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Biology

Revision Guide

Ian J. Burton

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Preface

Revision tips for IGCSE biology students

Understanding IGCSE Biology is not usually a problem, but committing facts to memory can often be a major obstacle to success. Many students are at a loss to know exactly how to set about what seems to them to be a task of immense proportions. I offer the following method, one that I devised myself when, as a student, I was faced with the same problem. It has the advantage, if followed carefully, of improving one's factual knowledge as a result of time spent.

This revision guide is full of important terms and phrases. The method that I offer for learning it is as follows:

1. Take a sheet of file paper and divide it with a vertical line such that three quarters of the sheet is on the left of the line.
2. Read a page of the revision text and, each time you come to an important word or phrase, think up your own simple question to which that word or phrase is the answer.
3. Write these simple questions on the left hand side of your sheet of file paper, leaving a space between each, and number them. Continue on further sheets of paper if necessary.
4. If there is a diagram in the text, then draw a quick sketch of the diagram on the left-hand side of your sheet with numbered label lines vertically above each other extended towards the right-hand side of your sheet.
5. When you have reached the bottom of the page of text, close the book and see how many of the answers you can write down on the right hand side of your sheet. When you have attempted all answers, check them against the text. You will probably be surprised at how well you do, but since you wrote the questions, carefully phrased around the required answer, perhaps it is not so surprising after all.
6. Continue until you have a list of questions and answers to the section you are trying to learn.
7. Take a second sheet of paper (folded if writing would otherwise show through it) and use this to cover the answers. Test yourself again, writing your answers on the folded sheet, and continue this until you are able to score over 80%. (You can, of course, set your own target. Some will not be content until they can score 100%.)
8. File away your Question/Answer sheet for further revision at a later date.
9. Continue this process systematically until you have, effectively, a full set of revision notes for later use.
10. In the last few weeks before the examination, it is better to revise by reading the text of this book carefully, section at a time. Concentrate on every sentence, making sure you understand what you have read. It is so easy to get to the bottom of a page in a book and realise that your mind was elsewhere as you were reading it and, as a result, nothing registered at all. If that happens, be honest with yourself. Go back to the top of the page and start again.
11. In the last few days before the examination, your Question/Answer sheets should now prove invaluable for last-minute consolidation of your facts.

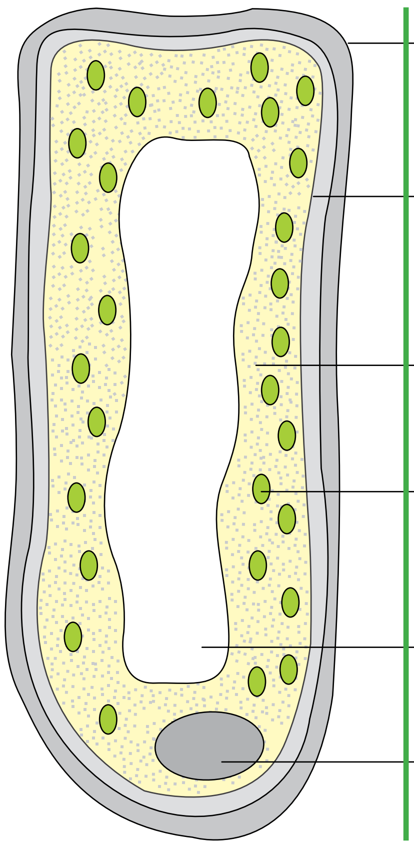
It cannot be stressed too strongly that examination results depend on knowledge. It is important that you have a very good grasp of simple knowledge to do well, and interpretation questions rely heavily on a sound knowledge of the subject matter.

The advantage of this revision method is based so firmly on the student phrasing the questions to which he or she will already know the answer that it would defeat the object if more than a short example of the technique were given. The success of the method relies only on the student following the technique carefully. It does work, but you must be prepared to spend the necessary time. You may even enjoy the experience!

Example of a Revision Sheet, based on information in this revision guide:

1. What word is used for organisms containing only one cell?	unicellular
2. Give an example of a one-celled organism.	a bacterium
3. What word is used for organisms made of many cells?	multicellular
4. What structure controls the passage of substances into and out of a cell?	cell membrane
5. In what state must all chemicals be before they can enter or leave a cell?	in solution
6. What is the jelly-like substance where chemical reactions occur in a cell?	cytoplasm
7. What is the correct term for the chemical reactions in a cell?	metabolic reactions
8. Whereabouts in a cell are chromosomes found?	the nucleus
9. What do chromosomes contain?	genes
10. Of what chemical are chromosomes made?	DNA
11. What makes up protoplasm?	cytoplasm +nucleus
12. What is the space in the centre of a plant cell?	vacuole
13. What does the space in the centre of a plant cell contain?	cell sap
14. What is the name of the box in which a plant cell is contained?	cell wall
15. What chemical is this box made of?	cellulose
16. Name the green structures in photosynthesising cells.	chloroplasts
17. What pigment do they contain?	chlorophyll

Here is how you can test yourself on the labels to a diagram.



As the examination approaches and a greater amount of time is spent on revision, it is usually more productive to set aside a certain time each day for revision. Do not allow yourself to be persuaded to do anything else during that time.

Work **on your own** with **no distractions around you**. Some people say they can work better listening to music. If that really is so in your case, then keep the music quiet and, at least, it may shut out other distractions!

You may find it helpful to make a calendar by dividing a piece of paper into a space for each day during your revision period before the examination. Then you can divide the syllabus into the same number of parts as there are days for revision and enter one such part per day on your calendar. In this way you will know exactly what you are going to revise on each day. Your day's revision will not be complete until you have revised everything on your calendar for that day.

People vary as to how long they can work at a stretch. It is important to have a break from time to time (again, preferably, the same time each day). When you stop, set yourself a time to resume your revision **and stick to it**.

It would indeed be a pity if, armed with a sound factual knowledge, you then failed to use that knowledge effectively in the examination. You may find the following advice useful:

Teacher's tips for answering examination questions

1. It can **never** be said often enough: **read the question**. You must answer the question asked, not any other. It is probable that, on first reading, you feel worried that you can't answer it. You may think you have never learnt that particular topic. But, wait a moment, then read it again and you will often be surprised how much more sense it makes the second time!

2. Do not omit facts simply because you consider them too obvious to mention. They will often be credited.
3. The space provided for your answer on the question paper is a guide to how long your answer should be. Don't waste time or space writing irrelevant material.
4. Make sure that you do not contradict yourself. You are unlikely to get credit for a correct statement when you have also stated the contradiction.
5. If a question involves the interpretation of a graph, try to include some numerical information read from the graph and, if they are available, remember to include the appropriate units.

Finally, good luck with your revision. This method can work. I know, because it did so for me!

Ian J. Burton

How to use this book

Learning outcomes

By the end of this chapter you should understand:

- The characteristics of living organisms
- How to use the binomial system for naming organisms
- How living organisms are classified
- The characteristics of some vertebrates
- The characteristics of some invertebrates
- Viruses, prokaryotes (bacteria), protoctists and fungi
- The construction and use of a dichotomous key

Learning outcomes – set the scene of each chapter, help with navigation through the book and give a reminder of what's important about each topic.

Supplement material – indicated by a bold vertical line. This is for students who are taking the Extended syllabus covering the Core and Supplement content.

Terms – words in bold indicate important terms and definitions that are explained clearly in each topic.

Tips – quick suggestions to remind you about key facts and highlight important points.

Glossary terms – terms in green can also be found in the Glossary

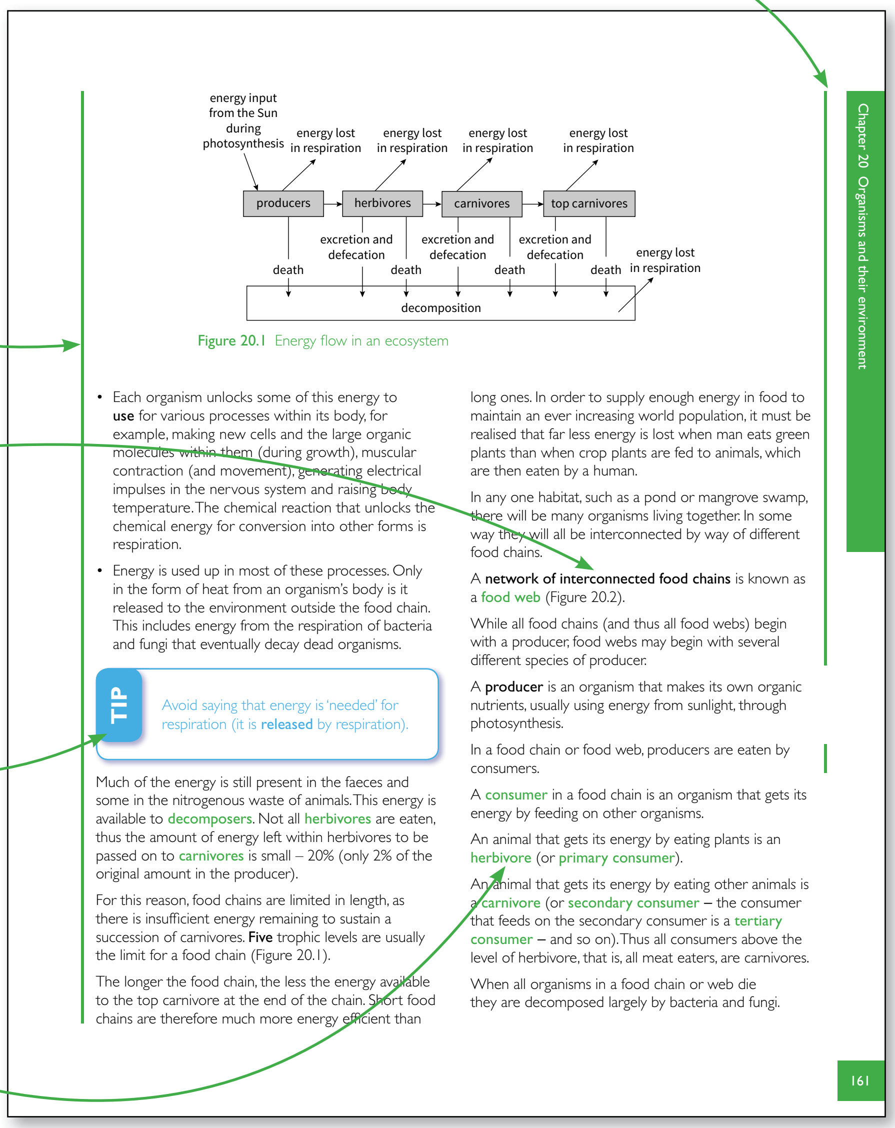


Figure 20.1 Energy flow in an ecosystem

- Each organism unlocks some of this energy to **use** for various processes within its body, for example, making new cells and the large organic molecules within them (during growth), muscular contraction (and movement), generating electrical impulses in the nervous system and raising body temperature. The chemical reaction that unlocks the chemical energy for conversion into other forms is respiration.
- Energy is used up in most of these processes. Only in the form of heat from an organism's body is it released to the environment outside the food chain. This includes energy from the respiration of bacteria and fungi that eventually decay dead organisms.

TIP

Avoid saying that energy is 'needed' for respiration (it is **released** by respiration).

Much of the energy is still present in the faeces and some in the nitrogenous waste of animals. This energy is available to decomposers. Not all herbivores are eaten, thus the amount of energy left within herbivores to be passed on to carnivores is small – 20% (only 2% of the original amount in the producer).

For this reason, food chains are limited in length, as there is insufficient energy remaining to sustain a succession of carnivores. **Five** trophic levels are usually the limit for a food chain (Figure 20.1).

The longer the food chain, the less the energy available to the top carnivore at the end of the chain. Short food chains are therefore much more energy efficient than long ones. In order to supply enough energy in food to maintain an ever increasing world population, it must be realised that far less energy is lost when man eats green plants than when crop plants are fed to animals, which are then eaten by a human.

In any one habitat, such as a pond or mangrove swamp, there will be many organisms living together. In some way they will all be interconnected by way of different food chains.

A **network of interconnected food chains** is known as a food web (Figure 20.2).

While all food chains (and thus all food webs) begin with a producer, food webs may begin with several different species of producer.

A **producer** is an organism that makes its own organic nutrients, usually using energy from sunlight, through photosynthesis.

In a food chain or food web, producers are eaten by consumers.

A consumer in a food chain is an organism that gets its energy by feeding on other organisms.

An animal that gets its energy by eating plants is an herbivore (or primary consumer).

An animal that gets its energy by eating other animals is a carnivore (or secondary consumer – the consumer that feeds on the secondary consumer is a tertiary consumer – and so on). Thus all consumers above the level of herbivore, that is, all meat eaters, are carnivores.

When all organisms in a food chain or web die they are decomposed largely by bacteria and fungi.

Chapter 20 Organisms and their environment

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PRACTICAL

A demonstration of the effects of a lack of nitrates and of magnesium ions in a growing plant

Apparatus: 2 small cuttings or seedlings (e.g. sorghum)
2 containers
Cotton wool
Black paper or black polythene
Culture solutions

Method:

Two seedlings or small cuttings, with the same number of leaves, are selected from a quick-growing plant and held in the top of two containers (A and B) using cotton wool as shown in Figure 6.10.

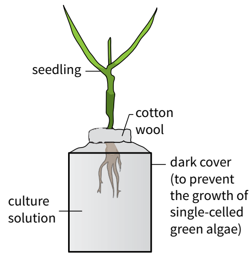

Figure 6.10 Experiment to show effects of a lack of nitrates and of magnesium ions in a growing plant

Practical skills – reinforce your practical knowledge and skills with clear explanations and diagrams.

Make sure you turn the page when you see this arrow in the corner!

Progress check 13.3

1 It is easier to see the outline of an object in dim light by looking to the side of it. Can you explain why this is?

2 Why do you think that a 'round-arm', punch aimed at the side of a boxer's face is often more successful than one aimed straight at him?

Progress check questions – check your own knowledge and see how well you're getting on by answering regular questions.

Worked example

Describe how the structure of a cell membrane is adapted to the process of active uptake.

Cell membranes contain protein molecules called 'channel proteins'. These molecules fit loosely together leaving minute channels between them extending from the outside of the cell to the cell cytoplasm. Suggest how these channel proteins may play a part is the processes of diffusion and osmosis.

Answer

The question calls first for a realisation that there is a special structural feature of the cell membrane making it able to undergo active uptake. That feature is the presence of carrier proteins. Since they have to work against a concentration gradient (there may be a lower concentration of the chemical to be absorbed outside than inside the cell) then energy must be used. All energy within a cell is initially released by respiration and, in this case, the energy is used to move the carrier proteins. First the carrier protein opens to the outside and allows the molecule to be absorbed to attach (bind) to the protein. Only one type of molecule will bind as the site is not suitable for any other molecule. The protein then changes shape again (again using energy) – closing the outer opening, and opening into the cytoplasm of the cell. The molecule is released into the cell cytoplasm, then changes shape again, closing to the inside and opening to the outside ready to bind with another molecule to be absorbed. (Note that the complete cycle of carrier protein movements is described as a continuous process.)

Diffusion requires pores in the membrane before molecules can enter. The channel proteins would provide the pores. However, the size of the pores might prevent larger molecules from entering. Water is a small molecule and thus could enter by osmosis, and the pores may be too small to allow larger molecules to enter – making the membrane semi-permeable.

Chapter 3 Movement in and out of cells

Worked examples – a step by step approach to answering questions, guiding you through from start to finish.

Chapter summary

- You have learnt how cells are involved in the processes of diffusion, osmosis and active transport.
- You have learnt how these processes are important to living structures.
- You have learnt how to demonstrate these processes experimentally.
- You have also learnt about the factors that affect them.

Chapter summary – at the end of each chapter so you can check off topics as you revise them.

Exam-style questions

1 Describe how different substances in a leaf move by diffusion during a 24-hour period. [6]

2 a Figure 3.13 shows a piece of partially permeable tubing, tightly tied at each end, and containing a concentrated sugar solution that is coloured with blue dye. It has been placed in a beaker of pure water.

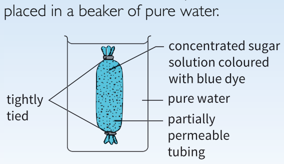

Figure 3.13

Describe what will happen to the tubing and its contents over the next 20 minutes. [3]

b After 20 minutes, apart from what happens to the tubing, the water in the beaker has turned blue. With reference to diffusion and osmosis, explain the results of this experiment. [7]

3 a Explain how a plant root absorbs from the soil:

i) water [6]

ii) essential mineral ions that are in very short supply. [4]

b Suggest why a plant may have great difficulty in absorbing essential mineral ions that are in very short supply in a water-logged soil. [4]

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Exam-style questions – prepare for examinations by completing the Exam-style questions and checking your answers, which are provided at the back of the book.

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Chapter 1

Classification

Learning outcomes

By the end of this chapter you should understand:

- The characteristics of living organisms
- How to use the binomial system for naming organisms
- How living organisms are classified
- The characteristics of some vertebrates
- The characteristics of some invertebrates
- Viruses, prokaryotes (bacteria), protoctists and fungi
- The construction and use of a dichotomous key

1.01 Characteristics of living organisms

All living **organisms** possess the 'characteristics of life'. The one group of organisms that does not show all the characteristics of life is the **viruses**. Thus they are considered to be on the border between living and non-living.

All truly living organisms display the following characteristics:

- **Movement.** This may be the movement of a part of an organism in relation to the rest of its body (such as the movement of an arm or of a shoot tip), or it may involve the movement of the whole organism from one place to another – when it is called locomotion. It commonly involves the contraction of muscles (as in the arm) or cells growing at different rates (as in the shoot tip).

  It is thus defined as **an action by an organism (or part of an organism) causing a change of position or place**.

- **Respiration**. This is a chemical reaction that takes place in living cells. It involves the breakdown of large, nutrient organic molecules (usually **carbohydrates**, such as glucose) to release (not to 'make', 'manufacture' or 'produce') the energy contained within the molecule. The glucose molecule contains energy in the form of chemical energy, which is converted into other forms for use in doing work – such as electrical energy in nerve impulses.

  Respiration is defined **as the chemical reactions in cells that break down nutrient molecules and release energy (for metabolism)**.

TIP

Breathing and respiration are not the same thing. When we take air into and expel air from our lungs, we are breathing. This process is to supply oxygen to the blood that takes it to the cells where respiration occurs.

- **Sensitivity**. This is the ability to detect and respond to changes in the environment (known as **stimuli**). The stimuli may be from the internal environment – for example, the effect of **hormones** on a cell or tissue, or from the external environment – for example, light. The internal environment is a term that refers to the conditions inside an organism. Sensitivity is also the ability to detect or sense stimuli in the internal or external environment and to make appropriate responses.

- **Growth.** It is customary for organisms to start life small in size and gradually become larger with time. Some organisms grow to a certain size then stop, while others grows continuously throughout their lives. Growth is defined as **a permanent increase in size**.

  Growth involves an increase in dry mass by an increase in cell number or cell size or both. Dry mass is the mass of all the components within an object except any water present.

- **Reproduction.** In order to maintain (or increase) their numbers, all organisms have the ability to make more of the same kind.

- **Excretion.** This is the removal from organisms of toxic materials and substances in excess of requirements.

  The material removed includes the waste products of **metabolism** – chemical reactions in cells including respiration.

> **TIP**
> Remember that excretion does NOT include the removal of undigested waste from the intestines since it has never taken part is a chemical reaction within the body's cells.

- **Nutrition.** In order to provide the raw materials and the energy for all the other characteristics of life listed previously, organisms must take in energy-containing materials that are required for growth and development.

  Nutrition is thus defined as **the taking in of materials for energy, growth and development**.

  Plants require light, carbon dioxide, water and ions; animals need organic compounds and ions and usually need water.

> **TIP**
> The first letters of each of the characteristics together spell the name of 'MRS GREN' – a lady well known to students trying to remember the characteristics of living organisms!

1.02 The concept and use of a system of classification

The living universe comprises well over 10 million different types of organism, which are sorted into groups based on common features. This is called **classification** (or **taxonomy**). Those organisms that share many similar features are placed in the same group. Those that share few features are placed in separate groups. The number of shared features between different groups gives an indication of how closely related the groups may be.

The largest groups are called **kingdoms**, of which there are five:

- Prokaryote (Bacteria)
- Protoctist
- Fungus
- Plant
- Animal.

Each kingdom is divided into sub-groups and each sub-group is divided into smaller groups. The last two groups in this succession are the **genus** and finally, the **species**. (The plural of genus is genera.)

A **species** is defined as **a group of organisms that can interbreed (reproduce) and produce fertile offspring**. A species is therefore said to be 'reproductively isolated'.

Organisms within a species are not identical and the differences between them are called **variations**.

The binomial system of classification

'bi' = two and 'nomial' from the Latin *nomen* = name

All living organisms are usually known by the **binomial system**, an internationally agreed system using two names.

These two names indicate the **genus** and the **species** to which the organism belongs.

The genus is always written with an upper-case first letter and the species is written with all lower-case letters. Both names are always underlined when hand-written and appear in italics in print. Both names often have a Latin or Greek origin. Thus, the lion is

<u>Panthera leo</u> (hand-written) and
Panthera leo (in print).

The binomial system is useful because:

- Sometimes, different species in different parts of the world share the same name. When different countries work together on schemes to conserve endangered species, it is vital that they are all considering the same organisms (e.g. there are three different species of arthropod all called 'Daddy Long-legs' in different parts of the world.)
- The same species may have different names in different languages.
- The common name may be misleading (a jellyfish is not a fish).
- All organisms placed in the same genus will share a set of features common only to that group. Knowing the genus, even without actually seeing the organism, therefore tells the biologist a great deal about organisms and about their evolutionary history and relationships (i.e. how recently they separated from one another as they have evolved).

For many years, the classification of organisms was based on studies of their morphology, that is, their outward appearance, for example, the number and type of limbs, or the shape of the flowers produced by a plant. It may include internal morphological features, such as the skeleton (useful when classifying fossils, for example). These studies were also supported by consideration of shared anatomical features, that is, internal features visible as a result of dissection of organisms.

RNA and DNA sequencing

The sequence of chemical bases in the DNA and RNA molecules found in different organisms gives a very accurate indication of how closely related those organisms are. Mutations are constantly changing this sequence and those changes are handed on to the next generation. (See Chapter 18.)

The sequence of bases in the DNA molecule determines the sequence of amino acids in the proteins made by the organism. Thus, a mutation in an organism's DNA leads to a change in its protein structure. The longer ago the two different organisms separated from a common ancestor, the larger the number of mutations will have occurred, and the greater the differences in the sequence of bases there will be in these organisms' DNA and RNA. This, in turn, leads to a greater difference in the amino acid sequence in their proteins.

Data from the analysis of DNA/RNA base sequences is now so accurate that we are able to identify human beings in the same family.

Progress check 1.1

1 Find out what you can about a DNA molecule. How many bases are there?

2 Make sure you know what each of the letters in 'Mrs Gren' stand for.

3 What describes respiration?

- A breathing in oxygen
- B breathing out carbon dioxide
- C releasing energy from nutrient molecules
- D using energy to construct nutrient molecules

1.03 Features of organisms

All living organisms share the possession of a cellular structure, that is, they are all made up of one or more living units called cells.

Cells include the following features:

- Cytoplasm – a jelly-like substance that contains smaller structures (organelles) and in which all the metabolic chemical reactions occur.
- **DNA** – the chemical that forms the genes of the cell that are responsible for the nature of the proteins made within the cell and also for handing on this information to future generations.
- Cell membrane – the living, selectively permeable structure that encloses the cell contents and is responsible for the entry of substances into and exit of substances from the cell.

Two of the most familiar kingdoms in the living universe are the animals and the plants. The distinguishing features of these two kingdoms are as follows:

Animals

- Animals take in (**ingest**) and use organic materials from other living organisms as their source of energy for growth and development.
- Animals are able to move from one place to another (movement known as **locomotion**). (Sponges are exceptions to this as they are animals that remain fixed to the surface on which they live.)
- Sexual reproduction – animals reproduce using specialized reproductive cells (gametes). The male gamete is the sperm and the female gamete the egg cell (or ovum). Few animals reproduce by asexual reproduction.
- Most animals have **diploid** nuclei. That is to say that each nucleus has **two** full sets of genetic material contained in matching chromosomes. Only the X and Y chromosomes (the sex chromosomes) do not exactly match.
- There is no rigid cell wall surrounding the cell membrane.

Plants

- Plants manufacture their own food from carbon dioxide and water, using energy from sunlight that is trapped by the green pigment called **chlorophyll**. The process is called **photosynthesis**.
- Plant cells are surrounded by a rigid cell wall made of **cellulose**. Pressure within the cell caused by the entry of water keeps the cell firm and supplies rigidity to the plant.
- Plants have a complex reproductive cycle, involving various agents to bring about the processes of **pollination** and, later, fruit or seed dispersal.
- Most plants have only a few, but easily identifiable **organs** – leaves, flowers, stems and roots.
- Asexual reproduction, where a parent plant gives rise to may offspring without the involvement of gametes, is relatively common in plants.
- Although most plants in their familiar form have diploid nuclei, very few have the non-matching XY sex chromosomes.

NB Both plants and animals are made up of many cells (they are thus both described as being **multicellular**).

Classification within the animal kingdom

Animals either possess or do not possess a **vertebral column**.

TIP

Avoid the word 'backbone'. It is not a very accurate term as there are many bones in the vertebral column. Those possessing a vertebral column are called **vertebrates**. (Those without are called invertebrates.)

There are five groups of vertebrates:

- Fish
- Amphibians
- Reptiles
- Birds
- Mammals.

Fish

All fish share the following characteristics (Figure 1.1):

- A **skeleton** made of **bone** or of the more pliable material, **cartilage**
- A skin covered with **scales**
- **Fins** that present a large surface area to push against the water when swimming
- **Gills** for extracting oxygen from water and supplying it to the blood.

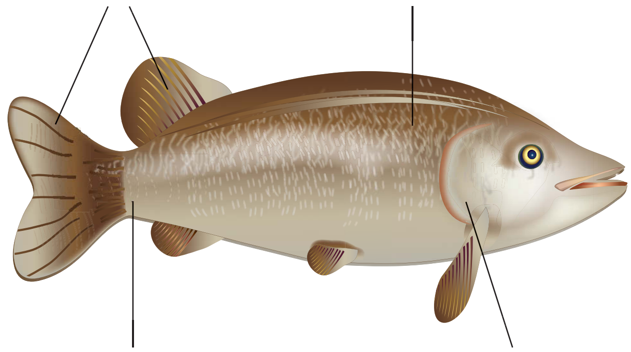


Figure 1.1 A fish

Amphibians

Frogs, toads, newts and salamanders all have the following characteristics (Figure 1.2):

- A **soft skin** with no scales
- **Live** or can survive **on land** but always **return to water to lay eggs**
- Adults have **lungs** to breathe air
- Eggs hatch into larvae called **tadpoles** that live in water
- **Tadpoles** breathe using **gills**
- Tadpoles change into adults by **metamorphosis** (metamorphosis = a change in form and feeding habits from larva to adult).

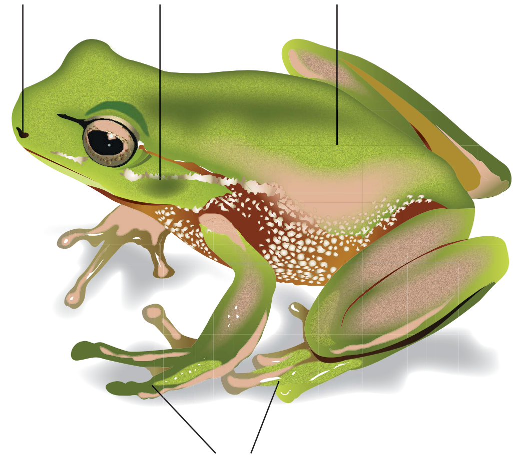


Figure 1.2 An amphibian (frog)

Reptiles

Lizards, snakes, tortoises and turtles all have the following characteristics (Figure 1.3):

- A tough, **dry**, **scaly skin**
- Lay **eggs** with leathery **shells on land**
- Have **lungs** for breathing air.

Figure 1.3 A reptile (crocodile)

Birds

Birds including the flightless birds (such as the ostrich) have the following characteristics (Figure 1.4):

- Skin covered with **feathers**
- Forelimbs modified to form **wings**
- A **beak** for feeding
- Have **scales** on their legs and toes
- **Lungs** for breathing
- Lay **hard-shelled eggs** on land
- Maintain body at a **constant temperature** – usually **above atmospheric temperature**.

TIP

Use the terms 'warm-blooded' and 'cold-blooded' with care. They are not very helpful terms, since some reptiles when basking in the sun may have a blood temperature higher than that of birds.

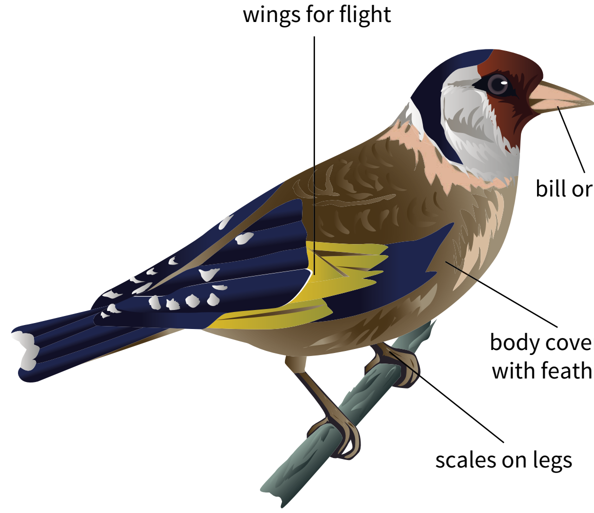


Figure 1.4 A bird

Mammals

Mammals, including kangaroos, cows, whales and human beings, have the following characteristics (Figure 1.5):

- Have **hair** on at least some part of the skin
- Internal fertilisation and **internal development** of the embryo
- Young ones fed on **milk from mammary glands**
- **Lungs** for breathing
- Maintain body at a **constant temperature** ('warm-blooded' – but sometimes not as warm as the surrounding atmosphere).

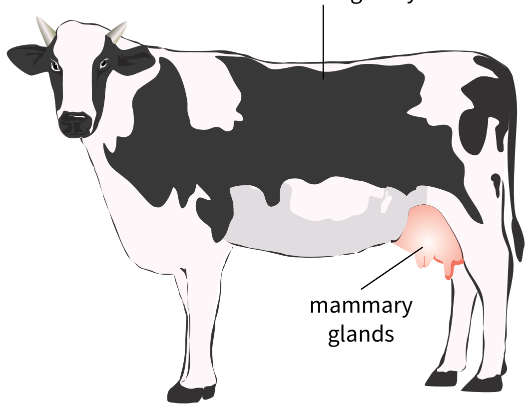


Figure 1.5 A cow

Test yourself by writing at least two characteristic features of each of the five vertebrate classes.

Worked example

a A student is told that an animal he is about to be shown is either an amphibian, a reptile or a mammal. Describe the features common these three groups.

b Describe the external features that would indicate to which group it belongs.

Answer

a Since these are all vertebrates, then the question is asking for vertebrate features shared by the three groups. All vertebrates have a vertebral column (avoid calling it a 'backbone') and a bony skeleton. They will possess eyes, a mouth, two front legs ('arms') and two rear legs. They will all have the following internal organs: lungs, heart, blood vessels, liver, kidneys and an alimentary canal.

b If it is an amphibian, it will have a soft, smooth and most probably moist skin. If it is a reptile, its skin will be tough, dry and will be covered with scales. If it is a mammal, it will have a skin covered, or partly-covered, with hair. It is likely to be warm to the touch. If it is a female, then it will have at least one pair of mammary glands on the front of its thorax (chest).

(Note that part (b) asks about external features. Mention of internal or external fertilization, laying of unprotected eggs in water that hatch into tadpoles (amphibian) or of shelled eggs on land (reptiles) are facts that are not relevant to the question.

The invertebrates

These are the animals that **do not have vertebral columns**. Like the vertebrates, they are divided into **phyla** (the plural of 'phylum'), but such is the diversity of the invertebrates that they include over **30 different phyla**. The largest group (phylum) of invertebrates, by far, is the **arthropods**.

The arthropods

These include several Classes of which the largest and better-known ones are:

- The insects
- The crustaceans (crabs and lobsters)
- The arachnids (spiders)
- The myriapods (centipedes and millipedes).

All arthropods have the following features:

- They have **segmented bodies**.
- They have limbs with clearly visible joints.
- They have an **exoskeleton** (i.e. a skeleton on the outside of the body). (Muscles are attached internally to the exoskeleton – the opposite of ourselves, where muscles are attached externally to our endoskeleton.)
- The exoskeleton is composed of the chemical **chitin**. (See fungi.)

The insects

In addition to the characteristics of arthropods listed, insects have the following features (Figure 1.6):

- The **body** is divided into **three parts** – head, thorax and abdomen. The head, thorax and abdomen are not segments.
- They have **three pairs** of (jointed) **legs** – attached to the thorax.
- They usually have **wings** – one or two pairs attached to the thorax.
- They have **one pair** of **antennae** – attached to the head.
- They have **compound eyes** – each one with hundreds of small units called ocelli.
- **Breathing** is through **small holes** (spiracles), occurring in pairs, one each side of the abdominal segments and two on the thoracic segments. The spiracles lead into branched tubes called tracheae.

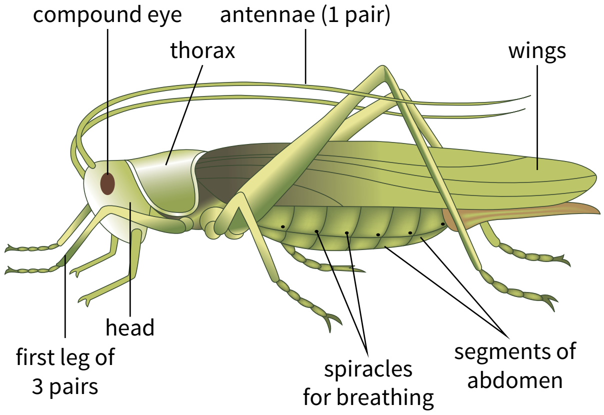


Figure 1.6 An insect

The crustaceans

These live mostly in water (e.g. a lobster) and those that live on land (e.g. some crabs) live in damp places.

As well as the characteristic of arthropods, crustaceans have other features: (Figure 1.7):

- There are **two pairs** of **antennae** that are attached to the head.
- There are **three pairs** of **mouthparts** that, with the antennae, make up the **five** pairs of appendages attached to the head.
- The **exoskeleton** is often strengthened with **calcium salts**. (This protects the animal from predators, but can make the animal very heavy. The additional mass is supported by the water in which most crustaceans live.)
- The head and thorax are often joined to form the cephalothorax.
- The abdomen often has a **pair of limbs** on **each segment**, which are modified for many purposes, but often for swimming.

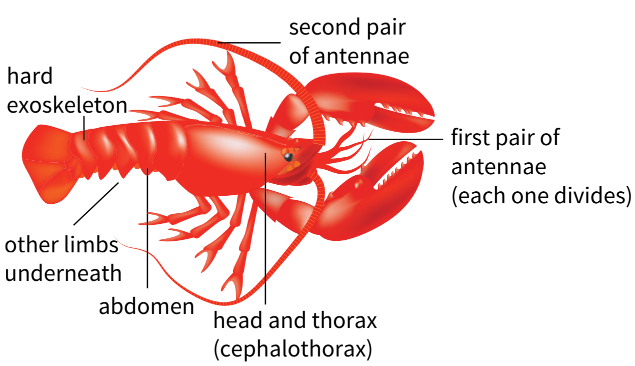


Figure 1.7 A lobster

The arachnids

This group includes the spiders and the scorpions and, as well as those features possessed by arthropods, the arachnids also have the following (Figure 1.8):

- A **body** divided into two parts (the head and thorax, called the cephalothorax, and the abdomen).
- **Four pairs** of jointed legs joined to the cephalothorax.
- **No antennae**.

Figure 1.8 A spider

The myriapods

Myriapod means 'countless legs' and includes the centipedes and millipedes. As well as possessing the features common to arthropods, they also possess (Figure 1.9):

- **One pair** of **antennae.**
- **One** or **two pairs** of **legs** attached to **every segment**.

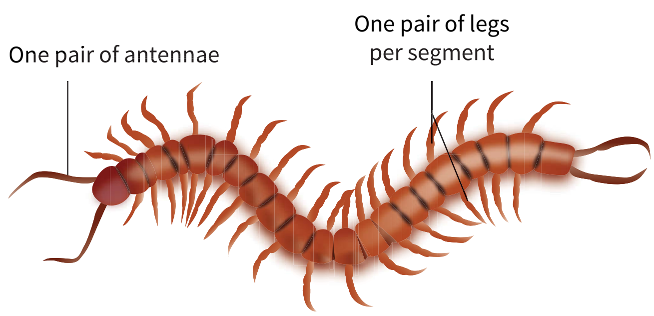


Figure 1.9 A centipede

Progress check 1.2

1 Name the chemical found in the exoskeleton of arthropods.

2 Which animals possess visible body segments?

A birds

B insects

C mammals

D reptiles

Other features present in cells

As well as cytoplasm, DNA and a cell membrane, the cells of all truly living organisms also contain within their cytoplasm structures ('organelles') called ribosomes.

Ribosomes are:

- about 20 nm in diameter (1 nm = 1 millionth of a millimetre)
- the place where amino acids are joined together to make proteins.
- made of protein and the nucleic acid RNA.

Some of the proteins made will be enzymes and amongst the enzymes will be those used in the process of anaerobic respiration. This occurs in the cytoplasm of all cells with the release of a relatively small amount of energy. If oxygen is available within the cell, then the end-products of anaerobic respiration will be further broken down (oxidised during aerobic respiration) to release greater amounts of energy.

The main features used in classifying viruses, prokaryotes (bacteria), protoctists and fungi

Since a microscope is required to study viruses and prokaryotes, protoctists and also for some fungi – such as yeast – they are referred to as microorganisms.

Occupying a position below the plants and animals in the evolutionary tree, the prokaryotes, protoctists and the fungi each form their own kingdoms (see earlier).

Viruses

Viruses are **not truly** living organisms. They have the following main characteristics (Figure 1.10):

1 They are **less than 300 nm** in size – around 50 times smaller than a bacterium. (1 nm, or nanometre, is 1 thousand millionth of a metre). They can be seen only with an **electron microscope**.

2 They contain **nucleic acid** (**DNA** or **RNA**).

3 The nucleic acid is surrounded by a **protein coat** (known as the **capsid**).

4 They can **reproduce** only inside living (**host**) cells.

5 Since they are parasites, they cause disease (i.e. they are pathogenic). Examples of diseases caused by viruses are influenza, measles and AIDS.

6 Viruses are **not** affected by antibiotics.

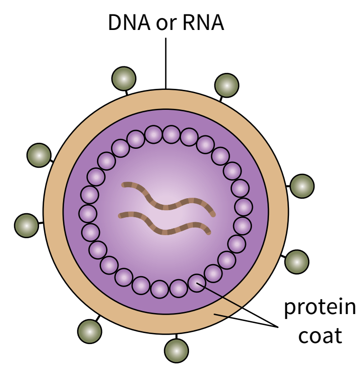


Figure 1.10 A virus

Their extremely small size allows them to be easily transmitted from host to host in very considerable numbers, both by air currents as well as by contact. The protein coat gives the nucleic acid considerable protection. Once inside a living host cell, they take over the host cell's metabolism and use it for their own reproduction. Some viruses (e.g. influenza virus) have a high mutation rate; thus a person may recover from flu, but still fall victim to the next epidemic caused by a mutated strain of the virus to which they have no immunity.

Prokaryotes (or bacteria)

Prokaryotes are truly living organisms, with the following characteristics (Figure 1.11):

1 They have a size in the range of **0.5–5 μm** (1 μm = 1/1000 mm).

2 They are unicellular (made of one cell only).

3 They have **no true nucleus** (their DNA lies 'loose' in the cytoplasm).

NB Some prokaryotes contain a loop of DNA called a plasmid – a feature sometimes employed in biotechnology.

4 They have a cell wall.

5 They may be (pathogenic) parasites or they may be saprotrophs. Some may be involved in nitrogen fixation and **denitrification**. (See the Nitrogen Cycle.)

Pathogenic = disease-causing; Saprotrophic = feeding on dead organic matter causing it to decay.

6 They are **killed** by **antibiotics**.

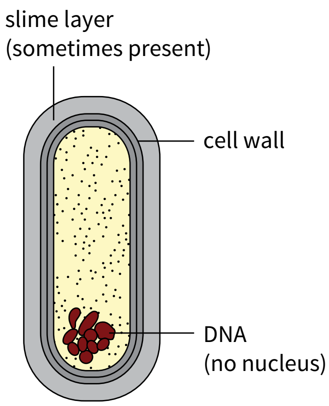


Figure 1.11 A bacterium

They can form resistant spores that are easily carried by air currents and by contact. Once within a suitable **substrate**, they reproduce quickly – dividing every half an hour.

Progress check 1.3

1 In suitable conditions, one bacterium could become how many in 5 hours?

2 What is the purpose of ribosomes?

Protoctista

These are a group of largely microscopic, truly living organisms.

1 They are mostly unicellular but some are multicellular.

2 They are either free-living or parasitic.

3 They have **aerobic** respiration involving mitochondria.

4 Unlike the prokaryotes, structures that lie in their cytoplasm are surrounded by **membranes**.

5 They have true **nuclei** (i.e. they are eukaryotes).

6 They reproduce both sexually and asexually.

7 They are grouped into **three categories**: animal-like (protozoa) that have animal-like nutrition; plant-like (algae) that feed by photosynthesis and fungus-like.

Fungi

Fungi are usually much larger organisms, mostly visible to the naked eye. For example: yeasts, moulds and mushrooms. They have the following characteristics (Figure 1.12):

- They have **no chlorophyll**. (They release enzymes to digest large molecules externally, then absorb the soluble products.) They are thus **parasites** or saprotrophs.
- They have a 'cell' wall made of **chitin**.
- They are usually made of a large number of tubular threads (**hyphae**) intertwined to form a **mycelium**.
- Hyphae are not divided into individual cells. The lining of **cytoplasm** has **many nuclei** and the central space in the hyphae is a vacuole full of (vacuolar) sap.
- If they store carbohydrate, they store glycogen.
- They reproduce by producing **spores**.

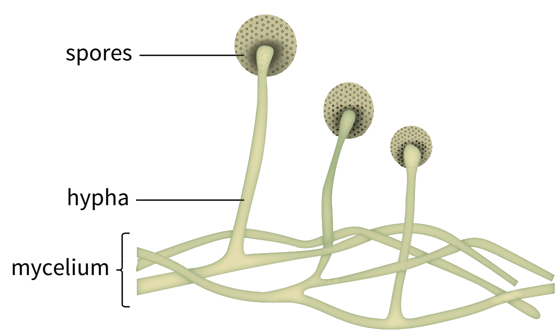


Figure 1.12 A fungus

The branching mycelium of a fungus ensures that the maximum amount of food substance (substrate) is digested as quickly as possible before it dries up, or is digested by bacteria. Fungi are important in the decay of dead, organic matter. Fungal spores are light and easily carried by air currents from one substrate or host to another.

1.04 Classification of the plant kingdom

In plant classification, the term 'division' is often used instead of phylum, but like phyla, divisions are divided into classes. Two major divisions of plants are the **ferns** and the **flowering plants**.

Characteristics of ferns

Ferns have the following characteristics (Figure 1.13):

- They are green photosynthesising plants.
- They have conducting tissue (**xylem** and **phloem**) forming veins.
- They have, often compressed, stems called **rhizomes**.
- They do **not** produce flowers.
- Instead, they produce **spores** that are light and easily carried away by the wind.
- Spores are released from **spore cases** (sporangia) that are found on the lower surfaces of fronds.
- **Frond** is the term for the leaves of ferns.

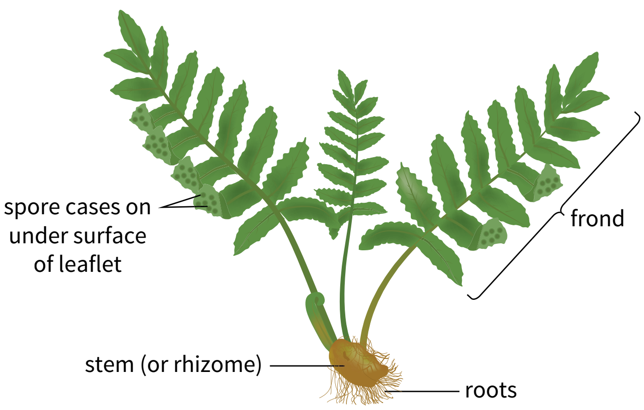


Figure 1.13 A fern plant

By far the largest division of the plant kingdom is the **flowering plants** that are sub-divided into two classes: the **monocotyledons** and the **dicotyledons** (usually shortened to 'monocots' and 'dicots').

(NB The dicots have more recently been divided into several separate smaller groups, the most important of which is called the 'eudicotyledons'.)

1.05 Classes of flowering plant

Monocotyledons

Mono = one, cotyledon = a leaf that forms part of the structure of the seed.

This class includes the grasses, cereals, lilies and orchids, all of which share the following characteristics (Figure 1.14):

- **One** cotyledon inside each seed
- Leaves that are **narrow** and **strap-like**
- Leaves that have **parallel veins**
- A mass of equally sized (**fibrous**) roots
- **Flower** parts that are usually arranged in **threes** (i.e. three petals etc.).

Figure 1.14 A monocotyledon (*Iris*) with thin strap-like leaves that have parallel veins

The (eu)dicotyledons

This class includes cabbage, hibiscus, geranium and sweet potato, all of which have features that differ from those of the monocotyledons mentioned earlier (Figure 1.15).

- **Two** cotyledons are present inside each seed. Not only do these become the first photosynthesizing leaves when the seedling emerges above ground, but generally store food used during the process of seed germination.
- The leaves are **broad**.
- The leaves have **branched veins** usually radiating from a central thicker vein called the midrib with the branches linked by a network of veins.
- **Fewer,** thicker **roots** which are often joined to one long central root called the **tap root**.
- **Flowers** have parts usually arranged in **fours** or **fives**.

Figure 1.15 Flower of a dicotyledonous plant (flax)

Progress check 1.4

1 Which chemical is found in the cell walls of fungi?

A cellulose

B chitin

C glycogen

D protein

2 An organism possesses xylem but never produces flowers. Which of the following will it be?

A a dicotyledon

B a fern

C a fungus

D a monocotyledon

3 An organism has three petals. Which of the following will it be?

A a dicotyledon

B a fern

C a fungus

D a monocotyledon

1.06 Dichotomous keys

Dichotomous means cutting (or dividing) into two.

Organisms are often identified using a book of illustrations. This is possible only if such a book is available, and this is the case only with certain organisms such as common plants, birds and butterflies. Even when such a book is available, identification will rely on the accuracy of the illustration, and it can be a time-consuming process if the organism is at the back of the book! For these reasons, biologists use dichotomous keys.

A dichotomous key consists of a series of questions. Each question has two alternative answers. Depending on which answer is chosen, the user is directed to the next question. Thus, by starting at the first question, and then by a process of elimination, a specimen may be identified.

This process is reliable because it directs the user to observe particular characteristic features. Also it is quicker since, at each question, possible alternatives are eliminated.

Dichotomous keys are usually presented in the following format. The example chosen is a key in its simplest form – namely to identify the kingdom into which an organism should be placed. More detailed keys are used when determining precisely to which species from many within the same genus an organism belongs.

1	Is it unicellular (i.e. made of only one cell)?	Yes	go to 2
		No	go to 3
2	Does it have a nucleus?	Yes	protoctist
		No	bacterium
3	Does it have hyphae?	Yes	fungus
		No	go to 4
4	Does it have cell walls?	Yes	plant
		No	animal

When identifying one organism from amongst a large number of possibilities, the most effective dichotomous key asks questions that each time divides the remaining possibilities into roughly equal halves. In this way, half the possible organisms are discarded at each step.

Progress check 1.5

1. Six different geometrical shapes, identified by the letters A to F are shown in Figure 1.16.

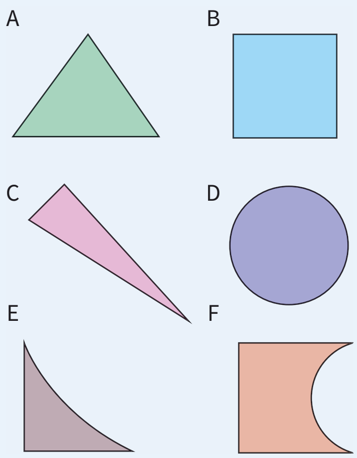


Figure 1.16

Construct a dichotomous key to identify the six shapes.

2. Now construct a key to identify the shapes using different features from those you have used already.

   You should now find that several different keys may be constructed, all of which may be perfectly suitable for the purposes of identification.

Chapter summary

- You now know the characteristics of living organisms.
- You have learnt how to use the binomial system of naming organisms.
- You are able to list the five classes of vertebrate and know how to distinguish between them.
- You have learnt the differences between the microorganisms viruses and bacteria and how they differ from fungi.
- You are now able to write down the names and characteristics of the four phyla of invertebrates and the four classes of arthropods that are described.
- You have learnt the differences between the two classes of flowering plant.
- You have learnt how to use and also to construct a dichotomous key for identifying organisms.

Exam-style questions

1 Figure 1.17 shows six arthropods.

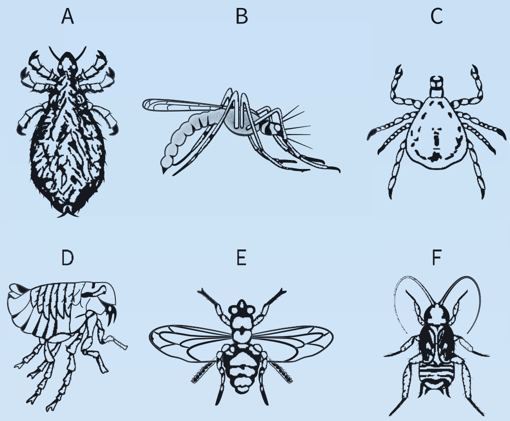


Figure 1.17

Use the key to identify each of the arthropods. Copy Table 1.1 and write the name of each arthropod in the correct box. As you work through the key, put a tick (✓) in the boxes to show how you identified each arthropod.

As an example, the appropriate boxes for arthropod A have been ticked for you.

Key

			Arthropod
1	a	segments on abdomen clearly visible	go to 3
	b	segments on abdomen not clearly visible	go to 2
2	a	3 pairs of legs	*Pediculus*
	b	4 pairs of legs	*Ornithodorus*
3	a	wings present	go to 4
	b	wings absent	*Pulex*
4	a	wings clearly longer than abdomen	*Musca*
	b	wings not clearly longer than abdomen	go to 5
5	a	antennae curved	*Periplaneta*
	b	antennae straight	*Anopheles*

	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b	name of arthropod
A		✓	✓								*Pediculus*
B											
C											
D											
E											
F											

[10]

Table 1.1

2 Figure 1.18 shows a centipede.

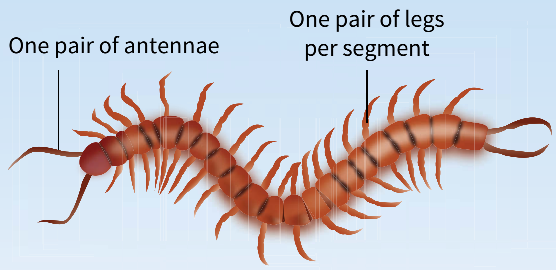


Figure 1.18

The centipede is a myriapod, one of the four groups of arthropod. It is a carnivore that lives on land and, compared with most other arthropods, its outer body covering is thin and permeable.

a Name **two** other groups of arthropod.

For each group, state one feature found only in arthropods of that group. [4]

b Suggest and explain two reasons why centipedes are often found under stones, decaying wood and leaves. [4]

3 a Explain the fact that viruses are almost always harmful to other organisms. [6]

b Describe how viruses differ structurally from bacteria. [5]

Cells

Learning outcomes

By the end of this unit you should understand:

- The structure of animal and plant cells and the differences between them
- How certain plant and animal cells are adapted to the functions they perform
- How cells work together to form tissues, organs and organ systems within living organisms

2.01 Cell structure and organisation

The basic unit of life is the **cell**. The simplest living organisms have one cell only. Such organisms are described as **unicellular**. Bacteria are examples of unicellular organisms. Most other living organisms have many cells. They are described as **multicellular**.

All cells have the following structural features in common (Figure 2.1 and Figure 2.2):

1. **Cell surface membrane:** This surrounds the cell and **controls** the passage of substances into and out of the cell. One of the most important of those substances is water. All other substances that pass through, do so in **solution**.
2. **Cytoplasm:** A jelly-like substance in which the chemical reactions of the cell (**metabolic reactions**) take place and which contains the nucleus.
3. **Nucleus:** This contains a number of **chromosomes** made of the chemical DNA.

NB Cytoplasm and nucleus together may be referred to as protoplasm.

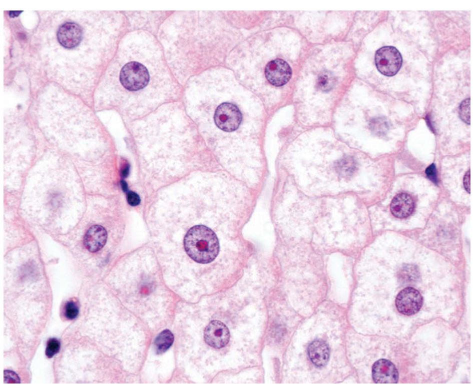


Figure 2.1 Stained liver cells

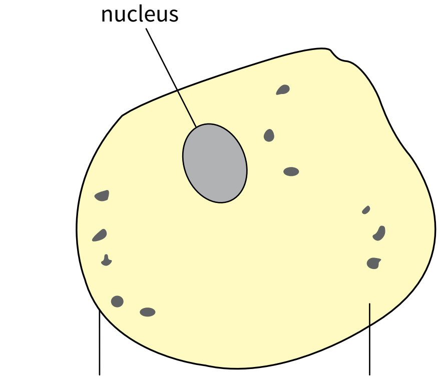


Figure 2.2 Animal cell (liver)

Plant cells have the following additional structures (Figure 2.3):

1. A large, central **vacuole:** a space full of **cell sap** (thus sometimes called the **sap vacuole**), which is a solution mostly of sugars. It is separated from the cytoplasm by the **vacuolar membrane**. (Plant cells undergoing cell division do **not** have a vacuole.)
2. **Cell wall**, which is a 'box' made of **cellulose** that contains the cell.
3. Chloroplasts. These are present only if the cell is involved in the process of **photosynthesis**. These are small bodies lying in the cytoplasm, which are green in colour because of the pigment **chlorophyll** that they contain.

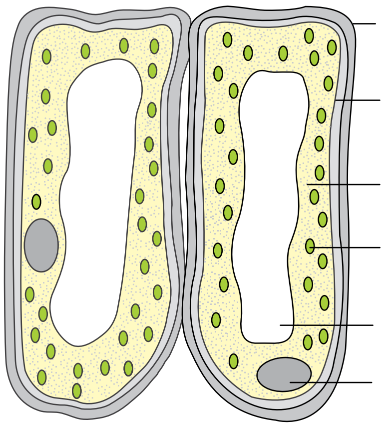


Figure 2.3 Palisade mesophyll cells from a leaf

In plants, the cell membrane is not usually easily visible as it fits tightly against the cell wall.

Progress check 2.1

1 Figure 2.4 shows a cell from the leaf of a plant.

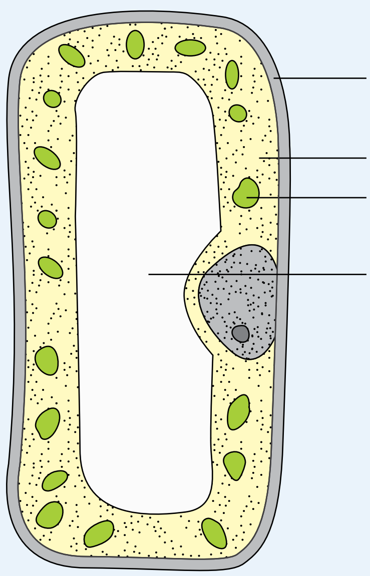


Figure 2.4 Palisade mesophyll cells from a leaf

Which labelled feature is also found in an animal cell?

2 Why do cells from the root of a plant rarely contain chloroplasts?

2.02 How the structural features in a cell are related to their functions

Cell surface membrane

This controls the passage of materials in and out of the cell since it is **partially** (or **selectively**) **permeable**. That means that it allows some chemicals to pass through it but not others. Some small molecules pass through minute pores in the membrane, and the process does not require energy. Other, usually larger, molecules pass through the membrane via specific pathways, and may pass through when there is a greater concentration inside compared with outside the cell. This process does require energy.

Cytoplasm

This is where the chemical reactions of the cell occur such as **respiration** and protein manufacture. It contains a range of small structures called **organelles** for example, the **chloroplasts** in plant cell cytoplasm where photosynthesis and carbohydrate (often starch in plants) storage takes place.

Further examples of structural features inside cells are:

- Mitochondria, the largest of which may just be visible using a light microscope and which are involved in the storage of energy (in the form of ATP) released by respiration (Figure 2.5, 2.6). Although mitochondria are present in almost all cells, they are **not present** in the cells of **prokaryotes**. A mitochrondrion has many folds (called cristae) on its inner walls, and it is on these folds that the process of **aerobic respiration** takes place. It is for this reason that mitochondria are referred to as the 'power houses' of the cells.

Figure 2.5 Photomicrograph of a mitochondrion with endoplasmic reticulum beneath with ribosomes on its walls

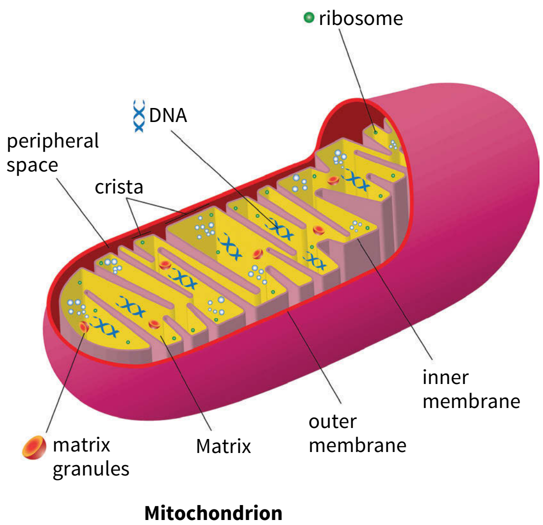


Figure 2.6 Diagram of a mitochondrion

- **Ribosomes** are where amino acids are linked together to form proteins. Ribosomes lie attached to the walls of a system of many-folded small tubes (microtubules) known as the endoplasmic reticulum – often shortened to **ER** (Figure 2.7). The ER runs throughout the cytoplasm of cells. Endoplasmic reticulum with ribosomes attached is known as rough endoplasmic reticulum.
- **Vesicles** are spherical bodies that break away from the endoplasmic reticulum and which contain proteins that have been made by the cell. They are used to transport and, sometimes, export these proteins.

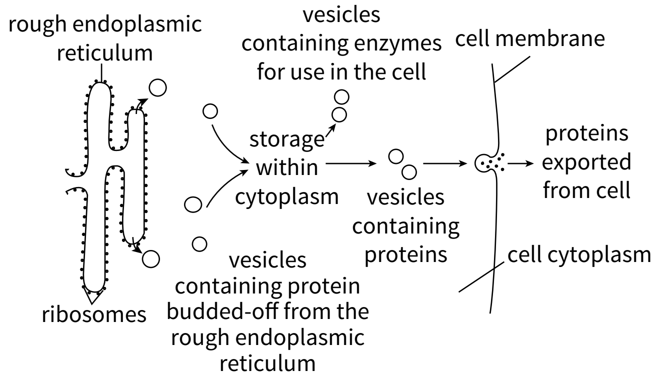


Figure 2.7 Endoplasmic reticulum and vesicles

Mitochondria are present in the largest numbers in cells that release large amounts of energy. For example, those involved in active uptake (absorption) of chemicals and in movement, for example, sperm cells. Ribosomes are made of RNA and protein.

Nucleus

This can be regarded as the organelle that controls the cell's activities. It contains thread-like structures called **chromosomes** that are made largely of DNA.

DNA forms genes that are responsible for programming the cytoplasm to manufacture particular proteins.

When any cell other than those that produce reproductive cells (**gametes**) divides, its nucleus does so by a process called mitosis during which each chromosome forms an **exact replica** of itself. The two cells formed are therefore genetically identical both with themselves and with the original cell.

Cell wall

Plant cells are enclosed in a 'box' of flexible but tough carbohydrate called **cellulose**, which is a **completely permeable** substance. Thus it does not in any way affect materials passing in and out, but it helps the cell to:

- keep its shape
- prevent the cell from bursting as it absorbs water
- maintain a pressure within the cell (turgor pressure) to keep the plant firm and upright.

Sap vacuole

The importance of this structure is to contain a solution more concentrated than the solution in the soil water around the plant. A more concentrated solution has a **lower water** potential and this causes water molecules to enter the plant from the soil by osmosis. (See Chapter 3, Osmosis.)

Similarities and differences between plant and animal cells are shown in Table 2.1.

TIP

Remember that 1 μm = $\frac{1}{1000}$ mm

	Animal cell	Plant cell
Similarities	cell membrane	
	cytoplasm	
	nucleus	
Differences	no sap vacuole	sap vacuole
	no cell wall	cell wall
	no chloroplasts	may have chloroplasts
	never stores starch	may store starch
	around 10–20 μm in diameter	around 40–100 μm in diameter

Table 2.1 Comparison of plant and animal cells

PRACTICAL

Make sure you are familiar with the procedure for preparing animal and plant cells for viewing under a microscope.

1 **To observe animal cells:**

Cut a cube of fresh liver, in section, approximately 1.5 cm square.

Scrape one of the cut surfaces of the cube with the end of a spatula (the end of a teaspoon would do).

Transfer the cells removed to a clean microscope slide. Add one drop of **methylene blue** (a suitable stain for **animal** cells) and one drop of glycerine.

Mix the cells, stain and glycerine together gently and leave for 30 seconds. (This time can be adjusted according to the depth of staining required.)

Carefully place a clean, dry cover slip over the preparation, and then wrap a filter paper around the slide and cover slip.

Place the slide on a bench and press hard with your thumb on the filter paper over the cover slip. The filter paper should absorb any surplus stain and glycerine, and the slide is then ready for viewing with a microscope (medium to high power).

Figures 2.1 and 2.2 show structures that should be visible.

2 **To observe plant cells:**

Peel off the dry outer leaves of an onion bulb.

Remove one of the fleshy leaves beneath.

Preferably using forceps, but fingers would do, peel away the outer skin-like covering (**epidermis**) of the fleshy leaf.

Place three drops of dilute iodine solution on a clean, dry microscope slide (iodine solution is a suitable, temporary stain for **plant** cells).

Transfer a small piece of the epidermis (a 50–75 mm square is large enough) to the iodine solution. (Make sure it lies flat and is completely covered by the iodine solution.)

Carefully place a glass cover slip on top of the preparation, remove any excess liquid with a piece of filter paper and transfer the slide to the stage of a microscope.

The structural features shown in Figure 2.8 should be visible (owing to the large size of the onion cells, it may not be necessary to use the high power of your microscope).

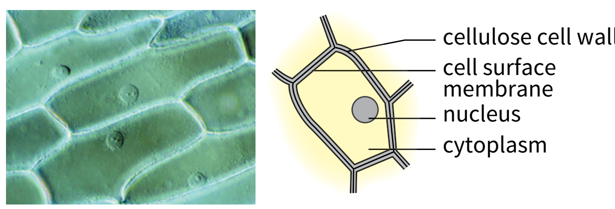


Figure 2.8 Photomicrograph and labelled drawing of onion cells

Progress check 2.2

1 Why are mitochondria referred to as the power houses of a cell?

2 Make a list of those features you would find in a plant cell that are absent from an animal cell.

3 How long is = $\frac{2}{100}$ mm expressed in µm?

2.03 Levels of organisation

Specialised cells, tissues and organs

In unicellular organisms, one cell must be able to carry out all the functions of a living organism. In multicellular organisms, cells are usually modified to carry out one main function. The appearance of the cell will vary depending on what that main function is.

Thus, there is a relationship between the structure and the particular function of a cell.

Examples of this relationship are discussed here.

Ciliated cells

Function

To sweep mucus, in which dust and bacteria are trapped, up the bronchi and trachea towards the throat where it is swallowed.

How they are adapted to this function

Ciliated cells are found lining the walls of the trachea (wind-pipe) in the respiratory tract. Each cell bears a fringe of minute projections (**cilia**). The singular of cilia is cilium.

The cilia perform an upward-beating motion that carries the mucus, made and released by neighbouring cells, upwards like a 'moving carpet'.

TIP

Remember that cilia do not form a network to 'trap' dust and bacteria.

Root hair cells

The tip of a root with its many root hair cells is shown in Figure 2.8.

Figure 2.9 A root tip showing root hairs

Function

The absorption of water and mineral ions (salts) from the soil.

How they are adapted to this function

The outer part of the cell wall of each **root hair cell** (i.e. the part in direct contact with the soil) is in the form of a long, tubular extension (the root hair).

This root hair:

- is able to form a very close contact with the water film surrounding many soil particles and
- it **greatly increases the surface area** of the cell available for uptake of water and ions.

Xylem vessels

Functions

1 To **conduct** water and ions (dissolved salts) from the roots to the stem, leaves, flowers and fruits.

2 To provide **support** for the aerial parts of the plant.

How they are adapted to these functions

Conduction

Xylem vessels are elongated dead cells forming long, narrow tubes, stretching from the roots, via the stem, to the leaves. They are stacked end to end like drain pipes.

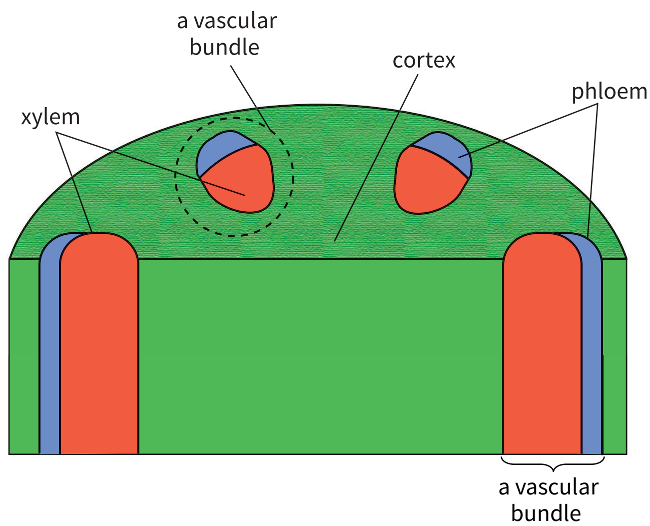
Support

1 Their walls have been strengthened by the addition of the chemical lignin. (As the lignin in the walls builds up, it eventually kills the xylem vessels. There is then no layer of cytoplasm to restrict the flow of water and dissolved salts.)

2 Xylem vessels are part of the vascular bundles (Figure 2.9), which run the entire length of the stems of plants thus resisting bending strains caused by the wind.

TIP

Vascular bundles help to strengthen a stem since they work like iron reinforcements in concrete pillars.



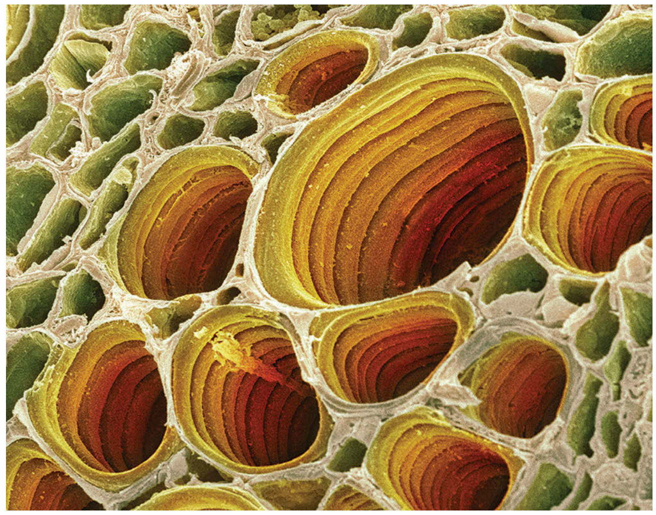


Figure 2.10 3D section of stem showing xylem as part of the vascular bundles and a photomicrograph of xylem vessels

Palisade mesophyll cells

The inner structure of a plant leaf includes two specialised types of cell known as mesophyll cells.

The lower cells are called spongy cells and the upper layer are the palisade mesophyll cells (Figure 2.3). The palisade mesophyll cells form the main **photosynthesising tissue** of the leaf, helped by the fact that they:

- contain the greatest number of chloroplasts
- they are the first to receive the Sun's rays as they enter the leaf
- their chloroplasts are able to move, within the cytoplasm of the cell, towards the upper surface of the leaf to receive more sunlight.

Nerve cells (or neurones)

These may be long, thin cells that carry electrical impulses from the receptor organs to the central nervous system, or from the central nervous system to the organs that are required to respond (the effectors) (see Chapter 13, Figure 13.3). Neurones in the central nervous system, especially the brain, are more compact.

Red blood cells

Function

To carry **oxygen** around the body.

How they are adapted to this function

1. The cytoplasm of red blood cells contains the pigment hemoglobin, which combines (in the lungs) with oxygen to become oxyhemoglobin.
2. They are small (**7 µm × 2 µm**) (Figure 2.11), and there are many of them. This gives them a **very large surface area** for oxygen absorption.
3. They have a **biconcave** shape, increasing their surface area for absorption still further.
4. They are flexible allowing them to be pushed more easily through capillaries.

Points 2, 3 and 4 are also relevant to their other function of carrying carbon dioxide.

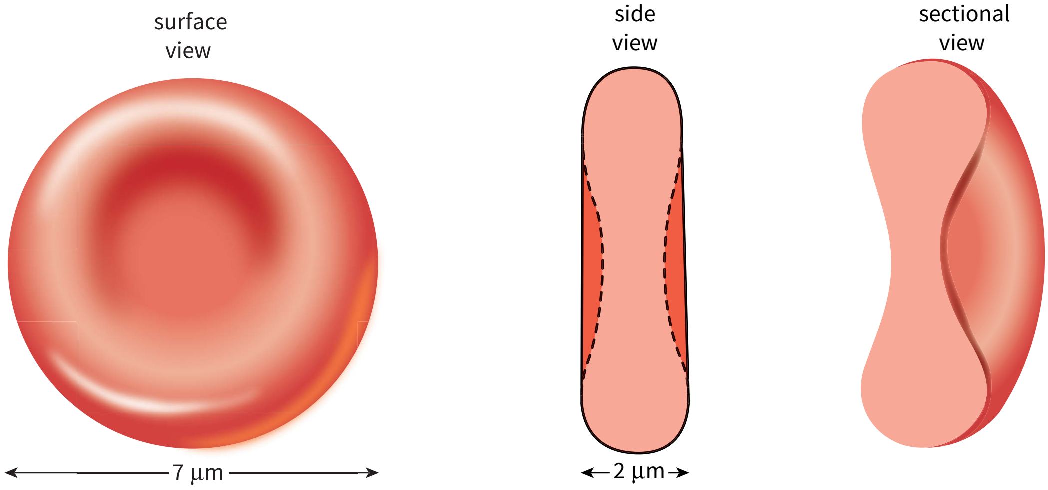


Figure 2.11 Red blood cells

Sperm and egg cells

Together known as **gametes**, these are the cells used in sexual reproduction. They are produced by a form of cell division (meiosis) that halves the number of chromosomes they possess, that is they become haploid. In this way, when they unite at **fertilisation**, the full number of chromosomes (the diploid number) is restored.

The sperm

This is the male gamete, it is made of:

- a head containing the haploid nucleus
- a middle piece that supplies energy for movement
- a tail that beats to provide propulsion as it swims through the female reproductive system to locate the egg cell.

Sperms are released in millions at a time to increase the chances of fertilisation. A human sperm is about 100 µm in length.

The egg cell (or ovum)

This is the female gamete with the following features:

- The haploid nucleus is contained within a large amount of nutritive cytoplasm.
- It does not possess the ability to move on its own, but is moved by the action of cilia and muscles in the female reproductive system.
- It is spherical and much larger than the sperm, measuring between 0.10 and 0.15 mm in diameter.
- Egg cells are released one at a time.

Progress check 2.3

1. In what way are cells in the trachea adapted to carry mucus up to the throat?
   - A They are biconcave in shape.
   - B They contain many fibrils.
   - C They have strengthened cell walls.
   - D They possess many cilia.
2. What features do root hair cells and red blood cells have in common and what common purpose do these features serve?
3. Which cells in a plant leaf have the greatest number of chloroplasts and why is this?

2.04 How cells combine to improve their efficiency

One cell working on its own would achieve very little in an individual plant or animal, thus it is usual to find many similar cells lying side by side and working together, performing the same function.

A tissue is therefore: **many cells with similar structure working together and performing the same (shared) function**.

Examples of tissues: xylem tissue in the vascular bundles of a plant, muscular tissue in the intestine wall of an animal.

Different types of tissue often work together in order to achieve a combined function. **Several tissues working together to perform specific functions** form a structure called an organ.

Examples of organs: the leaf of a plant – an organ for the manufacture of carbohydrates during photosynthesis, the eye of an animal – the organ of sight.

Several different organs may be necessary in order to carry out a particular function. **A group of organs with related functions working together in order to perform a particular body function** is called an organ system.

Examples of organ systems: the sepals + petals + stamens + carpels (i.e. the flowers) of a plant for reproduction; the heart + arteries + veins + capillaries in an animal, i.e. the circulatory system.

An **organism** is a collection of organ systems working together.

The increasing order of cell organisation found within any living organism is thus:

cell → tissues → organs → organ systems → organisms

Progress check 2.4

1 The following are structures found in living organisms:

P the eye

Q the muscles in the intestine wall

R a flower

Which shows the level of organisation in these three structures?

	Tissue	Organ	Organ system
A	P	Q	R
B	Q	R	P
C	R	P	Q
D	Q	P	R

2 Make a list of two different types, other than those mentioned in the text, of cell, tissue, organ and organ system. (Check with your teacher that you have correctly classified you chosen examples.)

Worked example

Explain how the terms cell, tissue and organ may be applied to the structure of a leaf.

Answer

It is easiest to begin with the fact that leaves are made up of a large number of cells. This would then be followed by some different examples of types of cells found in a leaf – for example, palisade cells and, if you have looked up leaf structure, you could include spongy cells, epidermal cells and cells found in the vascular bundles (e.g. in the xylem – which start out as living cells). The answer should then refer to the fact that the cells are modified for different functions – palisade cells contain chloroplasts for photosynthesis and xylem cells become modified for support and conduction.

The cells are found working beside many other similar cells, each one of which is modified in the same way and performs the same function. Such a group of cells forms a tissue – for example, the palisade tissue for making starch during photosynthesis (and the xylem tissue for bringing water and ions into the leaf and for supporting the leaf). A leaf thus contains a number of groups of different cells, each group performing its own job, but with each group performing one of the necessary functions of a leaf. Thus, the leaf is an organ, since it have several tissues working together performing specific functions.

The size of specimens

Biologists deal with specimens with a wide variety of sizes. If a specimen is rare, then a description of it is invaluable to other biologists in particular (and other people in general). A drawing is often the best way to record observations, but such a drawing is of little value if it does not give an indication of the size of the object being observed.

All drawings of biological specimens should, therefore, include a reference to the magnification of the drawing.

TIP

When drawing, measure in mm – avoid cm – so give a measurement as 5 mm rather than 0.5 cm, 50 mm rather than 5 cm.

Clearly state the **linear** dimension measured from the drawing over the matching (linear) dimension measured on the specimen when calculating the magnification, e.g. 42 mm/18 mm = × 2.3.

Remember, if the specimen is large, then the magnification will almost certainly be less than 1.

- Magnification should be written, e.g. × 4.4.
- Don't round off too much, × 4.4 is not × 4.
- No calculated magnification should include more significant figures than the least accurate of the measurements used to calculate it, e.g. 61 mm/14 mm = × 4.4 (not × 4.3571429).
- If the subject is a **photograph** it may also have a **stated magnification** that needs to be taken into account – and shown – in the calculation. Example: a photograph may bear the caption '× 4' thus the measurement taken from the photograph must be divided by four in your calculation, e.g. 14 mm / (12 mm/4) = × 4.7).

(Remember that diagrams and photographs of specimens as seen using a microscope may have dimensions in micrometres (μm) and 1 micrometer = 1000th of a millimetre.)

Chapter summary

- You have learnt the component parts of a cell.
- You have also learnt how plant and animal cells are similar and how they differ.
- You know how cells, tissues, organs and organ systems are related.
- You have learnt how cells are modified to perform different functions.
- You have also learnt what is required when drawing a specimen.

Exam-style questions

1 Figure 2.12 shows two cells.

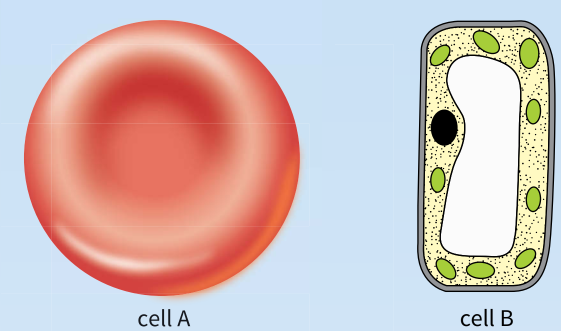


Figure 2.12

a i) State where, in a human, Cell A would normally be found. [1]

ii) Name the chemicals responsible in each case for the colour of the two cells: Cell A and Cell B. [2]

b Using only words from the list provided, complete the statements about Cell B.

air spaces	cellulose
chloroplasts	membrane
mitochondrion	nucleus
starch	vacuole
cell wall	cytoplasm

Photosynthesis occurs in the ________________ situated in the ________________ of the cell. It uses carbon dioxide absorbed from the ________________ in the leaf. The ________________, which is made of ________________, under pressure from the ________________ in the ________________, helps the cell to maintain its shape. [7]

[Total 10]

2 Figure 2.13 shows the structures that produce urine and excrete it from the body.

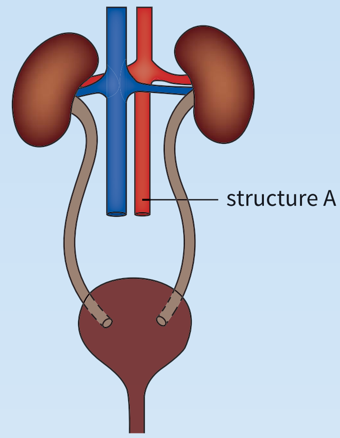


Figure 2.13

a In Table 2.2, put a tick (✓) in the box next to the term that states the level of organisation of structure A.

organism	
organ system	
organ	
tissue	
cell	

[1]

Table 2.2

b With reference to the kidney, ureters and bladder, explain the difference between the terms *organ* and *organ system*. [6]

3 Explain how a plant's xylem is particularly suited to its functions. [10]

Chapter 3

Movement in and out of cells

Learning outcomes

By the end of this chapter you should understand the processes responsible for the movement of substances into and out of cells:

- diffusion
- osmosis
- active transport

3.01 Diffusion

Chemicals must be able to move from one part of a cell to another, into and out of a cell and from one cell to another if an organism is to remain alive.

It is an advantage if this movement requires no effort (or, more correctly, no 'expenditure of energy') on the part of the organism, and, so long as there is no obstruction, chemical molecules carry out this process by diffusion.

Diffusion relies on the fact that all molecules are in a constant state of random (kinetic) motion, but before diffusion can occur, there must be a concentration gradient of the molecules, that is, a region of their (relatively) high concentration immediately beside a region of their (relatively) low concentration.

Diffusion can then be defined as **the net movement of molecules and ions from a region of their higher concentration to a region of their lower concentration, down a concentration gradient as a result of their random movement**.

The energy that causes the movement of chemicals is the kinetic energy that results from the movement of molecules and ions.

3.02 Examples of diffusion

Living organisms make regular use of the diffusion of gases or chemicals in solution (solutes). Only those molecules small enough to pass through the cell surface membrane are able to pass in and out of a cell.

Some examples of diffusion are described here.

In plants

1 The movement of **carbon dioxide**, first as a gas from the atmosphere into a leaf, then in solution, from the water film surrounding the mesophyll cells in a leaf, to the **chloroplasts** during photosynthesis.

2 The movement of **water vapour** and **oxygen** (both in **gaseous** form) released from the water film surrounding the mesophyll cells inside a leaf, and both then passing through the intercellular spaces of the leaf, and out through the stomata. Oxygen first diffuses in solution from the photosynthesising cells into the water film surrounding the cells.

The loss of water vapour in this way is called transpiration.

In animals

1 The movement of **oxygen** after it has dissolved in the moisture lining the air sacs of the lungs through the walls of the air sacs (alveoli) into the blood.

2 The movement of **carbon dioxide**, in solution, from the cells through tissue fluid, into the blood in blood capillaries.

In all the examples given here – apart from water vapour, the substance that diffuses has first **dissolved in water** (i.e. it is the **solute** molecules that are diffusing).

Progress check 3.1

1 How many examples of diffusion can you think of – first in the world around you, then in plants and in animals? (Check your list with your teacher to see how many of your examples were correct.)

2 What causes molecules to move by diffusion?

The rate at which a substance diffuses is controlled be a number of different factors:

Chemicals are absorbed faster by diffusion:

- when the structure absorbing them has a large surface area compared with its volume. This is achieved by the absorbing structure being long and thin (e.g. in **root hair cells** of plants or the villi in the small intestines of mammals), or simply by being very small
- when the temperature is higher, increasing the amount of kinetic energy in the molecules involved
- when the concentration gradient across which the diffusion is occurring is greatest
- when less distance has to be travelled by the diffusing molecules. For this reason, respiratory surfaces, for example, the walls of the alveoli in the lungs that absorb oxygen and release carbon dioxide are only one cell thick.

PRACTICAL

Investigations of the factors that influence the rate of diffusion

1 The effect of surface area

Apparatus:
- A petri dish
- Three cork borers of different sizes
- Two medium-sized beakers
- Two dropping pipettes
- Safety goggles and thin protective gloves

Materials:
- Agar tablets or powdered agar
- Phenolphthalein pH indicator
- 1 mol/dm^3 hydrochloric acid
- Bench dilute sodium hydroxide
- A supply of water (preferably ionised or distilled) and a means of heating it.

Method:

Following the instructions on the bottle, dissolve some agar in hot water. When it has dissolved, using a pipette, add a few drops of phenolphthalein indicator to the agar solution. If the agar solution is alkaline, it will turn pink*; if not, using the second pipette, add drops of sodium hydroxide until it does so. Pour the pink agar solution into the petri dish and allow it to cool and set in a refrigerator.

*Colour-blind students may find this investigation easier if they use a pH indicator that does not include pink as a significant colour.

Wearing the gloves and goggles, fill the second beaker to a depth of at least 3 cm with the hydrochloric acid (the beaker should be large enough to very easily accommodate the agar cylinders mentioned later).

Using each cork borer, in turn, bore out three cylinders of agar from the petri dish.

(If you have trouble in removing the agar from the cork borers, you can, instead, using a sharp blade, cut the agar into three different-sized cubes, which you should measure carefully.)

Transfer the three cylinders/cubes to the beaker of hydrochloric acid and note the time.

Keep a constant watch on the cylinders/cubes and record the time at which each cylinder loses its pink colouration.

Calculate the volume and the surface area of each agar cylinder/cube.

The volume of each cylinder can be calculated by measuring the depth of the agar in the petri dish and the diameter of the cork borer and using the formula $\pi r^2 h$ (where h is the depth of the agar and r is half the diameter of the cork borer).

The surface area of each cylinder is calculated using the formula $2\pi r^2 + 2\pi rh$.

Results:

The larger the ratio of surface area to volume for the cylinders/cubes, the shorter time it takes for the pink colour to disappear.

Explanation: The greater the surface area to volume ratio, the more H^+ ions are able to diffuse from the hydrochloric acid into the agar blocks changing their pH thus the quicker the indicator loses its pink alkaline colouration.

→

2 The effect of temperature

The investigation of surface area previously can be adapted to demonstrate the effect of temperature on diffusion.

Apparatus: 1 cork borer
4 medium-sized beakers
(size dependent of the size of the cork borer)
A container of ice and water and a water bath set at 40 °C

Materials: As before

Method:

Prepare the agar as in Investigation 1 – The effect of surface area.

Wearing the gloves and goggles, fill three beakers with the hydrochloric acid each to a depth of 3 cm.

Place one of the three beakers in the container of ice and water, one on the bench at laboratory temperature and one in the water bath, leave for 10 minutes.

Bore three cylinders of agar each with the same cork borer (or, cut three identical cubes of agar, as described previously).

Transfer one of the cylinders/cubes to each of the three beakers and note the time.

Keep a constant watch on the cylinders/cubes and record the time at which each one loses its pink colouration.

Results and explanation:

The cylinder/cube in the water bath loses its colour first and the one in the ice and water is last to lose its colour. Thus diffusion occurs faster the higher the temperature.

3 The effect of concentration gradient

Investigation 2 can be adapted to demonstrate this effect.

Materials: As in 1 and 2 previously, but a supply of 2 mol / dm^3 hydrochloric acid is required, which, by dilution, should be used also to provide a supply of 1 mol / dm^3 and 0.2 mol / dm^3 hydrochloric acid. (Although these concentrations are suggested, the investigation should work well enough with three other differing concentrations.)

Apparatus: As in Investigation 2, but no container of ice and water or a water bath are required.

Method:

Prepare the agar as in Investigation 1 – The effect of surface area.

Fill the three beakers to the same depth (around 3 cm), one with 2 mol / dm^3, one with 1 mol / dm^3 and one with 0.2 mol / dm^3 hydrochloric acid. All three beakers should be kept at the same (laboratory) temperature.

Bore three cylinders each with the same borer, or cut three identical cubes of agar.

Transfer one of the cylinders/cubes to each of the beakers and note the time.

Keep a constant watch on the cylinders/cubes and record the time at which each one loses its pink colouration.

Results and explanation:

The agar in the most concentrated acid is first to lose its colour and last to lose its colour in the least concentrated. There is a steeper concentration gradient of H^+ ions, the more concentrated the acid, hence there is also a faster rate of diffusion of the H^+ ions.

4 The effect of distance

This can be easily investigated by using two glass containers of significantly different volume. Each is filled with water, then placed side by side and left for the water to become still. Two of three drops of a concentrated solution of potassium permanganate are added, at the same time, to both containers, and the time is noted. The containers are then observed until the water in each of them is uniformly purple in colour and the time for each is recorded.

Results:

It takes longer for the water in the larger container to become uniformly coloured.

Explanation: It is not just that the potassium permanganate has further to travel, but also that its concentration gradient is progressively declining as it spreads out in the container.

The effect of distance can also be demonstrated by spraying aerosol deodorant, or fly-killer at one side of a classroom, and asking students to note the time taken before they can smell it. The further away they are, then, perhaps not surprisingly, the longer it takes for the chemical to reach them (by diffusion through the air).

3.03 Osmosis

If we were to take a container, completely divided into two sections by a piece of cloth, and then, at the same time pour a dilute sugar solution into one side and a concentrated sugar solution into the other side, within several minutes, by diffusion, both the water molecules and the sugar molecules would move down their respective concentration gradients, until both sides were at the same concentration (Figure 3.1). The pores in the cloth would form no obstruction to the movement of the molecules in either direction.

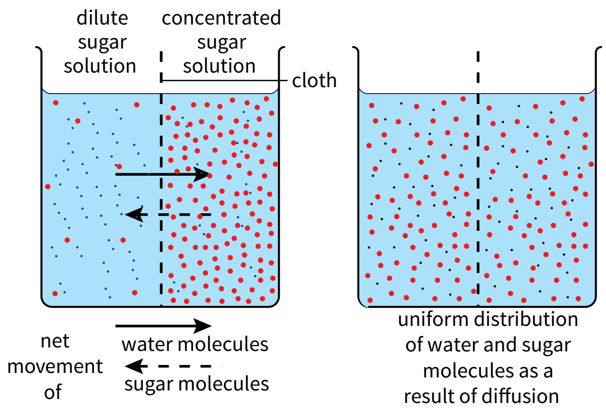


Figure 3.1 Sugar molecules moving one way, water molecules moving in the opposite direction until both sides were at the same concentration

If we now carry out a similar experiment but this time, instead of the piece of cloth, we separate the two sides of the container with a membrane with microscopic holes in it (Figure 3.2) – so small that they allow the passage of water molecules but not the sugar molecules, then water molecules will diffuse down their concentration gradient while the sugar molecules stay where they are. This **specialised** case of diffusion is called osmosis and the separating membrane is described as partially permeable.

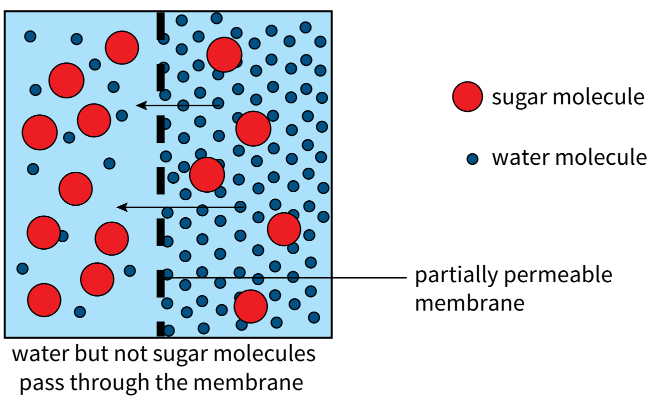


Figure 3.2 Partially permeable membrane allowing water but not sugar molecules to pass through

All cell membranes are partially permeable, therefore water will move into or out of cells by osmosis depending on the concentration gradient of water molecules inside and outside the cell.

Dilute solutions, which have a relatively large number of water molecules, are said to have a high water potential (i.e. a high concentration of water molecules). **Concentrated** solutions, with fewer water molecules, are said to have a low water potential.

During osmosis, since water molecules are in a constant state of motion, they will be moving through the partially permeable membrane in both directions, but always more will be moving from where they are in greater concentration towards the lower concentration.

Osmosis can then be defined as **the net movement of water molecules from a region of higher water potential (a dilute solution) to a region of lower water potential (a concentrated solution), through a partially permeable membrane**.

The cell sap of root hair cells has relatively **low** water potential. Soil water has a relatively **high** water potential. Thus water will move into the vacuole of root hair cells by **osmosis** (Figure 3.3). The cell wall offers **no obstruction** to the passage of water, since **cellulose**, of which it is made, is **completely permeable**. But, where the walls of neighbouring cells touch, water can pass into the root by simple diffusion – through the cellulose of the cell walls.

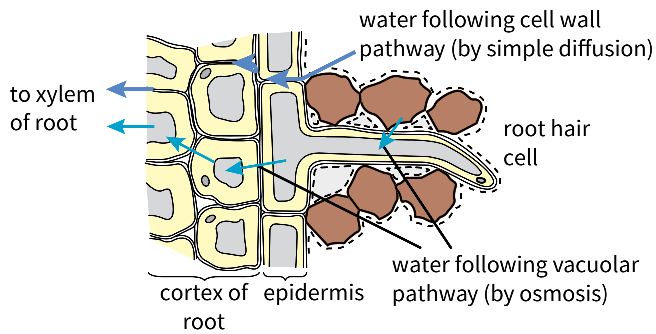


Figure 3.3 Uptake of water by osmosis (vacuolar pathway) and by diffusion (cell wall pathway)

Once water molecules have entered the root hair cell, their presence **increases** the water potential of that cell, compared with the next cell in towards the centre of the root. **Osmosis** will thus cause water to move into that cell from the root hair cell. This process continues until water molecules reach the **xylem** vessels in the centre of the root and are then transported away to the stem. This can be demonstrated in the laboratory using a piece of Visking tube that has been tied tightly at its lower end, that contains sucrose solution, and is tied tightly at its upper end to a piece of glass tubing. The apparatus is then supported in a beaker of water as shown in Figure 3.4.

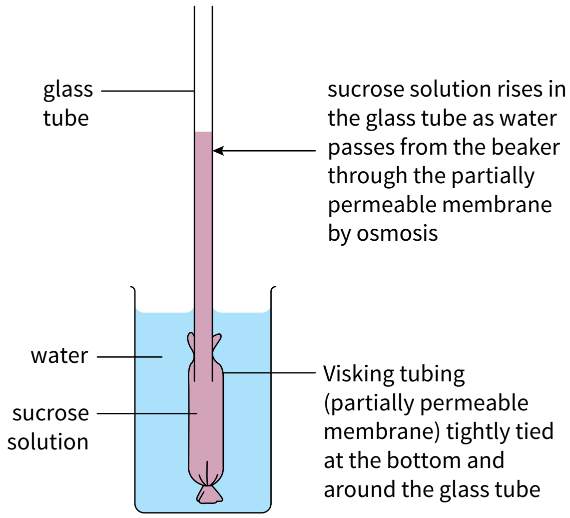


Figure 3.4 A demonstration of osmosis using an artificial partially permeable membrane

Progress check 3.2

1 What part of a cell is partially permeable?

2 What is the difference between the diffusion and osmosis?

The effect of osmosis on plant cells

The intake of water by osmosis

Water will always tend to enter plant (root) cells by osmosis, since soil water will always be likely to have a higher water potential than cell sap (Figure 3.5). As the vacuole thus increases in volume, it increasingly presses the cytoplasmic lining of the cell against the flexible, box-like cell wall.

(This pressure is called **turgor** pressure and it gives plant cells a firmness called **turgidity**.)

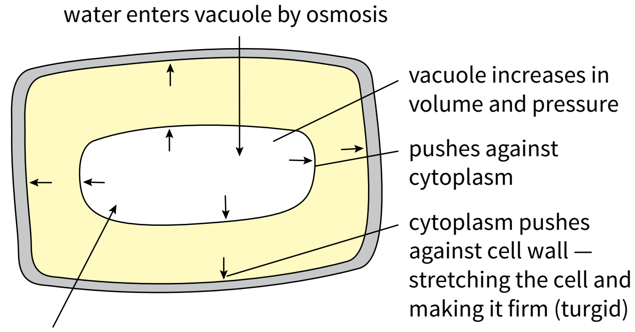


Figure 3.5 Plant cell in water

The increase in pressure resulting from osmosis can be demonstrated as shown in Figure 3.5 using a tightly-tied bag made of Visking tube, filled with sugar solution and placed in water for 20 minutes (Figure 3.6).

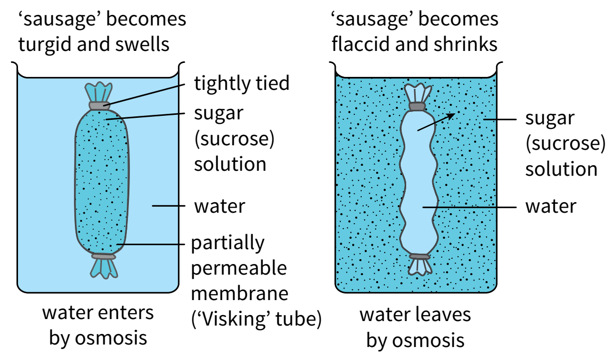


Figure 3.6 A firm, turgid, Visking sausage and one that has become flaccid

The pressure caused by the water pushing outwards on the cell wall (turgor) in plant cells helps:

1 to keep **stems upright**

2 to keep **leaves flat** so they can better absorb sunlight.

The water potential inside most **animal** cells is often the same as the solution in which the cells are naturally bathed. (See Chapter 12, Kidney Function.) Thus there is little movement of water by osmosis into or out of the cell.

However, a red blood cell placed in a solution with a relatively high water potential, starts to take in water by osmosis, and since there is no cell wall to resist the increased pressure that results, the cell **bursts**.

The loss of water by osmosis

Plant cells placed in a solution of relatively low water potential, lose water from their vacuoles. As a result they lose their internal pressure since the cytoplasm is no longer being forced against the inelastic cell wall. They become soft (Figure 3.7).

When a cell loses its internal pressure, it is said to be flaccid.

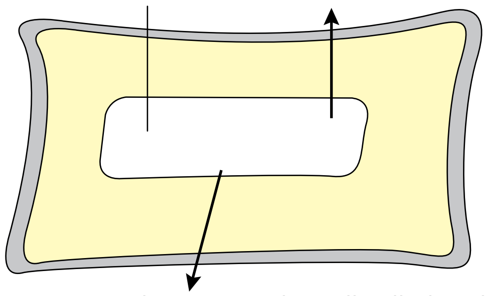


Figure 3.7 A flaccid plant cell

Further exposure to a bathing solution of lower water potential (such as a sugar solution) will draw so much water from the vacuole that the cytoplasm is pulled away from the cell wall (Figure 3.8). (Such a condition is called plasmolysis.)

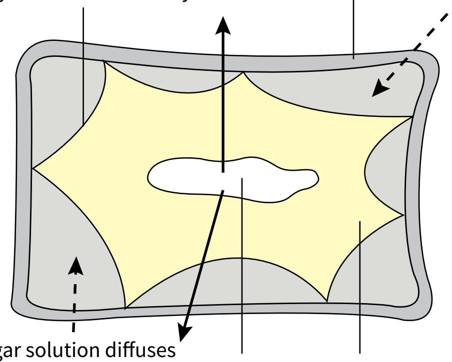


Figure 3.8 A (plasmolysed) plant cell after it has been left in a sugar solution of low water potential for some time

Animal cells placed in solutions of **lower water potential**, lose their shape and what turgidity they have, as water moves out of their cytoplasm. A red blood cell shrinks in size and its cell membrane becomes unevenly creased ('**crenated**') as shown in Figure 3.9.

Animal cells placed in a solution with a **high water potential** (e.g. pure water) take in water by osmosis. They have no inelastic cell wall to resist the intake and to make them turgid, so they **burst**.

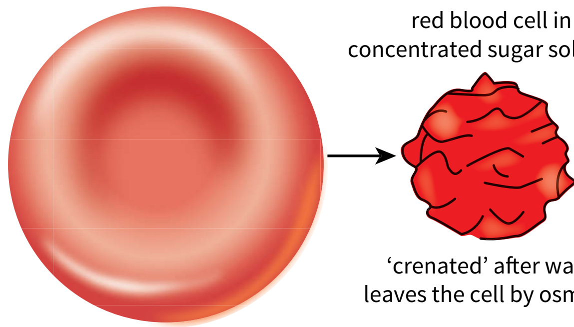


Figure 3.9 A normal and a crenated red blood cell

In animals, the cells of the body are usually bathed in a fluid that is maintained at a constant water potential (one of the jobs of the kidneys, in vertebrates). This ensures that the concentration of chemicals in the cell cytoplasm remains constant and, therefore, so too is the rate of metabolism.

PRACTICAL

Investigation of the effect on plant tissues of the entry and exit of water by osmosis

Apparatus and materials:

- Two large potatoes
- Two containers (e.g. beakers) at least 10 cm deep
- A sharp knife
- A supply of sucrose (table sugar) or table salt (sodium chloride)
- A ruler measuring in mm
- A supply of water

Method:

Peel one or both potatoes to provide six similar strips ('chips') at least 7 cm long, and no more than 0.5 cm × 0.5 cm in cross-section. Then cut all the strips to the same length and record that length.

Fill one beaker to within 2 cm of the top with water, and the other with a concentrated sucrose or sodium chloride solution.

Submerge three of the potato strips in each of the beakers.

Leave the strips for at least half an hour (the more dilute your sugar/salt solution, the longer you should leave them), then remove them, measure them and record their lengths. Note the texture of the strips.

Results:

The strips in the water will have increased in length and will be firm to the touch; those in the sugar or salt solution will have decreased in length and be soft to the touch.

Explanation:

For the strips in water, the cell sap in the cells of the potato will have a lower water potential than the water the strips were submerged in, thus water has entered the cells, stretching them and increasing the pressure inside them, making the potato feel firm.

For the strips in the sucrose or salt solution, the water potential of the cell sap is higher than the water potential of the solution, thus water has moved out of the cells. The cells have decreased in size and lost their firmness. Thus the strips are shorter and are soft to the touch.

The effect of the gain or loss of water on a plant

When a plant has access to water and absorbs it by osmosis, its cells become firm as the water enters the cell vacuoles and presses outwards on the cell walls. Like the potato strips, the tissues of the plant become firm and, when this happens in the stem and leaves, the plant is supported and held upright and the leaves are firm and held open to the sunlight for photosynthesis.

Loss of water from cells makes stems soft and no longer able to support the plant and leaves curl and are less able to photosynthesise.

Place a fruit sweet between your teeth and your cheek and leave it there for about a quarter of an hour without biting or sucking it. Then remove it and feel the inside of your cheek with your tongue. Write down a description of how it feels and attempt an explanation.

Progress check 3.3

1 Why, when a plant cell and an animal cell are both placed in water, does only the animal cell burst?

2 Figure 3.10 shows two liquids separated by a partially permeable membrane at the start of an experiment.

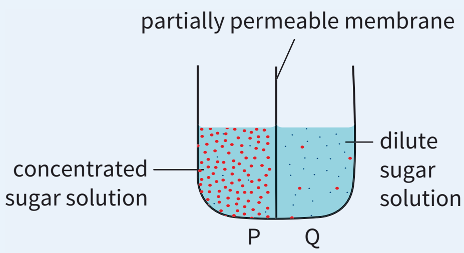


Figure 3.10

Which part of Figure 3.11 shows and explains the results 20 minutes later?

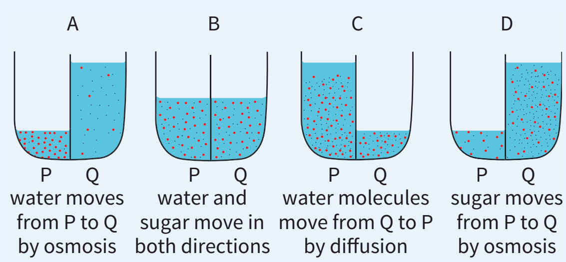


Figure 3.11

3 Why do the leaves and stems of a plant shoot, whose cells have started to undergo plasmolysis, begin to droop?

3.04 Active transport

We have seen how chemicals move into and out of cells by diffusion down a concentration gradient. Sometimes, a living cell may be in need of a chemical, even though there is a lower concentration of it outside than inside the cell. In such a case, the chemical would have to be absorbed **against a concentration gradient**. This can be achieved only with the use of **energy** released by **respiration** inside the cell in conjunction with the cell membrane. This energy allows the cell to absorb the chemical through the cell membrane and prevent any of the chemical already inside the cell from leaving.

This process is called active transport and is defined as **the movement of particles through a cell membrane from a region of lower concentration to a region of higher concentration using energy from respiration**.

The energy released in respiration is stored in the chemical ATP in the mitochondria. Cells that undergo active transport characteristically have a large number of mitochondria.

The energy used in this process not only affects the kinetic energy of the molecules that are being absorbed, but it is used to move molecules in the cell membrane so they actively 'pump' the required molecules into the cell.

This situation arises in **plant roots** where the ions needed for a plant's metabolism may be in very short supply in the soil water. Ions are thus absorbed by root hair cells by active transport.

The situation also arises in the **small intestine** of an animal, when digested food (such as **glucose**) is absorbed by the epithelial cells of the **villi** by active transport.

3.05 How particles are moved by active transport across a cell membrane

Particles, usually in molecular form, are taken up by cells against a concentration gradient. This is achieved by proteins, called **carrier proteins**, that are bedded in the cell membrane (Figure 3.12). They are the same thickness as the membrane and thus they are in contact with the surrounding of the cell on the outside and the cytoplasm of the cell on the inside.

Energy is used to open up a channel on the part of the molecule facing the outside of the cell. The molecule or ion to be absorbed enters the channel and binds to a special site in the centre of the carrier protein molecule. Each carrier protein will bind to only one particular molecule. Thus, like enzymes, they are specific. Further energy is then used to close off the opening to the outside of the cell, and to open up a similar channel, this time into the cytoplasm of the cell. The molecule being absorbed is then released from its binding site into the cell's cytoplasm.

The carrier protein then reverses the process, again using energy so that it is available to take in another molecule.

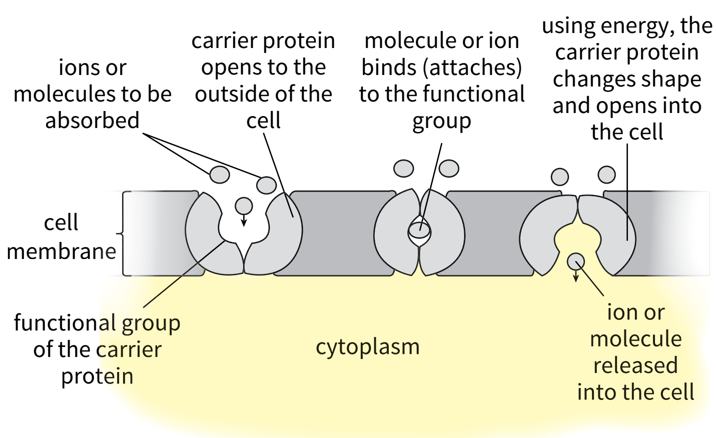


Figure 3.12 Diagram of carrier protein at work

Worked example

Describe how the structure of a cell membrane is adapted to the process of active uptake.

Cell membranes contain protein molecules called 'channel proteins'. These molecules fit loosely together leaving minute channels between them extending from the outside of the cell to the cell cytoplasm. Suggest how these channel proteins may play a part is the processes of diffusion and osmosis.

Answer

The question calls first for a realisation that there is a special structural feature of the cell membrane making it able to undergo active uptake. That feature is the presence of carrier proteins. Since they have to work against a concentration gradient (there may be a lower concentration of the chemical to be absorbed outside than inside the cell) then energy must be used. All energy within a cell is initially released by respiration and, in this case, the energy is used to move the carrier proteins. First the carrier protein opens to the outside and allows the molecule to be absorbed to attach (bind) to the protein. Only one type of molecule will bind as the site is not suitable for any other molecule. The protein then changes shape again (again using energy) – closing the outer opening, and opening into the cytoplasm of the cell. The molecule is released into the cell cytoplasm, then changes shape again, closing to the inside and opening to the outside ready to bind with another molecule to be absorbed. (Note that the complete cycle of carrier protein movements is described as a continuous process.)

Diffusion requires pores in the membrane before molecules can enter. The channel proteins would provide the pores. However, the size of the pores might prevent larger molecules from entering. Water is a small molecule and thus could enter by osmosis, and the pores may be too small to allow larger molecules to enter – making the membrane semi-permeable.

Chapter summary

- You have learnt how cells are involved in the processes of diffusion, osmosis and active transport.
- You have learnt how these processes are important to living structures.
- You have learnt how to demonstrate these processes experimentally.
- You have also learnt about the factors that affect them.

Exam-style questions

1 Describe how different substances in a leaf move by diffusion during a 24-hour period. [6]

2 a Figure 3.13 shows a piece of partially permeable tubing, tightly tied at each end, and containing a concentrated sugar solution that is coloured with blue dye. It has been placed in a beaker of pure water.

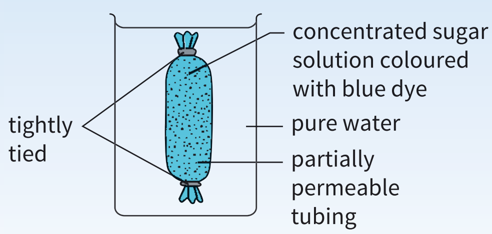


Figure 3.13

Describe what will happen to the tubing and its contents over the next 20 minutes. [3]

b After 20 minutes, apart from what happens to the tubing, the water in the beaker has turned blue. With reference to diffusion and osmosis, explain the results of this experiment. [7]

3 a Explain how a plant root absorbs from the soil:

i) water [6]

ii) essential mineral ions that are in very short supply. [4]

b Suggest why a plant may have great difficulty in absorbing essential mineral ions that are in very short supply in a water-logged soil. [4]

The chemicals of life

Learning outcomes

By the end of this chapter you should understand:

- The structure of important chemicals found in organisms, including fats, proteins, carbohydrates and DNA
- The structure of the different chemicals that organisms use in their nutrition
- How to carry out food tests to detect their presence

4.01 Biological molecules

Three of the most common organic molecules found in living organisms are:

- **carbohydrates**
- **fats**
- **proteins**.

Carbohydrates

Carbohydrates are organic chemicals containing the elements **carbon**, **hydrogen** and **oxygen** only. The ratio of atoms of hydrogen to atoms of oxygen in a carbohydrate molecule is always 2:1.

(It may help to remember this to know that 'carbo' refers to the carbon, 'hydrate' refers to water – where the ratio of H to O is also 2:1.)

Carbohydrates with large molecules, such as **starch**, glycogen and cellulose, are **insoluble**. (Although it is common to refer to a 'starch solution', it is really a starch suspension.)

They are synthesised in living organisms by linking together molecules of simple sugar (**glucose**). Large carbohydrate molecules can be broken down into simple sugars.

Smaller carbohydrate molecules are soluble and occur as:

- 'complex' sugars, such as **maltose** and **sucrose** (table sugar), all with the formula $C_{12}H_{22}O_{11}$ or
- 'simple' sugars, such as **glucose** or **fructose**, with the formula $C_6H_{12}O_6$.

Fats

TIP

Watch out for questions that refer to oils and remember that oils are fats that are liquid at 20°C.

Fats are organic chemical substances that contain the elements **carbon**, **hydrogen** and **oxygen** only. This time, however, the ratio of H to O in the molecule is very much higher than 2:1. They are all insoluble in water and are formed by the joining of a **glycerol** molecule with **fatty acid** molecules.

Proteins

Proteins contain the elements carbon, hydrogen, oxygen and **nitrogen** (and often other elements such as sulfur and phosphorus).

They are large, usually insoluble, molecules that are built up from simple, soluble units known as amino acids, of which up to 20 are used in the production of protein in living organisms.

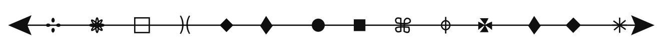


Figure 4.1 Amino acids linking to form a protein molecule (each different symbol represents one of the 20 different amino acids)

A relatively few amino acids link together to form a **polypeptide**, while polypeptides link together to form protein.

Amino acids are of different sizes and shapes, thus, when linked together to form protein molecules, the proteins formed will also be of different shapes.

This structural difference is very important when the protein in question is an **enzyme** since part of the molecule, known as the **active site** is of exactly the right shape to fit the molecule (the **substrate molecule**) of the chemical reaction that it will catalyse.

Similarly, if the protein is an **antibody** in the blood, part of its molecule (the **binding site**) will be exactly the right shape to stick to ('bind with') the pathogen or toxin that the antibody has been made to counteract.

Progress check 4.1

1 Name the elements found in i) carbohydrates ii) fats iii) proteins.

2 Name the units from which i) fats, ii) starch and iii) proteins are made.

Tests to show the presence of carbohydrates, fat and protein

These are often referred to as 'food tests'. The tests are shown in Table 4.1 (carbohydrates), Table 4.2 (fat) and Table 4.3 (protein).

Carbohydrates

Benedict's solution does not distinguish between the complex sugar such as **maltose**, and the simple sugar such as **glucose**. In their reaction with Benedict's solution, both sugars work as chemicals known as reducing agents, and thus belong to a group of sugars referred to as **reducing sugars** all of which react in this way.

Carbohydrate	Chemical reagent used	How test is carried out	Result
Starch	iodine solution	put a few drops on the substance to be tested	blue-black colour if starch is present brown if starch is absent
Maltose and glucose	Benedict's solution	add a few drops to a solution of the substance to be tested and heat in a water bath at 90 °C	red/orange/yellow/green if either of the sugars is present blue if neither of the sugars is present

Table 4.1 Tests for carbohydrates

Worked example

a Explain the chemical similarities and differences between glucose and sucrose.

b Explain how you could distinguish between them by performing a simple food test.

Answer

a It is best to split this part into its two natural sections – similarities and differences. The first similarity is that they are both sugars and they are both soluble so that they can be more easily moved from place to place within an organism. The fact that they are sugars is indicated by the ending '-ose'. They will therefore both also be carbohydrates – a term you should explain. The clue is, again, in the word: 'carbo-' because they contain carbon and 'hydrate' because they contain the same elements as water – hydrogen and oxygen, and in the same ratio as well – 2 Hs to each O. Some carbohydrates can be very large molecules, but these sugars are comparatively small ones.

The differences are that one, glucose, is a simple sugar and is the basic unit of many larger carbohydrates (such as starch). Sucrose is a complex sugar and one molecule of sucrose ($C_{12}H_{22}O_{11}$) is approximately twice as big as one molecule of glucose ($C_6H_{12}O_6$).

b This part hinges on the fact that the simple test for sugars identifies only simple (or 'reducing') sugars. Glucose is a reducing sugar but sucrose is neither a reducing nor a simple sugar. Therefore, the Benedict's test will identify the glucose but not the sucrose. You are asked how you would distinguish between them, so you will need to give a description of the test and state the result you would expect. The test is to heat a little of each sugar in test-tube together with a few drops of Benedict's solution. The glucose will turn red, but the sucrose will remain the colour of the Benedict's solution – blue. (NB If you mention a bunsen burner for heating, you would be advised also to mention the use of goggles.)

Fat – the ethanol emulsion test

Reagent used	How test is carried out	Result
Ethanol	a dried sample of the substance to be tested is mixed with ethanol, which is then poured into a test-tube of water	water turns cloudy if fat is present water remains clear if fat is not present

Table 4.2 Tests for fat

TIP

When performing ethanol emulsion test, the test is more reliable if a dried sample is used, but if it is not possible to dry the sample, then the ethanol drained from it may already be cloudy, indicating the presence of a fat.

Proteins – the biuret test

Reagent used	How test is carried out	Result
biuret solutions 1 and 2	add equal volumes of solution 1 and 2 to a solution of the substance to be tested	purple colour if protein is present blue colour if protein is absent

Table 4.3 Test for protein

Biuret 1 contains sodium hydroxide that is harmful to the skin and thus appropriate safety precautions should be taken.

Since '**biuret**' is a chemical – not a person as in 'Benedict's solution' – it does not begin with a capital letter, unless it is the first word in a sentence.

TIP

Never say that a food test is 'positive' or 'negative'. State the observed colour and the conclusion you draw from that result.

The test for vitamin C

As indicated, these tests are usually referred to as 'food tests' because they are mostly carried out to investigate the presence of chemicals in various foods. Another important constituent of foods is **vitamin C** and there is a test that is used to decide whether a food contains vitamin C. The reagent used is known as **DCPIP** which is in the form of a blue solution.

Reagent	How test is carried out	Result
DCPIP	add solution of substance drop by drop to DCPIP	DCPIP changes from blue to colourless if vitamin C is present

Table 4.4 Test for vitamin C

Progress check 4.2

1 Name the chemicals used to test for: i) starch; ii) vitamin C.

2 A food test gives a purple colour. What reagent has been used and what chemical is present?

3 When using Benedict's solution, why is it not possible to be absolutely sure that a food contains glucose?

DNA

Chromosomes, situated in the **nuclei** of all living cells (except bacteria, which have no true nucleus) have, as their major component, the chemical substance **DNA**. The DNA molecule, looking rather like a very long, twisted rope ladder, is made up of two strands (of alternating sugar and phosphate units) held together by pairs of chemical units called **bases** (these bases form the 'rungs' of the ladder). The molecule is described as a **double helix** (because the Greek word *helix* means a 'spiral'.)

There are only **four** bases, known by their initial letters **A**, **T**, **C** and **G**, and the sequence in which they occur in one of the two DNA strands is responsible for the sequence of amino acids in the protein molecules that are made in the cell. Since the sequence of bases on a DNA molecule is likely to be different for each (sexually produced) individual, it follows that no two individuals will make protein molecules with exactly the same sequence of amino acids.

As stated previously, the bases are always paired when forming the 'rungs' of the DNA double helix, but there is a '**rule of base pairing**', since **A** always pairs with **T**, and **C** always with **G**.