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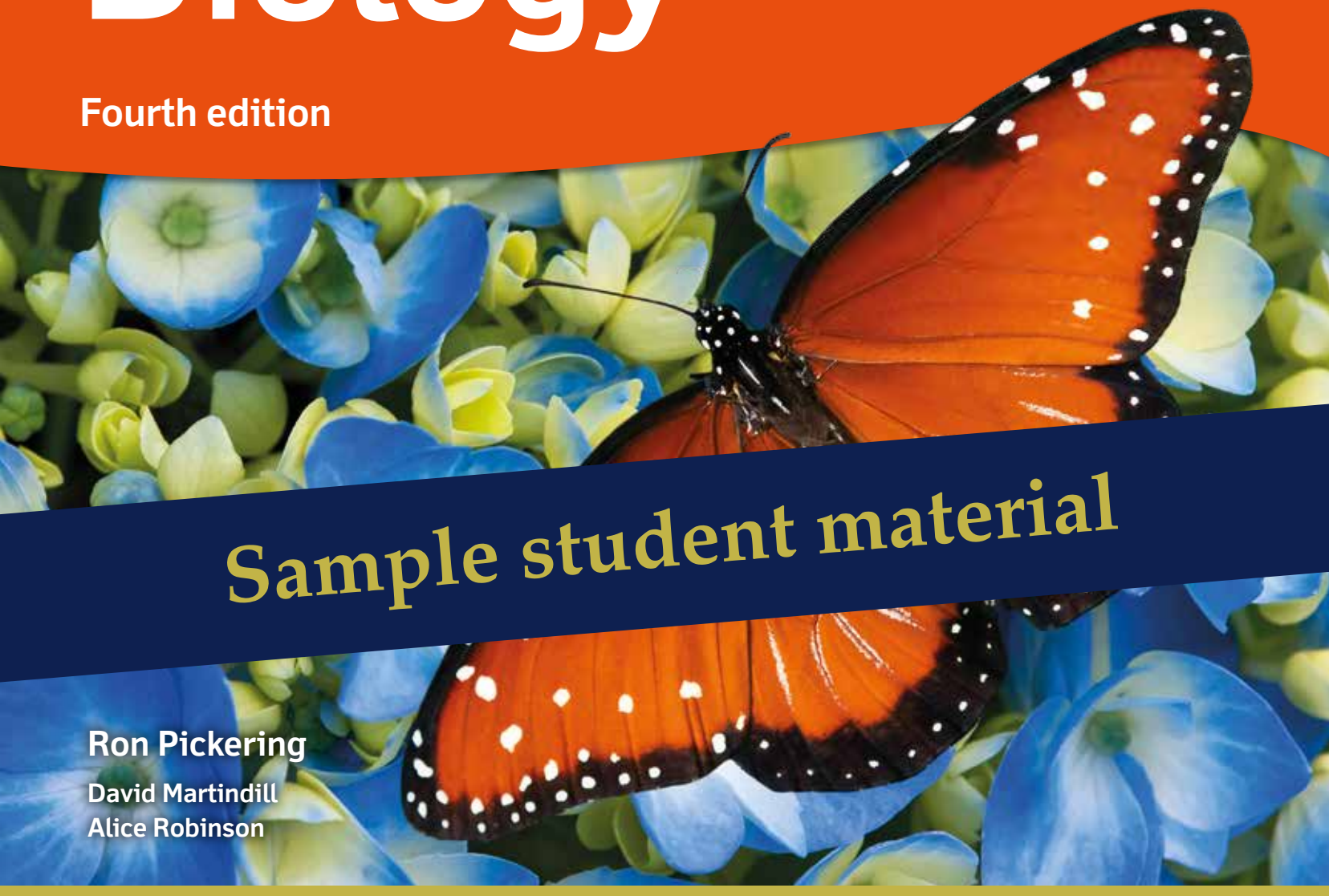
Fourth edition



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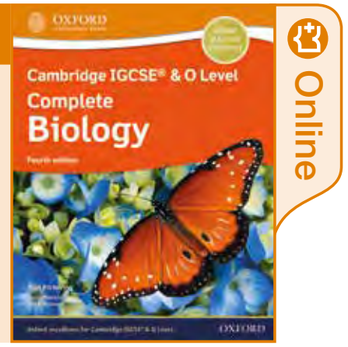

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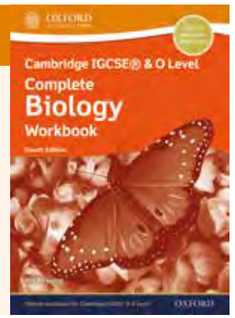

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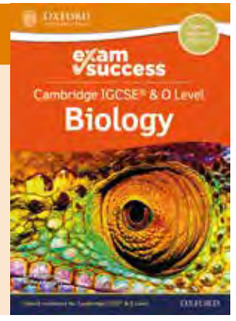

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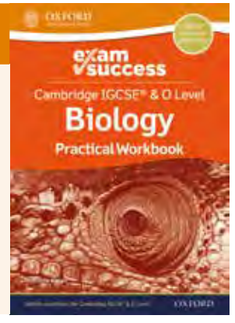

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1.1 Biology is the study of life and living organisms

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 238). 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.

E For example, classification is important in

- **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

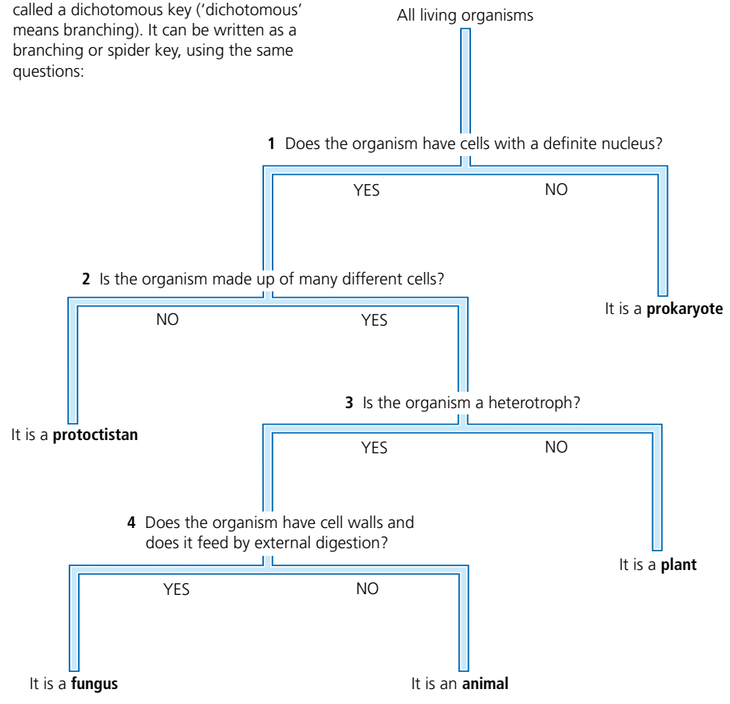
Taxonomists (people who study classification) place organisms into groups by asking questions about their characteristics, such as 'Does the organism photosynthesise?' or 'Does the organism contain many cells?'. A series of questions like this is called a **classification key**. Examples of such keys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

E 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
Prokaryote
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').

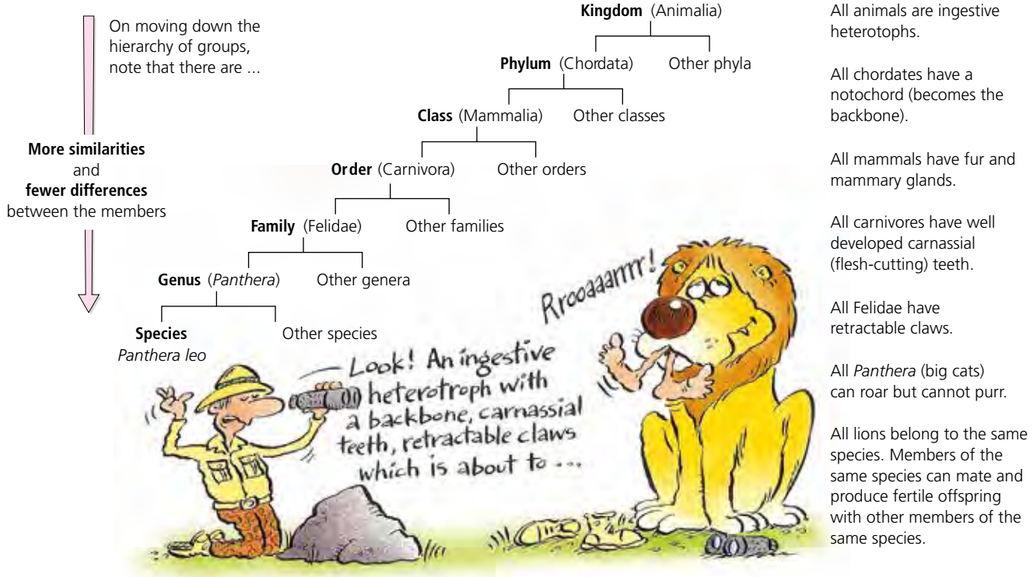
E New species today may be classified based on characteristics such as protein structure, chromosome number or gene (DNA or RNA) sequence, which Linnaeus knew nothing about. Each organism, even each individual, has its own DNA profile. Scientists can compare the DNA profiles of different species.

E 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 214) because there has been less 'evolutionary time' for mutation to change these base sequences.



▲ The hierarchical classification of the lion

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

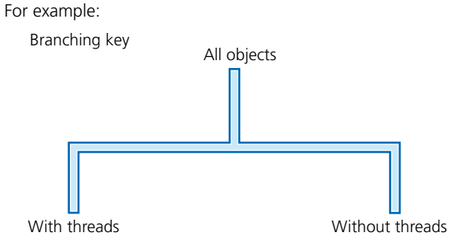
   - **b** Suggest why many biologists believe that respiration is the most significant characteristic of a living organism.

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:



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

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 below.

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:

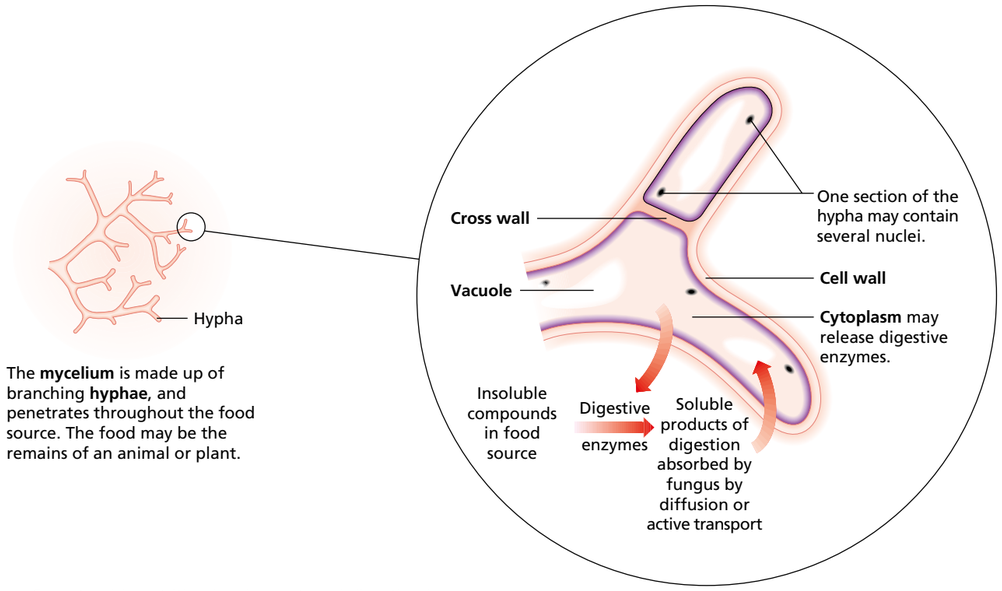
- a moist environment, so that they can absorb the soluble products of digestion of their food source in solution
- a warm environment, so that enzymes can work at their optimum temperature
- a nutrient source to provide the raw materials and energy required for growth.

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 254)
- mould fungi consume food which might otherwise be eaten by humans (see page 254)
- 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 276) are entirely dependent on the activities of yeast, for example.



▲ Saprotrophic nutrition involves external digestion by enzymes

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

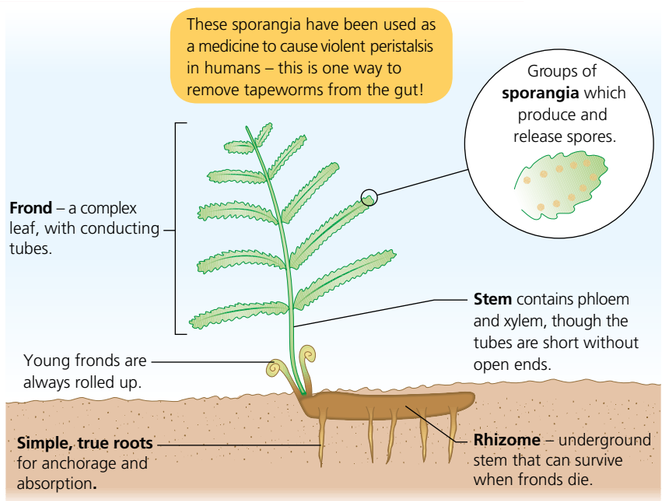
As **autotrophs**, plants manufacture food molecules from simple, inorganic sources by the process of photosynthesis using light as a source of energy. Plants all **contain the light-absorbing pigment chlorophyll** (or similar molecules which perform the same function) inside cells which **have a definite 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 have complex leaves, vascular tissues and true roots. They reproduce by producing spores.

Ferns

Ferns are much better adapted to life on land than either mosses or algae. 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.

Angiosperms

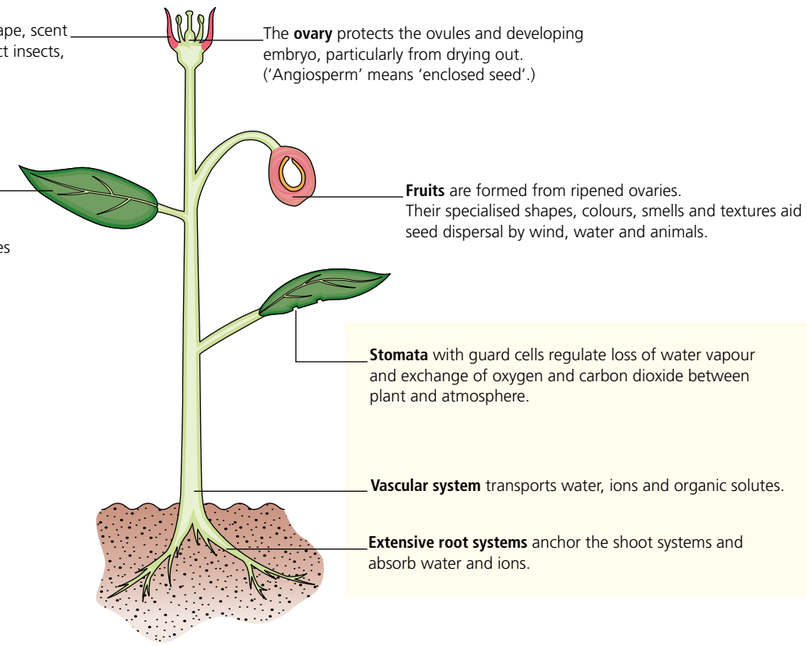
The angiosperms or flowering plants are the most successful of plants – they have evolved into many species and have colonised almost every available habitat. More than 80% of all plants are angiosperms (plants with enclosed seeds). Many features of the lives of flowering plants are covered elsewhere in this book (see pages 46–59, 86–93, 170–173 and 178–187, 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

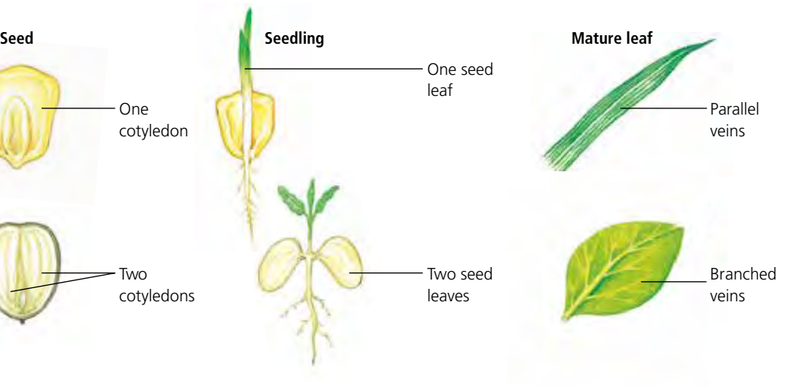
There are two major subgroups within the angiosperms. In one group, there is a single cotyledon in the seed (see page 185) – these are the **monocotyledons**. In the other group, there are two cotyledons – these are the **dicotyledons** (eudicotyledons). There are other differences between monocotyledons 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

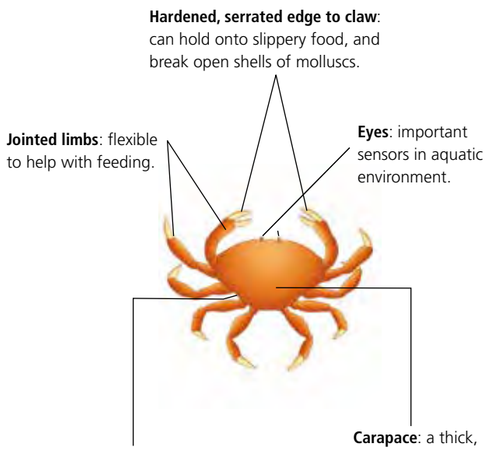
The arthropods are the most numerous of all animals, both in terms of the number of different species and the number of individuals in any one species. The insects are arthropods that show an interesting adaptation in their life cycle called **metamorphosis** that allows them to use the resources of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

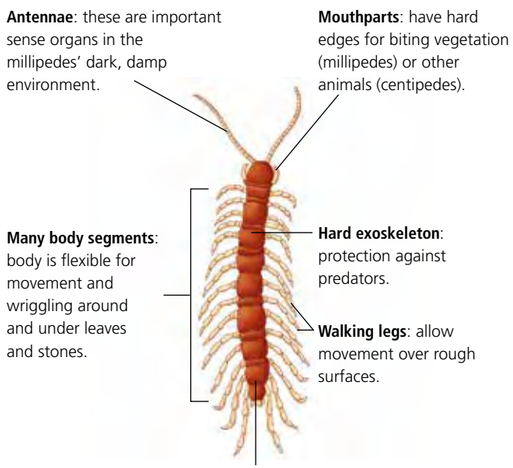
	Insects	Spiders
Body sections	3	2
Legs	3 pairs	4 pairs
Wings	Usually 2 pairs	None
Eyes	Compound	Simple

Crustacea

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

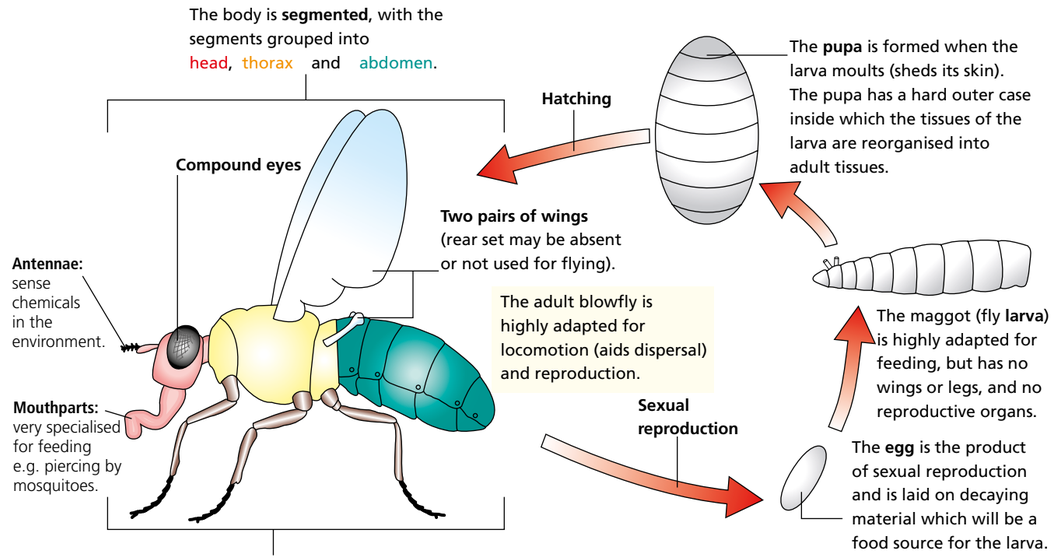


Myriapods



Insects

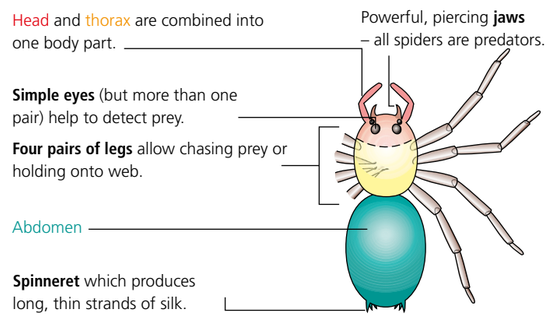
e.g. blowfly, mosquito



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 _____. _____ and 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

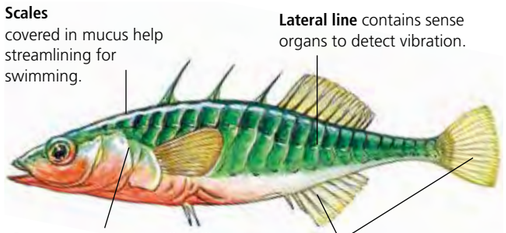
OBJECTIVES

- 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

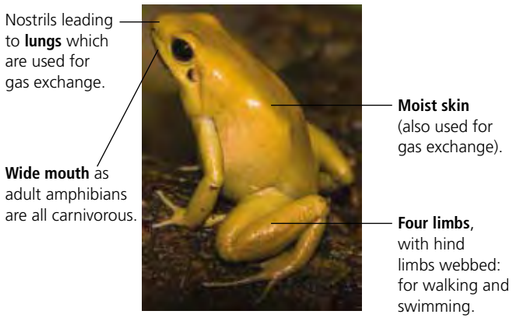
If asked to name an animal, most people would probably name a mammal because these are the most familiar animals to us. Mammals are just one class of the phylum **Chordata**. The chordates are often called the **vertebrates**, although strictly speaking there are a few chordates that are not vertebrates. 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.

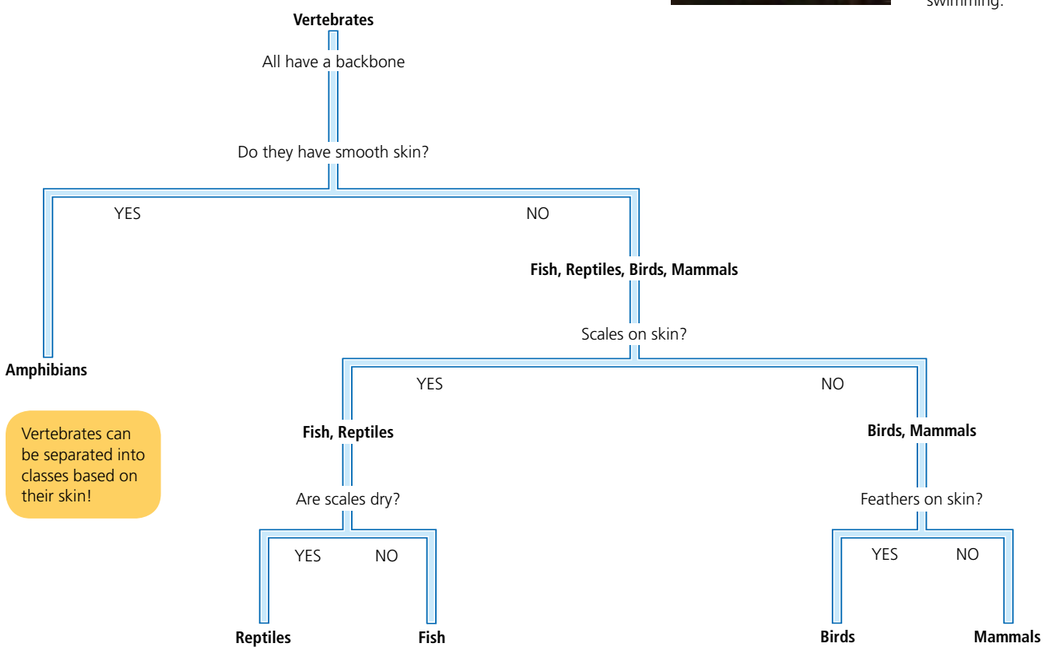
There are five classes of vertebrates, which, like the members of the Plant Kingdom, show gradual adaptations to life on land. The classes are **fish**, **amphibians**, **reptiles**, **birds** and **mammals**.

Fish

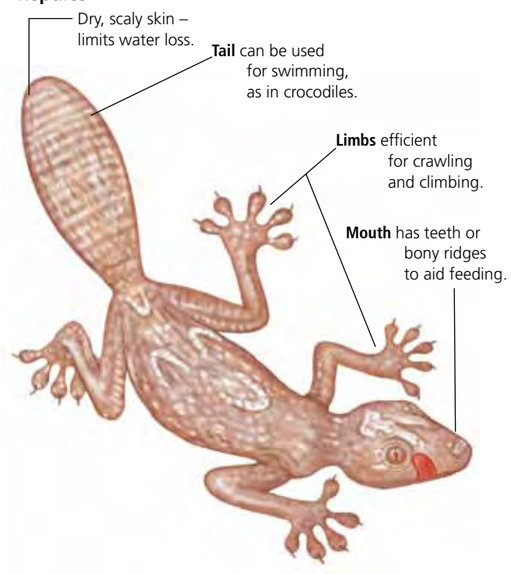


Amphibians



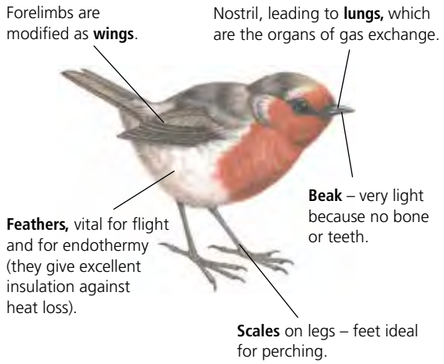


Reptiles



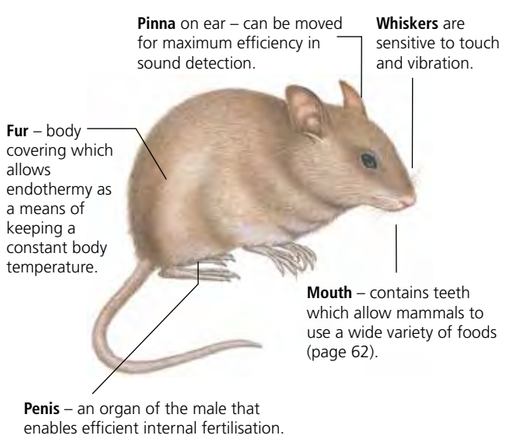
▲ The crocodile has the typical dry scaly skin of reptiles. The eyes on the top of its head and its sharp, pointed teeth adapt it for catching prey in water.

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

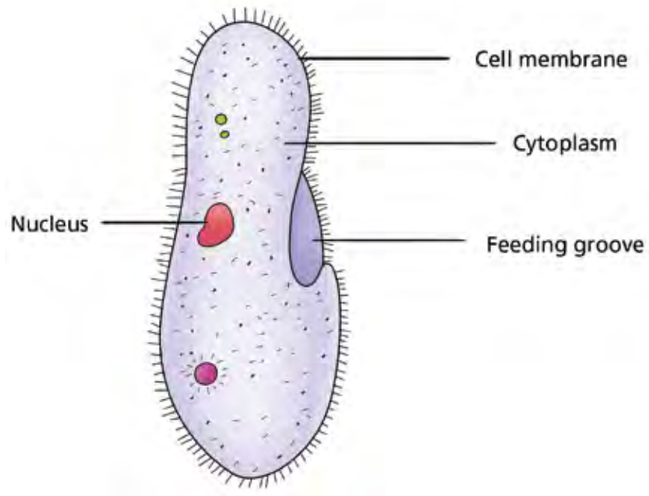
- To know the structure of a protoctist
- To know the structure of a bacterial cell, an example of a prokaryote
- To know the difference between a protoctist and a prokaryote

Tips!

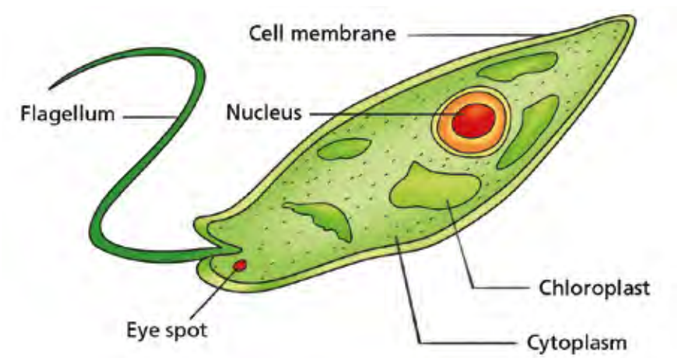
Remember: if a unicellular organism has a nucleus, then it is a protoctist and *not* a prokaryote.

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

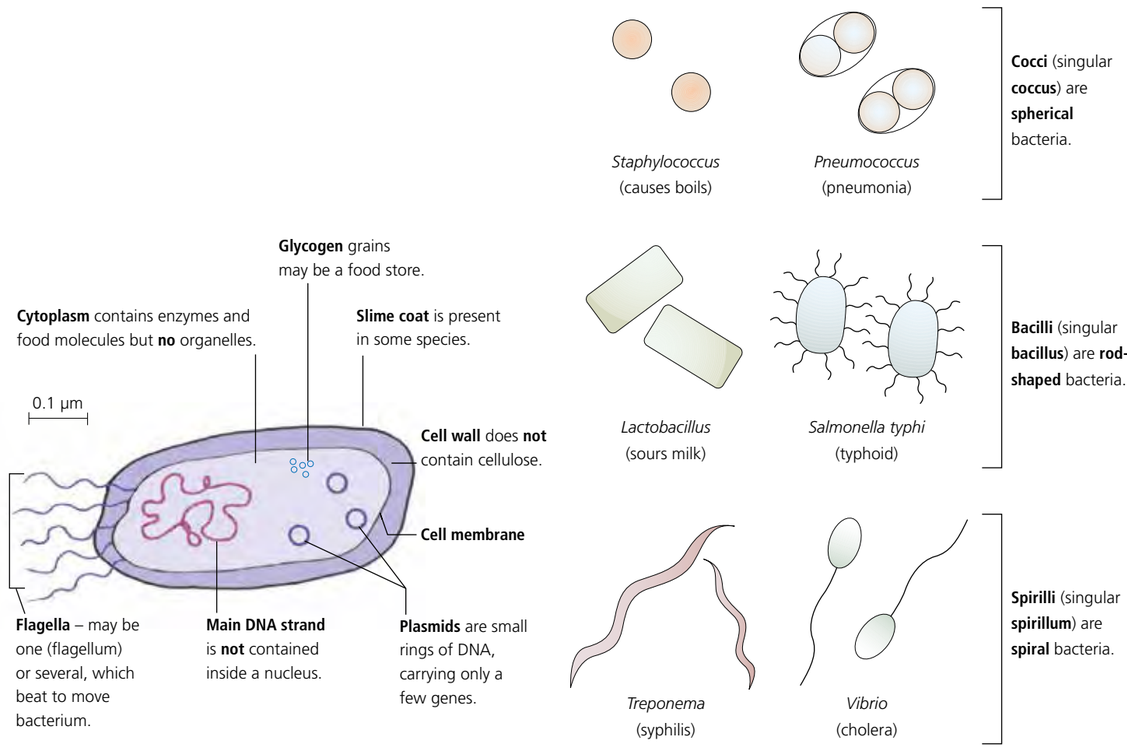
Bacteria are examples of prokaryotes.

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 268).



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

▲ Bacterial shapes

1.8 Viruses

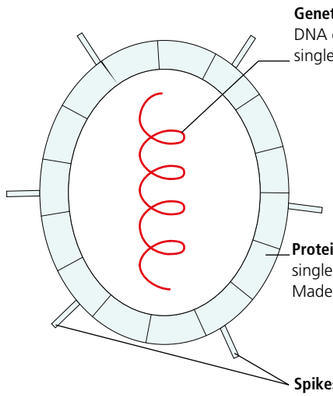
OBJECTIVES

- 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 268.

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**.

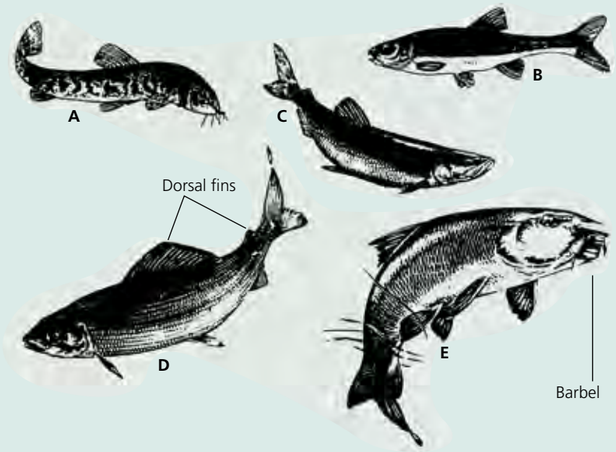
Group	Description of characteristics
a spider	**1** cells with a definite cell wall but no chlorophyll
b insect	**2** produces spores and cells contain chlorophyll
c fungus	**3** two body parts and eight jointed legs
d fern	**4** body is made of a single cell, with a clear nucleus and cytoplasm
e protoctist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

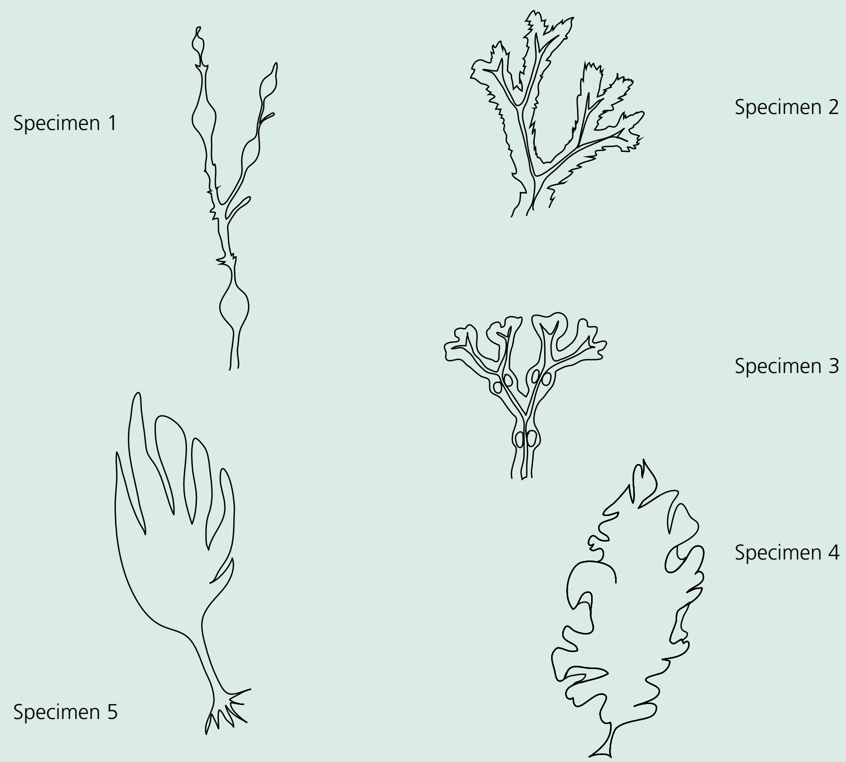
5 Use the key to identify the five fish shown in the drawings. Write down the letter of each fish and its name. [4]



Key		
1. One dorsal fin	2	
Two dorsal fins	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*	

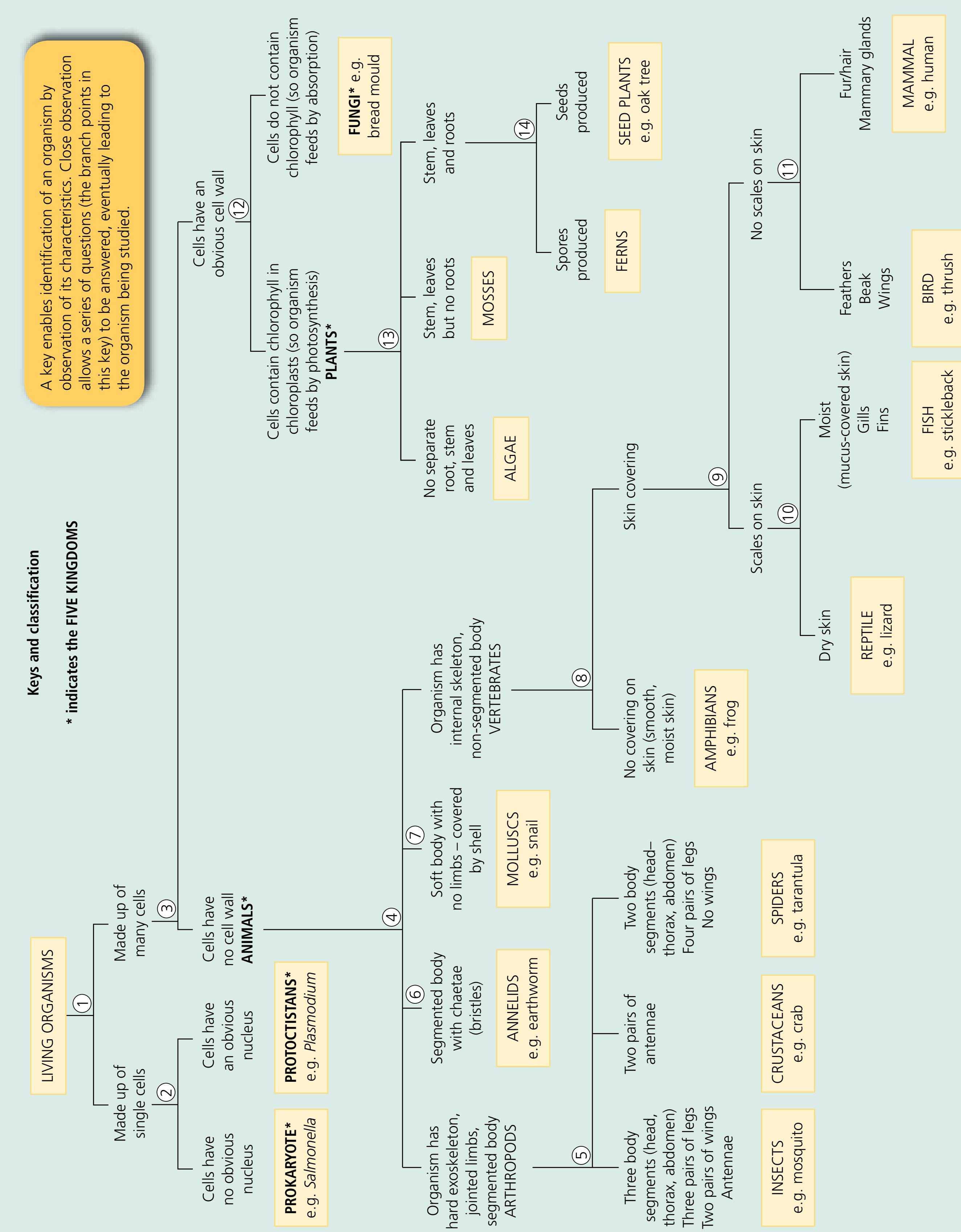
[4]

6 The figure shows five different seaweeds.



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]

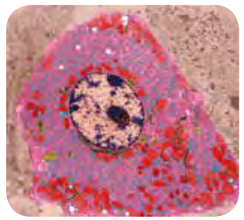


2.1 Organisms are made up of cells

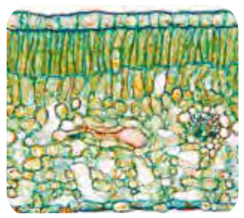
OBJECTIVES

- 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.



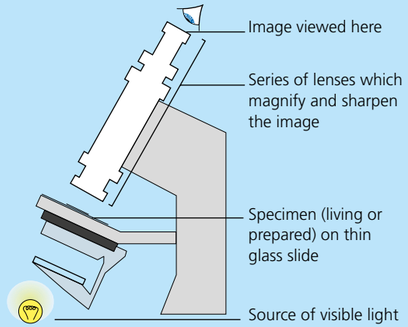
▲ A cell from the inside of the liver, viewed using a light microscope (magnified × 1500 times)



▲ 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**.



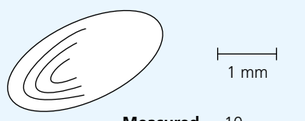
A typical animal cell is about one-fortieth of a millimetre in diameter. This is rather a clumsy term, so scientists use smaller units: one metre (m) contains 1000 millimetres (mm), and one millimetre contains 1000 micrometres (µm). So a typical animal cell is about 25 µm in diameter.

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.

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

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

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

For example, look at this poppy seed.

Mag × 50

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

Tips!

1. Make sure that measured and actual lengths are given in the same units.
2. To help remember the formula:
   Magnification = $\frac{\textbf{M}\text{easured}}{\textbf{A}\text{ctual}}$
3. Core students can use millimetres as a unit. Extended 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.

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.

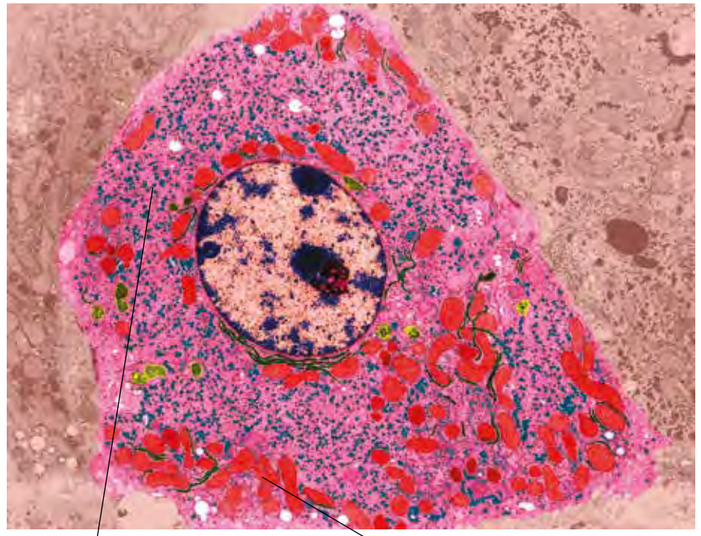
Starch (in the cytoplasm or the chloroplasts) is the storage form of carbohydrates.

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.**

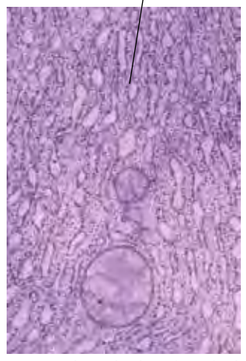
▲ The features of plant and animal cells allow these cells to carry out the basic processes of life. The differences between plant and animal cells are due to the differences in lifestyle between animals and plants, especially to their different methods of nutrition.

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 microscope



▲ Rough endoplasmic reticulum

Rough endoplasmic reticulum is made up of flattened membranes with ribosomes on their surface. These are the sites of protein synthesis (see page 214) and so are common in cells which make many proteins (liver cells, for example).

▲ Mitochondrion

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.

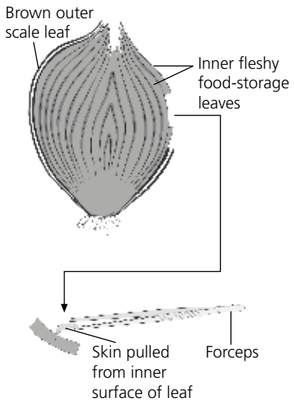
Cell investigations

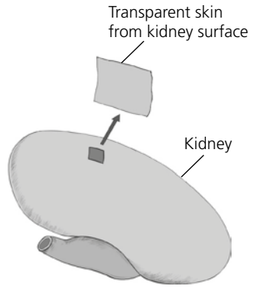
1 LOOKING AT CELLS

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?

An onion cut in half





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*.

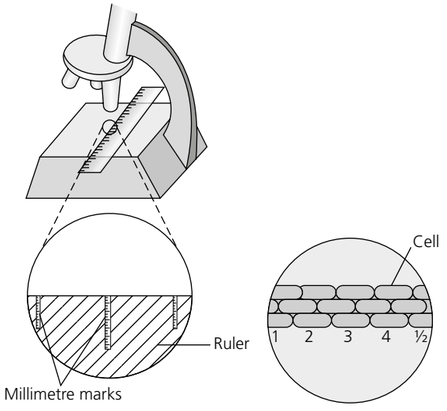
2 MEASURING CELLS

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.

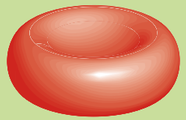
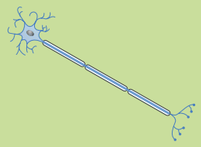
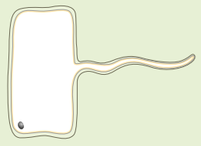
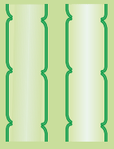
2.2 The organisation of living organisms

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 156)		**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 192). 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 …

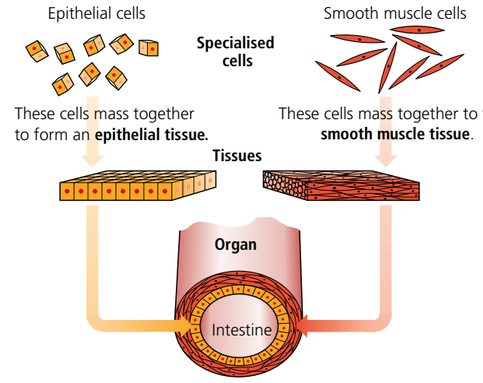
Cells with similar structures and functions are massed together in **tissues**. Some plant and animal tissues are shown in the tables below.

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 …

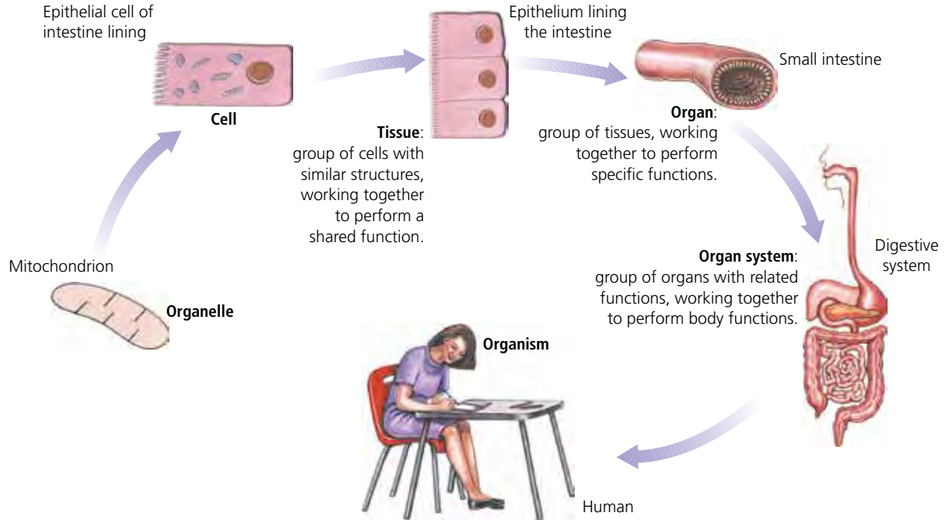
Several tissues may be combined to form an **organ**, a complex structure with a particular function, such as the small intestine shown right.



… 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.

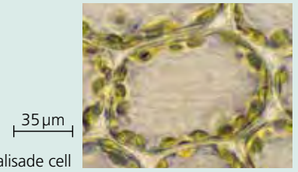
2 Arrange these units of length in order, starting with the largest and ending with the smallest:

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).

Epithelial cell



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]

c Show your working in each case:

i Assume that the epithelial cell is a sphere. Calculate its volume (volume of sphere $= \frac{4}{3}\pi r^3$).

ii Assume that the palisade cell is a cylinder. Calculate its volume (volume of a cylinder = $\pi r^2 h$).

iii How much greater is the volume of the plant cell than that of the animal cell? Express your answer as a ratio. [6]

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]

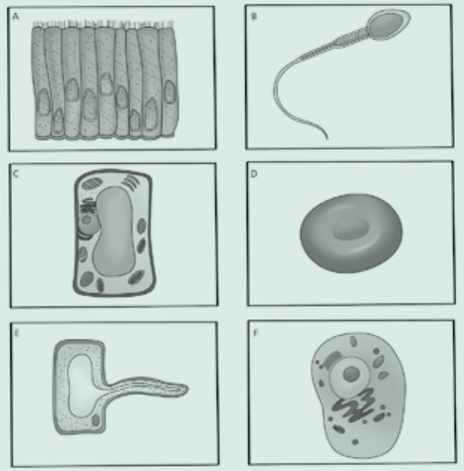
6 The following diagrams show six cells. One of the cells transports oxygen in the blood. This cell does not contain a nucleus.

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.

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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:

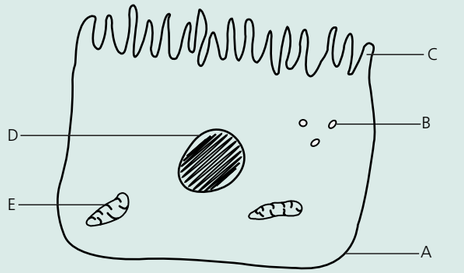
a which structure carries out aerobic respiration

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]

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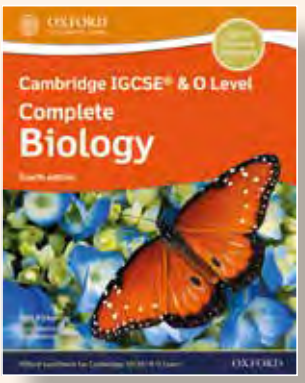

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