 40% within 70 minutes. Scientists have developed a way of implanting the enzyme PLA2 into the body without affecting the cholesterol needed in cell membranes. The enzyme is immobilised inside thin hollow fibres. Pores in the walls of the fibre are large enough for cholesterol particles to diffuse through, but too small for blood cells to enter. The enzyme breaks down the cholesterol, and the products are rapidly taken up by liver cells and removed from the bloodstream.

The scientists are cautious about using enzyme therapy in humans. 'We need to know exactly what happens to the products from the cholesterol in the body', says the head of the laboratory that developed the technique. 'Several drugs already on the market can safely be used to lower cholesterol levels. However, an implant of the immobilised enzyme PLA2 could be easily inserted and could last for years'.

a Explain the advantage of lowering the level of the fatty substance, cholesterol, in the blood.
b Suggest how the enzyme might be immobilised inside the fibres.
c Suggest why it is an advantage to immobilise the enzyme inside hollow fibres.
d The enzyme PLA2 occurs naturally in humans. Explain why the enzyme could not be used as an implant if it did not occur naturally in the human body.

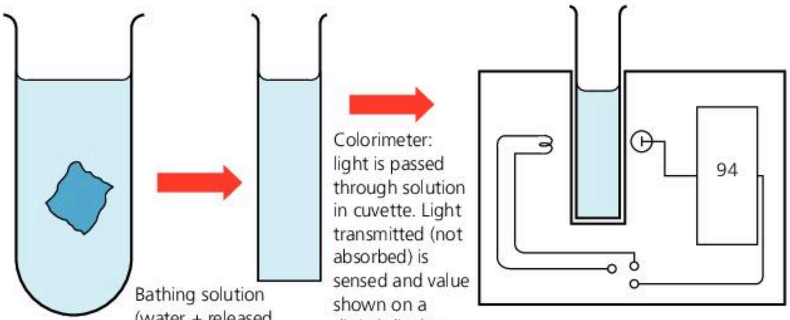
ENZYMES IN BIOLOGICAL WASHING POWDERS

Enzymes such as proteases, lipases and amylases are some of the active ingredients in modern biological washing powders. For example, amylase catalyses the breakdown of starch-based stains to smaller segments that make up the larger starch molecule. These smaller units released from the enzyme's hydrolytic action are soluble; thus, the stain is physically cut off from the surface of the fabric piece by piece and then washed away.

Because detergents, especially bath soaps, are generally formulated to degrade mainly oil and grease, protein-based stains have traditionally been among the hardest to remove.

Casein (milk protein) easily binds to a blue dye. Small pieces of fabric can be stained by soaking in a solution of dyed casein. The dye separates from the casein if the protein is broken down by the action of an enzyme.

Suggest how you would compare the effect of a bacterial protease and a commercial detergent on a protein-based stain. Assume that you can use a colorimeter (an instrument that can measure the absorption of light by a solution).



How could you extend your experimental work to investigate:

- how temperature affects protease activity (what is the temperature in a washing cycle using biological powders?)
- how pH affects protease activity (what is the pH in a solution of a biological powder?)
- whether a biological washing powder contains lipase.

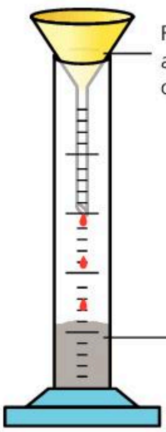
Human skin contains both proteins and lipids. Suggest a possible result of over-use of biological washing powders.

EXTRACTION OF APPLE JUICE WITH PECTINASE

Pectinase is an enzyme that catalyses the breakdown of pectin, a component of the cell wall in fruits such as apples and oranges. Pectinase is used commercially because, by enzymatically breaking down the cell wall, pectinase releases the juice from within the cells. Pectinase can also be used to 'clear' the extracted juice.

Procedure

1. Chop the apples into cubes that are roughly 5 mm on each side.
2. Weigh 50 g of chopped apple into each of eight boiling tubes.
3. A solution of pectinase will be supplied to you. Add 2 cm^3 of pectinase solution to four of the boiling tubes, and 2 cm^3 of distilled water to the remaining four tubes. Mix the contents of each of the tubes separately, using a glass rod.
4. Stand two tubes (one with pectinase solution and one with distilled water) into water baths set to 30°C, 40°C and 60°C. Leave the final pair of tubes at room temperature (record the room temperature!).
5. After 25 minutes, filter the juice from each boiling tube separately, as shown in the diagram.
6. Record the volumes of juice collected at 1-minute intervals until no more juice is collected.



SAFETY

Do **not** drink the juice, because the pectinase solution is much more concentrated than would be used in commercial production of fruit juice.

Handle knives carefully.

Wipe up any enzyme spills and wash the area with water.

EXTRACTION OF APPLE JUICE WITH PECTINASE CONTINUED

Record your results in a suitable table, showing the volume of juice collected after a 5-minute period at each of the four different temperatures.
Plot a suitable graph of your results.

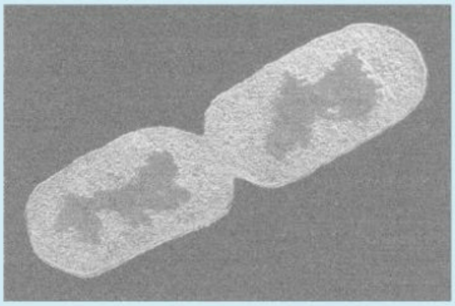
Analysis

a State the independent and dependent variables in this investigation.
b State the reason for including tubes with distilled water in this investigation.
c Explain why temperature affects the activity of pectinase.
d Suggest how you could extend the investigation to study pectinase in other fruits.

Extension

e Describe a chemical test for lactose (a reducing sugar).
f Suggest how you would show that lactase is necessary for the breakdown of lactose.

2 The image below shows a photomicrograph of a reproducing bacterium.



Magnification ×25 000

a Calculate the actual length of a single bacterium.
Give your answer in micrometres (μm). Show your working. [3]

b Bacteria may be used to produce enzymes useful to humans.
Look at the table below. Match each enzyme to a process useful to humans.
Write the letter and number to show your answer, for example, **a–3**.

Enzyme	Process
a protease	**1** breakdown of starch in water washed from laundries
b pectinase	**2** removal of fatty stains from clothing
c lactase	**3** softening of leather for jackets and handbags
d amylase	**4** clearing of fragments of fruit from fruit juice
e lipase	**5** preparation of milk for patients with milk sugar intolerance

c State **three** reasons why enzymes are useful for industrial processes. [3]

d State **two** reasons why immobilised enzymes are used in industrial processes. [2]

3 The enzyme **glucose oxidase** can be incorporated into a test strip used to test for the presence of glucose in biological fluids. The enzyme can convert glucose to an acid which then changes the colour of a dye if the sugar is present.

a Suggest the names of **two** biological fluids which can be tested in this way. [2]

b State the name of the medical condition which could result in high levels of glucose in these biological fluids. [1]

c State which **two** of the following foods are **most** likely to cause a rise in glucose concentration in these fluids:
butter, pasta, lean meat, breakfast cereal, milk chocolate. [2]

21.3 Baking and brewing: the economic importance of yeast

OBJECTIVES

- To appreciate that some microorganisms are useful to humans
- To recall an equation for anaerobic respiration
- To understand the industrial production of alcohol and bread

Bread production

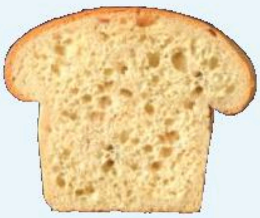
Flour, sugar, water and salt are mixed with **yeast**. This process is called **kneading** and produces **dough**.

The dough is rolled into shape, then kept in a warm (about 28°C), moist environment. The yeast ferments the sugar, and the bubbles of carbon dioxide are trapped by the sticky proteins of the dough. The dough expands or **rises**.

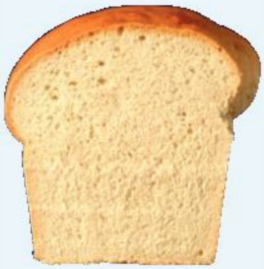
Cooking at 180°C – **baking**:
- kills the yeast and stops fermentation
- causes alcohol to evaporate
- hardens the outer surface to form a crust.

The product is **bread**, which should be:
- spongy in texture, because of trapped carbon dioxide
- fresh smelling (partly alcohol vapour!).

If a loaf is not left to rise, it will be small and dense



If a loaf is left to rise for too long too much carbon dioxide is produced and there are too many large holes



The perfect loaf

'Wholemeal' bread is made with flour which has **not** had the husk removed from the wheat – hence 'whole' meal. It is rich in B vitamins and dietary fibre.

Bread may be fortified – in the UK, bread often has added protein, calcium and vitamins A and D – not to mention preservatives and whitening agents.

Yeast performs alcoholic fermentation

Much of the commercial use of microorganisms is based on the process of **fermentation**. This term covers *any* metabolic process carried out by microorganisms using carbohydrate as a starting material. The best-known fermentation reaction is the anaerobic respiration of glucose by the single-celled fungus **yeast**:

glucose ⟶ carbon dioxide + ethanol + energy

Because one of the products is ethanol (ethyl alcohol), this process is often known as **alcoholic fermentation**. As well as making alcohol, the carbon dioxide produced is valuable commercially. For the yeast, the useful product is energy – the alcohol and carbon dioxide are by-products.

Alcohol has a high energy content and is toxic

Alcohol contains a great deal of energy, a fact that is exploited when alcohol is used as a biofuel source (see page 284). Alcohol is also toxic (poisonous) and the yeast excretes it into the surrounding liquid medium. If the alcohol concentration in the medium gets higher than 8–9%, the yeast is killed and fermentation stops. Alcohol is toxic to humans too.

Baking and brewing use fermentation

The processes of **baking** and **brewing** have both been around for thousands of years. The process of baking is outlined on the left.

Fine tuning the fermentation process

Because of the enormous commercial significance of these processes, much research has gone into making them as efficient as possible. For example:

- strains of yeast that are tolerant to higher concentrations of alcohol have been developed
- high-yielding strains of wheat have been selectively bred
- genetic engineers have developed yeasts which can convert starch to maltose, and thus remove the need for the 'malting' stages in brewing.

Questions on biotechnology

1 The diagram below shows a bioreactor which can be used for the production of penicillin.

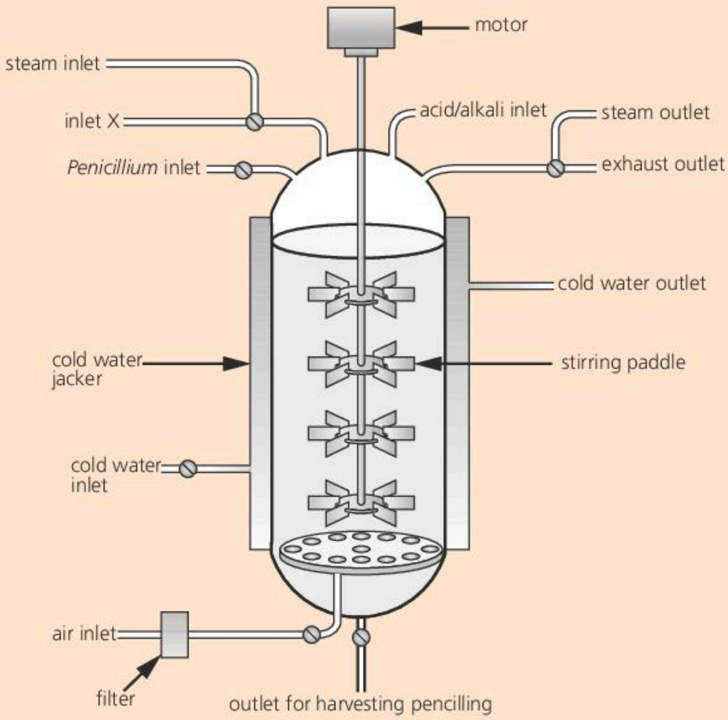
a State the name of the organism used to produce the penicillin. [1]

b **i** Explain *why* a constant temperature must be maintained in the reactor. [2]

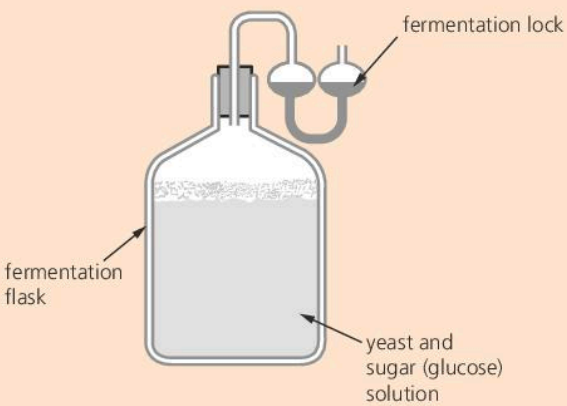
ii Explain *how* this constant temperature is maintained. [2]

c Explain why the chamber must be sterilised after use. [2]

d State **two** reasons why doctors are unwilling to prescribe penicillin for a common cold. [2]



2 Wine can be produced on a small scale using the apparatus shown below.



a The yeast cells in the flask respire anaerobically. Write a chemical equation for this process. [3]

b Wine produced in this way rarely has an alcohol content greater than 12%. Explain why. [2]

c Yeast can respire aerobically, but does not produce alcohol under these conditions. Explain how aerobic respiration is prevented in this apparatus. [1]

3 Mycoprotein is a single cell protein which can be used as a substitute for chicken or for beef. The table below shows the composition of burgers made from beef and from mycoprotein.

Nutrient	Total / g per 100 g	
	Beef	Mycoprotein
carbohydrate	3.4	5.6
fat	24.2	4.5
cholesterol	0.02	0.00
fibre	0.4	4.0
protein	16.0	12.5
total energy content / kJ	**1200**	**500**

a State **two** differences in composition between beef and mycoprotein. [2]

b Suggest **two** reasons why eating mycoprotein is healthier than eating beef. [2]

21.4 Genetic engineering

OBJECTIVES

- To understand the term genetic engineering
- To understand the value of enzymes in genetic engineering
- To be able to describe a technique in genetic engineering
- To list some products of genetic engineering that are of value to humans

What is genetic engineering?

The examples of selective breeding described on page 236 are a form of genetic engineering, because humans are interfering with the natural flow of genetic material from one generation to the next when they choose the animals or plants that will be allowed to reproduce (and pass on their genes). However, what we now call genetic engineering is a much more predictable and refined process than selective breeding. In this process:

- Genes that code for characteristics valuable to humans are identified.
- These genes are removed from the animal or plant that normally shows this characteristic.
- The genes are transferred to another organism, usually one that grows very quickly.
- This organism 'reads' the gene it has received, and shows the characteristic that is valuable

  to humans.

S

Recombinant DNA technology

In many cases the characteristic is the ability to manufacture a product that has some medical or industrial value. Because DNA (a gene) from one organism is being transferred to the DNA of another organism to make a new combination of DNA, this 'modern' genetic engineering is often referred to as **recombinant DNA technology**. The principle of this technique sounds very straightforward, but in practice it is extremely difficult.

- The genetic material is microscopic in size. A technician can't use a pair of scissors to cut out a gene!

S

- The **host** organism, that is, the one that will receive the valuable gene, would not normally take in DNA from another organism.
- The host organism might not show the valuable characteristic, for example it may not make a particular protein, even though it now has the DNA that codes for the protein.

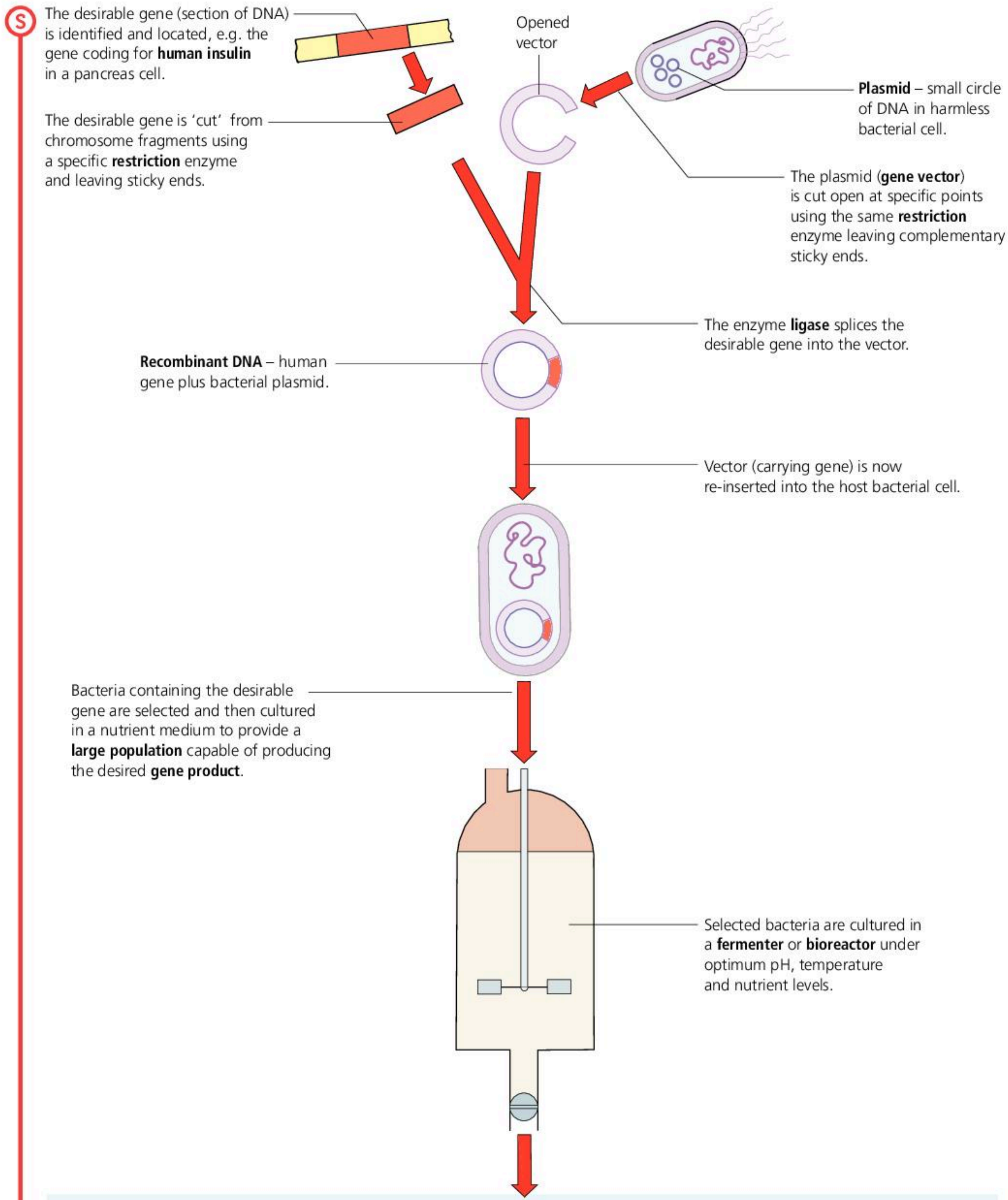
Technological advances have overcome these potential problems. Key to success has been the discovery of:

- **enzymes** that can cut DNA from one chromosome and paste it into another, acting like scissors and glue
- **vectors** that can carry the gene from one organism to another
- **culture techniques** that allow large quantities of the valuable product to be produced and collected, even if the host organism would not normally produce it.

Many compounds can be manufactured by genetically engineered bacteria, including insulin and other products which are used directly by humans. These products are otherwise often taken from animals. For example, insulin can be isolated from the pancreas of a pig.

Recombinant DNA technology has several advantages:

- The product is very pure, and can be the human version of a protein rather than a version produced by another animal. The human protein is likely to work more efficiently in a person, and is less likely to be rejected by the body's defences.
- The product can be made in large quantities, making it less expensive and more readily available. Insulin produced in this way costs about 1% as much as insulin produced from pig pancreas.
- The process can be switched on or off easily as the bacteria can be stored until needed again. The product can be made as required rather than just when animal carcasses are available.



Product

After some processing, for example to remove the bacterial cells for recycling, the product is extremely pure and relatively inexpensive. Important examples of such gene products are:

- **insulin** (required for the treatment of diabetes)
- **human growth hormone**
- **factor VIII** (blood clotting factor for haemophilia)
- **BGH** is an important animal hormone used to speed up the growth of beef cattle (see page 265).

▲ Genetic engineering (recombinant DNA technology) depends on enzymes and the culture of microorganisms

21.5 Gene transfer in higher organisms

OBJECTIVES

- To describe how organisms other than bacteria may be altered by genetic engineering
- To appreciate that there are moral and environmental problems associated with the use of genetic engineering

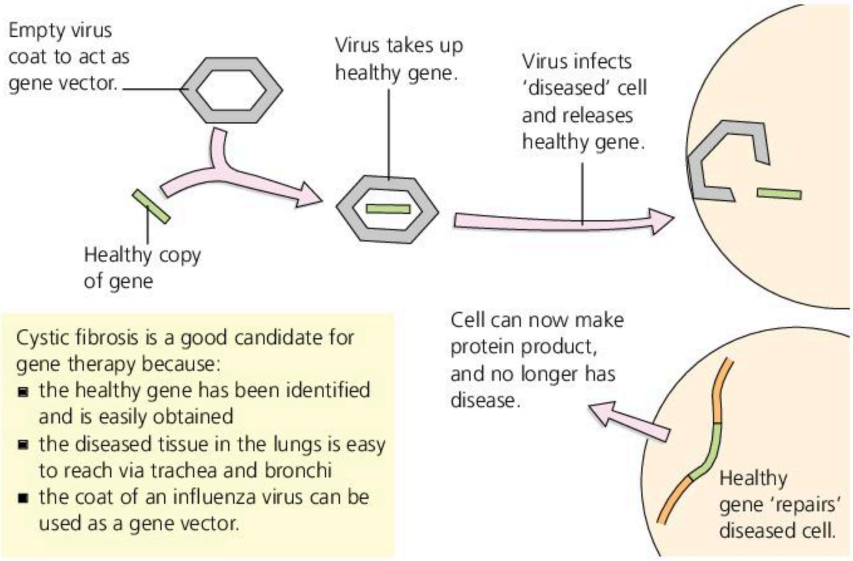
Transgenic organisms

Bacteria are not the only organisms that can be modified by gene transfer. Genetic engineers have been able to transfer genes into flowering plants, fungi and mammals and thus alter the characteristics of these higher organisms. An organism that has received genes from a different species is called a **transgenic** organism. The major problem is finding a vector that can carry the gene into the new host. Different vectors have been used for different hosts. A bacterium, for example, may be a vector to transfer useful genes into a plant, as described on the page opposite.

Gene therapy*

Gene therapy is the transfer of healthy human genes into a person's cells that contain mutant alleles which cause disease. The principle of gene therapy is outlined below. This technique uses a harmless virus to transfer the useful gene.

Gene therapy may be able to repair diseased human cells



Cystic fibrosis is a good candidate for gene therapy because:
- the healthy gene has been identified and is easily obtained
- the diseased tissue in the lungs is easy to reach via trachea and bronchi
- the coat of an influenza virus can be used as a gene vector.

Q

1. Why are vectors useful to genetic engineers?
2. What might be the benefits of transferring nitrogen-fixing genes from bacteria to other organisms?
3. Describe one example of gene therapy. Explain why this form of treatment is thought likely to be successful in the example which you describe.

(S) Moral and environmental concerns about genetic modification

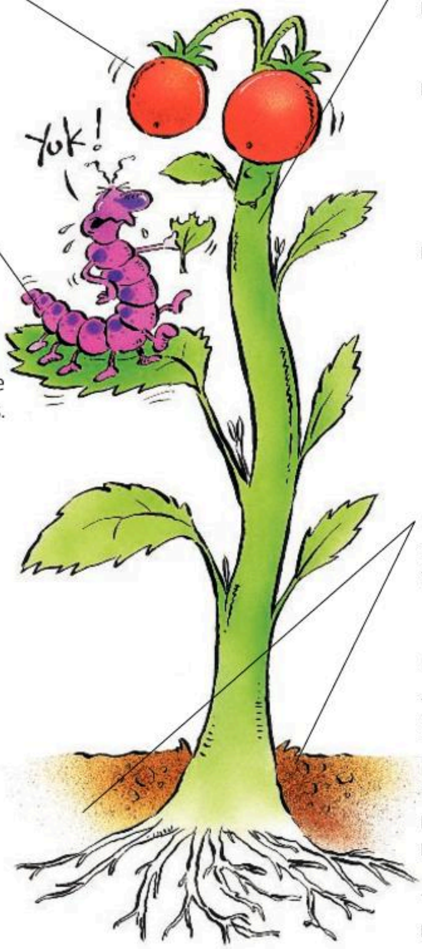
The benefits claimed for genetically modified products, and potential problems, are shown in the table below.

Benefits	Problems
Engineered organisms can offer higher yields from fewer resources. With plants, for example, this might reduce the need for pesticides and fertilisers.	Plants engineered for pesticide resistance could cross-pollinate with wild relatives, creating 'superweeds'.
Crops engineered to cope with extreme environmental conditions will open up new areas for cultivation, and reduce the risk of famine.	Engineered bacteria may escape from the laboratory or the factory, with unpredictable consequences.
Genetic engineering gives much more predictable results than selective breeding.	'New' organisms might be patented. A company that has spent a lot of money on developing such an organism might refuse to share its benefits with other consumers, making the company very powerful.
Foods can be engineered to be more convenient, such as potatoes which absorb less fat when crisps are made, or even to contain medicinal products such as vaccines.	How far should we allow research into human gene transfer to go? Will we allow the production of 'perfect' children, with characteristics seen to be desirable by parents?

How plants may be genetically modified to be useful to humans

Improved shelf life – a gene has been introduced into tomatoes which inhibits the enzymes causing deterioration. 'Flavr Savr' tomatoes keep for several weeks. Less wastage should mean lower prices.

Resistance to pests and herbicides – A gene is inserted into the crop plant which enables it to make **insecticidal crystal protein** (ICP) which affects the guts of caterpillars so that they cannot feed and eventually die.
A gene is inserted which makes the crop plant resistant to herbicides. The field of growing crop can then be sprayed with the herbicide, which will selectively kill the weeds.



Resistance to envionmental conditions – gene transfer has produced:

- **drought resistance** – plants with thicker, more waxy cuticles which can grow well in dry areas
- **uniform fruiting** – plants produce flowers and fruits in response to daylight. Soya bean plants have been engineered to produce beans even in temperate regions of the world with a different light pattern to their normal habitat.
- **resistance to wind damage** – soya plants have been engineered to have stronger stems of a more uniform height which makes them more resistant to wind damage and makes machine harvesting of the beans more efficient.

Nitrogen fixation – this is the conversion of nitrogen gas from the atmosphere into a form that plants can use (see page 254).

N_2 from atmosphere → NH_4^+ ammonium ions → amino acids and other compounds

This key step is contolled by enzymes coded for by genes.

Most plants cannot fix nitrogen but gene transfer might either:

- insert these genes directly into a plant, or
- make a plant more likely to form root nodules with nitrogen-fixing bacteria

This could:

- produce cereal crops which also manufacture large amounts of protein
- reduce the need for nitrogenous fertilisers.

Golden Rice is a genetically engineered variety of rice which produces β-carotene. This is converted into vitamin A, and the food is designed to be eaten in areas with vitamin A deficiency.

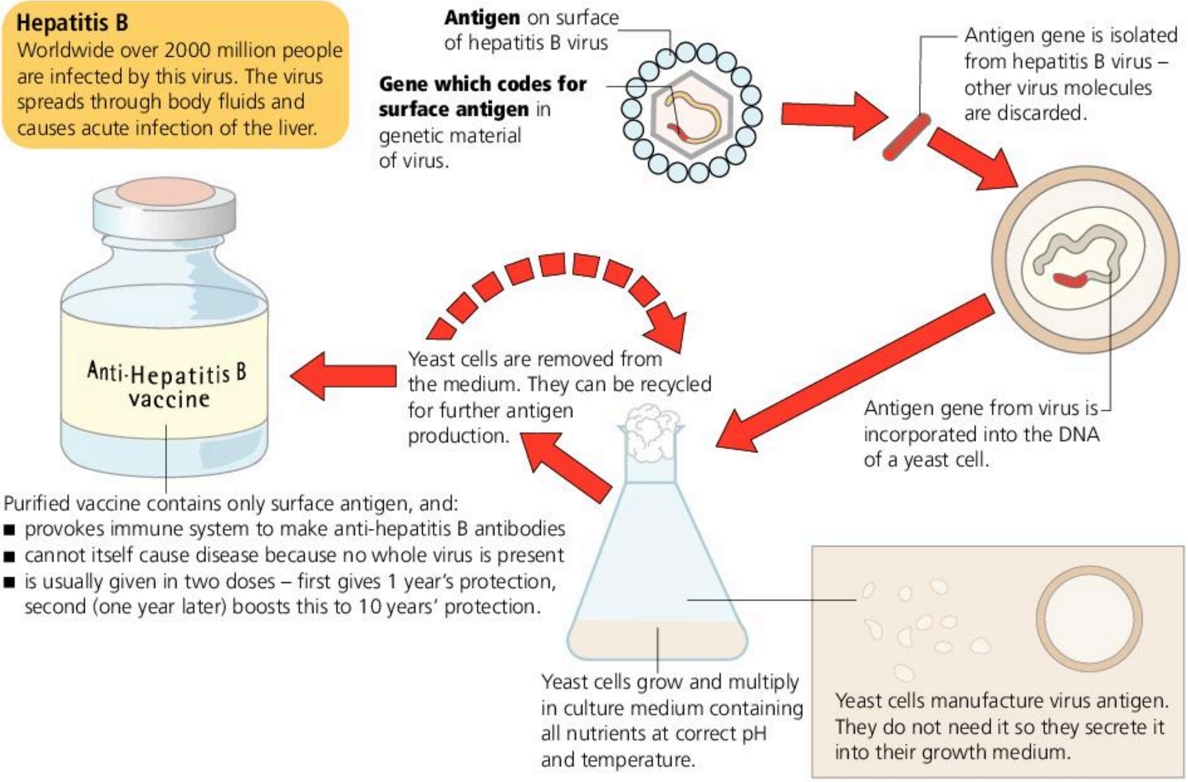
Genetic engineering is used to produce vaccines

The vaccine used to give people artificial immunity must be:

- effective – it must protect against disease
- safe – it should not cause health problems.

Hepatitis B is a serious disease of the liver, caused by a virus. The production of the hepatitis B vaccine is described below.

Hepatitis B
Worldwide over 2000 million people are infected by this virus. The virus spreads through body fluids and causes acute infection of the liver.



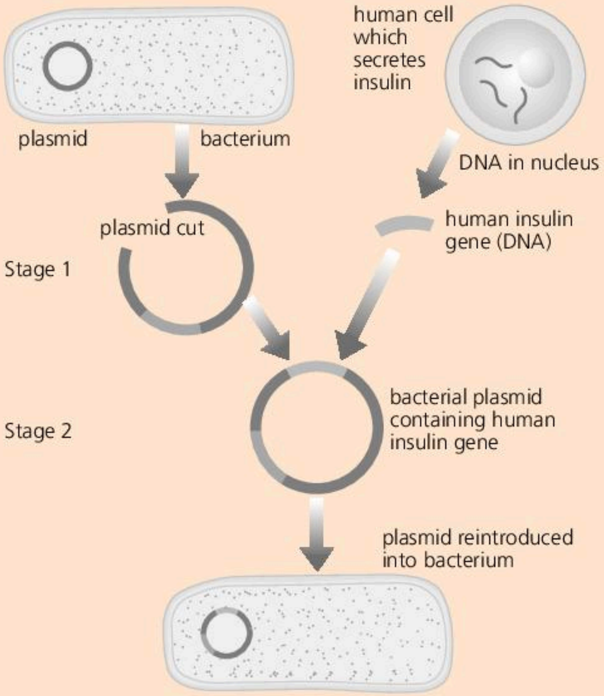
▲ Genetic engineering provides a safe vaccine against hepatitis B, given to people likely to be exposed to this virus (such as a surgeon who might come into contact with patients' blood)

Q

1 Suggest how scientists might be able to develop a vaccine to reduce the dangers of infection by this virus. In your answer include
  a **Why** the development of a vaccine is important
  b **How** an effective vaccine could be developed, and
  a **How** the scientists can ensure that the vaccine is safe to use.

Questions on genetic engineering

1 The diagram below shows the main stages in transferring the human insulin gene to a bacterium.



a Name the enzyme used

i to cut the plasmid at stage 1 [1]

ii to stitch the gene and plasmid at stage 2. [1]

b Explain the function of the plasmid in this process. [2]

c Suggest why the insulin produced by genetic engineering is preferable to insulin extracted from the bodies of other animals. [2]

d Some people are worried about the use of genetic engineering. State **two** concerns about the use of this technique. [2]

2 A vaccine against hepatitis B can be made by genetic engineering (see page 292).

a In this process:

i State which part of the virus is transferred to a yeast cell. [1]

ii State which part of the virus is produced by the yeast cell. [1]

b Before genetic engineering was developed, vaccines contained viruses that had been heated or treated chemically to stop them reproducing. Whole virus particles were present in the vaccine.
Explain why a genetically engineered vaccine is safer than a vaccine made directly from hepatitis B virus. [3]

3 The following table lists events from the identification of a human gene coding for a hormone "X" to the commercial production of hormone "X".
Genes can be transferred into plasmids, tiny circles of DNA which are found in bacteria.
Show the correct sequence of events 1 to 8 by copying the table below and writing the appropriate number in each box provided. The first (number 1) and last (number 8) have been completed for you. [5]

Event	Number
Cutting of a bacterial plasmid using restriction enzyme	
Cutting of human DNA with restriction enzyme	
Identification of the human DNA which codes for hormone "X"	1
Many identical plasmids, complete with human gene, are produced inside the bacterium	
Mixing together human gene and "cut" plasmids to splice the human gene into the plasmid	
Some of the cloned bacteria are put into an industrial fermenter where they breed and secrete the hormone	8
The bacterium is cloned	
Using the plasmid as a vector, inserting it, complete with human gene, into a bacterium	

Practical assessment

The basis of scientific subjects is experimental: hypotheses are tested to establish theories and observations and measurements made to provide the factual background to science. Examiners believe that it is important that an assessment of a student's knowledge and understanding of biology should contain a practical component.

Schools' circumstances (e.g. the availability of resources) differ greatly, so two alternative ways of examining the relevant assessment are provided by Cambridge Assessment International Education (CAIE). The two alternatives are:

- Paper 5 – practical test
- Paper 6 – alternative to practical (written paper).

The following points should be noted for both types of practical assessment:

- the same proportion of marks is available – 20% of the subject total
- the same practical skills are to be learned and developed
- the same benefits to theoretical understanding come from all practical work.

Paper 5: Practical test

The CAIE specification states:

Exercises may be set requiring the candidates to:

- follow carefully a sequence of instructions
- use familiar, and unfamiliar, techniques to record observations and make deductions from them
- perform simple physiological experiments, e.g. tests for food substances and the use of hydrogencarbonate indicator, litmus and Universal Indicator paper
- use a scalpel or a razor blade, forceps, scissors and mounted needles skilfully
- use a hand lens of not less than ×6 magnification to recognise, observe and record familiar, and unfamiliar, biological specimens
- make a clear line drawing of a specimen provided, indicate the magnification of the drawing and label, as required
- perform simple arithmetical calculations.

Candidates may be required to do the following:

- record readings from apparatus
- describe, explain or comment on experimental arrangements and techniques
- complete tables of data
- draw conclusions from observations and/or from information given
- interpret and evaluate observations and experimental data
- plot graphs and/or interpret graphical information
- identify sources of error and suggest possible improvements in procedures
- plan an investigation, including suggesting suitable techniques and apparatus.

Paper 6: Alternative to practical

This paper is designed to test candidates' familiarity with laboratory practical procedures.

Questions may be set requiring the candidates to:

- follow carefully a sequence of instructions
- use familiar, and unfamiliar, techniques to record observations and make deductions from them
- recall simple physiological experiments, e.g. tests for food substances, the use of a potometer and the use of hydrogencarbonate indicator, litmus and Universal Indicator paper
- recognise, observe and record familiar, and unfamiliar, biological specimens
- make a clear line drawing from a photograph (or other visual representation) of a specimen, indicate the magnification of the drawing and label, as required
- perform simple arithmetical calculations
- record readings from apparatus
- describe, explain or comment on experimental arrangements and techniques
- complete tables of data
- draw conclusions from observations and/or from information given
- interpret and evaluate observations and experimental data
- plot graphs and/or interpret graphical information

- identify sources of error and suggest possible improvements in procedures
- plan an investigation, including suggesting suitable techniques and apparatus.

Throughout this book there are a number of examples of the type of experiment or exercise that might appear in either the practical test or the alternative to practical. These are listed in the table below, and should give you a great deal of help in dealing with whichever of these papers is used in your practical assessment.

List of practical exercises

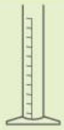
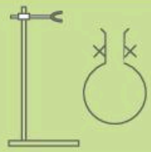
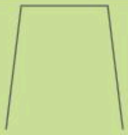
Exercise	Spread reference	Comment
Making a key	1.2	
Looking at cells	2.1	
Measuring the size of objects	2.1	
Testing for biochemicals/foods	4.2	
Testing leaves for starch	6.1	Factors affecting photosynthesis
Measurement of the rate of photosynthesis	6.2	Includes analysis of experimental design
Photosynthesis and gas exchange	6.6	Use of hydrogencarbonate indicator
Plants and minerals	6.7	
Measurement of energy content of food	7.3	
Tracing xylem	8.1	Use of eosin
Bubble potometer	8.3	
Water loss from leaf surfaces	8.4	Use of cobalt chloride paper
Demonstration of respiration	11.1	Germination and respiration
The measurement of respiration	11.3	Respirometer / measurement of carbon dioxide released
Investigation of tropisms	14.9	Phototropism and gravitropism
Structure of flowers	16.2	
Experimental design: using models for pollination	16.3	
Conditions for germination	16.5	Gives references to enzymes, and the need for energy
Sampling populations	19.3	Use of quadrats, line transects, pitfall traps and pooters
Commercial use of enzymes	21.2	
Effectiveness of antibiotics	15.1	
Enzyme experiments and the scientific method	p. 312	Includes drawing tables and graphs

Laboratory equipment

You will find that the practical paper or the alternative to practical will be much more straightforward if you recognise certain standard pieces of equipment, and understand what they are used for.

Apparatus and materials

Safety equipment appropriate to the work being planned, but at least including eye protection such as safety spectacles or goggles.

3D image	Name and function	Diagram
	**Watch glass**: used for collection and evaporating liquids with no heat, and for immersing biological specimens in a liquid.	
	**Filter funnel**: used to separate solids from liquids, using a filter paper.	
	Measuring cylinder: used for measuring the volume of liquids.	
	**Thermometer**: used to measure temperature.	
The other very important measuring device in the laboratory is a balance (weighing machine).		
	**Spatula**: used to for handling solid chemicals; for example, when adding a solid to a liquid.	
	**Pipette**: used to measure and transfer small volumes of liquids.	
	**Stand, boss and clamp**: used to support the apparatus in place. This reduces the risk of dangerous spills. This is not generally drawn. If the clamp is merely to support a piece of appartus, it is usually represented by two crosses as shown.	
	**Bunsen burner**: used to heat the contents of other apparatus (e.g. a liquid in a test tube) or for **directly** heating solids.	
	**Tripod**: used to support apparatus above a Bunsen burner. **The Bunsen burner, tripod and gauze are the most common way of heating materials in school science laboratories.**	
	Gauze: used to spread out the heat from a Bunsen burner and to support the apparatus on a tripod.	
	**Test tube and boiling tube**: used for heating solids and liquids. They are also used to hold chemicals while other substances are added and mixed. They need to be put safely in a test tube rack.	
	**Evaporating dish**: used to collect and evaporate liquids with or without heating.	
	**Beaker**: used for mixing solutions and for heating liquids.	

Chemical reagents

In accordance with the COSHH (Control of Substances Hazardous to Health) regulations operative in the UK, a hazard appraisal of the list below has been carried out. The following codes are used where relevant:

C = corrosive substance; **F** = highly flammable substance; **H** = harmful or irritating substance; **O** = oxidizing substance; **T** = toxic substance

Table of hazard symbols

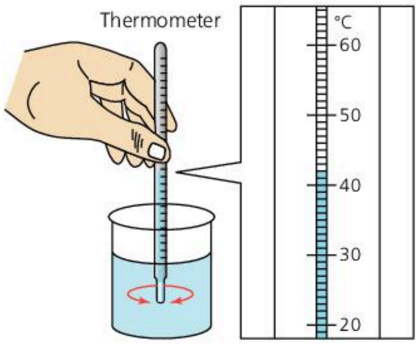
Symbol	Description	Examples	Symbol	Description	Examples
	**Oxidising** These substances provide oxygen which allows other materials to burn more fiercely.	Bleach, sodium chlorate, potassium nitrate		**Harmful** These substances are similar to toxic substances but less dangerous.	Dilute acids and alkalis
	**Highly flammable** These substances easily catch fire.	Ethanol, petrol, acetone		**Corrosive** These substances attack and destroy living tissues, including eyes and skin.	Concentrated acids and akalis
	**Toxic** These substances can cause death. They may have their effects when swallowed or breathed in or absorbed through the skin.	Mercury, copper sulfate		**Irritant** These substances are not corrosive but can cause reddening or blistering of the skin.	Ammonia, dilute acids and alkalis

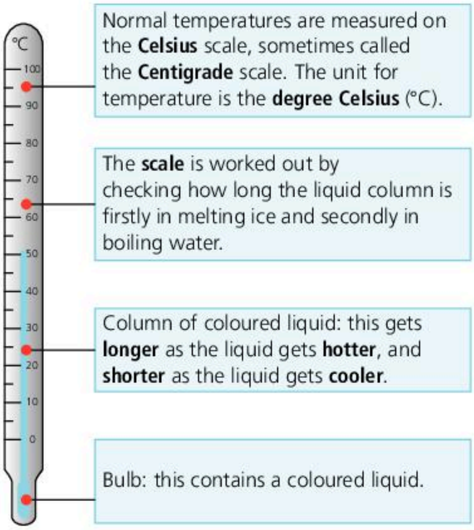
Reagent	Use in biology	Spread reference
methylene blue	A stain for animal cells	2.1, 8.1
iodine in potassium iodide solution (iodine solution)	Detection of starch	2.1, 4.2, 6.1, 6.2
Benedict's solution (or an alternative such as Fehling's)	Detection of a reducing sugar, such as glucose	4.2
Biuret reagent(s) (sodium or potassium hydroxide solution and copper sulfate solution)	Detection of protein	4.2
ethanol/methylated spirit	For dissolving lipids in testing for the presence of lipids. Also used to remove chlorophyll from leaves during starch testing.	4.2, 6.1
hydrogencarbonate indicator (bicarbonate indicator)	Detect changes in carbon dioxide concentration, for example in exhaled air following respiration	6.1, 6.2, 6.6, 11.3
cobalt chloride paper	Detects changes in water content	8.4
pH indicator paper or Universal Indicator solution or pH probes	Changes in pH during reactions such as digestion of fats to fatty acids and glycerol	
litmus paper	Qualitative detection of pH	
glucose	Change in water potential of solutions	
sodium chloride	Change in water potential of solutions	
aluminium foil or black paper	Foil can be used a heat reflector: black paper as a light absorber	6.1, 6.6, 6.7
a source of distilled or deionised water	Change in water potential of solutions. Also used in making up mineral nutrient solutions.	4.2, 6.7, 21.2
eosin/red ink	To follow the pathway of water absorbed by plants	8.1
limewater	A liquid absorbent for carbon dioxide, for example in exhaled air	11.3
potassium hydroxide	Removes carbon dioxide from the atmosphere, for example during experiments on conditions for photosynthesis	11.3
sodium hydrogencarbonate (sodium bicarbonate)	Very mild alkali: use for adjusting pH of solutions for enzyme activity	
petroleum jelly (or similar)	Blocks pores such as stomata, and so prevents water loss	8.4, 11.3

Measurement of variables

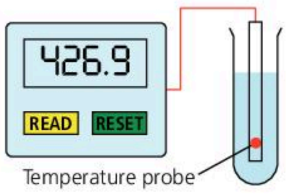
In many investigations, biologists need to measure variable quantities such as volume, temperature, mass and time. It is very important to be able to read scales accurately and to choose the correct units for the quantities that have been measured. Some of the common measuring equipment used in biology laboratories is shown below.

Measuring temperature using a thermometer

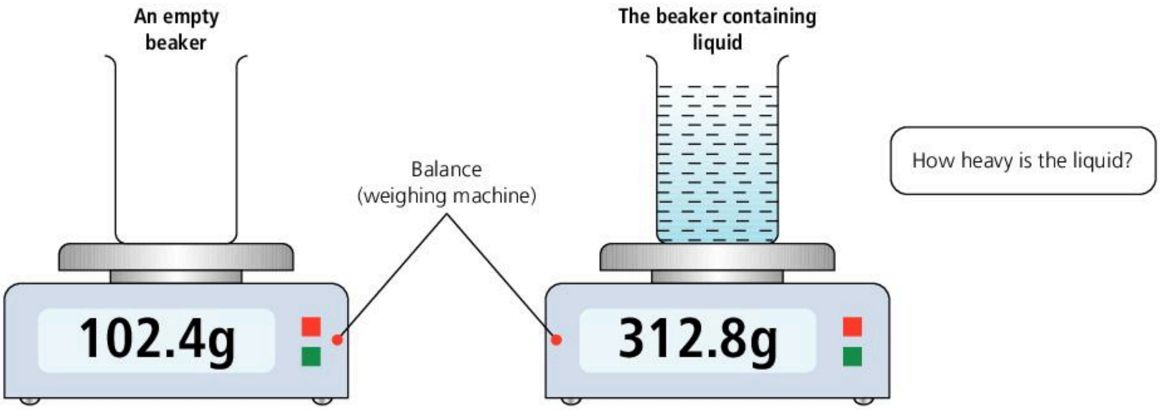




An electronic thermometer and probe. Equipment like this will be necessary if a scientist needs to measure temperature above 100°C or below 0°C.

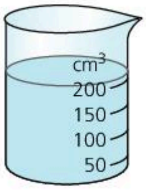


Measuring mass using an electronic pan balance



Measuring volume using a beaker or a measuring cylinder

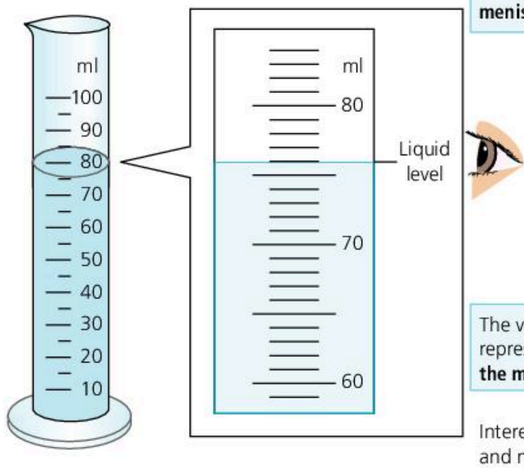
BEAKER
It is not accurate to use a beaker because the scale is not fine enough.



Is it cm^3 or ml? Some equipment is scaled in cm^3, and some is scaled in ml. It really doesn't matter – 1 cm^3 has exactly the same volume as 1 ml.

MEASURING CYLINDER

When using a measuring cylinder, stand the measuring cylinder on a level bench, so that the liquid is level.



Make sure that you read the level carefully. You may notice that the surface of the fluid is curved; this is called the **meniscus**.

Get your eye level with the liquid level. It may look as though there is a thick 'skin' on the water. This is because you are looking at the minute amount of liquid that has been drawn up the glass.

The volume of liquid is represented by the **bottom** of **the meniscus**.

Interestingly, plastic beakers and measuring cylinders often do not give rise to a meniscus!

Reading the measurement from a measuring cylinder by getting your eye level with the liquid level

This table gives a summary of the measuring equipment used in laboratories.

Quantity	Units	Equipment
Volume (fluid)	Cubic centimetres (cm^3) Litres (dm^3) 1 litre = 1000 ml	Measuring cylinder or beaker
Temperature	Degrees Celsius (°C)	Thermometer
Time	Seconds (s) Minutes (min)	Stopclock (can be analogue or digital)
Mass	Grams (g) Kilograms (kg) 1 kg = 1000 g	Balance (usually top pan balances and electronic)

Enzyme experiments and the scientific method

What is the scientific method?

When scientists are faced with a problem, they tackle it using the **scientific method**. This starts off with an **observation**; for example, a farmer might notice that all his cows have stopped producing milk. The next step is to produce a **hypothesis**, a possible explanation for the observation (perhaps the cows' diet has been changed). Following this hypothesis, **predictions** are made, such as: *adding more protein pellets to the cows' feed will increase their yield of milk.* Then **experiments** are designed and carried out to test whether or not the predictions are true. The **data** (results of the experiment) are analysed and **conclusions** drawn. These conclusions will allow the experimenter to accept or reject the original hypothesis.

An illustration of the scientific method

In an experiment, apparatus is used to measure the effect of changing one factor (variable) on the value of a second factor (variable). For example, the experiment illustrated below is designed to test the hypothesis: *temperature affects the activity of catalase.*

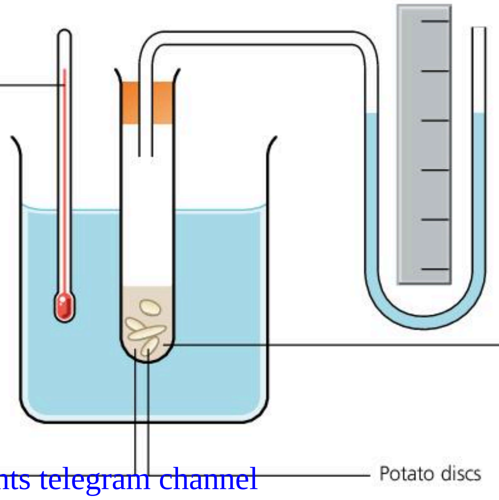
Catalase is an enzyme that catalyses the breakdown of hydrogen peroxide:

hydrogen peroxide ⟶ oxygen + water

Catalase is present in potato tissue. Discs of potato are put into a solution of hydrogen peroxide. The catalase breaks down the hydrogen peroxide into water and oxygen, and
the oxygen passes into the manometer. The changing level of the manometer fluid shows how much oxygen is being produced, and gives
a measure of the activity of the enzyme. The rate of oxygen production is measured at different temperatures.

An identical **control** experiment is also set up, in which the input variable (the temperature) is not changed. This confirms that the changes in temperature, and not an unknown variable, are causing the changes in enzyme activity. A control experiment ensures that the experiment is a **fair test**, and that the data collected is valid.

If the experimenter suspects that an error has been made, part of the experiment may be **repeated**. Taking a series of results and calculating the mean gives more accurate results than taking just one set, as any single inaccurate result then has less effect on the overall results.



Dealing with data: recording results

Raw data are gathered in a table during the experiment. They may then be manipulated (converted into another form), and are often displayed as a graph to allow the experimenter to draw conclusions from the results.

Put units in the column heading, not beside each number.

Raw data independent variable in left-hand column

Manipulated data derived from the raw data. For example, the mean of three readings would be manipulated data.

Temperature / °C	Time taken to produce $5 cm^3$ of oxygen / s	Rate of oxygen production / cm^3 per s
20.00		
26.25		
–		
30.75		

Present numerical data
- in decimal form
- to the same number of decimal places
- as true numbers, e.g. 0.7 not .7

Do not leave blanks: use – for a missing value and 0 for zero.

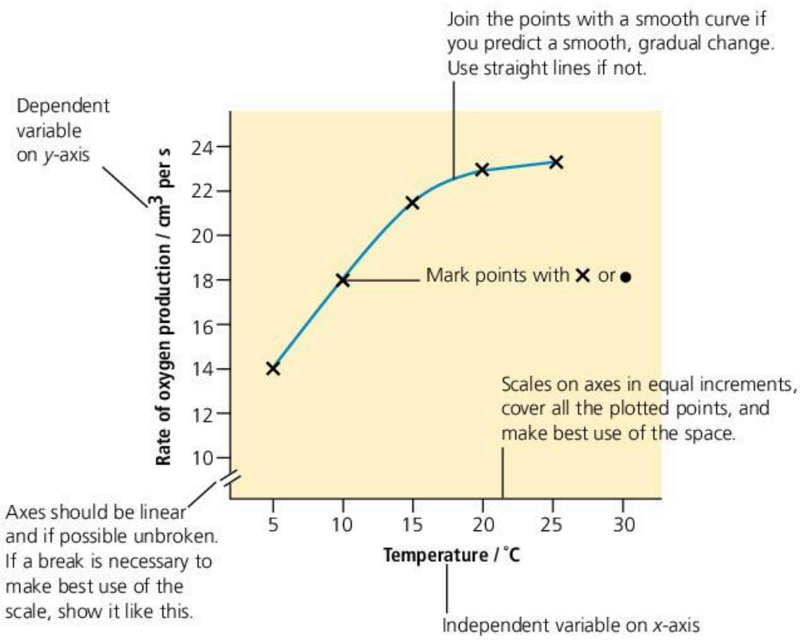
▲ Results are recorded in a table during the experiment. Give an informative title, such as: *The effect of temperature on the activity of catalase.*

Drawing a graph

A graph is a visual representation of data which often helps to make a relationship more obvious.

Evaluating an experiment

Scientists often look back at the results of their experiments and the methods used to gather them. This **evaluation** process is an important part of the scientific method because the scientist needs to be sure that the techniques and apparatus used have given the most reliable results before he or she draws conclusions from them.



Q

1 Using the apparatus shown opposite, a student investigated the effect of temperature on the activity of the enzyme catalase. Here are the results:

a Copy and complete the table by calculating the rate of oxygen release.

b Present the data in the form of a graph.

c Explain the shape of the graph.

Temperature / °C	Time taken to evolve $10 cm^3$ of oxygen / s	Rate of oxygen release / cm^3 per s
15	40	
25	20	
35	5	
45	20	
55	40	
65	120	
75	No gas evolved	

Mathematical skills

Accuracy, precision and reliability

Accurate data can be obtained by:

- repeating measurements to calculate a mean
- using a different measuring instrument, and checking that readings are the same
- using measuring instruments with finer gradations.

Precise data can be obtained by:

- using measuring instruments with finer gradations – use a stopwatch to measure reaction times (not the clock on the classroom wall) or a pH meter rather than litmus paper.

Errors and anomalies

- **Errors** can be random (usually the result of poor technique – not carrying out the experiment consistently) or systematic (consistent technique, but repeating the error such as inaccurate reading of a scale).
- **Anomalous results** do not fit in with the pattern of the other results. A large sample size will allow anomalous results to be easily spotted in the data set. They can then be discarded, leading to a more accurate calculation of the mean.

Significant figures and decimal places

- **Significant figures** refer to the number of important single digits in a value, often a measurement. All non-zero digits are considered significant. For example, 37 has two significant figures (3 and 7), while 567.89 has five significant figures (5, 6, 7, 8 and 9).
- Zeros to the *left* of the significant figures are not significant. For example, 0.00048 has two significant figures: 4 and 8.
- **Decimal places** refer to the number of digits after a decimal point in a number. For example, 34.65 is a number to two decimal places.

It is important that any manipulated data (for example, a calculated mean) is presented to the same number of significant figures as the input data (for example, a series of measurements of the same quantity).

A common error in answering numerical questions is to rely on a calculator – this may give an answer to six significant figures when the measurements were only made to two significant figures, often because of the limited scales of the measuring instruments.

For precise and reliable data

- Repeat and calculate a mean.
- Use measuring instruments with appropriate scale divisions.
- Make sure that the experimental method is the same each time a reading is made.
- Discard anomalous results

Planning an investigation or experiment

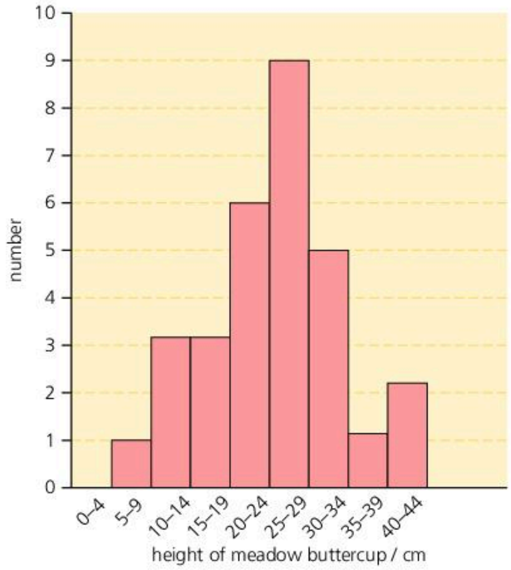
All experiments are basically the same – they must be designed to collect **valid data**.

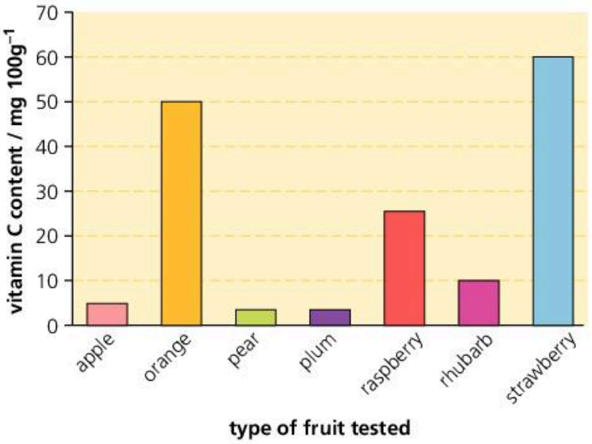
- Identify the independent variable – the one that is to be changed.
- State how the independent variable is to be changed (which apparatus, for example).
- Identify the dependent variable, and state how it will be measured or observed.
- Identify other variables that might affect the experiment, and suggest how these fixed variables can be controlled.
- Suggest the number of repeat measurements to be made, and the calculation of mean values.
- Suggest how results will be recorded and how they may be displayed in a graph or chart.
- Suggest any safety precautions that should be taken.

Histogram

- Used when plotting the distribution of continuous data.
- Shows range of continuous variable (**height of buttercup** in the example on the right) on *y*-axis and **number/percentage within range** (number in this example) on *x*-axis.
- Each range is drawn in a block. Blocks are drawn in order of increasing or decreasing data.
- Blocks should never overlap, e.g. 25–29, 30–34, 35–39 is correct but 25–30, 30–35, 35–40 is not.
- The blocks should be of the same width.
- The blocks should be touching.

Continuous variables are usually the result of the combined effects of genes and the environment.





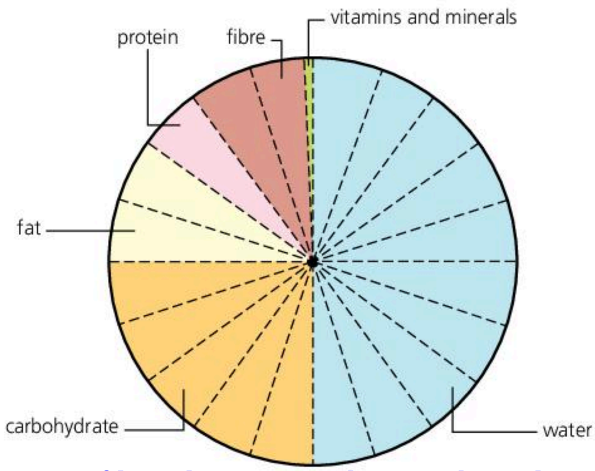
Bar chart

- Drawn when one of the variables is non-numerical.
- The non-numerical variable (**type of fruit** in this example) is on the *x*-axis and the numerical variable (**vitamin C content** in this example) on the *y*-axis.
- The blocks should be the same width, and can be in any order.
- The blocks should **not** be touching – the blocks are not related to one another.

Categoric variables are usually the result of the effects of genes alone.

For all forms of graphs and charts:

- label axes with quantity
- add units if the data is numerical
- separate the quantity and units with a solidus (/), e.g. vitamin concentration / mg per 100 g of tissue (**never** use a solidus as part of the unit, e.g. mg/100 g of tissue).



Pie chart

- Data displayed as proportions of the whole data set.
- The proportions are displayed as **sectors** of a circle (which represents the whole data set).
- The sectors should begin at 'noon', i.e. the twelve o'clock position.
- The sectors should be drawn in rank order, with the largest first.
- Charts should preferably not contain more than six sectors.

An example would be the proportions of the different components of a meal.

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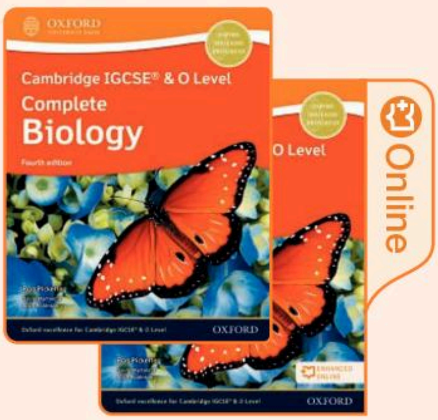

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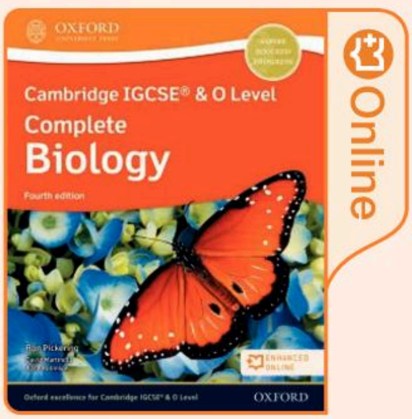

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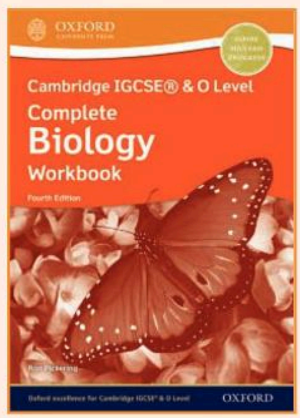

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