ESAT Guide

Biology

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Contents

Introduction 3

B1. Cells 5

B2. Movement across membranes 17

B3. Cell division and sex determination 27

B4. Inheritance 42

B5. DNA 54

B6. Gene technologies 68

B7. Variation 84

B8. Enzymes 89

B9. Animal physiology 100

B10. Ecosystems 174

B11. Plant physiology 205

INTRODUCTION

This is worth reading before you use this guide.

We have three aims in writing this guide:

First, we want to set out what we expect you to know for the ESAT. We do this by basing each part of the guide on the relevant part of the specification.

Second, we want to encourage you to think deeply and carefully about science and mathematics and to develop a good understanding of the topics in the specification. To help with this, we have added a lot of discussion and examples as well as some exercises throughout the guide.

Third, we want to make sure that all candidates have access to a free resource to help them prepare for the ESAT.

How to use this guide

You do not need to work through all this guide as you will find that you know many of the topics in the specification very well already. Use this guide as a resource to help you clarify and review topics that you are less familiar with. We have broken down our discussion to fit exactly with the specification to make things as simple to navigate as possible.

What this guide is not

This guide is not a comprehensive textbook: we do not cover every topic to the same level of detail, and we do not develop every topic from scratch. It is also not a substitute for sustained hard work and preparation. It is a resource to help you and to guide you in the right direction.

Should I take an ESAT course?

We do not recommend that you take a course, and we do NOT endorse any courses. No one from the ESAT development team teaches on any courses. All the resources you need to prepare are available from the UAT-UK website and are entirely free.

A final note

We have used boxes throughout the guide to help you navigate.

The relevant part of the specification is found in these sorts of boxes:

Specification

and exercises [answers are at the end of each section] in these sorts of boxes:

Exercises

We hope to be able to update and, if necessary, correct the guide now and again. Look at the date on the front page to see when the guide was last edited.

B1. Cells

B1.1 Know and understand the structure and function of the main sub-cellular components of eukaryotic cells (both animal and plant) including:

a. cell membrane
b. cytoplasm
c. nucleus
d. mitochondrion
e. cell wall (plant only)
f. chloroplast (plant only)
g. vacuole (plant only)

B1.2 Know and understand the structure and function of the main sub-cellular components of prokaryotic cells (bacteria) including:

a. cell membrane
b. cytoplasm
c. cell wall
d. chromosomal DNA/no 'true' nucleus
e. plasmid DNA

B1.3 Know and understand the levels of organisation within organisms as: cells to tissues to organs to organ systems.

All living things are made up of one or more units called cells. Cells are microscopic.

Eukaryotes are organisms made up of a cell or cells containing DNA inside a recognisable nucleus. The DNA is present in the form of one or more linear chromosomes within the nucleus.

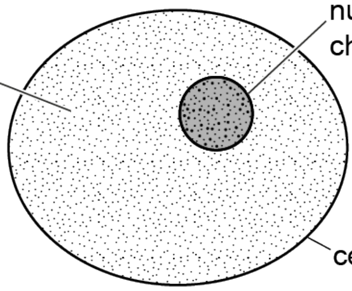
A unicellular organism or single-celled organism is an organism that consists of only one cell. Multicellular organisms are made up of many cells. These may be specialised to perform particular functions. The size and shape of these cells depend on the role they perform. Plant cells tend to be larger than animal cells.

Structure and function of the main sub-cellular components of animal and plant eukaryotic cells

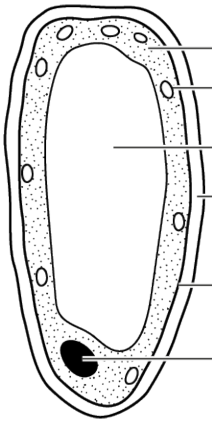
The features present in cells are known as their sub-cellular components. All eukaryotic cells have a cell membrane and cytoplasm. Mitochondria (singular: mitochondrion) are present in the cytoplasm, but these are not visible using alight microscope. Most eukaryotic cells have a nucleus. Exceptions are mature red blood cells in mammals.

Plant cells also have a cell wall and a sap vacuole. In addition, photosynthetic cells contain chloroplasts.

Simplified structure of an animal cell – a liver cell



Simplified structure of a plant cell – a palisade cell from a leaf



This table summarises the sub-cellular components of animal and plant cells:

Sub-cellular component	Structure and description	Function
Cell membrane	A partially permeable layer that forms a boundary around the cytoplasm of the cell.	Contains the cell contents and controls the movement of some substances into and out of the cell. It allows water, oxygen and nutrients to enter and allows waste products (e.g. carbon dioxide) to leave.
Chromosomal DNA	One or more linear pieces of double-stranded DNA.	Stores the genetic material required for the various cell processes.
Cytoplasm	A jelly-like region, surrounded by the cell membrane. Salt ions and sugar molecules are dissolved in it. Fat molecules and proteins, e.g. enzymes, are suspended in it. It also contains food reserves (e.g. glycogen in some animal cells, starch in some plant cells) and organelles such as the nucleus and mitochondria. Chloroplasts are present in the cytoplasm of photosynthetic plant cells.	Is the site of chemical reactions and contains enzymes that control these reactions. It holds the cell organelles.
Nucleus	Usually round or oval, contained by two nuclear membranes and containing DNA in the form of chromosomes. It is found inside the cytoplasm.	Regulation of cell functions through directing the production of RNA and protein required for all cell processes, including cell division, cell differentiation (specialisation) and cell metabolism (chemical reactions).
Mitochondrion	A small organelle (can be viewed using an electron microscope) with an inner and outer membrane. The inner membrane has many inward-pointing folds.	Controls the production and release of ATP (usable energy) from aerobic respiration.
Cell wall (plant only)	A tough, rigid layer surrounding the cell membrane made primarily of cellulose. It is freely permeable to water and salts.	Provides a rigid external coat to plant cells, providing mechanical strength which allows cells to resist bursting when the cell is turgid.
Chloroplast (plant only)	A small organelle with its own double membrane, found in the cytoplasm of photosynthetic plants, containing chlorophyll and other pigments.	Traps (absorbs) light energy and converts it to chemical energy by the process of photosynthesis.
Vacuole (plant only)	A fluid-filled space surrounded by a membrane in plant cells. It is found inside the cytoplasm. The fluid is called sap, which is a watery solution of sugars and salts. In some cells, e.g. rhubarb, it is also coloured.	Stores water-soluble chemicals and ions and helps to keep plant cells and tissues firm.

Exercise 1

a. Name three cell parts which are common to both a liver cell and a palisade mesophyll cell.
b. Which plant cell part is not found in a root hair cell? Explain your answer.

Exercise 2

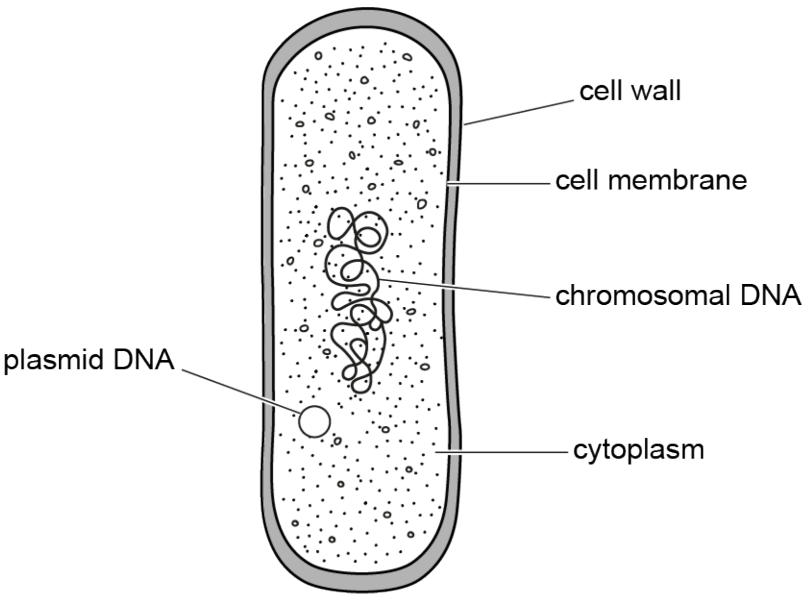
Match the cell parts to their descriptions. There is only one description for each, and one match has been completed for you.

cell part	description
cell wall	jelly-like, containing particles and organelles
chloroplast	partially permeable layer that forms a boundary around the cytoplasm
cytoplasm	round or oval structure containing DNA in the form of chromosomes
membrane	tough, non-living layer made of cellulose, surrounding the membrane
nucleus	organelle containing chlorophyll
sap vacuole	fluid-filled space surrounded by a membrane

Structure and function of the main sub-cellular components of prokaryotic cells (bacteria)

Prokaryotic cells are typically smaller and simpler in organisation than plant or animal cells. They have some features in common with eukaryotic cells.

Simplified structure of a bacterial cell



This table summarises the sub-cellular components of a prokaryotic cell:

Sub-cellular component	Structure and description	Function
Cell membrane	A partially permeable layer that forms a boundary between the cytoplasm and the cell wall. Functions as a boundary to restrict materials moving between the inside and outside of a cell.	Contains the cell contents and controls the movement of some molecules into and out of the cell.
Cytoplasm	A jelly-like region, surrounded by the cell membrane. It may contain glycogen granules, fats (lipids) and other food molecules.	Is the site of chemical reactions and contains enzymes that control these reactions. It holds the cell's DNA.
Cell wall	A tough, rigid external coat that surrounds the cell membrane. It is made of a complex mixture of proteins, lipids (fats) and sugars. This makes it different from plant cell walls, which are made of cellulose. Some bacterial cells have a slime capsule surrounding the cell wall.	Provides structural support and protection to bacteria. It is freely permeable to small molecules, so does not control the intake or loss of materials.
Chromosomal DNA (bacteria)	A large closed circular coiled molecule of double-stranded strand DNA located within the bacterial cytoplasm (no nucleus or enclosing membrane).	Carries genetic information that regulates most bacterial cell processes.
Plasmid DNA	A small molecule of closed double-stranded circular DNA, usually present in multiple copies per cell.	Carries genetic information for specialist cell functions (like antibiotic resistance). It can replicate and operate independently from the chromosomal DNA. Can be readily moved between different bacterial cells, including for genetic engineering (biotechnology) purposes.

Exercise 3

With reference to DNA, outline how an animal cell and a prokaryotic cell are different.

Levels of organisation

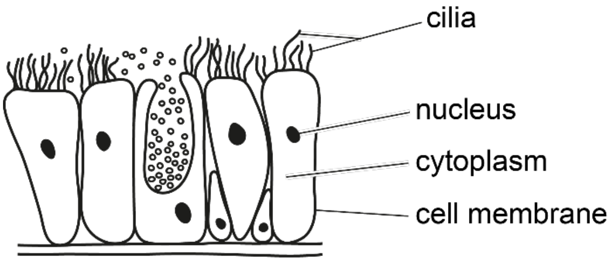
Most eukaryotic cells become specialised when they have finished dividing and growing. This process is called differentiation.

Specialised cells tend to carry out one particular function (job) and have certain features which allow them to do this:

- they have a distinct shape
- they undertake specific chemical reactions and processes in their cytoplasm

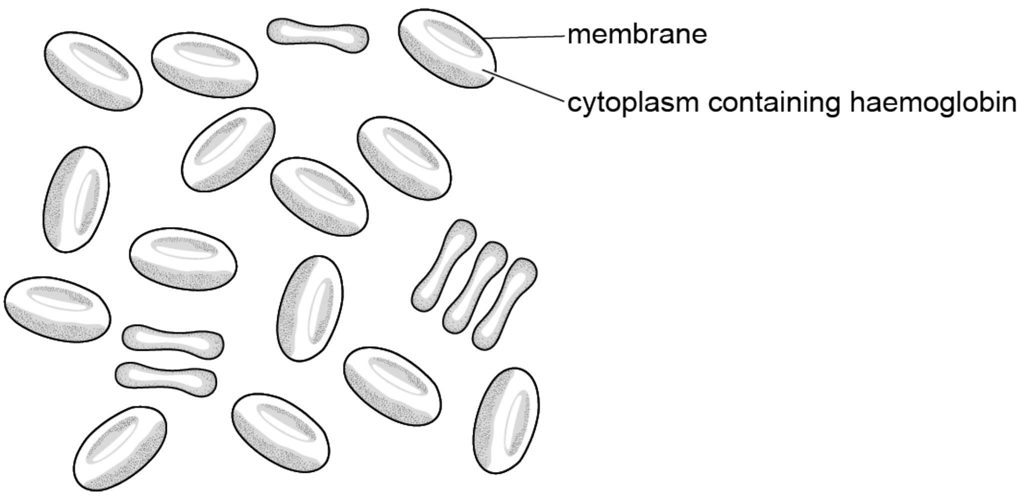
Examples of specialised cells are ciliated cells, red blood cells, nerve cells (neurones), sperm cells, root hair cells and palisade mesophyll cells.

Simplified diagram of ciliated cells



Animals have many structures containing ciliated cells. For example, ciliated cells form the lining of the trachea. Function: moving mucus to protect the lungs from infection and irritants.

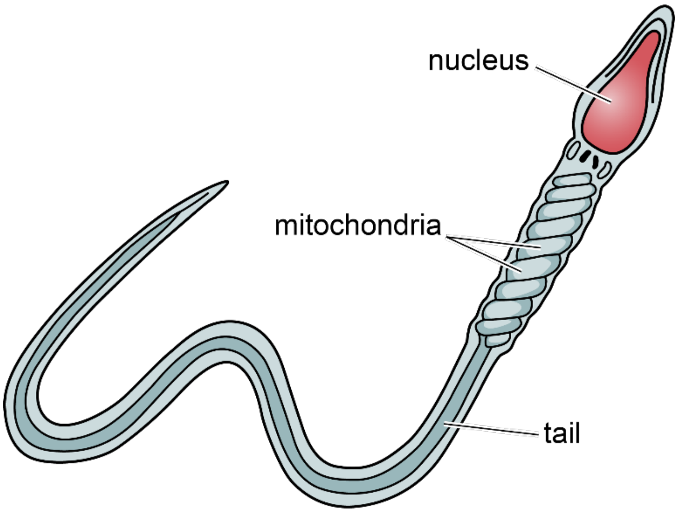
Simplified diagram of red blood cells



Red blood cells have a biconcave shape, which gives them a larger surface area for absorbing gases. They also contain a pigmented molecule called haemoglobin that binds to oxygen and carbon dioxide. Red blood cells in mammals have eliminated their nucleus and chromosomal DNA during the process of differentiation.

Function: transport of gases around the body.

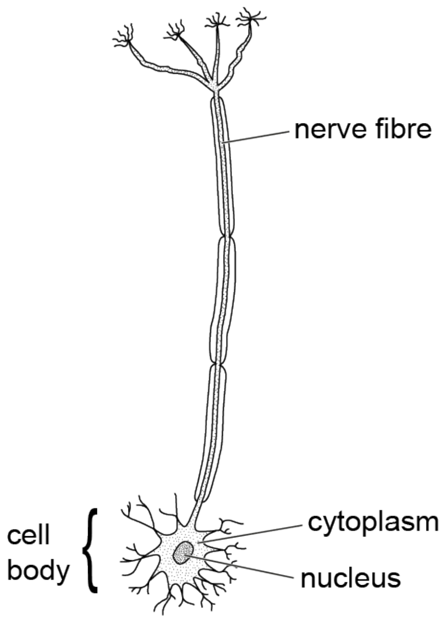
Simplified diagram of a sperm cell



Sperm cells contain a nucleus which carries genetic information about the father. The mid-section contains mitochondria to provide energy for movement. The tail is used for cell movement (swimming).

Function: reproduction, by fertilising an egg cell.

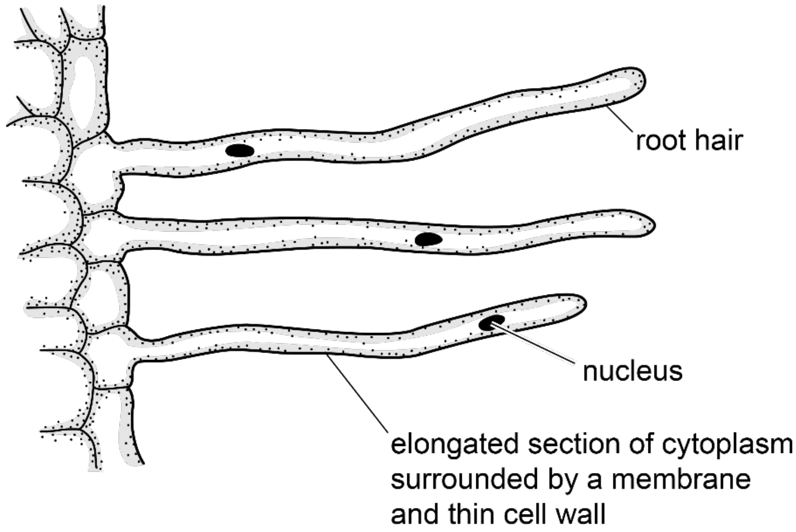
Simplified diagram of a nerve cell (neurone)



Nerve cells are often elongated to conduct nerve impulses from one part of the body to another. Chemical reactions cause the impulses to travel along the fibre.

Function: conducting nerve impulses.

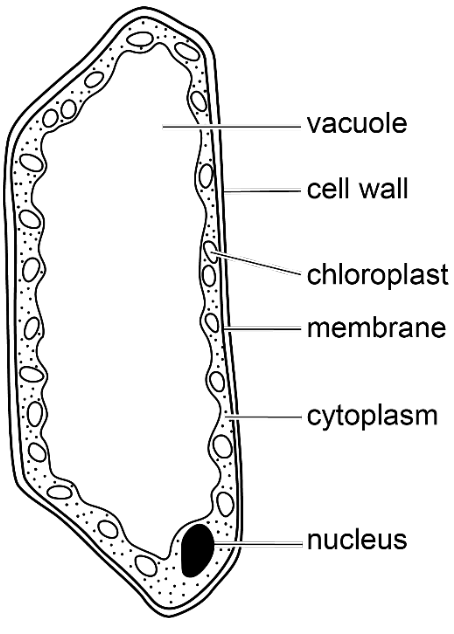
Simplified diagram of root hair cells



Root hair cells have an elongated 'hair-like' structure. This gives them a large surface area for the absorption of water and mineral ions.

Function: absorption of water and mineral ions from the soil.

Simplified diagram of a palisade mesophyll cell



Palisade mesophyll cells are columnar (elongated) and the cytoplasm is packed with chloroplasts to trap (absorb) sunlight.

Function: to make food for the plant through the process of photosynthesis.

Cells in multicellular organisms tend to work together in groups to carry out their functions effectively.

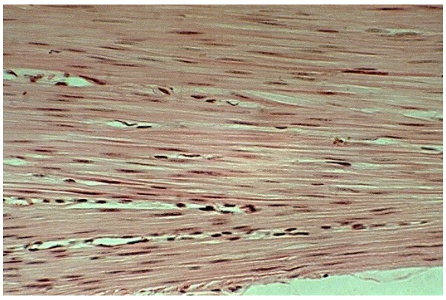
A tissue is made up of one or a few different cell types, working together to perform a shared function. Examples include muscle (contractile tissue) associated with the skeleton, blood circulating around the body, xylem vessels in a plant stem and palisade mesophyll of a leaf.

An organ is a structure made up of a group of tissues, working together to perform a specific function. Examples include the heart (pumps blood) and a leaf (harvests energy).

An organ system is a group of organs with related functions, working together to perform a body function. Examples include the circulatory system, made up of blood, the vessels and the heart; and the shoot of a plant, made up of the stem, leaves and buds.

Examples of tissues

Muscle tissue



Some of the solid components of blood

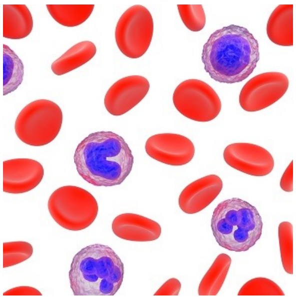
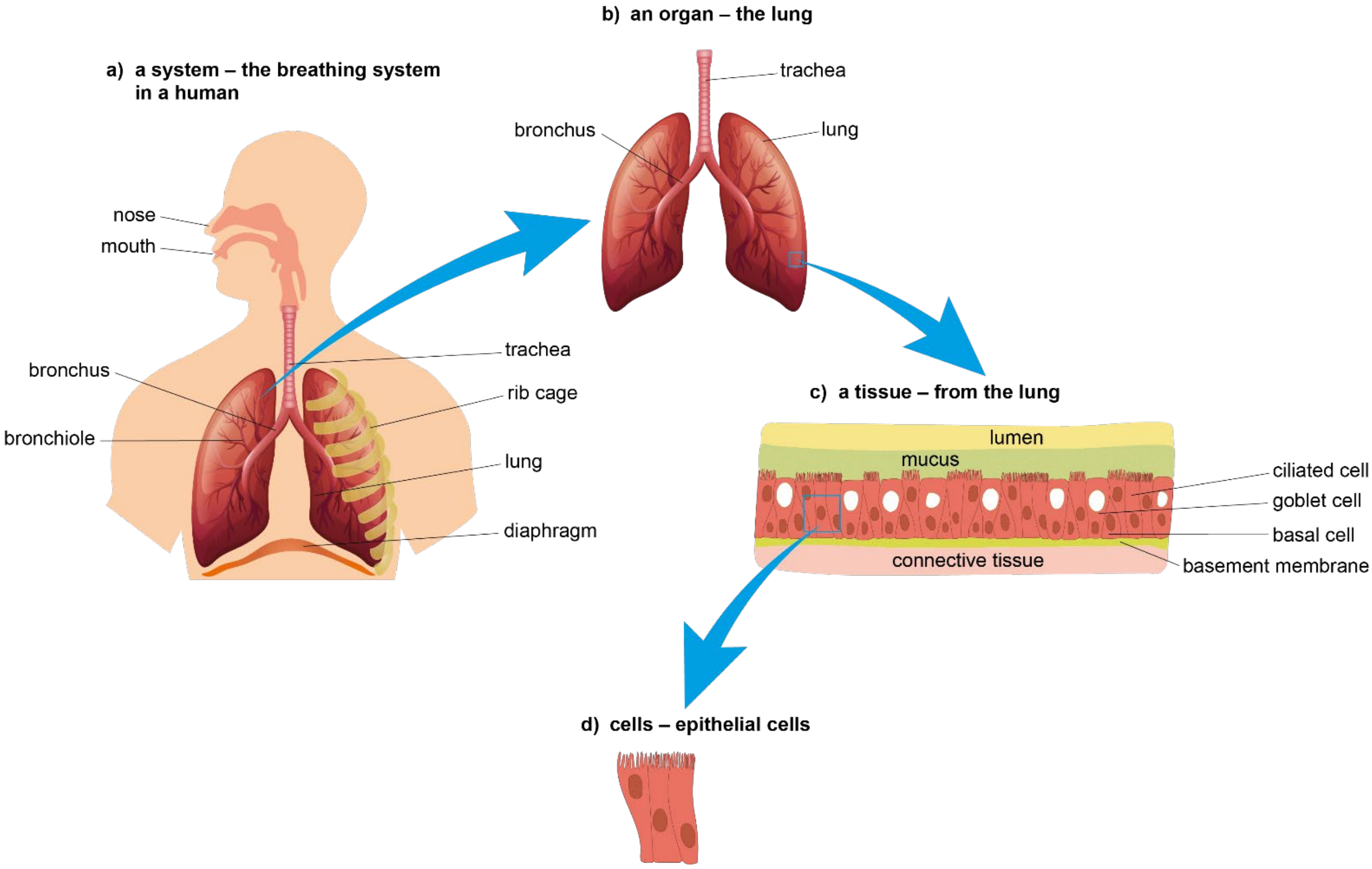


Diagram showing the relationship between cells, tissues and organs in the human respiratory system.



Exercise 4

a) Name four organ systems found in multicellular animals.

b) For each system, name two organs associated with it.

c) Name one system possessed by both plants and animals.

Exercise 5

Place the following levels of organisation for a multicellular animal in order of size from smallest to largest: cell, organ, sub-cellular component, organism, organ system, tissue.

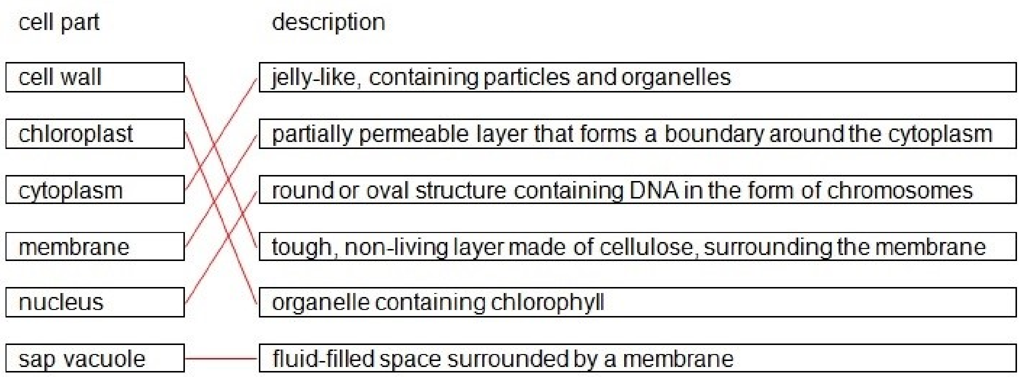
Solutions to Exercises 1 to 5

Exercise 1

a) Cell membrane, cytoplasm, nucleus, cell wall, chloroplast and sap vacuole are present in plant cells. However, animals do not have a cell wall, chloroplasts or a sap vacuole.

b) Chloroplasts are not found in root hair cells because these cells are not exposed to light. Their function is the absorption of mineral ions and water, as well as anchorage, and they are adapted to do this by having an elongation to the cell – the root hair.

Exercise 2



Exercise 3

Quick answer: An animal cell has a nucleus which contains DNA, and a prokaryotic cell has DNA but no nucleus. Animal cells usually contain several large chromosomes, but a prokaryotic cell usually only contains one per cell. DNA in prokaryotic cells is circular with no free ends, but the DNA of eukaryotic cells forms large linear chromosomes with free ends.

More detailed acceptable answers include: In an animal cell the DNA is surrounded by membrane, but in a prokaryotic cell the DNA there is no nuclear membrane. A prokaryotic cell contains a plasmid but an animal cell does not. The DNA of a prokaryotic cell contains fewer genes than the DNA of an animal cell.

Exercise 4

Parts a) and b)

Any four organ systems, and two organs for each system, from:

Organ system	Organ 1	Organ 2
circulatory	heart	artery
digestive	stomach	small intestine
excretory	kidney	urethra
nervous	brain	nerve
reproductive	testes	penis
respiratory	lungs	diaphragm
skeletal	skull	femur

Other organs for each of the organ systems would also be acceptable answers.

For example:
circulatory – vein, capillary digestive – oesophagus, rectum excretory – ureter, bladder, lungs nervous – spinal cord, eye reproductive – ovary, uterus respiratory – trachea, ribcage skeletal – any other named bones.

c) Reproductive system.

Exercise 5

Smallest to largest: sub-cellular component, cell, tissue, organ, organ system, organism.

Sub-cellular components are the smallest structures as they are found within cells. A tissue is a group of one or a few cell types, performing a shared function. An organ is a structure made up of a group of tissues working together to perform a shared function. An organ system is a group of organs with related functions, working together to perform a body function. An organism is a whole living being capable of reproduction. In the example of a multicellular animal, it is made up of the levels of organisation named in this question.

Photos: Science Photo Library

B2. Movement across membranes

B2.1	Know and understand the processes of diffusion, osmosis (in terms of water potential), and active transport, including examples in living and non-living systems.

A membrane is a selective barrier. All cells have a cell membrane which forms a highly flexible barrier to stop the cell contents from escaping and control which substances enter and leave the cell.

Processes occurring in cells require certain substances to move across the cell membrane. Raw materials, like water, nutrients and ions must cross the membrane to enter cells. Cells also need to get rid of waste substances that have accumulated, as these may be toxic or interfere with essential chemical reactions. Prokaryotes must acquire nitrogen, carbon, salts and water from their surroundings in order to grow. Plant cells also need carbon dioxide for chloroplasts in their photosynthetic cells to generate energy from the sun. Animal cells also need oxygen for their mitochondria to generate energy from food molecules with high efficiency.

To enter or exit the cell, nutrients and other substances must cross the cell membrane. This can occur by a passive process that does not require energy (diffusion or osmosis) or an active process which requires the cell to use energy (active transport).

Particles in liquids and gases move about randomly. The rate of movement is affected by factors such as concentration gradients and temperature. Over time, any uneven distribution of particles will become even as a result of this random motion.

Diffusion

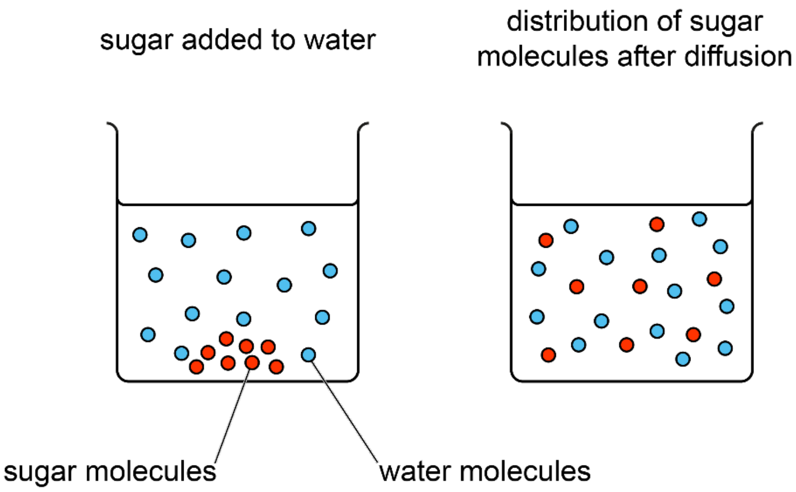
Diffusion is the net movement of molecules and ions from a region of their higher concentration to a region of their lower concentration down a concentration gradient, as a result of their random movement. This continues until there is no net movement.

Factors affecting the rate of diffusion:

- Concentration gradient – the greater the difference in the concentration of particles between two locations, the faster the rate of diffusion. The particles move due to the transfer of kinetic energy to and from the water molecules.
- Distance – the further the particles have to travel, the longer it takes the molecules to diffuse.
- Size – the smaller the particles, the faster they can diffuse.
- Surface area – the larger the surface area, the faster the molecules will diffuse.

If a small amount of a substance such as a single crystal of sugar is put into water, the sugar molecules will dissolve in the water. Initially the sugar will have highest concentration near where the crystal is placed. Over time, the kinetic energy of the water molecules will cause the dissolved sugar molecules to diffuse. Eventually the sugar molecules will become evenly distributed in the water.

Sugar molecules in water

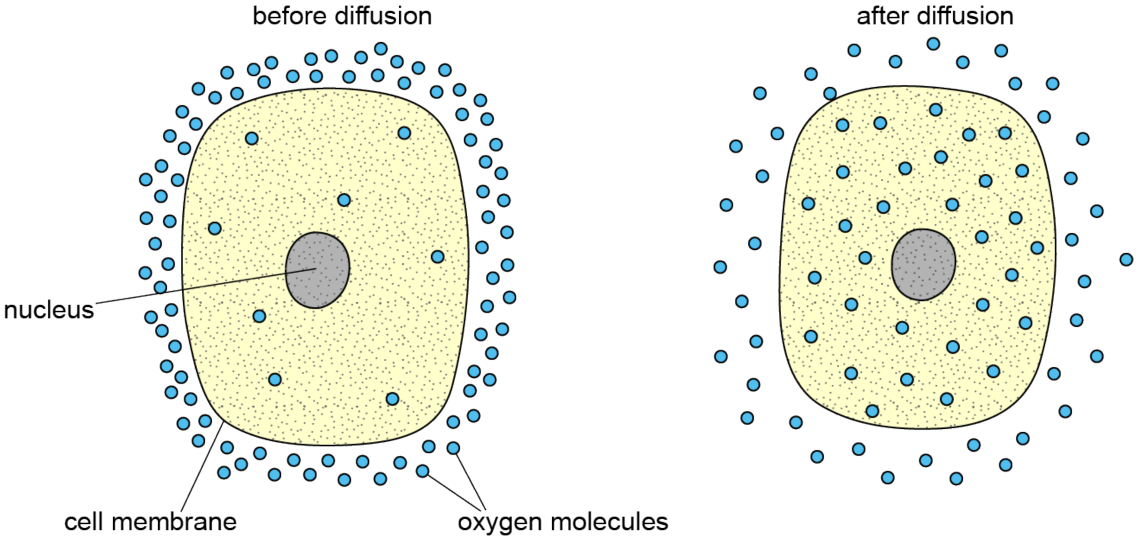


If a cell is placed in a situation where there is a higher concentration of molecules outside the cell, the process of diffusion could result in a net movement of the molecules into the cell. However, this depends on whether the cell membrane will let the molecules through. This is because cell membranes are partially permeable. This means they allow some substances to move across but not other substances.

In general, small molecules can pass freely through the cell membrane by diffusion but large molecules cannot. For example, oxygen, carbon dioxide, glucose and water can pass through the cell membrane, but large molecules like starch and proteins cannot.

As cell membranes are permeable to oxygen, if a cell is placed in a situation where there is a higher oxygen concentration outside the cell, oxygen molecules will diffuse across the membrane until its concentration is equal on both sides.

Diffusion



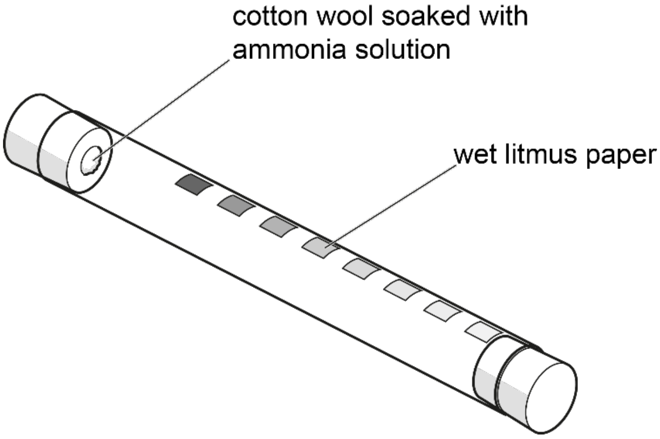
Examples of diffusion in living systems include:

- gas exchange in the lungs (oxygen and carbon dioxide)
- absorption and release of oxygen by red blood cells
- absorption of solutes into the blood stream from the kidney tubules
- absorption of digested food molecules into the blood stream from the ileum
- movement of neurotransmitter substances across synaptic gap in the nervous system
- absorption of carbon dioxide by palisade mesophyll cells in a leaf
- loss of water vapour from plant leaves during transpiration.

Examples of diffusion in non-living systems include:

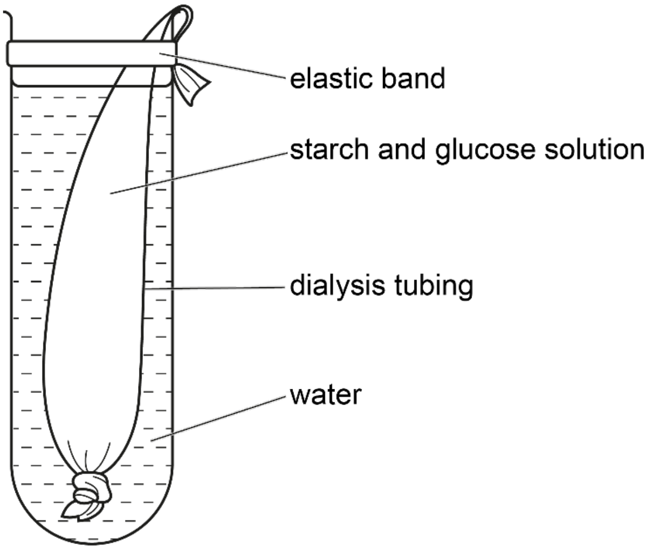
- spread of the smell of perfume across a room (no membrane involved)
- spread of the brown-coloured pigments out of tea leaves in a bag when placed in hot water (non-living membrane involved)
- spread of potassium manganate (VII) when a crystal is dropped into a beaker of water (no membrane involved)
- movement of ammonia along a hollow glass tube, indicated by a change in colour of litmus paper placed at regular intervals inside the tube (no membrane involved)
- movement of glucose but not starch across dialysis tubing (non-living membrane involved).

Movement of ammonia along a hollow glass tube



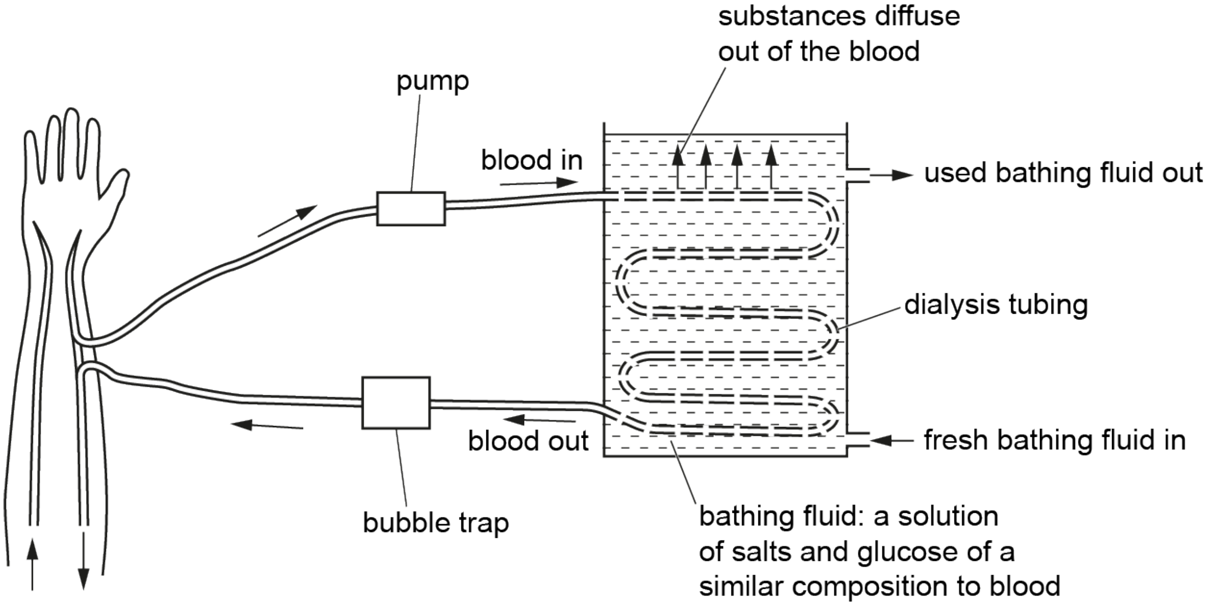
Spread of the brown-coloured pigments from a tea bag

Demonstrating diffusion in dialysis tubing



A mixture of glucose and starch dissolved in water is sealed inside a section of dialysis tubing. The starch molecules are too large to pass through the tubing into the water but the glucose is small enough to freely diffuse.

Kidney dialysis machine using diffusion through a membrane to regulate the composition of the patient's blood



Using the process of diffusion through the dialysis tubing, urea, uric acid and excess salts are removed from the blood as it passes along the dialysis tubing.

Exercise 6

A mixture of glucose and starch dissolved in water is sealed inside a section of dialysis tubing and the tubing placed into a test tube containing only water. How would the rate of diffusion of glucose change in the following circumstances:

a) The temperature of the bathing solution was increased?

b) The concentration of glucose was decreased?

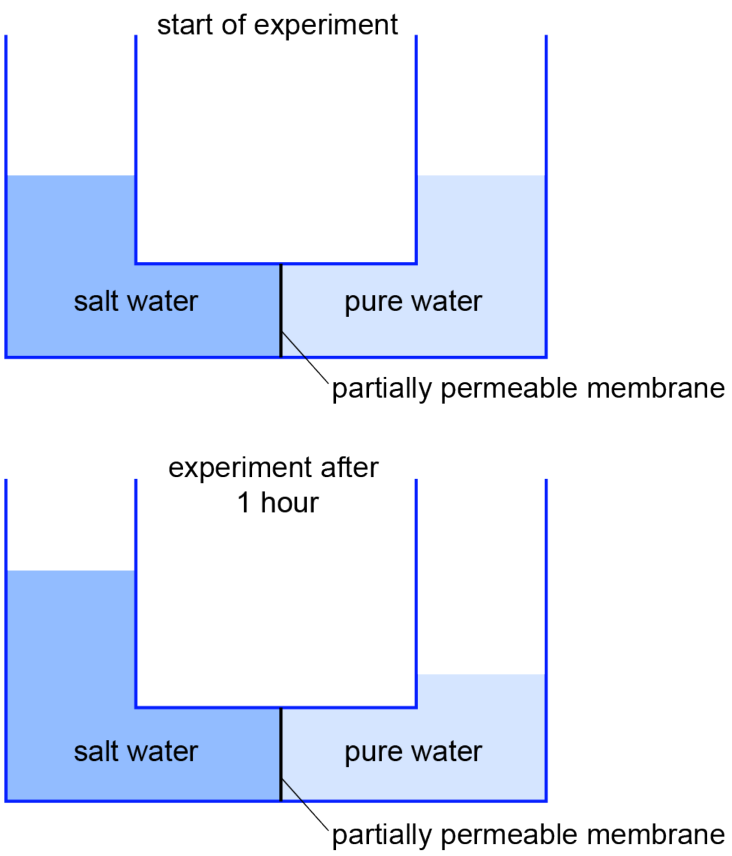
c) The dialysis tubing used had a thicker wall?

Osmosis

Osmosis is the movement of water from a region of higher water potential (dilute solution) to a region of lower water potential (concentrated solution) through a partially permeable membrane.

The model below demonstrates the process of osmosis. A U-shaped tube is divided in half by a semi-permeable membrane. At the start of the experiment, equal volumes of salt water and pure water are placed into the two halves. As time progresses, the water molecules in the pure water (which have the higher water potential) show a net movement through the membrane into the salt water (which has a lower water potential). The salt particles are too large to pass through this membrane, so they don't move through it. Gradually the height of the salt water column rises and the pure water column falls as a result of osmosis.

Osmosis



A plant cell contains water in the sap vacuole and cytoplasm in the form of solutions. The cell wall is freely permeable to water.

An animal cell contains water in the cytoplasm, in which a variety of solutes are dissolved.

Cells in water

When a plant cell is placed into pure water, there is a large difference in water potential between the outside of the cell (higher water potential), and the inside (lower water potential). As a result, water will flow across the membrane into the cell. This is called osmosis.

In a plant cell, the sap vacuole fills up and exerts pressure on the cytoplasm, which presses against the cell wall. The cell becomes turgid, but the cell wall prevents the cell from bursting.

When an animal cell is placed in water, osmosis will cause water to enter the cell. The volume of the cytoplasm will increase and the cell membrane will stretch. Eventually the membrane will burst because animal cells do not have a cell wall and the membrane is not strong enough to withstand the pressure of the extra fluid in the cell.

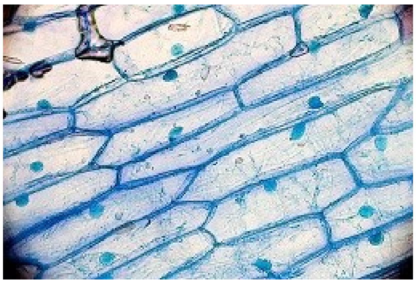
Cells in concentrated solutions

When cells are placed into a concentrated salt solution (lower water potential than their cytoplasm), both plant and animal cells will lose water through their membranes by osmosis.

Plant cells become flaccid when placed in concentrated sugar solutions. This is because the volume of fluid in the sap vacuole decreases and the pressure reduces, resulting in much of the cell membrane and the cytoplasm shrinking away from the cell wall.

Animal cells such as red blood cells become crenated when placed in concentrated sugar solutions. This is because the volume of their cytoplasm decreases as water leaves the cell by osmosis.

Onion cells in water

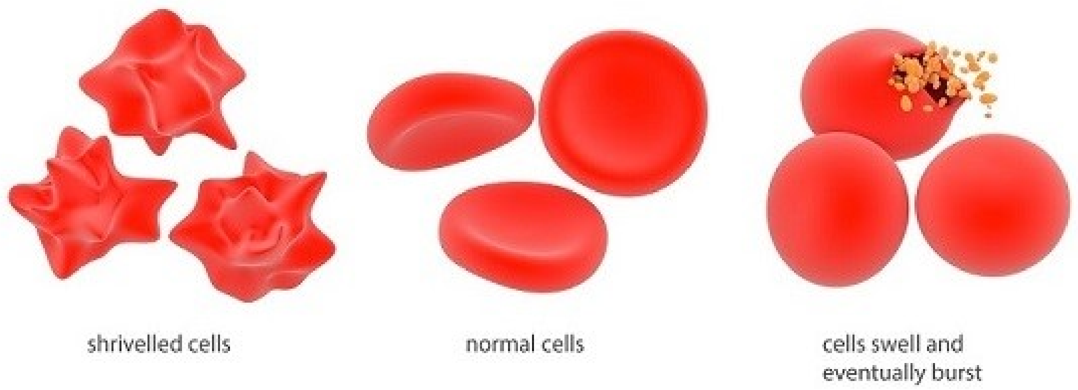


Onion cells in a concentrated solution

In water, the cells are turgid: in each cell the cytoplasm is pressing against the cell wall, making the wall bulge outwards.

In concentrated solution the cells are flaccid: in each cell the cytoplasm is shrinking away from the cell wall.

Osmosis in red blood cells

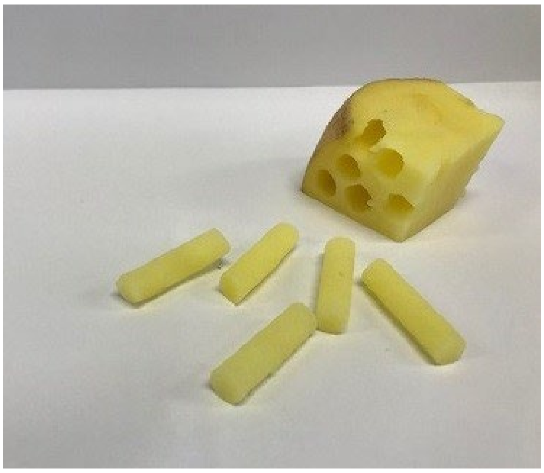


Experiments using plant tissue can be used to demonstrate osmosis. Single cells are microscopic, so are not easy to measure or weigh, but plant tissue can be measured as it contains many cells.

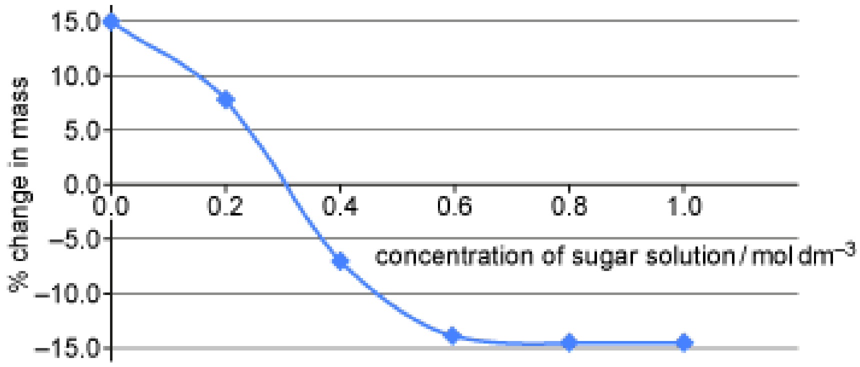
Experiment to investigate the effect of the concentration of a solution on length or mass of potato cores.

- Cores of raw potato in the form of cylinders or chips are cut to the same length.
- Samples are placed in solutions of a range of concentrations.
- After an hour, these are removed and re-measured or weighed.
- The potato pieces in pure water get longer and gain mass.
- Those in concentrated solutions get shorter and lose mass.

Cores of the same length or mass cut from a potato and placed in a range of concentrations of sugar solution.



Graph of results



Examples of osmosis

- Plants rely on osmosis to obtain water through their roots. Water is transferred from cell to cell by osmosis.
- When plant cells are turgid, their rigidity can keep the whole plant firm and upright. Leaves can be held in the best position possible to trap (absorb) sunlight for photosynthesis.
- When plant cells are flaccid, they lose their rigidity and the whole plant can wilt.
- If animal cells are exposed to pure water, they can swell up and burst (in a red blood cell this is called haemolysis). Red blood cells, for example, would not then be able to carry oxygen.
- If animal cells lose water, they become flaccid. Red blood cells, for example, would be less efficient at carrying oxygen.
- Water is absorbed by osmosis from the ileum and colon as food passes along the alimentary canal.
- Water is reabsorbed in the kidney tubules by osmosis.

Exercise 7

a) With reference to osmosis, explain why a cylinder of raw potato cut from a slice of uniform thickness:

i) gets longer and gains mass when placed in pure water

ii) gets shorter and loses mass when placed in a concentrated sugar solution.

b) Explain why cells in the potato cylinder do not burst when placed in pure water.

Active transport

Active transport is the movement of particles through a cell membrane from a region of lower concentration to a region of higher concentration using the energy from respiration.

Movement of the particles is in the opposite direction to diffusion (moving up a gradient instead of down a gradient). Cells have to provide the energy to achieve this, through respiration using ATP. Mitochondria control the energy release, so cells involved with active transport tend to have large numbers of mitochondria in their cytoplasm. The chemical energy from respiration is converted to kinetic energy for movement of the particles. Anything which interferes with respiration, e.g. toxins or lack of oxygen, prevents active transport from taking place. Active transport is thought to be achieved by carrier proteins embedded in the membrane. They move the particles from one side of the membrane to the other.

Examples of active transport

- Plant root hair cells use active transport to move mineral salts from the soil into the root. These salts are commonly in lower concentrations in soil than in the plant root cells, so diffusion is not adequate to absorb them.
- Glucose is moved from the small intestine into the blood stream of mammals by active transport. Absorption of glucose by diffusion would stop once the concentration in the blood reached that of the intestine.
-

Exercise 8

a) Explain why the rate of respiration in root hair cells of plants may increase when they are taking in mineral salts.

b) Explain why the uptake of the mineral salts slows down when the root hairs are exposed to a respiratory poison.

c) Suggest why uptake of the mineral salts does not completely stop after exposure to the respiratory poison.

Solutions to Exercises 6 to 8

Exercise 6

a) The rate would increase.
Reason: At the higher temperature the glucose molecules have more kinetic energy. So they would be able to move faster from inside the dialysis tubing into the surrounding water.

b) The rate would decrease.
Reason: The concentration gradient between the inside of the tubing and the water surrounding the tubing would be lower.

c) The rate would decrease.
Reason: There would be a greater distance for the glucose molecules to travel between the inside of the dialysis tubing and the surrounding water.

Exercise 7

a)

i) The water surrounding the potato cylinder has a higher water potential than the fluid in the cytoplasm and sap vacuole of the potato cells. Water moves into the potato cells by osmosis, from the higher water potential to the lower water potential. The cells become turgid, making the cell walls bulge outwards. Each of the cells gets longer and heavier, so the cylinder gains length and mass.

ii) The water surrounding the potato cylinder has a lower water potential than the fluid in the cytoplasm and sap vacuole of the potato cells. Water moves out of the potato cells by osmosis, from the higher water potential to the lower water potential. The cells become flaccid, removing pressure on the cell walls. The cells get shorter and lighter, so the cylinder loses length and mass.

b) Potato cells are plant cells, so they have cell walls. Plant cell walls are made of cellulose, which provides rigidity and prevents the cells bursting when they are turgid.

Exercise 8

a) The concentration of salts surrounding the root hair cell may be higher than inside. This would mean that diffusion would not move salts into the cells (it may even cause the cells to lose salts). Active transport is needed. This process requires energy, which is supplied by the process of respiration.

b) Active transport requires energy to move the mineral salts. The energy is provided by respiration. If respiration is inhibited by a poison, little energy is available, so active transport will stop. However, some salts may still move by diffusion, so movement of salts may not stop completely.

c) Although active transport will not be available to move salts into the root hair cells, if there is a higher concentration of salts in the soil around the root hair cells, salts will still move into the cells by diffusion, which does not require an energy source.

Photos: Science Photo Library/Umberto Salvagnin - CC BY 2.0

B3. Cell division and sex determination

B3.1 Mitosis and the cell cycle:

a. Know and understand that the mitotic cell cycle includes interphase (involving cell growth and DNA replication) and mitosis (involving one cell division leading to two daughter cells which are genetically identical to each other and to the parental cell).
b. Know and understand the importance of mitosis in the growth of an organism: specifically, its roles in increasing the number of cells, repairing tissues, replacing cells and asexual reproduction.
c. Know and understand that cancer is the result of changes in cells, including mutations, that lead to uncontrolled cell division.

B3.2 Meiosis and the cell cycle:

a. Know and understand that the meiotic cell cycle includes interphase (involving cell growth and DNA replication) and meiosis (involving two cell divisions leading to four daughter cells, each with a single copy of each chromosome).
b. Know and understand the role of meiosis in producing genetically different haploid gametes so that the zygote (fertilised egg cell) produced at fertilisation is diploid.

B3.3 Asexual and sexual reproduction:

a. Know and understand that asexual reproduction involves one parent and that offspring are genetically identical when no mutations occur.
b. Know and understand that sexual reproduction involves two parents and that offspring are genetically different in relation to each other and the parents, leading to (increased) variation.

B3.4 Sex determination:

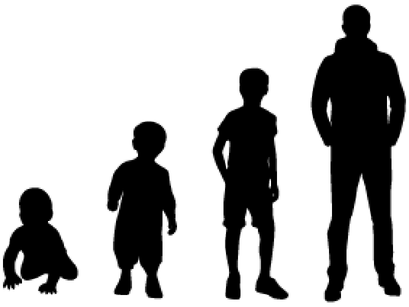
a. Know that, in most mammals including humans, females are XX and males are XY.
b. Analyse genetic data and diagrams to establish the sex and ratio of offspring.

Growth

All living organisms grow during their lifetime.

Humans are multicellular organisms; our bodies are made up of trillions of cells.

Every human begins life as a single cell, a zygote (fertilised egg cell).

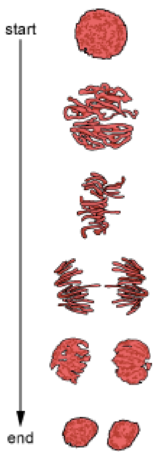


The zygote cell divides to produce two new daughter cells, and these cells in turn also divide to produce new cells. In this way, the zygote develops from a single cell into a complex ball of cells and a new human life begins to grow.

The process of cell division in eukaryotic cells which results in growth is called mitosis.

Mitosis

The diagram shows the arrangement of chromosomes during various stages of mitosis.



When a cell divides by mitosis:

- the nucleus breaks down
- the DNA from the nucleus is split into two new, identical nuclei.

The cell then splits into two new daughter cells, a process called cytokinesis.

The two daughter cells produced by mitosis:

- are genetically identical to each other
- are genetically identical to the parent cell which produced them
- have the same number of chromosomes as the parent cell.

The cell cycle

To prepare for mitosis, the parent cell goes through a sequence of specific steps.

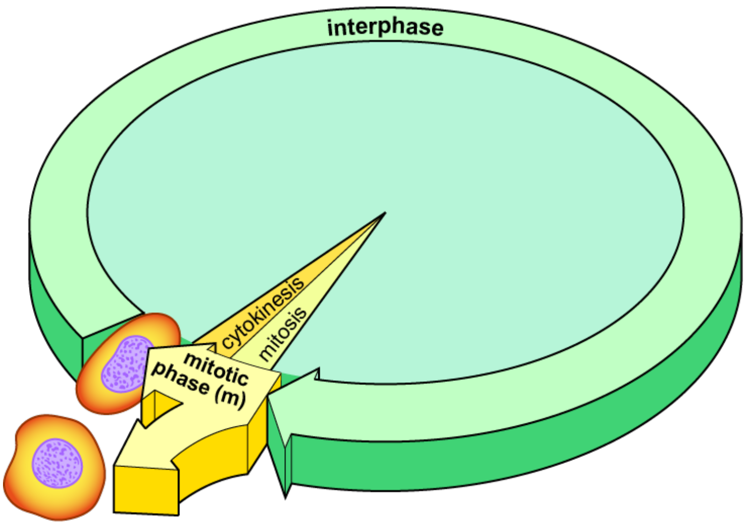
This period of preparation for cell division is called interphase.

During interphase:

- the cell grows
- the chromosomes in the nucleus are replicated
- the cell respires to provide energy for mitosis.

This process of interphase and mitosis is called the cell cycle.

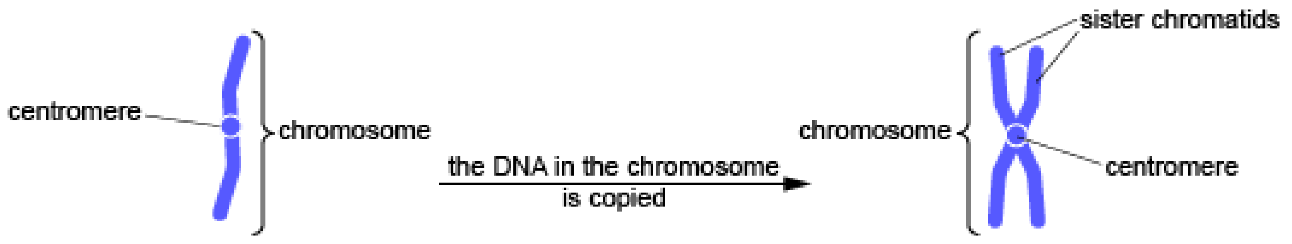
The cell cycle



Chromosome replication during interphase

Immediately after cell division, each chromosome consists of a single molecule of DNA. During interphase, all of a cell's DNA gets replicated. This replication is important as it allows a full set of chromosomes identical to that of the parent cell to be passed to each daughter cell.

Chromosome replication



One chromosome before replication

The chromosome contains one DNA molecule.

Chromosomes appear like this at the end of mitosis.

One chromosome after replication

A newly replicated chromosome is made of the identical sister chromatids – each chromatid is a single DNA molecule.

Chromosomes appear like this at the end of interphase and the beginning of mitosis.

Roles of mitosis

Mitosis:

- allows organisms to grow in size by increasing their total number of cells
- allows worn-out and dead cells in a tissue to be repaired and replaced
- allows some species to reproduce by asexual reproduction.

Some organisms, such as the plant in the photograph below, reproduce using asexual reproduction.

Mitosis in a plant

The cells in this plant leaf are dividing by mitosis to produce tiny plantlets.

The plantlets will eventually drop to the ground and grow into new plants. As these new plants have been produced by mitosis of cells in one parent plant, they will be genetically identical to both the parent plant and to each other.

Mitosis and cancer

As a cell prepares for mitosis during interphase, the cell cycle pauses temporarily for a short time to check the cell is healthy and the DNA has been copied correctly.

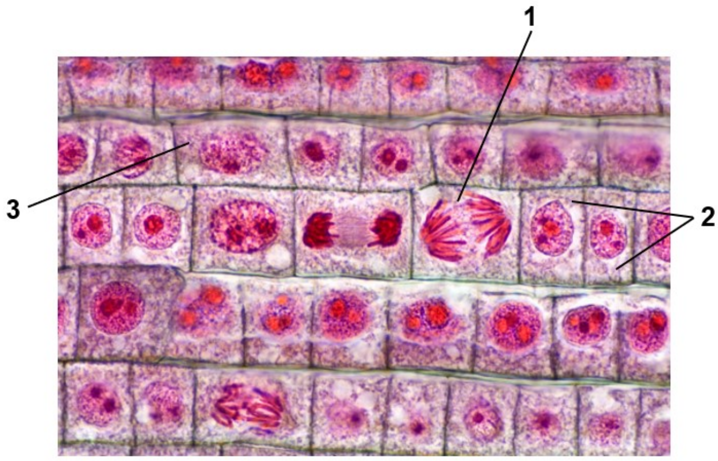
If errors are detected in a cell, such as a mutation in the DNA that cannot be repaired, the cell will be destroyed.

If a cell with changes is not destroyed, the cell cycle will continue and the cell will divide by mitosis.

This may lead to a group of cells that are defective and divide uncontrollably, which can form a tumour. This is how cancer develops.

Exercise 9

The photomicrograph shows a number of cells in a tissue where mitosis is occurring.



a) Are the cells animal or plant cells? Explain your answer.

b) Name three parts of a cell that are visible in the photomicrograph.

c) Describe what is happening to the cells labelled 1, 2 and 3.

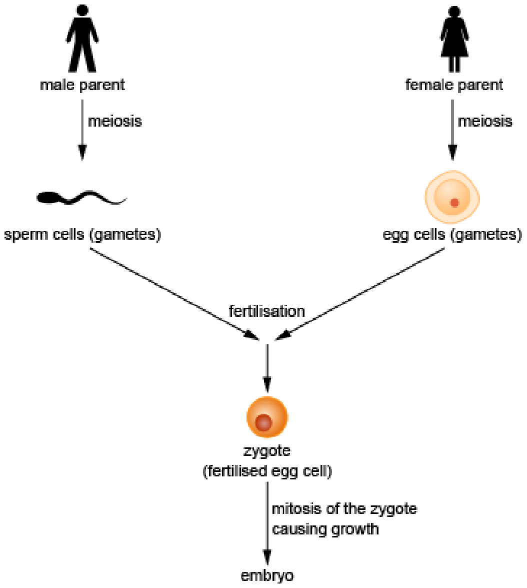
d) A student wrote: ‘During the cell cycle, interphase is the stage in which nothing happens’. Why is this statement incorrect?

Meiosis and sexual reproduction

Many eukaryotic organisms, including humans, reproduce by sexual reproduction. This requires a special form of cell division called meiosis. Specialised reproductive cells called gametes are produced containing half the normal complement of chromosomes per cell.

In sexual reproduction, gametes formed by the parents fuse together at fertilisation to form a new individual, called a zygote.

Gametes fusing together.

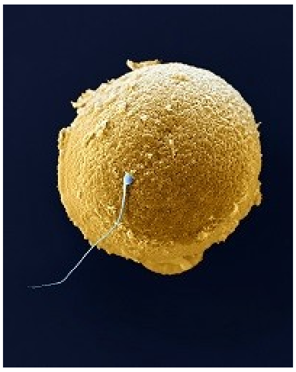


Chromosome number and gametes

When a male and a female gamete fuse at fertilisation, their nuclei combine to form a zygote.

This means that the total number of chromosomes in the zygote is the sum of those in the two gametes.

Scanning electron micrograph of a human ovum (egg cell) and a human sperm

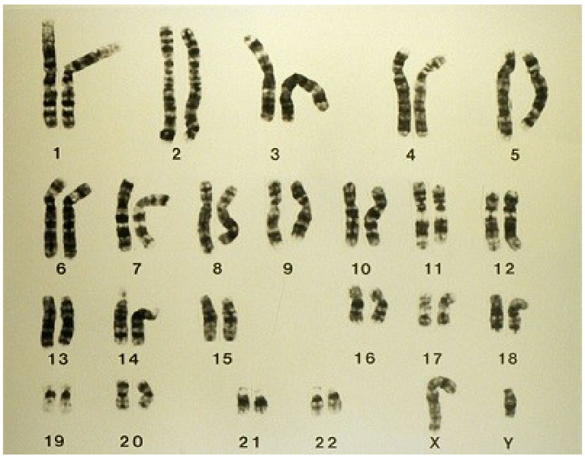


A human ovum (egg cell) has 23 chromosomes in the nucleus, and a human sperm cell has 23 chromosomes in its nucleus.

Therefore, when these gamete cells fuse at fertilisation, the human zygote has 46 chromosomes in the nucleus, in 23 pairs.

Plants and animals whose zygotes contain two full sets of chromosomes are called diploid. One chromosome from each pair originated from the sperm and the other from the ovum. In this way, offspring produced by sexual reproduction can display characteristics inherited from each of their parents.

Human chromosomes



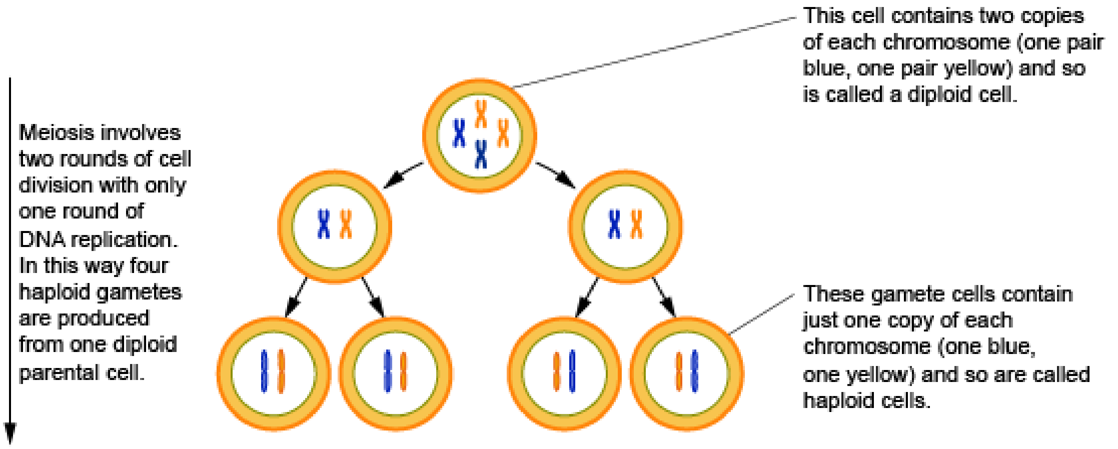
The photograph shows the chromosomes from a human body cell. There are 46 chromosomes and they are arranged in 23 different pairs.

Gametes are produced by meiosis.

In sexually reproducing animals (including humans), sperm carrying half the normal number of chromosomes are produced by meiosis in the testes. Ova with half the normal number of chromosomes are produced by meiosis in the ovaries.

In most diploid species, meiosis will generate four daughter cells, each with only a single set of chromosomes compared with the two sets found in the parent cell. Mature gametes with only one set of chromosomes are described as haploid.

Meiosis



Importance of meiosis

1) Meiosis is sometimes referred to as reductional division since it halves the total number of chromosomes per cell.

It is very important that the chromosome number of each gamete is reduced to half the number found in an organism's body cells. This prevents chromosome number doubling when fertilisation takes place.

2) The gametes produced by meiosis are genetically different from each other and from the parent cell which produced them. This helps to produce genetic variation in offspring.

Comparing mitosis and meiosis

Characteristic	***Mitosis***	***Meiosis***
Number of daughter cells produced?	2	4
Daughter cells genetically identical to parent cell?	yes	no
Daughter cells genetically identical to each other?	yes	no
Chromosome number in daughter cells?	• the same number as the parent cell • diploid if parent cell is diploid • haploid if parent cell is haploid	• half the number of the parent cell • haploid
When used?	• growth • tissue repair • replacement of worn-out cells • asexual reproduction	• gamete formation during sexual reproduction

Exercise 10

a) Name the daughter cells formed by meiosis.

b) State two ways in which the daughter cells formed through meiosis are different from the parent cell that formed them.

Reproduction

All living organisms reproduce. Parent organisms produce offspring, passing on genetic material from one generation to the next to ensure the continuation of the species.

There are two types of reproduction:

1. asexual reproduction
2. sexual reproduction.

Asexual reproduction

Asexual reproduction:

- requires only one parent

  and

- there is no production or fusion of gametes.

This means that offspring produced by asexual reproduction only have one parent and inherit all of their genetic material from them. The offspring of asexual reproduction are genetically identical to each other and to the parent that produced them.

The photograph below shows a bacterial cell in the process of dividing.

E. coli dividing

One bacterial cell dividing into two new bacterial cells involves asexual reproduction.

This form of reproduction is referred to as binary fission and produces genetically identical offspring.

The importance of mutations

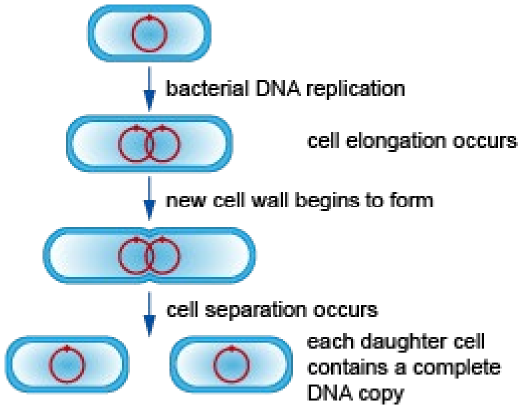
When a bacterial cell reproduces by binary fission, it produces a copy of the loop of chromosomal DNA found in the cell's cytoplasm.

The cell then divides into two, passing one copy of the chromosomal DNA to each new daughter cell.

Bacteria produced by binary fission are not always genetically identical. This is because a mutation may occur in the DNA when it is copied.

This means that there may be a change in the order of bases in the DNA, and the two loops of chromosomal DNA may not be exactly the same.

Binary fission in bacteria



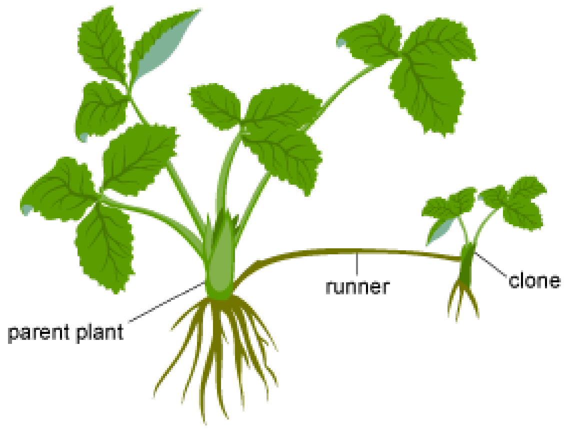
Certain multicellular organisms, including many plants, can reproduce asexually. Strawberry plants often reproduce by asexual reproduction.

The parent plant produces a runner and new offspring plants develop along the length of the runner.

Cells in the runner from the parent plant divide by mitosis and then undergo differentiation to form all the cell types required for a new plant.

The offspring plants are therefore genetically identical (clones) to the parent plant and to each other unless a mutation occurs.

Asexual reproduction in strawberry plants



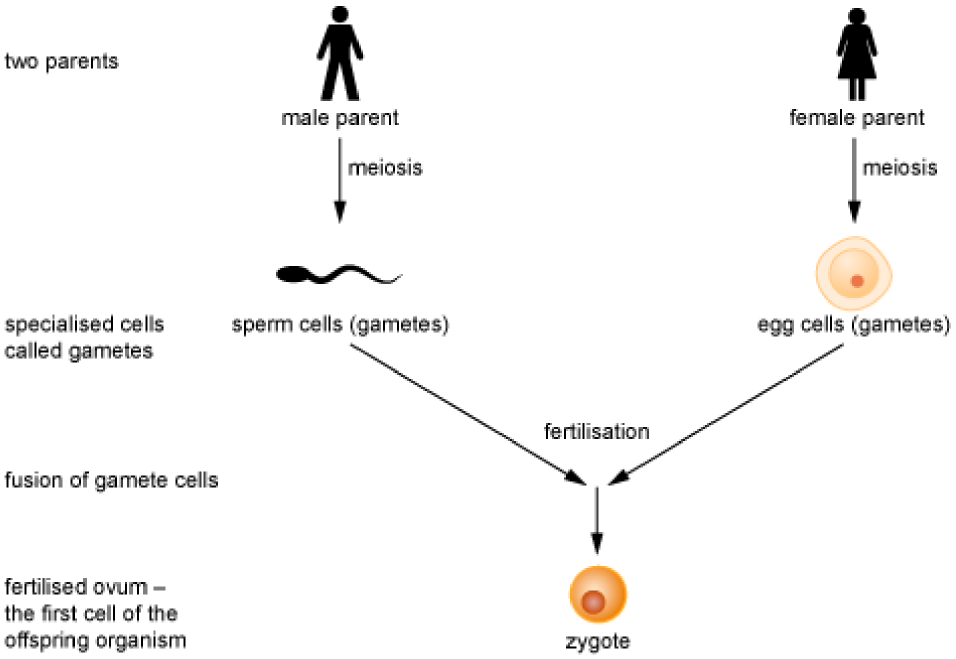
Sexual reproduction

Many organisms reproduce by sexual reproduction.

In sexual reproduction:

- two parents are involved
- each parent produces specialised cells called gametes
- gametes are produced by meiosis
- gametes fuse together at fertilisation
- offspring are genetically different.

An overview of the process of sexual reproduction



The offspring organism grows and starts to develop as the zygote cell divides by mitosis.

The offspring are genetically different:

- to their parents because they receive half of their genetic information from each parent in the gametes
- to each other because the gametes produced by meiosis are genetically different from each other and it is completely random which of the gametes from each parent will then fuse at fertilisation to form the zygote.

Importance of producing genetically different offspring

- It is important that sexual reproduction produces genetically different offspring so that genetic variation is maintained within a species.
- Genetic variation is essential for natural selection.
- Natural selection enables populations of organisms to adapt to changes in the environment. It ensures the successful continuation of a species over time.
- Genetic variation within a species also helps to reduce the frequency with which recessive inherited conditions occur.

Wolves with different coat colours showing genetic variation in their population.

This table shows the similarities and differences between asexual and sexual reproduction:

Characteristic	***Asexual reproduction***	***Sexual reproduction***
Number of parents needed?	1	2
Requires meiosis to produce gametes?	no	yes
Offspring are clones?	yes, in the absence of mutations	no
Mutations can create genetic variation in offspring?	yes	yes

Exercise 11

a) Why is reproduction important?

b)

1) What is a zygote?
2) How is a healthy human zygote different from a healthy human ovum?

Sex chromosomes and sex determination

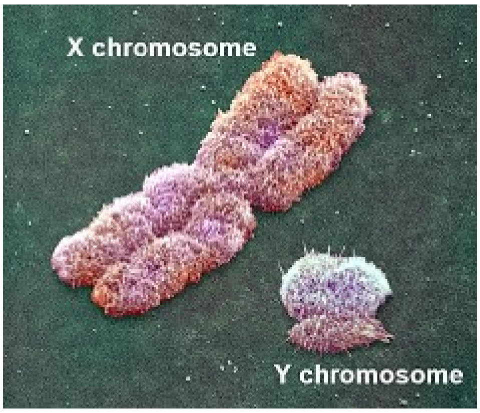
Of the 23 pairs of chromosomes in human cells, 22 pairs are referred to as autosomes, and one pair are referred to as sex chromosomes.

In humans as well as many other animal species, the sex of the individual is determined by the combination of sex chromosomes.

Being much smaller, the Y chromosome contains many fewer genes than the X chromosome.

The Y chromosome contains key genes needed to initiate male sexual development.

Sex chromosomes



The picture above has been taken with a scanning electron microscope. It shows the sex chromosomes from a human male.

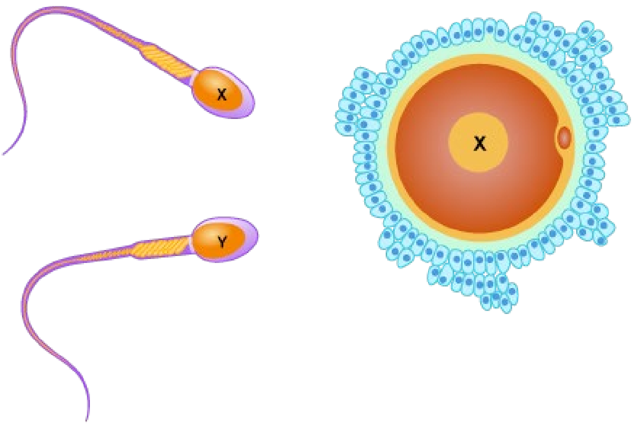
Human males have one X chromosome and one Y chromosome, XY. Human females have two X chromosomes, XX.

The sex of many other mammals is determined by sex chromosomes, exactly as it is in humans.

Sex chromosomes in gametes

Each human sperm contains 23 chromosomes, one of which is a sex chromosome (either an X or a Y). Each human ovum contains 23 chromosomes, one of which is always an X chromosome.

Sperm and egg



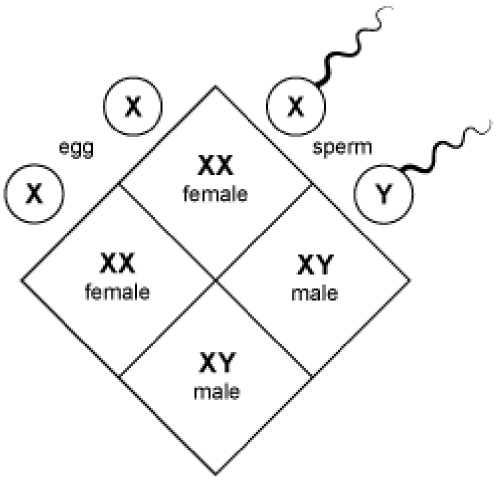
At fertilisation it is the sperm cell that determines the sex of the resulting zygote.

When a Y chromosome is delivered to the egg by the sperm the zygote will develop into a male.

When an X chromosome is delivered to the egg by the sperm the zygote will develop into a female.

Punnett square diagrams can be used to show the probability that a child will be male or female.

Probability showing sex ratio.



From the Punnett square we can conclude that the ratio of male to female individuals in the human population should be 1 : 1, as 50% of babies born will be male and 50% will be female.

Exercise 12

Explain why a zygote formed from the fertilisation of an ovum by a sperm cell carrying an X chromosome develops into a female child.

Solutions to Exercises 9 to 12

Exercise 9

a) The cells are plant cells. They can be identified as plant cells because they have a cell wall.

b) Any three from: cell wall, nucleus, cytoplasm, membrane.

c) Cell 1 is undergoing mitosis. DNA is in the form of pairs of chromosomes. These pairs are being pulled apart in preparation for the formation of two new identical cells.

The cells labelled 2 are two new daughter cells that have been formed as a result of mitosis and cytokinesis. The cells are roughly half the size of a mature cell (compare them with cell 3), but they will grow during interphase.

Cell 3 is mature (twice the size of those that have just divided) and is just starting the process of mitosis. This is identifiable because the nucleus is beginning to break down – the nuclear membrane is looking quite blurred.

d) The statement is wrong because a number of things happen during interphase:

i) the cell grows

ii) it carries out its normal functions

iii) chromosomes in the nucleus are replicated

iv) the cell respires to provide energy for mitosis.

Exercise 10

a) Gametes or sex cells. You could also give sperm, eggs (or ova), or ovules.

b)

1) The daughter cells are haploid (contain a single set of chromosomes) while the parent cells are diploid (contain a double set of chromosomes).

2) When the daughter cells are formed in meiosis, they are genetically different from the parent cell.

Exercise 11

a) The process of reproduction enables genetic material to be passed on from one generation to the next. This ensures continuation of the species – in other words, it prevents the extinction of the species.

b)

1) A zygote is a fertilised ovum (egg cell).

2) A zygote is diploid, while an ovum is haploid / the zygote contains 46 chromosomes (23 pairs), while the ovum contains 23 chromosomes. A zygote is genetically different from the ovum it was formed from.

Exercise 12

All the somatic (body) cells in a male contain an X and a Y chromosome. A sperm cell containing an X chromosome does not carry the key genes needed to initiate male sexual development.

Photos: Getty Images/Science Photo Library

B4. Inheritance

B4.1 Know and understand the nucleus as a site of genetic material in eukaryotic cells.

B4.2 Know and understand the following genetic terms:

a. gene
b. allele
c. dominant
d. recessive
e. heterozygous
f. homozygous
g. phenotype
h. genotype
i. chromosome
j. autosome

B4.3 Monohybrid crosses:

a. Use and interpret genetic data and diagrams involving monohybrid (single gene) crosses.
b. Use and interpret family trees/pedigrees and express outcomes as ratios, numbers, probabilities or percentages.
c. Understand the concept of inherited conditions.
d. Know that most phenotypes are the result of multiple genes and only some result from single gene inheritance.

Chromosomes and genes

Most animal and plant cells contain a nucleus which controls the activities of the cell.

The nucleus contains the genetic material (DNA), stored as linear chromosomes.

A chromosome is a long thread-like structure made of DNA which is wrapped around proteins.

Of the 23 pairs of chromosomes in human cells, one pair are referred to as sex chromosomes, and the other 22 pairs are referred to as autosomes (chromosomes that are not sex chromosomes).

Exercise 13

Which type of human cell has no nucleus and therefore no chromosomes?

A gene is a short section of a chromosome which carries the genetic information to code for one protein. Genes determine an organism’s characteristics, e.g. a gene determines our hair colour.

Another example, pea pods

Alleles

The chemical PTC tastes very bitter to certain people but others cannot taste it at all. The ability to taste PTC is genetically determined. The autosomal gene that controls this trait codes for a taste receptor found on the tongue.

People who can taste PTC have inherited the ‘tasting’ allele from one or both parents. People who cannot taste PTC have inherited two ‘non-tasting’ alleles, one from each parent.

Alleles can be dominant or recessive.

By convention, the alleles of a gene are usually represented as a single letter. Dominant alleles are shown with a capital (e.g. T) and recessive alleles as a lower-case letter (e.g. t).

The tasting allele T is dominant and the non-tasting allele t is recessive.

Genotype

The alleles we have that control a characteristic are called our genotype. We have two alleles for each gene, as one allele is inherited from each parent. This means a genotype can be written as two letters, each letter representing one allele of the gene.

Exercise 14

Which two genotypes could give a person the ability to taste PTC?

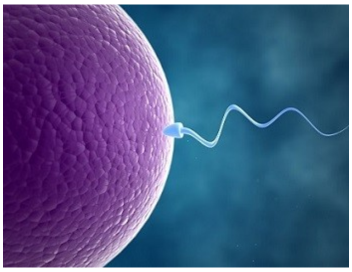
(Use the letter T to represent the tasting allele and the letter t to represent the non-tasting allele.)

Phenotype

The visible characteristics of an organism are called the phenotype. Genes determine our phenotype, although in some situations the environment can also influence the phenotype.

Inheritance of alleles

Humans have two copies of each gene in each cell. One copy is inherited from the sperm cell (father) and one copy is inherited from the egg cell (mother).



So, there are two copies of the gene which controls the ability to taste PTC in each cell in the body. These two copies of the gene may both be the same allele or they may be different alleles.

If an individual has two alleles of a gene that are the same, then their genotype is described as homozygous.

If an individual has two different alleles of that gene, then their genotype is described as heterozygous.

If an individual has at least one dominant allele of that gene, then this allele always determines the phenotype.

The recessive allele only determines the phenotype if there are two copies of the recessive allele in each cell. The non-tasting allele is a recessive allele and so a person who cannot taste PTC must have two recessive non-tasting alleles in each cell.

Exercise 15

Some people have hair growing on the second joint of one or more fingers on each hand. This phenotype is determined by an autosomal gene with two alleles. The presence of this hair is caused by the allele H, which is dominant. The allele h, which results in no hair on this finger joint, is recessive.

A child has fingers with no hair on them like her mother. Her father does have hair on the second joint of his fingers.

State the genotype of the father and explain how this genotype has been deduced.

Single gene (monohybrid) genetic crosses

Although a single chromosome encodes hundreds or thousands of different genes, the study of genetic inheritance is simplest if it starts by looking at just one gene at a time.

A mating between two individuals is also called a cross (derived from the term ‘cross fertilise’). A cross between two individuals of a species where the impact of only a single gene is considered is referred to as a monohybrid cross.

Genetic diagrams

Some people are able to roll their tongue into a tube.

The ability to tongue roll is controlled by an autosomal gene with two alleles. The allele which enables a person to tongue roll is dominant, the non tongue rolling allele is recessive.

Tongue rolling

A genetic diagram can be used to show how the alleles for this autosomal gene might be inherited.

Drawing a genetic diagram

1) The phenotype and genotype of both parents are shown. A parent who is a tongue roller has the genotype TT. The other parent is a non tongue roller and has the genotype tt.

parent	phenotype	tongue roller	non tongue roller
parent	genotype	TT	tt

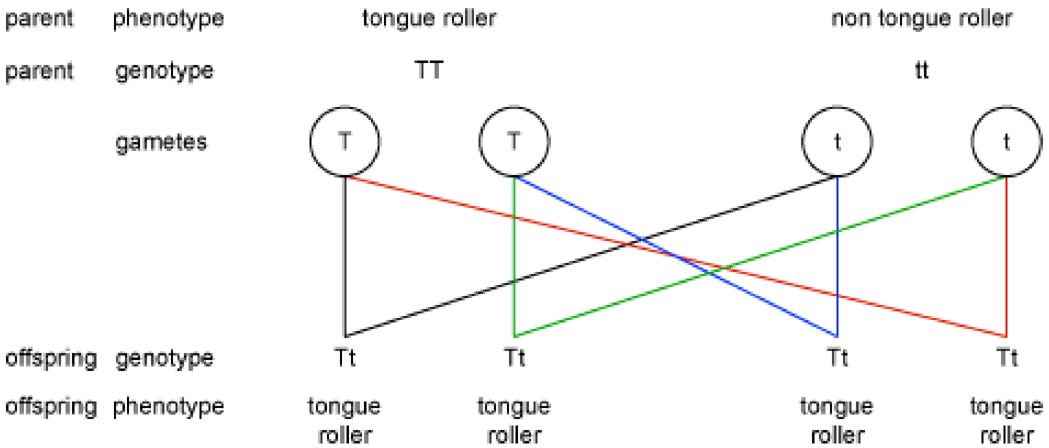
In this example, both parents are homozygous.

2) The two possible types of gametes are added to the diagram.

parent	phenotype	tongue roller		non tongue roller		
parent	genotype	TT		tt		
	gametes	T	T	t	t	

There is only one allele in each gamete as the gametes have been produced by meiosis.

3) Lines are drawn to show how each of the different gametes could combine at fertilisation and the resulting genotype and phenotype of the offspring produced.

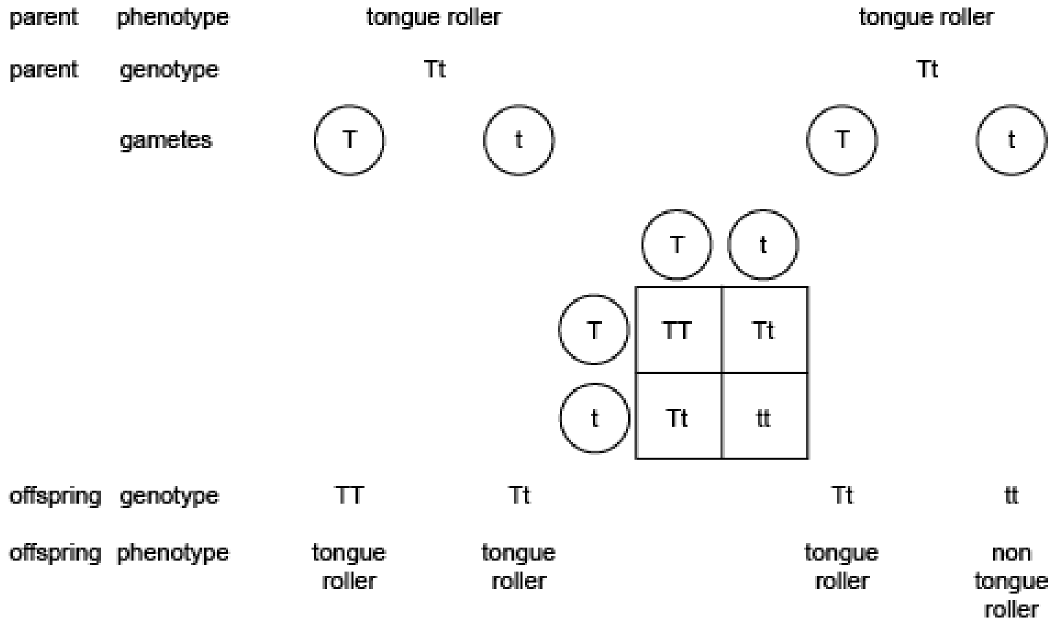


The genetic diagram shows that for these parents, 100% of the offspring are tongue rollers and that they are all heterozygous.

Punnett square

A Punnett square is another method of showing a genetic cross.

This Punnett square shows the cross between two tongue rollers who are both heterozygous.



The genetic cross shows that when both parents are heterozygous, 75% of the offspring produced will be tongue rollers and only 25% of the offspring produced will be non tongue rollers.

The outcome of a genetic cross can also be expressed as a ratio. In this example, the ratio of individuals with the dominant phenotype compared to the recessive phenotype is 3 **:** 1.

Exercise 16

Draw a Punnett square to show the possible offspring produced when one parent is a heterozygous tongue roller and one parent is a non tongue roller. State the ratio of tongue rollers to non tongue rollers in the offspring.

Inherited conditions

Genes and their alleles play an important role in determining our characteristics. They can also cause genetic conditions that can be passed from one generation to the next.

Polydactyly

The genetic condition polydactyly is caused by an autosomal dominant allele. People with this allele have extra fingers or toes.

Polydactyly

As the allele for the condition is dominant, a person only has to have one dominant allele to develop the condition.

parent	phenotype	polydactyly		no polydactyly	
parent	genotype	Dd		dd	
	gametes	D	d	d	d

	D	d
d	Dd	dd
d	Dd	dd

offspring	genotype	Dd	Dd	dd	dd
offspring	phenotype	polydactyly	polydactyly	no polydactyly	no polydactyly

In this example, one parent is heterozygous. This parent has polydactyly as there is one dominant allele in the genotype. One parent is homozygous recessive and so does not have the condition.

The genetic diagram shows that the probability of these parents having a child with polydactyly is 0.5 for each conception.

Cystic fibrosis

The genetic condition cystic fibrosis is caused by the autosomal recessive allele, f. The condition affects chloride ion transport across membranes, resulting in thick, sticky mucus.

The genotype of a person without cystic fibrosis could be either homozygous dominant (FF) or heterozygous (Ff).

For cystic fibrosis and other recessive conditions, a heterozygous individual is described as a carrier. They do not have the genetic condition but they carry an allele for the condition and can pass on that allele to the next generation.

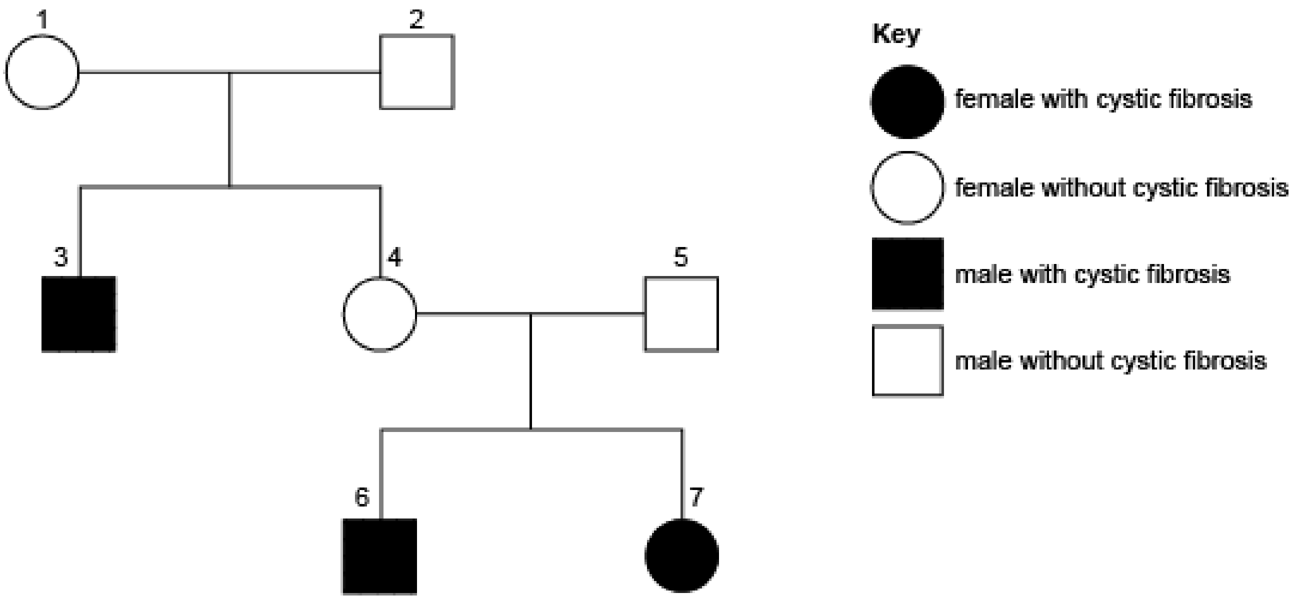
Persons affected with cystic fibrosis will be homozygous recessive and has therefore inherited one recessive allele from each parent.

Exercise 17

Two parents who are both carriers of the cystic fibrosis allele have four children and none of their children have cystic fibrosis. Suggest a reason why this does not follow the expected probability shown in the genetic cross diagram above.

Family pedigree diagrams

A family pedigree diagram shows the inheritance of a condition in one family.



These diagrams can be used to deduce the genotypes of each of the members of the family. This can then be helpful in allowing couples to assess the likelihood of having a child with a genetic condition.

The pedigree shows that the genetic condition is caused by a recessive allele because neither parent 1 nor parent 2 have the condition and yet they have a child (person 3) with the condition.

This can only happen if each parent is a carrier and they both pass the recessive allele to their offspring.

The pedigree shows that person 4 is also a carrier of the recessive allele. Person 5 must be heterozygous as they have two children, 6 and 7, with the condition. 6 and 7 must have inherited one recessive allele from each of their parents, so persons 4 and 5 must carry the recessive allele without showing the condition.

Multiple gene inheritance

All the examples of inheritance given so far in this section have shown autosomal monohybrid (single gene) inheritance. This assumes that each feature is controlled by one autosomal gene with several different alleles.

Scientists have discovered that a very large number of the characteristics that we inherit from our parents are the result of the action on more than one gene.

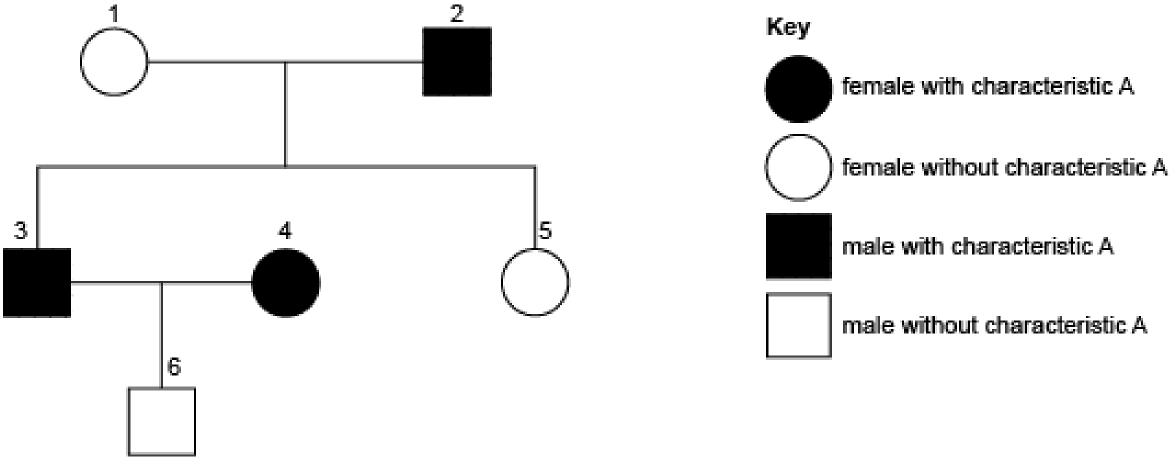
Height is an example of a characteristic which is controlled by more than one gene.

There are a very large number of possible final heights that a person could grow to. As there are so many different heights, it is unlikely that each height is caused by a different allele of one gene.

The final height of a person is controlled by a number of genes each contributing to the final phenotype.

Exercise 18

The family tree shows the inheritance of characteristic A in one family.



a) State whether the inherited characteristic is due to a dominant or recessive allele and give a reason for your answer.

b) State the probability that the next child of individuals 3 and 4 will show characteristic A in the phenotype.

Solutions to Exercises 13 to 18

Exercise 13

Mature red blood cells.

Exercise 14

The genotype must contain at least one dominant allele and so could be either TT or Tt.

Exercise 15

The child has no hair on her fingers and is therefore homozygous recessive, hh, as the question tells us that the allele for no hair is recessive.

Recall that humans have two copies of a gene that control a feature such as the one in the question. One copy is inherited from the sperm cell and one from the egg cell.

The child must have inherited one recessive allele from the father in a sperm cell and one recessive allele from the mother in an egg cell.

The father must have one dominant allele as he has hair on the second joint of his fingers. The dominant allele must be present in the genotype to determine this dominant phenotype.

It can therefore be concluded that the father's genotype is heterozygous, Hh.

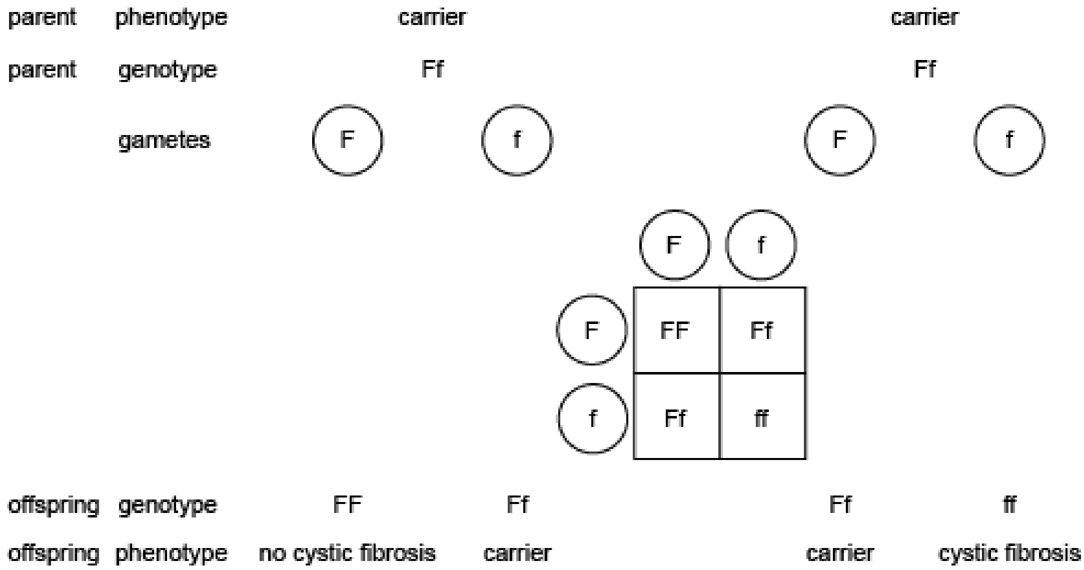
Exercise 16

parent	phenotype	tongue roller		non tongue roller	
parent	genotype	Tt		tt	
	gametes	T	t	t	t

	T	t
t	Tt	tt
t	Tt	tt

offspring	genotype	Tt	Tt	tt	tt
offspring	phenotype	tongue roller	tongue roller	non tongue roller	non tongue roller

Exercise 17



Although neither of the parents have cystic fibrosis, as both parents are carriers, the probability that they will have a child with cystic fibrosis is 0.25.

The family has only had four children; this is a very small sample size. Random fertilisation relies on chance, so in a small sample size, the expected probabilities may not be seen.

The expected probability will be seen in a much larger sample of offspring.

Exercise 18

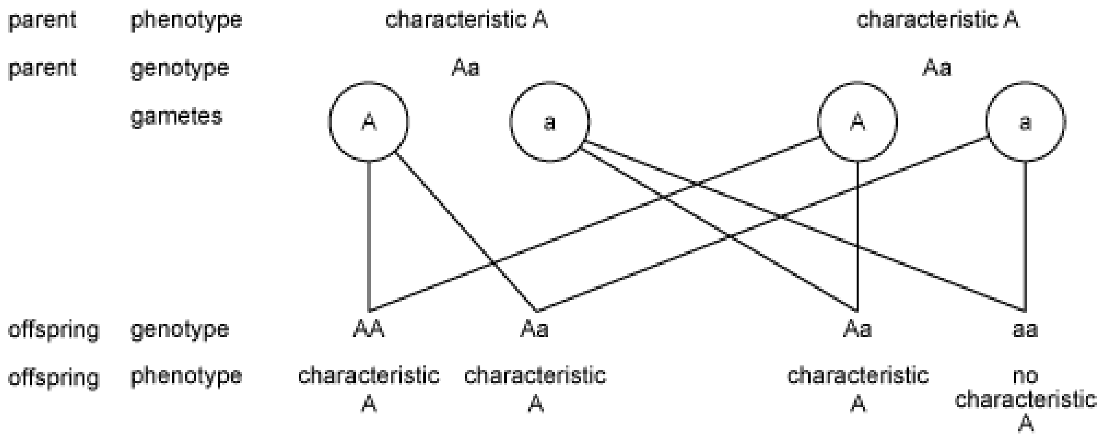
Characteristic A is due to a dominant allele.

Individuals 3 and 4 both have the characteristic and their child does not. This could only occur if this was due to a dominant allele.

The probability that the next child of individuals 3 and 4 will show characteristic A is 75%.

Individuals 3 and 4 must be heterozygous as they both have characteristic A but have produced a child without it.

The genetics diagram shows the probability that their next child will have the characteristic is 0.75.



Photos: Science Photo Library

B5. DNA

B5.1 Know and understand that

a. the genome is the full set of genetic material (DNA) of an organism.
b. this DNA is contained within chromosomes.

B5.2 Know and understand the structure of DNA:

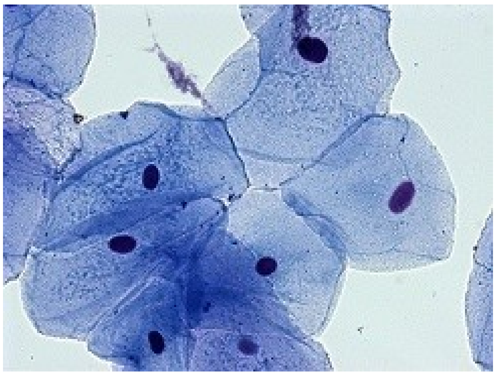
a. Know and understand that single-stranded DNA (ssDNA) is a polymer made up of nucleotides joined together to form one strand of DNA.
b. Know and understand that double-stranded DNA (dsDNA) is a polymer made up of two strands of DNA forming a double helix.
c. Know and understand that the structure of each nucleotide consists of a common sugar and phosphate group as well as one of four different nitrogenous bases.
d. Know the complementary pairs of DNA nitrogenous bases – adenine (A) pairs with thymine (T) and guanine (G) pairs with cytosine (C) – and that the sequence of these bases is the genetic code.

DNA and chromosomes

Eukaryotic plant and animal cells contain a nucleus.

The nucleus contains the genetic material of the organism, its DNA.

Cheek cells, stained to show the nucleus.



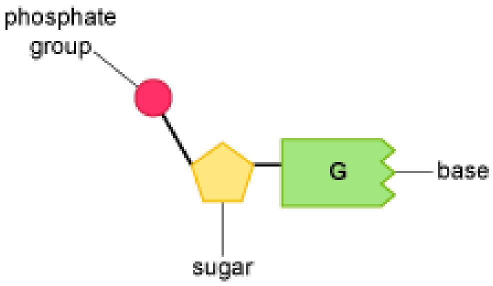
DNA is stored in the nucleus as long, thread-like structures called chromosomes.

All of the genetic material found in each cell of an organism is the organism’s genome.

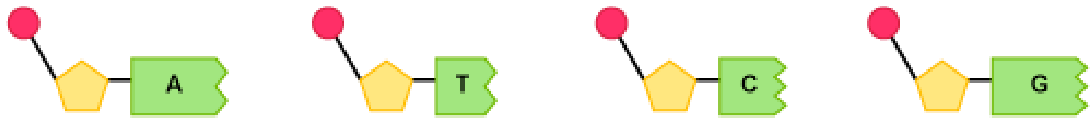
The structure of DNA

A DNA molecule is a very large polymer. This means it is made up of a chain of many similar, smaller subunits called monomers joined together by chemical bonds.

DNA is also sometimes called a polynucleotide, because the monomer unit is a nucleotide. A single nucleotide has three main components: a sugar (deoxyribose), a phosphate and a nitrogenous base.



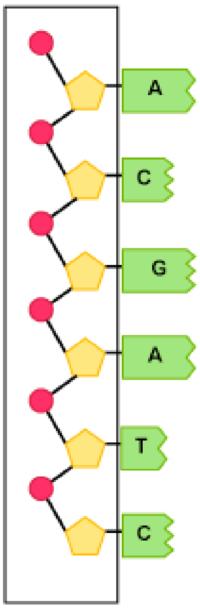
There are four different bases found in a DNA molecule. Each of these is joined to the same position on the sugar ring.



The four bases are called adenine (A), thymine (T), cytosine (C) and guanine (G).

The nucleotides in a DNA molecule are joined together by chemical bonds to form a chain called a polynucleotide.

The sugar and phosphate group always have the same structure in every nucleotide in the polynucleotide chain.



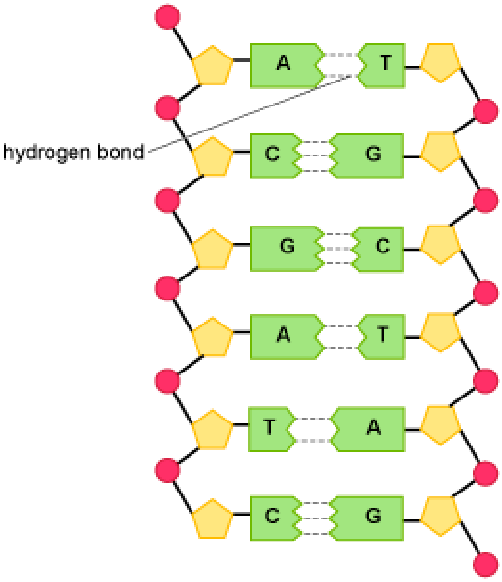
The section of the polynucleotide molecule shown in the box, made up of the sugars and phosphate groups, is sometimes referred to as the sugar-phosphate backbone. The whole polynucleotide molecule is called a strand.

The section shown is part of a single-stranded DNA (ssDNA). For some viruses their genome is found as ssDNA. However, for prokaryotes and eukaryotes, their genome is housed in double-stranded DNA (dsDNA).

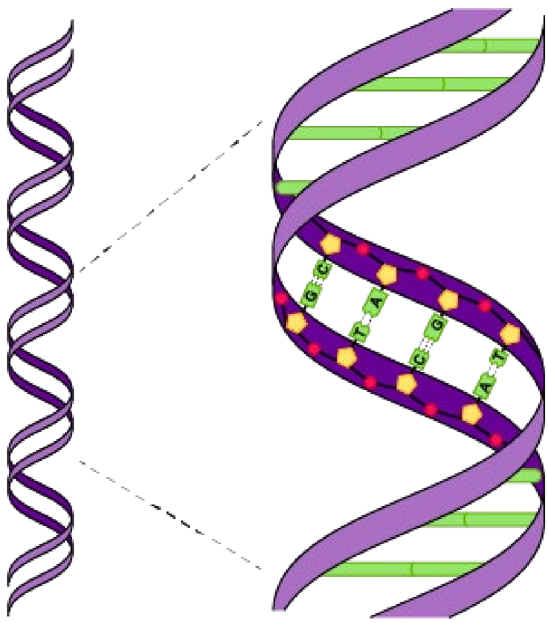
A dsDNA molecule, usually just referred to as a DNA molecule, is made of two polynucleotide strands held together by hydrogen bonds which form between the bases.

The bases in each of the strands always pair together in the same way. Adenine always pairs with thymine (A-T) and cytosine always pairs with guanine (C-G).

The two bases that pair together are described as complementary bases.



A DNA molecule is described as a double helix. This is because it is made up of two polynucleotide chains or strands which twist around each other in a helical (spiral) shape.



The genetic code

DNA is the genetic material of the cell and stores the genetic information as a code called the genetic code. This means DNA molecules store the instructions the cell uses to build proteins.

The genetic information is stored as a sequence of bases in a DNA molecule. This sequence of bases is important as it determines the structure of the proteins made by the cell.

Exercise 19

Which of the following statements about DNA is / are correct?

1) DNA is a polymer made up of a chain of monomers called polynucleotides.
2) Each nucleotide is linked to the next one by bonds formed between phosphate and sugar units.
3) Each nucleotide is made up of a phosphate group, a sugar and a pair of bases.

B5.3 Protein synthesis:

a. Know and understand that protein synthesis involves producing chains of amino acids called polypeptides.
b. Know and understand that one or more polypeptide(s) can form a functional protein.
c. Know and understand that the three-dimensional shape of a protein is determined by the sequence of its amino acids.
d. Know and understand that the sequence of nucleotide bases in a gene determines the sequence of amino acids in the polypeptide the gene codes for.
e. Know and understand that the sequence of nucleotides in a gene is 'read' as triplets, and that each triplet codes for an amino acid.

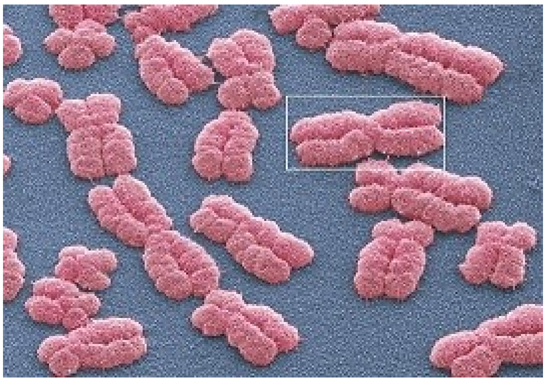
B5.4 Gene mutations:

a. Understand that a mutation changes the sequence of nucleotides in the DNA.
b. Know that most mutations have no effect on the phenotype, some will have a small effect, whilst occasionally others will determine the phenotype.

Chromosomes and genes

DNA is stored in the nucleus of a cell as long, thread-like structures called chromosomes.

The structure marked in a rectangle is a chromosome.



The chromosomes have a shape similar to that of an X. Each chromosome in the photograph is made of two long molecules of DNA. Each DNA double helix is wrapped around protein to package it into the nucleus.

Chromosomes are only visible in the cell when the cell is dividing.

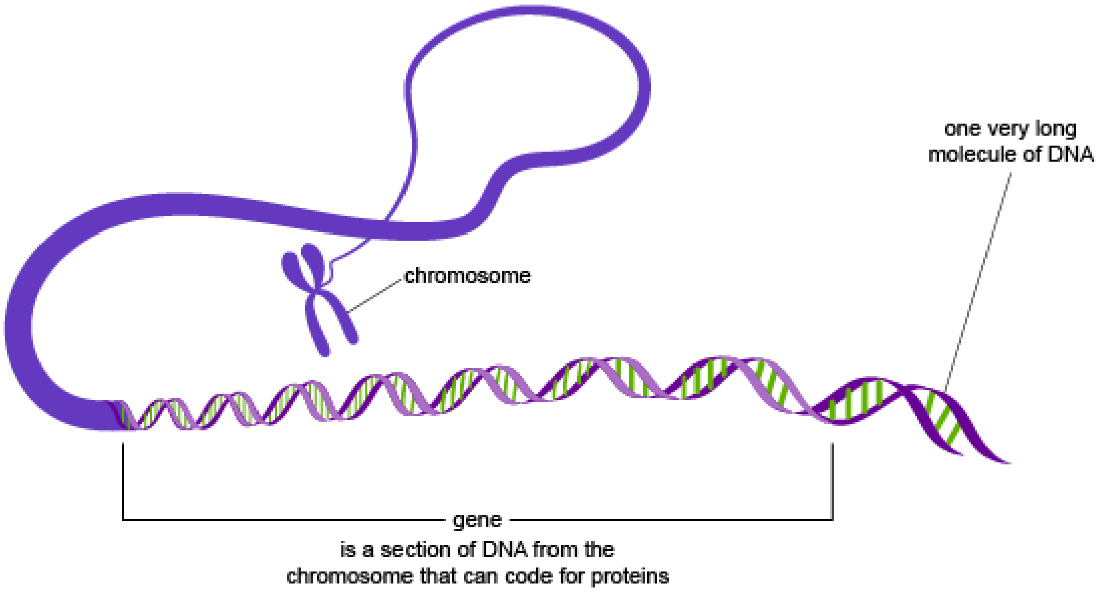
During most of the cell cycle a chromosome consists of one molecule of DNA.

Just before cell division this DNA molecule is copied so that the chromosome consists of two identical DNA molecules.

This allows one DNA molecule from each chromosome to be passed to each new daughter cell when the cell divides.

A DNA molecule is very large, and so a chromosome is a very long structure consisting of many millions of bases of DNA.

It can be divided into short sections. A section of the chromosome is called a gene.



DNA is the genetic material and stores the genetic information as a code called the genetic code.

Each gene on a chromosome stores the information needed to make a protein as a genetic code. Genes therefore code for proteins.

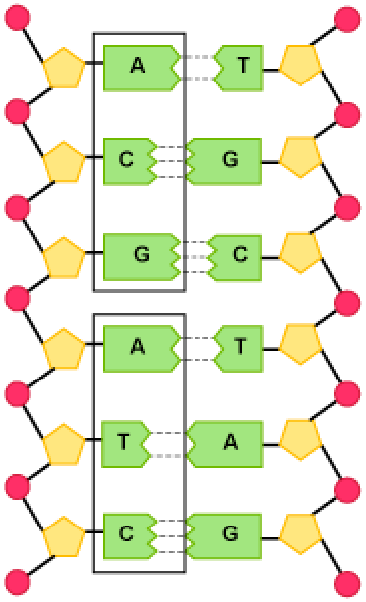
How the cell uses the genetic code to produce proteins

Proteins are large molecules. They are polymers. This means that a protein molecule is made up of a chain of many similar, smaller molecules called amino acids. All amino acids contain carbon, hydrogen, oxygen and nitrogen.

The process of assembling proteins from individual amino acids is called protein synthesis.

The cell uses the genetic information stored in one gene as instructions to build one protein.

A very short section of a gene



This section of the gene is made up of two DNA strands.

The cell only uses the base sequence on one strand (the template strand) in order to make a protein.

The cell reads the genetic code as triplets, ACG and ATC.

The section of DNA in the diagram contains two triplets. Each triplet is made up of three bases. Each triplet codes for one amino acid in the protein.

The cell uses the DNA to ensure amino acids are joined in the correct order during the process of protein synthesis.

Using the genetic code

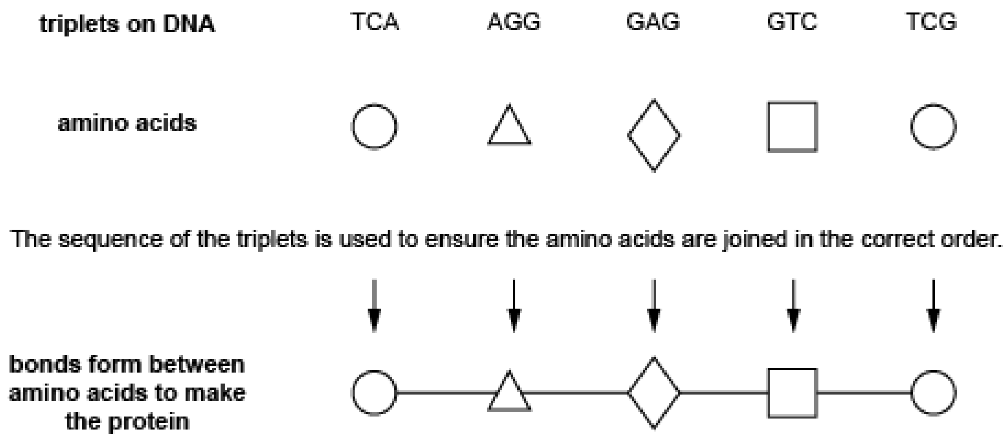
A section of the gene has the following sequences of bases:

TCAAGGGAGGTCTCG

This can be re-written to separate the bases into triplets.

TCA AGG GAG GTC TCG

Each triplet of bases codes for one amino acid.



When the genetic code was deciphered it was found that certain triplets code for the same amino acid. For example, TCA and TCG both code for the amino acid represented as a circle.

Exercise 20

a) Arrange the following terms in order of size, from smallest to largest:
    base
    DNA molecule
    gene
    nucleotide
    triplet

b) A gene is made up of triplets. Describe a triplet and its function.

For the cells to use DNA to make proteins, the following stages need to occur:

DNA template strand is 'read' as triplets of bases

⇓

Amino acids joined together in the correct sequence to make a polypeptide

⇓

Peptide folds into a three-dimensional shape

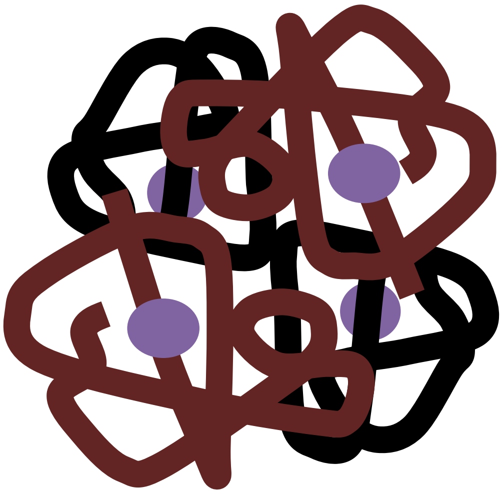
⇓ Becomes a functional protein

⇓ Joins with one or more folded polypeptides to become a functional protein

The table shows some examples of functional proteins

Name of functional protein	*Structural details (number of polypeptides with number of amino acids in brackets)*	*Description of the role of each functional protein*
Amylase	1 (≈496)	Digests starch in mouth and small intestine to simple sugars
Pepsin (a protease)	1 (327)	It is a protein that breaks down ingested proteins in the stomach
Glucagon	1 (29)	Increases blood glucose level by instructing the liver to release glucose into the blood
Insulin	1 x A chain (21) 1 x B chain (30)	Decreases blood glucose level by instructing the liver to absorb excess blood glucose
Collagen	3 x α chains (each chain is ≈ 1000)	A flexible, but stretch-resistant protein giving structural support to various tissues
Haemoglobin	2 x alpha (141) 2 x beta (146)	Absorbs oxygen at the lungs, transports it in blood and then releases the oxygen at respiring tissues such as at muscles and brain

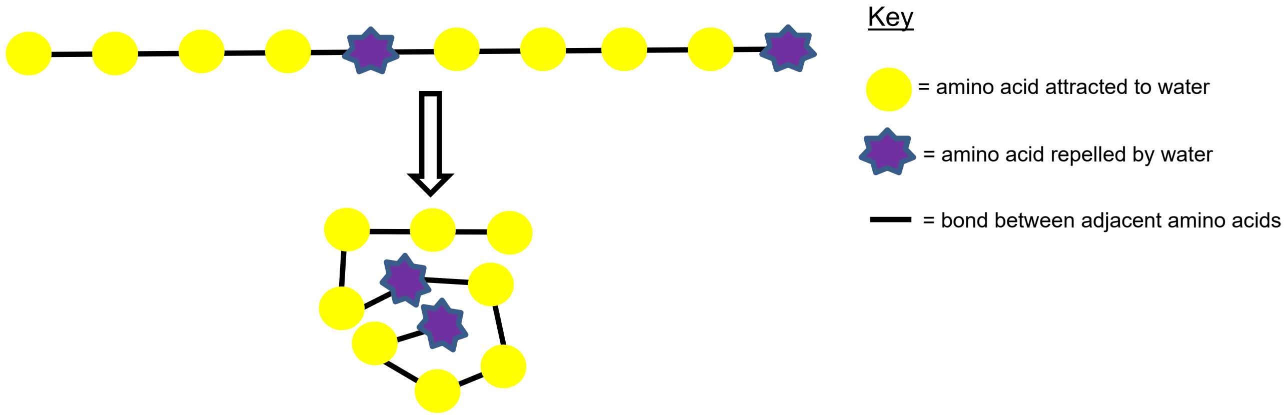
The diagram shows two of these functional proteins, each with a quite different arrangement of the polypeptide chains.

Collagen	Haemoglobin
Three chains twisted around each other to form a triple helix	One pair of identical folded alpha chains (black) and one pair of identical folded beta chains (red), and four oxygen-carrying haem groups
	

The folding process, and its importance

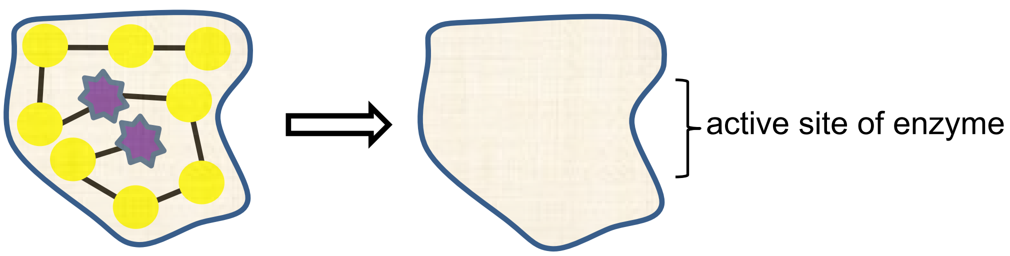
There are many reasons why the chain of amino acids in a polypeptide folds. One reason is that some amino acids are attracted to water, whilst others are repelled.

The diagram below shows one way that a polypeptide may fold in water.



The folding is such that those repelled by water are within the folded polypeptide and those attracted to water are on the outside in the watery solution. The watery solution could be cytoplasm, blood plasma, etc.

The polypeptide now has a three-dimensional shape and is functional. For example, the diagram shows the protein above in outline as an enzyme with an active site. (See topic B8 for enzyme details.)



If the water repelling amino acids were in a different position in the polypeptide chain, or the number of them was different, the folding would be different leading to the protein having a different three-dimensional shape. Therefore, the three-dimensional shape of a protein is determined by the sequence of its amino acids.

The outcome of this folding

Each protein has a different amino acid sequence, and therefore, a different three-dimensional shape, so each has a different function. Changing the sequences of nucleotide bases in a gene could change the amino acid sequence of the polypeptide, and alter the function of a protein, or indeed makes it non-functional. This change in DNA is a gene mutation.

Gene mutations

A gene mutation is a change in an organism's DNA.

It causes a change in the order of bases in the DNA.

This change in the base sequence may change a triplet in a gene. The triplet may code for a different amino acid and this may cause a change in the structure of the protein produced.

For example, a mutation may cause the protein it specifies to not function correctly because of the change in its 3dimensional structure.

Mutations and enzyme action

Enzymes are examples of proteins that must have a specific structure in order to function efficiently.

The shape of the active site must be complementary to the substrate in order for the enzyme to be able to catalyse a reaction.

A mutation may change a DNA triplet in a gene which codes for an enzyme.

This mutation in the DNA could cause the triplet to code for a different amino acid. This could result in an enzyme with an active site which is no longer complementary to the substrate.

The effect of such a mutation would be the production of an enzyme that was not able to perform its normal function.

If a non-functional enzyme is produced, this could affect the phenotype of an organism.

For example, if an enzyme which catalyses the production of the colour pigment in the petals of a flower is non functional, the cells in the petals will not contain this pigment.

The petals will therefore look different. The mutation has changed the phenotype of the organism.

The flower below is two different colours as a result of a rare gene mutation that has occurred in some of the cells in the flower during that flower's development.

Mutation

Certain mutations can have a small effect on phenotype.

The cat in the photograph below has polydactyly. This means that the cat has extra toes on each paw. This condition arises as a result of a mutation. The mutation has affected the phenotype of the cat, but the effect is only small.

Polydactyly

Most mutations have no effect on the phenotype.

This is because there are large sections of DNA between the genes on a chromosome which do not code for proteins.

Mutations that occur in DNA that does not code for proteins are unlikely to affect the phenotype of an organism.

Silent mutations can sometimes occur within a gene. The mutation changes the order of bases in the DNA, but this change does not affect the order of amino acids in the protein.

A silent mutation could occur when the mutation changes one of the bases in the triplet but the triplet still codes for the same amino acid.

The mutation is described as silent as it has no effect on the phenotype of the organism.

Exercise 21

The table shows some of the amino acids coded for by DNA triplets found in a gene:

Triplet of bases on DNA	Amino acid coded for by triplet
AGG	arginine
GAG	glutamic acid
GTC	valine
TCA	serine
TCG	serine
TTA	leucine
TTC	phenylalanine

A section of a gene has the following sequence of bases:
TCAAGGGAGTTCGTCTCG

When this is copied, there is a slight change in the base sequence:
TCAAGGGAGTTAGTCTCG

a) State the change in the base sequence.

b) With reference to the name of amino acids coded for in the triplet, explain why this change in sequence could affect the way the gene functions.

c) If the gene codes for an enzyme, explain what the possible implications are for the function of this enzyme when the change to the base sequence occurs.

Solutions to Exercises 19 to 21

Exercise 19

1) Incorrect – the monomer units are called nucleotides, not polynucleotides.
2) Correct – the phosphate unit of one nucleotide bonds to the sugar unit of the next nucleotide.
3) Incorrect – each nucleotide is made up of a phosphate group, a sugar and a single base, not a pair of bases.

Exercise 20

a) Base, nucleotide, triplet, gene, DNA molecule

   A base is part of a nucleotide. Three nucleotides in a chain form a triplet. A gene is composed of many triplets of bases. A DNA molecule contains many genes.

b) A triplet is a set of three bases. Each triplet codes for one amino acid and provides part of a template for making a protein.

Exercise 21

a) One of the C bases has changed to A. This has resulted in the triplet TTC being changed to TTA.

b) A mutation has occurred. Changing the triplet TTC to TTA will result in the amino acid leucine (coded by TTA) being added instead of phenylalanine (coded by TTC). This could affect the protein the gene is responsible for synthesising, so the protein could be different or faulty.

c) It may result in the active site of the enzyme no longer being complementary to its substrate, so the enzyme may not work.

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B6. Gene technologies

B6.1 Genetic engineering:

a. Understand the process of genetic engineering to include:
   i. taking a copy of a gene from the DNA of one organism
   ii. insertion of that gene into the DNA of another organism
   iii. the roles of restriction enzymes and ligases in recombining DNA.

b. Recall and interpret examples of genetic engineering in different cell types.

c. Explain the benefits and risks of using genetic engineering in medical applications.

B6.2 Stem cells:

a. Know and understand that some early embryonic cells are totipotent and have the potential to develop into a complete multicellular organism.

b. Know and understand that most embryonic stem cells are pluripotent and can differentiate into any cell type.

c. Know and understand that adult stem cells are multipotent and can differentiate into a limited number of different cell types.

d. Know and understand the likely benefits and risks of using stem cells in medical applications.

B6.3 Selective breeding:

a. Know and understand the differences and similarities between natural selection and selective breeding.

b. Understand the impact of selective breeding on populations.

Genetic engineering

Genetic engineering involves taking a copy of a gene from one organism and inserting that gene into the DNA of another organism, to create a genetically modified organism (GMO) or a transgenic organism.

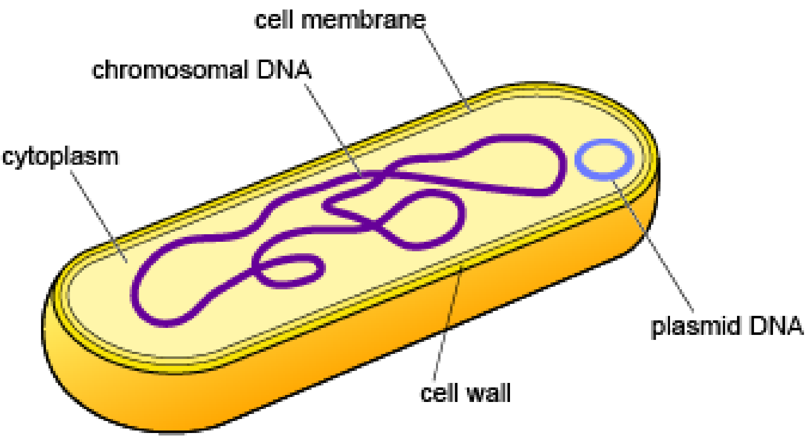
The first GMOs were bacteria. Scientists created bacteria which were resistant to the antibiotic kanamycin. They inserted a kanamycin resistance gene into a bacterial cell. This bacterial cell was then able to survive in the presence of the antibiotic.

Bacterial cells growing on agar plates.

Examples of genetic engineering in different cell types

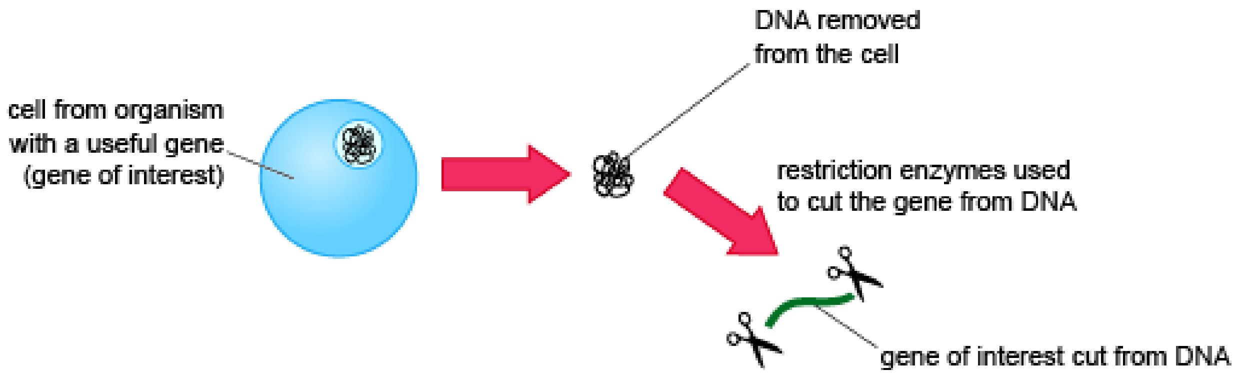
Genetic engineering of bacterial cells

Before looking at the techniques used to produce genetically modified bacteria, it is useful to review the structure of a bacteria cell, outlined in section B1. Cells.



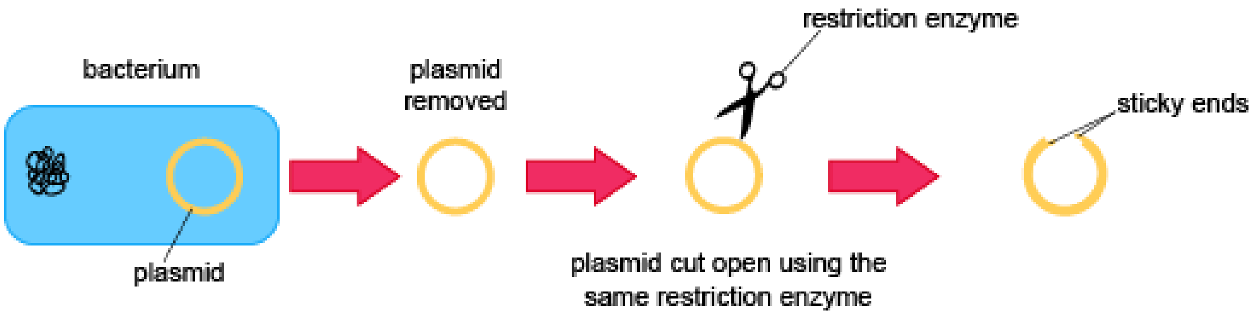
The process

1) A useful gene (gene of interest) is cut from the DNA of one organism using an enzyme called a restriction enzyme. This enzyme breaks bonds between nucleotides.

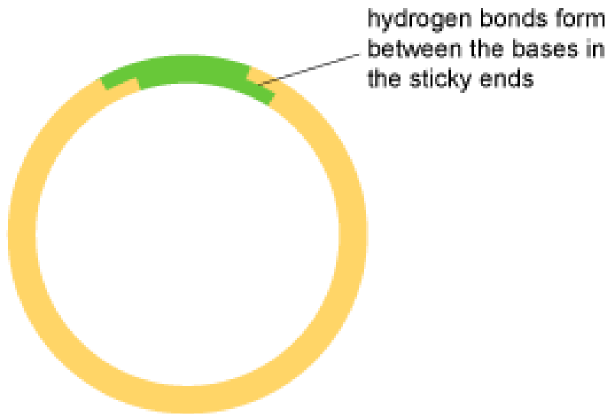


2) Restriction enzymes cut the DNA in a staggered way leaving short sections of single-stranded DNA at each end of the gene. These sections of single-stranded DNA are called sticky ends.

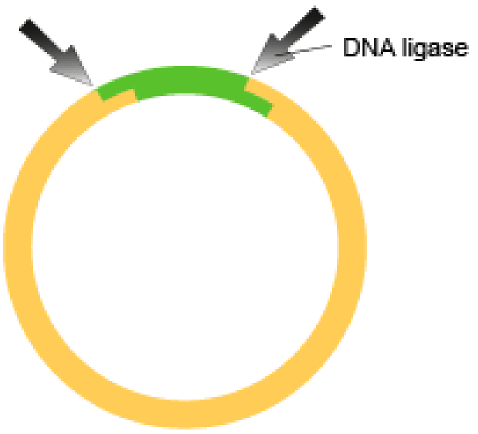
3) The bacterial plasmid DNA is cut open using the same restriction enzyme. The cut ends of the plasmid also have sticky ends.



4) The useful gene and the plasmid DNA are mixed and the gene is inserted into the plasmid. Hydrogen bonds form between the complementary bases in the sticky ends of the plasmid and the useful gene.

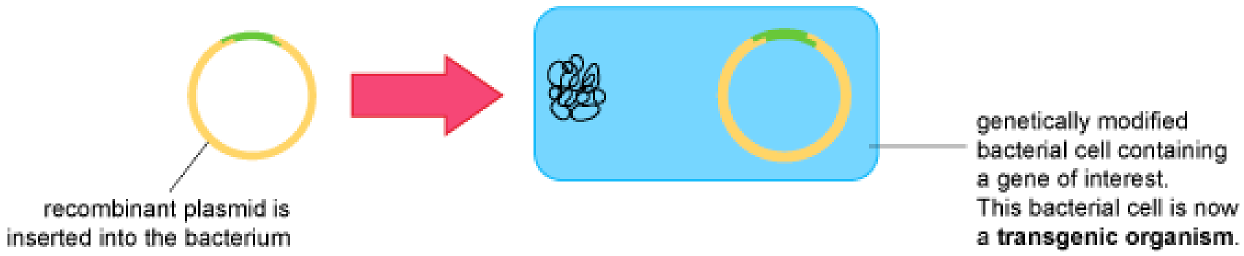


5) The enzyme DNA ligase is used to join the plasmid DNA and the useful gene together. The ligase joins the end nucleotides of the useful gene to the end nucleotides of the plasmid.



The plasmid is now called a recombinant plasmid. It is a plasmid that has been altered and now has DNA from more than one source.

6) The recombinant plasmid is then inserted into a bacterial cell. The plasmid acts as a vector, carrying the gene into the bacterial cell.



7) The bacterial cell is now a GMO. It can be cultured by cloning and the cell can use the gene that has been inserted into it to make a protein.

Proteins that can be produced by genetically modified bacteria

Type of protein produced by genetically modified bacteria	Examples
hormones	insulin
antibiotics	penicillin
enzymes	rennin used in cheese production
blood clotting factors	factor VIII used to treat haemophilia

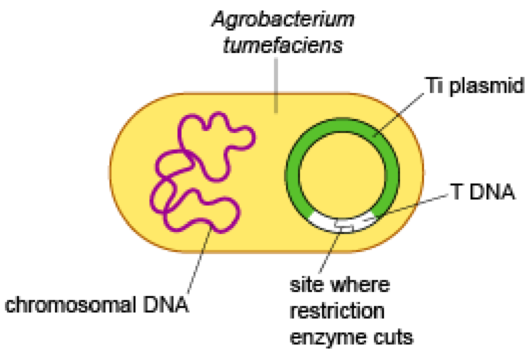
Genetic engineering of plants

The technique used to genetically modify plant cells is different to that used to create GM bacteria because plant cells do not have plasmids.

An alternative vector

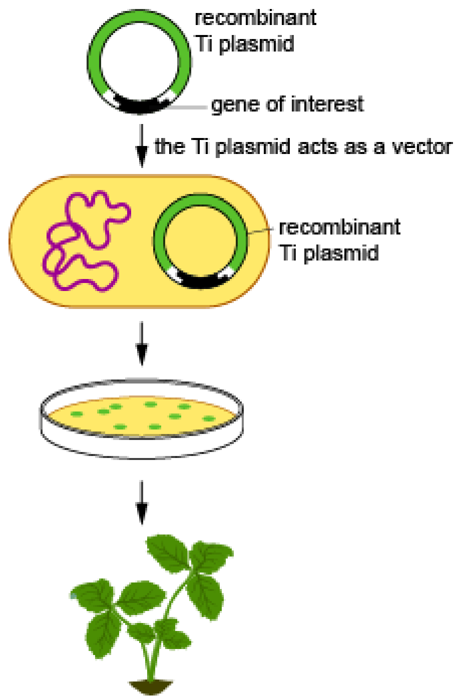
The bacteria *Agrobacterium tumefaciens* are commonly used to create GM plants.

These bacteria have a plasmid called a Ti plasmid. When the bacteria infect plants, the Ti plasmid is able to enter plant cells and a portion of the Ti plasmid inserts itself into the plant genome.



The process

1. A recombinant Ti plasmid is created by inserting a useful gene using steps 1 to 5 above.
2. The plasmid is then inserted into *A. tumefaciens* to create a transgenic bacterial cell.
3. Plant cells grown in the lab are mixed with transgenic *A. tumefaciens*. The Ti plasmid carries the useful gene into the plant cell and inserts it into the plant cell's chromosome.
4. The plant cells are grown in culture in the laboratory and develop into new plants. Each of these GM plants is able to produce the protein coded for by the useful gene. The plant has a new characteristic.



Uses of GM plants

GM plants could be extremely beneficial in agriculture. The new features they possess could result in a significant increase in yield of food crops, helping to feed the ever-increasing human population.

Characteristic of GM crop	Example of GM crop
pest resistance	Bt cotton is resistant to cotton bollworm, a pest that destroys cotton crops
herbicide resistance	GM crops resistant to weedkillers such as glyphosate-resistant soybean
disease resistance	bananas modified to resist the black sigatoka fungus
ability to produce nutrients to help prevent malnutrition	golden rice is a plant that has been modified so that it has an increased level of ß-carotene, in order to help prevent vitamin A deficiency

The benefits and risks of using genetic engineering in medical applications.

- **GMOs can be used to produce medicines.**

  e.g. GM bacteria produce the human insulin protein which is used to treat diabetes.

  e.g. GM sheep produce proteins in their milk that are used to treat lung disease.

  e.g. GM cells grown in culture produce proteins such as human blood clotting factor VIII to treat haemophilia, an inherited condition that means a person's blood does not clot if they cut themselves because they are unable to produce this clotting factor.

  The production of medicine from genetically engineered organisms enables larger quantities of medicine to be produced.

  The proteins that are made by bacteria are human proteins, so people taking the medication should have few side effects.

  Some people argue against the use of these medicines because products from GMOs have only been used for a short period of time, and so long-term consequences of their use are unknown.

A fermentation unit containing E.coli bacteria which have been genetically modified to produce human antibodies

- **GMOs have been used in the development of vaccines.**

  e.g. a recombinant hepatitis B vaccine produced by GM baker's yeast.

  e.g. GM plants are being developed with the aim of providing edible vaccines.

  This work aims to provide safer, cheaper vaccines for deadly diseases.

- **GM pigs are being developed with human-like organs.**

  Scientists hope they may be able to use the organs for human transplants, helping to reduce the shortage of suitable donor organs. There are concerns that the use of such organs could result in the spread of disease from pigs to humans. Some people will object to the use of these organs for ethical reasons.

- **GM insects have been created to reduce the spread of certain diseases such as malaria.**

  Scientists have genetically modified Anopheles mosquitoes so that they have a more efficient immune response when infected with the malarial parasite. This prevents the malarial parasite from being able to survive in the mosquito. The GM mosquitoes can breed with wild mosquitoes, passing the gene for a more efficient immune response to their offspring. It is hoped that these GM mosquitoes may play an important role in the eradication of malaria in the future. If successful, the use of these organisms could save many lives.

  Some people object to use of GMOs in this way as they may affect the success of wild populations of insects.

- **Genetic modification of cells in the human body can be carried out using gene therapy techniques to provide possible cures for genetic diseases such as cystic fibrosis.**

  Gene therapy treatment aims to introduce a therapeutic human gene into a person's cells to replace the function of a gene with a mutation.

  Gene therapy has many potential benefits but also presents risks, e.g. if the therapeutic gene is not accurately inserted into a chromosome it can cause cancer. Cancer arises when the therapeutic gene is inserted too close to a cancer-causing gene and this gene is then switched on.

  The therapeutic gene is inserted into the chromosome using a special type of virus and at the moment we are unable to control the position that it is inserted into a chromosome.

Gene therapy can target different types of cells in the body:

Cell type that is genetically modified	Example of treatment	Advantages of using this form of gene therapy
Body cells	○ Cystic fibrosis (CF) affects cells in the lungs. ○ Gene therapy aims to add a gene to lung cells to enable the cells to produce a therapeutic protein which reduces the symptoms of the condition.	Aims to provide: ○ a longer-lasting treatment ○ a reduced need for regular medication ○ an increased quality of life ○ a possible future cure for genetic conditions such as CF.
Stem cells	○ Sickle cell anaemia affects the production of haemoglobin proteins. Red blood cells carry haemoglobin molecules with a slightly altered shape which are unable to transport oxygen as efficiently. ○ GM bone marrow cells could be used to create red blood cells that carry haemoglobin proteins with a shape that is better able to transport oxygen.	Aims to: ○ provide a longer term cure as the GM stem cells will continually generate healthy red blood cells ○ remove the need to find a suitable donor to provide stem cells as stem cells from the patient can be used. ○ remove the risk of rejection of donor cells.
Gamete cells	○ Gene therapy on gamete cells is currently illegal in the UK. ○ This is because scientists are concerned that unexpected results could cause difficulties that affect many different organs in the body. ○ The therapeutic gene would be passed on to each new generation of offspring, so unexpected results could cause long term negative outcomes.	○ A therapeutic gene added to a gamete cell will be found in every cell in the body of a person that develops from GM gametes. ○ This could potentially prevent all offspring of a treated individual developing a genetic condition.

Exercise 22

a) What do the letters GMO stand for?
b) With reference to their structure, explain why bacteria are useful as GMOs.
c) State two uses of a restriction enzyme in the process of genetic engineering.
d) Name one other enzyme associated with genetic engineering and state its use in the process.

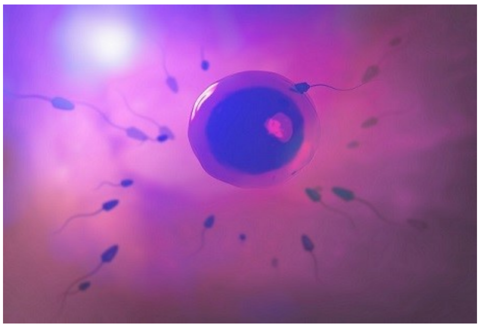
Stem cells

Stem cells are undifferentiated cells which can renew themselves by dividing by mitosis. They can also specialise by a process called differentiation into a variety of different cell types. There are different types of stem cells produced at different stages of a person's life.

Human development and stem cell types

Humans reproduce by sexual reproduction.

Fertilisation



Each parent produces specialised cells called gametes. Two gamete cells fuse together at fertilisation to produce a fertilised egg cell called the zygote.

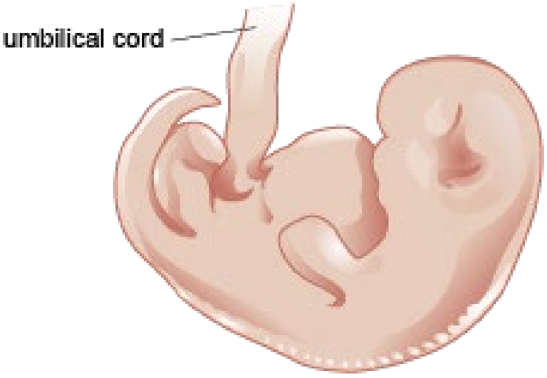
The zygote will then divide by mitosis to produce two daughter cells. These cells will also divide by mitosis to produce more cells and a new life starts to develop.

The cells that are produced in this very early stage of life are totipotent stem cells.

Totipotent stem cells can differentiate and develop into any of the wide variety of specialised cells found in an adult human.

As the number of cells in the new life increases further, an embryo forms.

The embryo is made up of embryonic stem cells which are pluripotent. Like the totipotent zygote, these cells can differentiate into any of the specialised cells in an adult. However, pluripotent cells cannot produce the cells that will become the placenta. Only totipotent cells can do this.



Humans have stem cells in their body throughout their life.

Adult stem cells can be found in a wide variety of organs in the body including the liver, heart, brain and skin.

These adult stem cells are multipotent. They are undifferentiated cells which can only differentiate into a small number of different cell types. The bone marrow contains an example of these stem cells and they can only differentiate into the different types of cells found in human blood.

All stem cells are undifferentiated and can divide by mitosis. All stem cells can differentiate into different types of cells. However, the number of different types of cells that can be produced by an individual stem cell reduces as a human develops from a zygote to an embryo and then eventually into an adult.

Stem cells and medicine

Bone marrow contains stem cells that can be transplanted into patients to treat some diseases, e.g. certain cancers.

This treatment with stem cells carries risks which include:

- an increased risk of cancer developing
- rejection by the immune system, because the transplanted cells are identified as foreign.

There has been a great deal of research looking at the uses of embryonic stem cells in medicine. Embryonic stem cells could be used to treat conditions which occur because body cells are damaged or destroyed. The stem cells could be stimulated to differentiate into specific adult cell types in the laboratory and then used to replace damaged cells in the body.

Examples of how embryonic stem cells could be used in this way include:

- treating diabetes by replacing insulin-secreting cells in the pancreas
- treating burns by replacing damaged skin tissue
- replacing neurones damaged by spinal cord injury
- replacing cells in the heart damaged by a heart attack.

As with bone marrow transplants, these treatments carry the risk of rejection by the immune system, because the transplanted cells are identified as foreign.

The use of embryonic stem cells is controversial because they must be obtained from human embryos. Many people object to their use on moral and ethical grounds.

Scientists have developed induced pluripotent stem cells (iPSC). These are stem cells that have been produced in the laboratory using adult body cells.

iPSC have many possible benefits including:

- the treatment of conditions in place of the more controversial embryonic stem cells
- stem cells produced from a patient's own body cells should not be rejected as foreign
- learning more about specific diseases by culturing cells from a patient in the laboratory and then inducing them to differentiate into a specific cell type which can be studied, e.g. brain cells cultured to learn more about Alzheimer's disease which affects the brain
- testing the effectiveness of drugs in cell culture before they are used in a patient.

Stem cell drug research

Exercise 23

a) Define the term *stem cell*.

b) i) Give one source of totipotent stem cells.
ii) State one similarity and one difference between totipotent and pluripotent stem cells.

c) State two disadvantages of using stem cells in medicine.

Selective breeding

Domesticated animals

Domesticated animals are those which humans have tamed. They are used for a variety of reasons such as for food or work. They may also be kept as pets. Domesticated animals rely on humans for survival. Humans have been using selective breeding for thousands of years to improve the quality of domesticated animals.

Pigs on a farm

The process of selective breeding

During selective breeding, a breeder will choose animals with desirable characteristics and use them for breeding. If these characteristics are controlled by genes, these genes may be inherited, and the offspring may also show the characteristics.

How selective breeding is carried out.

Animals with desirable characteristics, e.g. rapid growth rate, are selected for breeding.

↓

These animals are bred together.

↓

The animals with the most desirable characteristics are selected from the offspring.

↓

These offspring animals are then bred together.

↓

This cycle is repeated over many generations.

↓

Over time the desirable characteristic starts to increase in the population, e.g. animals which have a higher and higher growth rate.

Selective breeding of dogs

The dog breeds that exist today have all originated from wolves. It is thought humans selectively bred wolves with desirable characteristics, e.g. tameness.

Over time, many different breeds of dog have been produced as humans have selected for different desirable characteristics, e.g. the flat face of the bulldog, the intelligence of the greyhound.

The border collie has been bred for obedience and intelligence.

Dogs originated from wolves.

Disadvantages of selective breeding

Selective breeding produces animals that are genetically very similar and so it reduces the genetic variation within the population of animals. This is a result of inbreeding – breeding closely related animals over many generations. This increases the likelihood of genetic conditions arising in the animals.

This is because the alleles that cause genetic conditions are often recessive. If genetic variation is low in a population, there is an increased chance of animals being homozygous recessive and therefore developing an inherited condition, e.g. inherited hearing loss is common in Dalmatian dogs, and an inherited form of cataracts, an eye condition which causes blindness, is common in the bichon frise breed of dog.

There are ethical concerns that the effects of selective breeding can affect the welfare of animals. Sometimes the characteristics that are selected as desirable to humans are not desirable to the animals that are produced, e.g. humans have bred bulldogs because they found the flat face nice to look at. However, many bulldogs have breathing problems because of their set-back noses.

Bulldog

Inbreeding and the resulting reduction in genetic variation in the animal population can reduce the population's ability to adapt to a changing environment. This could have a significant impact on farming, e.g. cattle populations may be unable to adapt to new diseases that may arise. This could mean that large numbers of cattle are all killed by the same condition as none have resistance to it.

Cattle

Exercise 24

The following statements describe the process of selective breeding, but have been mixed up. Place them in the correct order.

A) Over time the desirable characteristic starts to increase in the population.

B) These animals are bred together.

C) The selected offspring animals are bred together.

D) Animals with desirable characteristics are selected for breeding.

E) The cycle is repeated over many generations.

F) The animals with the most desirable characteristics are selected from the offspring.

Solutions to Exercises 22 to 24

Exercise 22

a) Genetically Modified Organism

b) Bacteria have circular pieces of DNA called plasmids. These can be removed, have a gene inserted, then the plasmid can be put back into the bacterium. The bacterium will then produce the protein coded for by the gene that has been inserted. Bacteria reproduce quickly, so large amounts of the protein can be produced.

c) i) Cutting out a useful gene from the DNA of an organism.
ii) Cutting open bacterial plasmid DNA.

d) Ligase. It is used to attach a selected gene to plasmid DNA.

Exercise 23

a) Stem cells are undifferentiated (unspecialised) cells which can divide by mitosis and become differentiated to form a number of different cell types.

b) i) Cells produced by the first few divisions after an egg cell is fertilised. The zygote is also totipotent.
ii) Similarity: both totipotent and pluripotent stem cells can differentiate to form any of the specialised cells in an adult. Difference: totipotent cells can produce cells which become the placenta, but pluripotent cells cannot do this.

c) Any two from: an increased risk of cancer; rejection by the immune system; use of embryonic stem cells is controversial, so may be objected to on moral and ethical grounds.

Exercise 24

D) Animals with desirable characteristics are selected for breeding.

B) These animals are bred together.

F) The animals with the most desirable characteristics are selected from the offspring.

C) The selected offspring animals are bred together.

E) The cycle is repeated over many generations.

A) Over time the desirable characteristic starts to increase in the population.

Photos: Memurubu - CC BY 4.0/Matthias Zomer - Pexels/Pixabay/Sébastien Lavalaye – Unsplash/ Science Photo Library

B7. Variation

B7.1	Natural selection and evolution: a. Know that there is usually extensive genetic variation within a population of a species. b. Describe evolution as a change in the inherited characteristics of a population over time through a process of natural selection which may result in the formation of a new species. c. Know and understand how evolution can occur through natural selection of variants that give rise to phenotypes best suited to their environment. d. Know and understand that antibiotic resistance in bacteria is an example of evolution through natural selection.
B7.2	Sources of variation: a. Understand that variation can be genetic/inherited, resulting in a range of phenotypes. b. Understand that variation can also be environmental, which affects a range of phenotypes.

A species is the name given to all organisms that can interbreed with each other and produce offspring that can also interbreed once adult.

A population comprises all the organisms of one species found in an area.

These dogs are different breeds but they are all the same species

The blackbird and robin are different species of bird.

Genetic variation

Natural selection is the process whereby some organisms (variants) in a population are preferentially selected for and others selected against.

Due to mutations, there will be genetic variation in a population. This is usually extensive as the species is likely to have been in existence for a long time.

In a population, the genetic variation present means that not all the individuals will be the same. Individuals will have different characteristics (and show different phenotypes), such as differing fur colours in mammals or heights in pea plants.

Cat with kittens, each with different fur colouration

If some of these characteristics make the individuals better suited to the current conditions, they are more likely to survive and therefore reproduce. If the characteristic is inherited, then the allele that codes for that characteristic may be passed on to the offspring, giving the offspring a selective advantage over other individuals.

When referring to selective advantage, we mean that the organism or variant with this advantage is somehow better suited to the environment compared to other individuals. It may be, for example, that it is better camouflaged so less likely to be taken by a predator (which is acting as the selection pressure), or is a predator that can run a little faster than others so is more likely to catch the prey.

If this continues over many generations then the advantageous allele will become more common in the population and disadvantageous alleles less common. This is evolution.

Sometimes the changes over time become so great that one or more new species arise.

There are many examples of evolution through natural selection, including how bacteria became resistant to antibiotics used to treat bacterial infections.

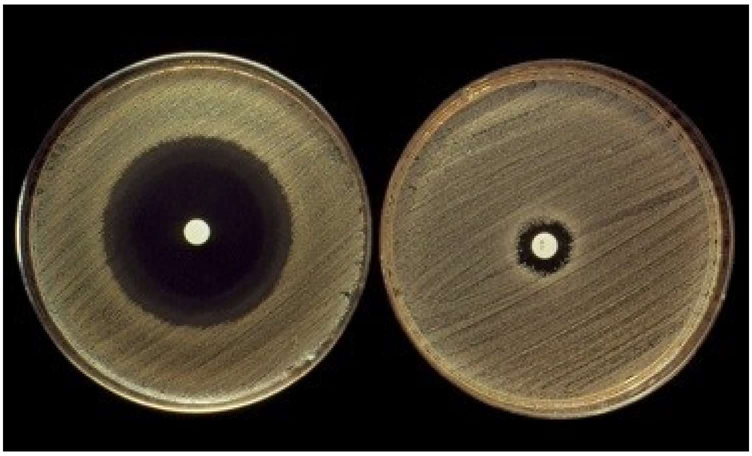
It is important to appreciate that within a population of bacteria there would be genetic variation including some individuals that would have had (by chance) a mutation that made them resistant to antibiotics. This mutation is in a gene found in plasmid DNA.

Subsequently antibiotics were used, by humans, to treat bacterial infections. The antibiotics were very successful against the majority of bacteria but were ineffective against those variants that had the antibiotic resistance gene. It was these bacteria that now had a selective advantage and, through natural selection, were more likely to survive.

These surviving bacteria reproduced through binary fission, a form of asexual reproduction, and so the antibiotic resistance gene became more common in the bacterial population. This has continued to occur over many generations and we are now increasingly finding that a range of antibiotics are becoming less useful in fighting bacterial infections.

Below are two Petri dishes containing penicillin antibiotic on the white disc. Each Petri dish has a different strain of the bacterium *Staphylococcus aureus* present. The strain on the left is more sensitive to the effects of penicillin than the strain on the right.

Staphylococcus aureus



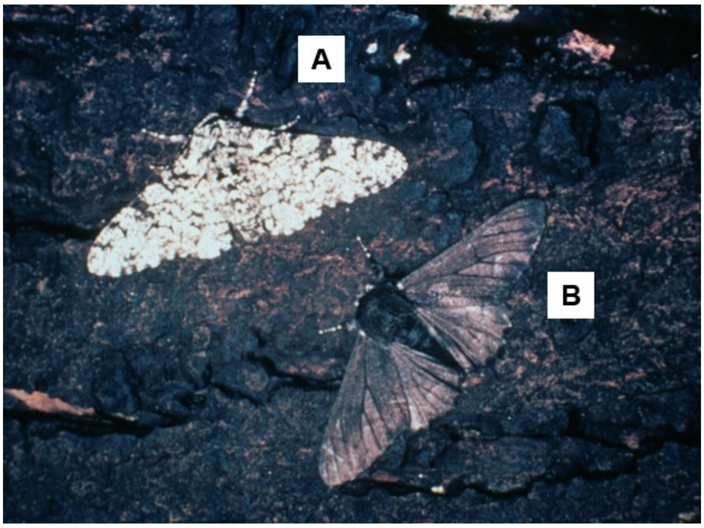
Sources of variation

As referred to above, mutations within a population are a source of variation. As mutations are changes in the sequence of bases in DNA, they can be inherited and so passed on to subsequent generations. The mutations may alter the functioning of the protein the mutant gene codes for, leading to an altered characteristic. This can be expressed in the phenotype. As there can be more than one mutation in a gene, a range of phenotypes can be seen. For example, the different blood groups seen in humans (i.e. the phenotypes of blood groups A, B and O) is due to the presence of three different alleles in most human populations (I^A, I^B and I^O).

In many cases the environment can have an impact on the phenotype which leads to further variation in a population. For example, clones of plants are grown in different light intensities and will appear different.

Exercise 25

The photograph shows two forms of the same species of peppered moth. They are predated by birds.



a) Suggest how the two forms of this moth could be shown to be the same species.

b) Suggest why form A of the moth would survive better and become the dominant form in an unpolluted environment where the tree trunks they settle on are pale coloured.

Solution to Exercise 25

Exercise 25

a) They could be bred together. If they reproduce successfully, producing fertile offspring, they are the same species. Alternatively, the DNA of the two forms could be sampled and compared.

b) The colour of the moths' wings would be similar to the tree trunks they settle on. This would provide camouflage so their predators would be less likely to see and eat them. They are therefore more likely to survive and breed. Their numbers would increase over time. The other form, B, would be more visible, so their predators would feed on them and their numbers would drop over time. Gradually the proportion of form A in the population would increase due to natural selection, as their phenotype is better suited to the environment.

Photos: Jozef Fehér - Pexels/Science Photo Library

B8. Enzymes

B8.1	Know and understand that enzymes are primarily proteins that function as biological catalysts.
B8.2	Know and understand the general mechanism of enzyme action, including the role of the active site and enzyme specificity.
B8.3	Know and understand how the factors of temperature and pH can affect the rate of enzyme action.
B8.4	Know the role of amylases, proteases and lipases in the digestion of carbohydrates, proteins and fats.

Enzymes are biological catalysts.

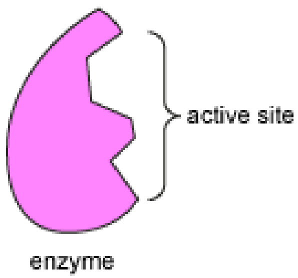
Metabolic processes in cells are due to chemical reactions and need a catalyst to speed them up because without enzymes they would occur too slowly.

Almost all metabolic processes need to be controlled by enzymes so that the reactions are fast enough to sustain life, e.g. respiration, protein synthesis, photosynthesis, digestion. They are biological catalysts.

The enzymes present within a cell determine which metabolic pathways can occur.

Enzymes contain an active site.

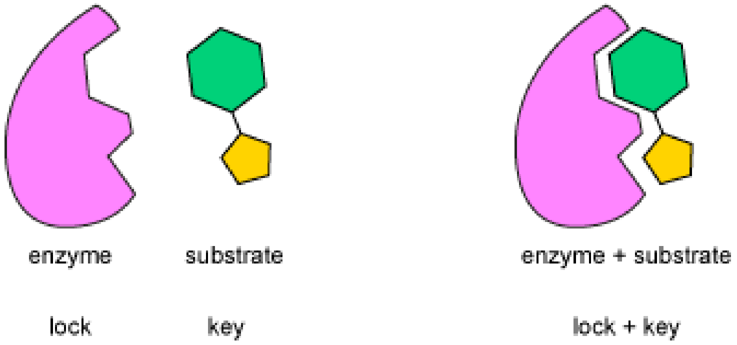
Enzymes are proteins that contain an area with a unique 3D shape called the active site where chemical reactions take place.



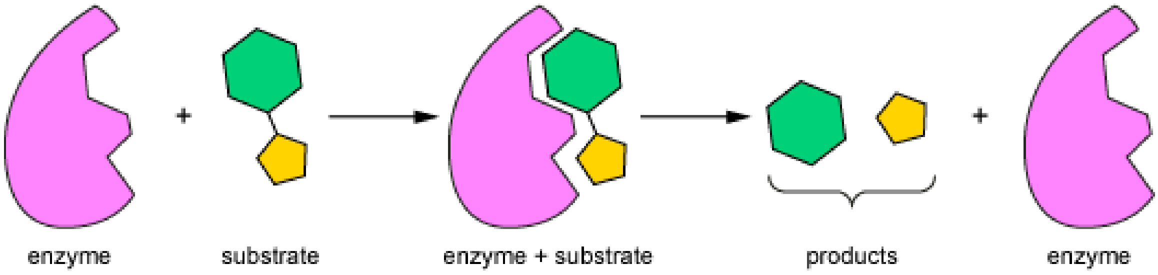
Enzymes are specific.

Enzymes are specific in that they only react with their substrate. The substrate may be a specific molecule e.g. starch, or one type of molecule e.g. protein. The substrate fits into the active site of the enzyme, like a 'key in a lock' e.g. starch binds with amylase and protein binds with protease.

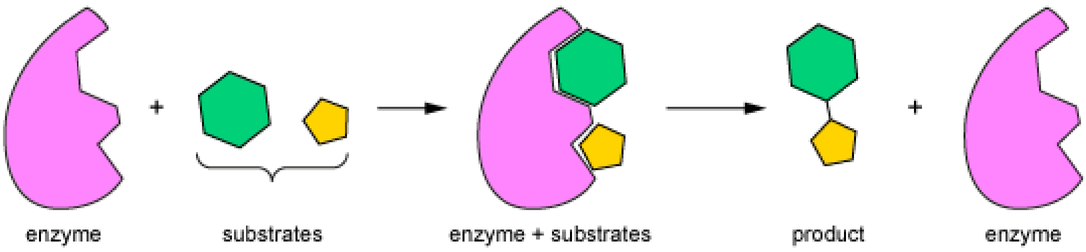
In the lock and key hypothesis, the active site of the enzyme has a unique 3D shape. Only the substrate with the complementary shape is the ‘key’ that fits the ‘lock’. This is known as specificity.



Enzymes convert molecules (substrates) into different molecules known as products.



Enzyme + substrate is called an enzyme substrate complex (ESC). The enzyme is unchanged by the reaction. An enzyme may act on one substrate to form two products or it may join two substrates to form one product.



The enzyme is not used up during the reaction and can be used again.

Breaking substrates and making products

A substrate may be broken by the addition of water = hydrolysis reaction.

A product may be formed by the removal of water = condensation reaction.

Induced fit theory of enzyme action

The active site of the enzyme is a specific shape and only catalyses one reaction.

The substrate with the correct shape enters the active site.

It is thought that the active site changes shape slightly once the substrate has entered it.

This makes the active site fit more closely around the substrate and helps the reaction to take place more efficiently.

Exercise 26

Why are catalysts necessary in order for reactions to take place in organisms?

Exercise 27

Some enzymes were mixed with a substrate.

Explain why only enzyme Y catalyses the reaction with this substrate.

Optimum conditions

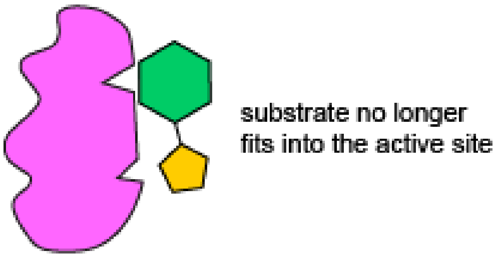
Each enzyme works best at a specific temperature and pH – the optimum conditions.

When conditions move away from the optimum, the rate of reaction decreases.

This may be due to:

- a reduction in energy available for the reaction
- the bonds holding the enzyme in a specific 3D shape have been broken (the enzyme is described as denatured).

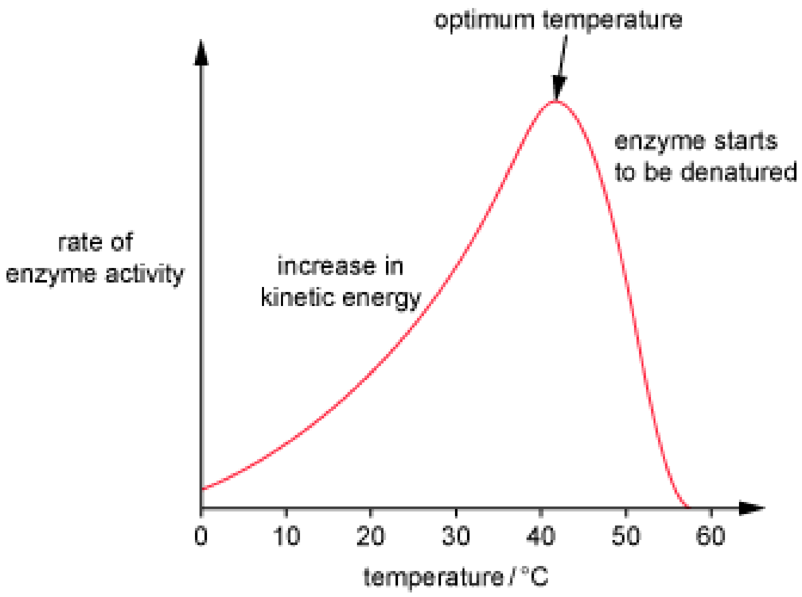
When an enzyme is denatured, the shape of the active site is altered so that the substrate no longer fits into the active site:



The active site is no longer complementary to the substrate.

Temperature affects the rate of reaction

Changing the temperature changes the rate of an enzyme-catalysed reaction:



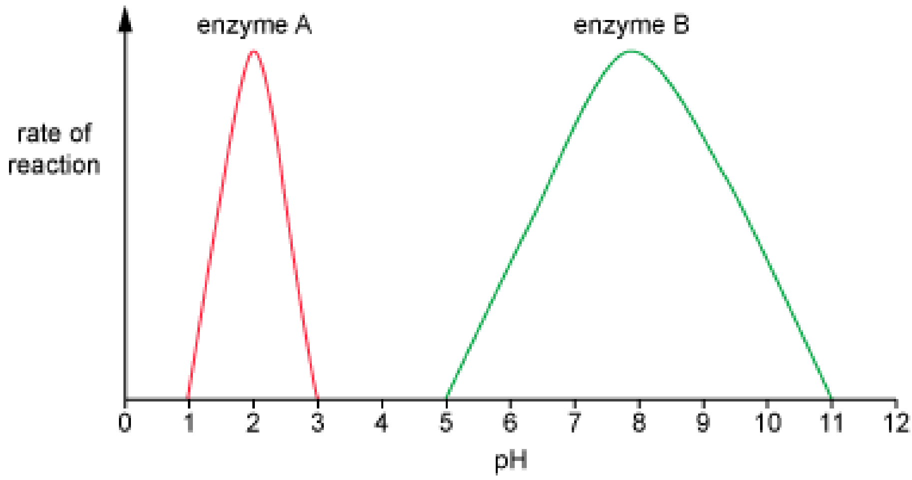
1) As temperature increases, the enzymes and substrates gain more kinetic energy and move around faster.
2) This increases the chance of the substrates colliding with the active sites of the enzymes with sufficient energy for reactions to occur, and so the rate of reaction increases.
3) The rate of reaction is fastest at the optimum temperature.
4) Above the optimum temperature, the enzyme begins to denature and the rate of reaction decreases until it stops when all of the enzymes are fully denatured.
5) Once denatured, the functional shape of the enzyme's active site is altered, and it can no longer catalyse the reaction, even when the temperature is lowered.

pH affects the rate of reaction

Different enzymes work best at different pH values.

A functional enzyme in the stomach will have an optimum pH of around pH 2, whereas a functional enzyme in the small intestine will have an optimum pH of around pH 8.

Changing the pH changes the rate of an enzyme-catalysed reaction:



As the pH moves further away from the optimum, in either direction, the enzyme begins to denature and the rate of reaction falls.

Once denatured, the functional shape of the enzyme's active site is destroyed and the enzyme can no longer catalyse the reaction, even when the pH is returned to optimum.

Different species have different optimum conditions

Organisms have adapted to exist in a variety of habitats.

Some species can survive in extreme environments e.g. hot springs. This means that their enzymes must have a higher optimum temperature than the enzymes of organisms living in a cooler environment e.g. Arctic. Often, these hot springs also have a very acidic or alkaline pH.

Other habitats include:

- extreme pressure
- high sodium chloride levels
- high levels of various metals
- low water availability

Wherever organisms grow, they must contain enzymes that are not denatured by the extreme conditions.

Exercise 28

The enzyme catalase is present in most cells, including potato cells. It catalyses the breakdown of hydrogen peroxide with the formation of oxygen.

A group of students investigated how a change in temperature affects the action of catalase.

Five 1cm3 cubes of raw potato were each placed in a test tube at different temperatures with 5cm3 of hydrogen peroxide. All other variables were kept constant.

The height of the foam produced when oxygen was released in this enzyme-catalysed reaction was measured after 1 minute.

Temperature / °C	Height of foam / cm
15	2.6
25	4.2
35	4.7
45	3.9
55	3.5

Some students concluded that the optimum temperature for the enzyme was 35°C and after this point the enzyme was killed.

Some students concluded that the optimum temperature for the enzyme was 35°C and after this point the enzyme started to lose its shape.

Some students concluded that further experiments were needed to identify the optimum temperature.

What conclusions can you make from this experiment?

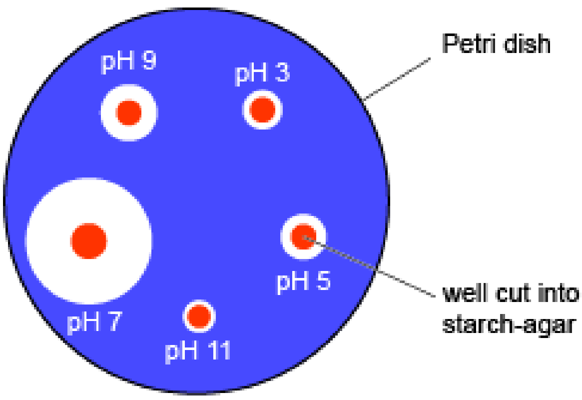
Exercise 29

A starch-agar plate was used to investigate the effect of pH on the enzyme amylase (which digests starch). Wells were made in a starch-agar plate with a cork borer and two drops of a different pH buffer solution were put into each well.

Two drops of 1% amylase solution were also put into each well and the starch-agar plates were incubated for 24 hours at 35°C. During this time the amylase could diffuse through the agar and catalyse the digestion of starch.

After 24 hours the starch-agar plate was flooded with iodine and if starch was present, the agar turned blue-black.

A clear zone around the wells indicated that starch had been digested by amylase. The diameters of the clear zones were measured and compared for each pH.

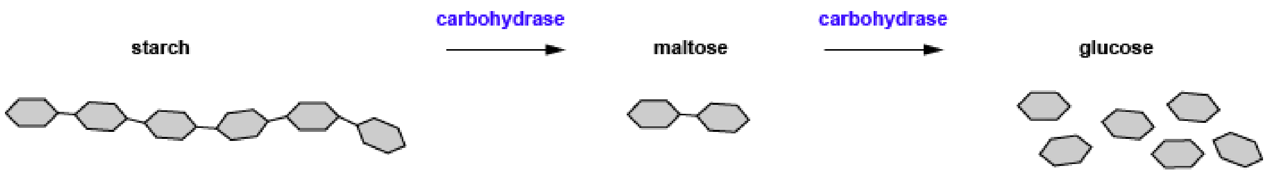


At which pH did the enzyme work best? Why was the clear zone small in pH 11?

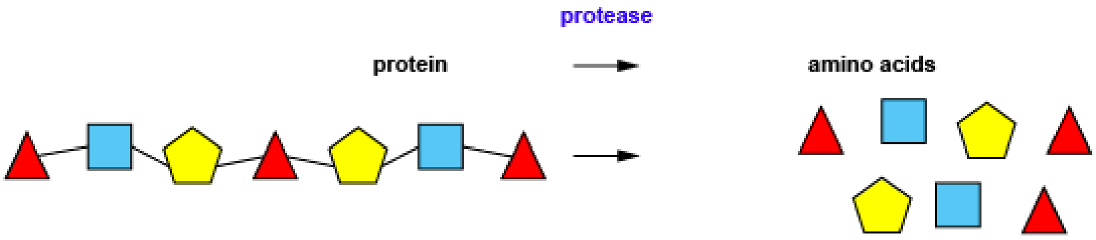
Digestion of food molecules requires enzymes

Enzymes are essential for speeding up the digestion (breakdown) of food molecules into products that can be absorbed in the small intestine and used by cells.

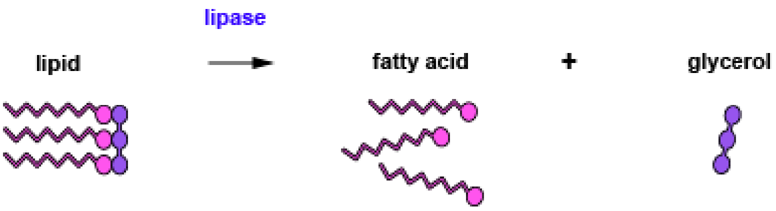
Carbohydrases digest large insoluble carbohydrates (polymers) into smaller soluble carbohydrates. Below is an example of a carbohydrase (amylase) breaking down starch.



Proteases digest large insoluble proteins (polymers) into smaller soluble amino acids:



Lipases digest lipids (fats and oils):



Intracellular and extracellular enzymes

Most enzymes work inside cells = intracellular

e.g. enzymes involved in respiration, photosynthesis.

Digestive enzymes work outside cells = extracellular

They are produced by specialised cells in glands and tissues, e.g. salivary glands, stomach lining, pancreas, intestinal lining.

The enzymes are secreted from the cells, e.g. into the mouth, stomach or small intestine, where they come into contact with the food molecules to be digested.

Digestive enzymes can be used commercially

When babies start to eat solid food, they are not good at chewing so proteases are often used to pre-digest the proteins in baby food so that the amino acids can be absorbed without digestion.

Biological washing powders contain enzymes to digest food stains on clothing.

Other commercial uses of enzymes include:

- production of sugar syrups
- manufacturing pharmaceuticals
- making ethanol from plants
- wine and beer production

Exercise 30

Why are the digestive enzymes of a human extracellular?

Exercise 31

Dead organic material and organic waste products are broken down by decomposers. The decomposers do this with enzymes. Are these enzymes intracellular or extracellular?

Exercise 32

Why do biological washing powders recommend washing at a maximum of 40°C?

Solutions to Exercises 26 to 32

Exercise 26

The body temperature of most organisms is too low for reactions to take place fast enough to sustain life, e.g. respiration.

Exercise 27

Biological molecules are digested by specific enzymes. Enzymes are proteins that are held together in a specific 3D shape. The reaction takes place in a part of the enzyme called the active site.

For an enzyme to catalyse the reaction, the substrate must be the correct shape to fit into the active site of the enzyme.

Therefore only enzyme Y is able to catalyse a reaction with this substrate. The enzyme Y is specific to the substrate.

Exercise 28

Enzymes are proteins and not living so are therefore unable to be killed.

They have a specific shape, the active site, which the substrate fits into and when this is lost, the enzyme cannot catalyse the reaction and is said to be denatured.

In this experiment the height of foam is reduced after 35°C so the reaction is still taking place but at a slower rate. Therefore, some of the enzymes are starting to lose their shape and become denatured.

The temperatures tested in this experiment were at intervals of 10°C and therefore the optimum temperature cannot accurately be identified. More experiments, with narrower temperature intervals, repeated to give mean values for the height of foam, would enable the optimum temperature for the enzyme to be more accurately identified. Carrying out repeats would also identify whether any of the original data obtained was anomalous.

Exercise 29

When the different pH buffers and amylase solution were dropped into the wells, they diffused through the agar away from the well.

When iodine is added to the agar after 24 hours at 35°C, the presence or absence of starch is indicated around each well. A clear zone around the well indicates that the enzyme has catalysed the breakdown of starch and a blue-black colour around the well indicates that the enzyme has been denatured.

The largest clear zone was seen around the well at pH 7. This indicates that in this experiment pH 7 allowed the enzyme to be the most effective and catalyse the breakdown of starch.

At the other pH values the clear zone was much smaller as the pH had started to cause the active site of the enzymes to change shape. The further away from the optimum pH more of the enzymes had denatured and were unable to catalyse the reaction. pH 11 has a very small zone indicating that most of the enzyme had been denatured.

Exercise 30

The molecules are too big to cross the membrane into the cells for digestion. Therefore enzymes need to be secreted into the gut to digest these molecules so their products can be absorbed and then used by cells.

Exercise 31

Extracellular (that is, they function outside cells).

Exercise 32

Enzymes in biological washing powders have an optimum temperature around 40°C. If the temperature is increased above this, the enzymes will be denatured and the powder will not be as effective at removing stains.

B9. Animal physiology

B9.1	Respiration:	
	a.	Know and understand the process of cellular respiration in living cells.
	b.	Know and understand the process of aerobic respiration in living cells, including the word equation.
	c.	Know and understand the process of anaerobic respiration in animal cells, including the word equation.

The process of cellular respiration

Respiration is a chemical reaction which occurs in cells to release energy. It is catalysed by enzymes and so the rate of respiration is sensitive to changes in temperature and pH.

Note that respiration is not the same as breathing. Breathing is the process of inhaling and exhaling.

All living things respire and living cells respire all the time. The energy released from the reaction is used to fuel many cellular processes including:

- protein synthesis and making other new molecules
- active transport
- cell division
- muscle contraction.

Aerobic respiration

Aerobic respiration requires oxygen. This form of respiration is more efficient than anaerobic respiration and releases more energy than anaerobic respiration. Energy is in the form of ATP.

In eukaryotic cells (including plants and animals), aerobic respiration occurs inside mitochondria. In prokaryotes (bacteria), aerobic respiration occurs in the cytoplasm.

The word equation for aerobic respiration is:

Glucose + Oxygen → Carbon Dioxide + Water + Energy (ATP)

Anaerobic respiration in animals

This type of respiration occurs without oxygen. It releases less energy than aerobic respiration but is important for cells that cannot obtain sufficient oxygen. This reaction takes place in the cell cytoplasm.

The word equation for anaerobic respiration in animals is:

Glucose $\longrightarrow$ Lactic acid + Energy (ATP)

Lactic acid is a toxic molecule and so this must be removed from the body.

Respiration and exercise

When an animal (including humans) starts to exercise, muscle cells need more energy for contraction to produce movement. This means that more respiration must take place compared to when resting.

During exercise the breathing rate will increase and the heart will start to beat faster, allowing more oxygen and glucose to reach the muscle cells. This allows more aerobic respiration to take place and more carbon dioxide can be removed from the muscle cells.

During exercise the body may also break down glycogen stores (in the liver and muscles) to release more glucose.

If the intensity of the exercise continues to increase, then cells may not receive enough oxygen from the circulation system. When this happens cells will start to use anaerobic respiration in addition to aerobic respiration. This produces lactic acid which can build up in muscles, causing pain and tiredness.

After exercise the breathing rate may remain high. Extra oxygen taken in during this period is used to replenish the oxygen debt required to remove any toxic lactic acid from the body.

Exercise 33

Which of the following statements are true, and which are false?

a) Respiration is the process of taking oxygen into the body.

b) Anaerobic respiration releases less energy than aerobic respiration.

c) Glucose and carbon dioxide are needed for aerobic respiration to occur.

d) Anaerobic respiration takes place in mitochondria in plants and animals.

e) Glycogen is used to store glucose in liver cells.

f) The oxygen debt is the volume of oxygen needed for cells to respire.

Exercise 34

Which of the following statements is/are correct?

1 In bacteria, carbon dioxide will be produced inside mitochondria.

2 An increase in temperature may decrease the rate of respiration in a plant cell.

3 The pH of animal cell cytoplasm may decrease during anaerobic respiration.

a) None of them

b) 1 only

c) 2 only

d) 3 only

e) 1 and 2 only

f) 1 and 3 only

g) 2 and 3 only

h) 1, 2 and 3

B9.2 Organ systems:

a. Nervous system:

i. Know and understand that the central nervous system comprises the brain and spinal cord.

ii. Know and understand the structure and function of sensory neurones, relay neurones, motor neurones, synapses and the reflex arc.

What is the nervous system?

The nervous system is a rapid communication system in the bodies of animals. It is made up of several different cell types that use electrical impulses to send cellular messages, producing quick but short-lived responses. The nervous system uses a system of nerves that connect to the organs and tissues. These link to the central nervous system which co-ordinates the inputs from the other nerves. A neurone is one of the cells of the nervous system. Nerves are made of bundles of the axons of neurones.

What is the central nervous system?

The central nervous system is made up of the brain, which is protected by the skull, and the spinal cord, a collection of nerves that run down the spine through the vertebrae. Nerves from the receptors in the sense organs bring impulses to the spinal cord which then sends them to the brain for processing. The brain interprets the impulses and then responds by sending an impulse via the spinal cord to the nerves which connect to the organs and tissues of the body.

Exercise 35

Which of these statements about the nervous system is correct?

g) The central nervous system consists of the brain and spine.

h) The responses produced from the nervous system are slow-acting.

i) Impulses from many nerves are processed and co-ordinated in the brain.

j) Receptors are always found in the central nervous system.

What is a neurone?

A nerve cell is called a neurone. These transmit electrical impulses. There are different types of neurone which all contain a single nucleus in their cell body, and extensions of their cytoplasm that allow electrical impulses to travel through them.

What are the types of neurone?

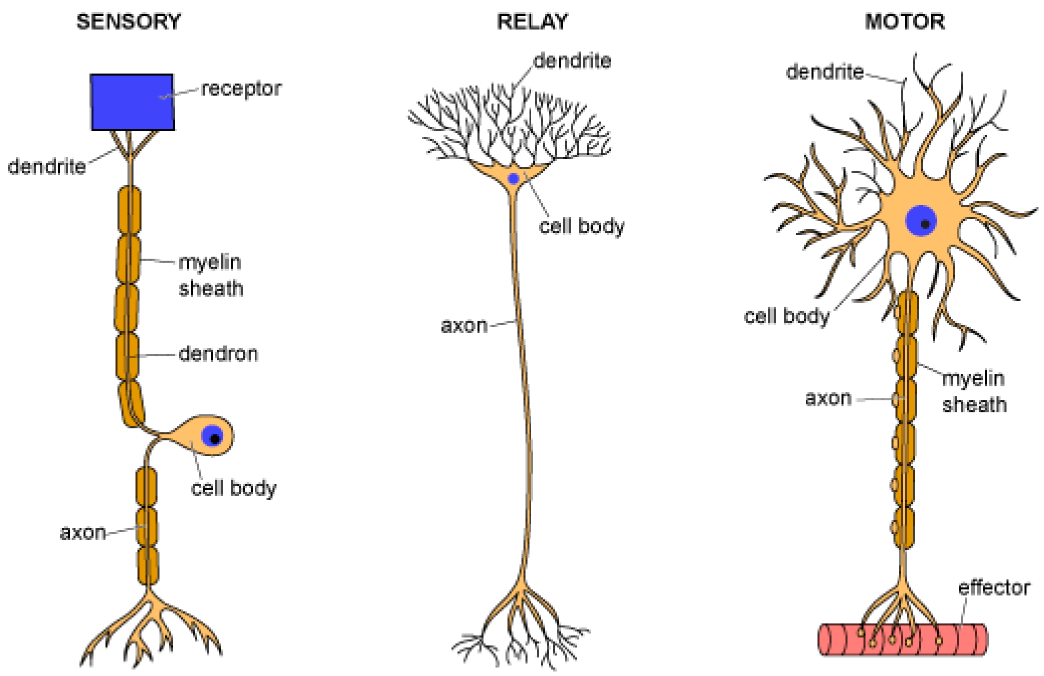
Three types of neurone are sensory, relay and motor neurones.

Sensory neurones connect receptors, which detect stimuli in the environment, with the central nervous system.

Relay neurones are found within the central nervous system. These connect the sensory as well as motor neurones and allow communication to and from the brain.

Motor neurones connect the central nervous system to effectors. These are the parts of the body that produce a response to the electrical impulse. Effectors include muscles and glands. The structures of these neurones are shown below.

Sensory, relay and motor neurones



The long section of the neurone through which an electrical impulse can travel is called the axon. This is surrounded by a myelin sheath. This protects the axon and makes the impulse travel faster. Each neurone also has a cell body containing its nucleus. They also have dendrites which allow them to make connections to other neurones.

Exercise 36

Which of these statements apply to either the axon or cell body of a neurone or both?

1 Contains cytoplasm.

2 Conducts the electrical impulse.

3 Contains the cell nucleus.

4 Allows connection to other neurones.

i) 1 and 3

j) 2 and 3

k) 1 and 4

l) 1, 2 and 3

m) 2, 3 and 4

Exercise 37

Which row of the table is correct?

	motor neurone	**relay neurone**	**sensory neurone**
a	connects to a receptor	connects to an effector	only found in the central nervous system
b	only found in the central nervous system	has no myelin sheath	connects to a receptor
c	connects to an effector	connects to other neurones	has a myelin sheath
d	has a myelin sheath	only found in the central nervous system	connects to an effector

What is a synapse?

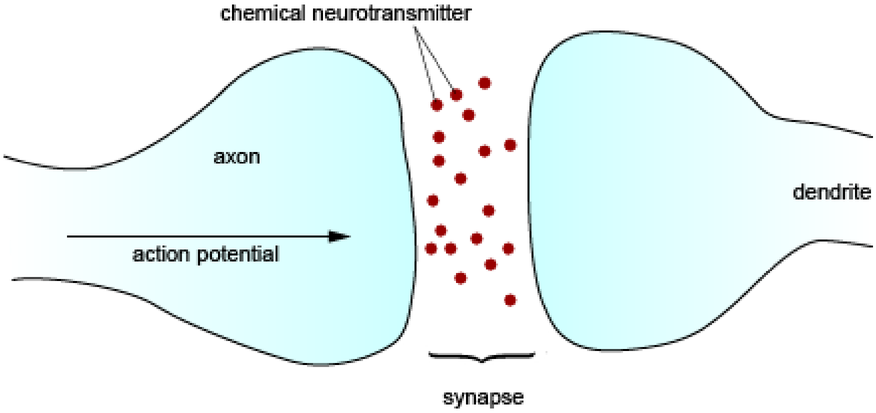
A synapse is a small gap between two neurones. This is usually about 1 μm in width. Synapses allow neurones to transmit electrical impulses to each other. They also allow multiple neurones to connect with each other at once.

These connections are made between the dendrites of different neurones.

How do impulses cross a synapse?

An electrical impulse travels along the axon of a neurone until it reaches the end of the neurone. Here the impulse causes a chemical to be released into the synapse. This chemical is called a neurotransmitter and it diffuses from the axon across the synapse to the neurone on the other side. When it reaches the surface of the dendrite, it binds to a receptor which allows the electrical impulse to be regenerated. This new impulse then travels down the axon of the other neurone. This process happens very quickly.

A synapse between two neurones



Exercise 38

Which of the following statements about synapses is correct?

a) Movement across a synapse depends on osmosis.

b) Chemicals are needed to pass an impulse across a synapse.

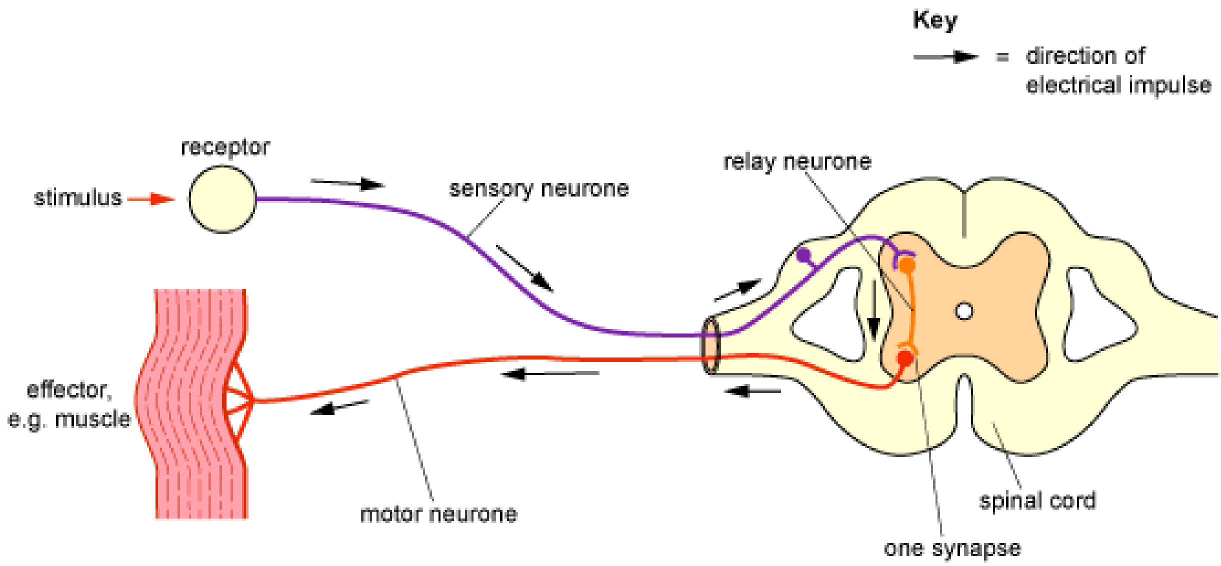
c) Synapses are often more than 1 mm across.

d) Neurotransmitters are electrical impulses.

What is a reflex arc used for?

A reflex arc is required in order to produce a quick reflex action. These are designed to protect the body from harm and so they occur very rapidly. In order to make sure reflex reactions occur quickly, they do not require processing in the brain.

The parts of a reflex arc



The diagram above shows a reflex arc. The reflex starts when a receptor detects a stimulus. This can be a pain stimulus, such as a pain from standing on something sharp or detecting the heat from a very hot object.

The receptor generates an electrical impulse which passes to a sensory neurone. The electrical impulse passes down the axon of the sensory neurone to the spinal cord. There the message crosses a synapse, using chemical neurotransmitters, producing an impulse within a relay neurone in the central nervous system.

The electrical impulse in the relay neurone connects via another synapse to a motor neurone. From there, the impulse progresses along the motor neurone until it connects with an appropriate effector.

The effector is a muscle which will contract when it receives the impulse. This contraction will move the body away from the source of harm.

Exercise 39

Using the items listed 1 to 5, select the correct sequence of structures in a reflex arc.

1 motor neurone

2 sensory neurone

3 receptor

4 relay neurone

5 effector

a) 5, 1, 4, 2, 3

b) 2, 4, 5, 1, 3

c) 3, 2, 4, 1, 5

d) 4, 3, 2, 5, 1

B9.2 Organ systems:

b. Respiratory system:

i. Know and understand the structure and function of the respiratory (breathing) system, including the structure of the thorax.

ii. Understand the processes of ventilation and gas exchange.

iii. Know and understand the importance of a high surface area : volume ratio for the gas exchange process.

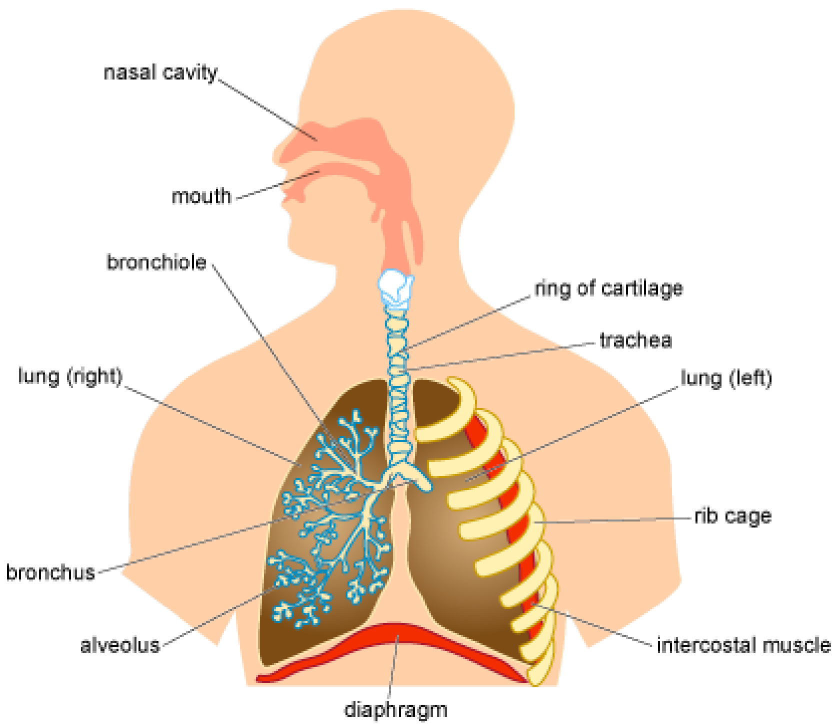
The structure of the respiratory system

The respiratory system is found inside the thorax (chest).

Air enters the human body through the nose and mouth and then through the larynx (voice box). It then passes into a tube called the trachea. This contains rings of cartilage which functions to ensure that the airway remains open.

The trachea splits into two smaller tubes called the bronchi. One bronchus enters each lung and they then split into a number of narrow tubes called bronchioles. Both the bronchi and the bronchioles also contain cartilage. At the end of the bronchioles are air sacs called alveoli (singular = alveolus).

Respiratory system



Surrounding the two lungs is the rib cage. This consists of the rib bones with intercostal muscles between them.

Together with the diaphragm, a sheet of muscle found under the lungs, these are important for breathing in and out.

The function of the respiratory system

The main function of the respiratory system is to provide the body with sufficient oxygen for aerobic respiration. It also removes carbon dioxide, a waste product of respiration. This gas exchange occurs between the alveoli and the blood.

What happens to air when it enters the respiratory system?

The air that leaves the body is different to the air that enters the airway.

Air entering the body	Air leaving the body
Contains more oxygen	Contains less oxygen
Contains less carbon dioxide	Contains more carbon dioxide
Contains less water vapour	Contains more water vapour
Contains pollen, dust and other particles, like viruses	Is cleaner with fewer particles

The air that enters the body is cleaned as it passes through the bronchi. The cells lining the bronchi produce mucus to trap any particles in the inhaled air. This includes pollen, dust, bacteria and viruses. Small hairs, called cilia, on the cells then move the mucus up to the top of the trachea where it can be swallowed into the acid contents of the stomach in the digestive system. This destroys them and then they are removed from the body.

Exercise 40

Which shows the correct order of the structures that a molecule of carbon dioxide would pass through when being exhaled? (Not all structures are included in each answer.)

a) mouth → bronchus → bronchiole → alveolus

b) alveolus → bronchiole → ring of cartilage → mouth

c) trachea → bronchiole → bronchus → alveolus

d) bronchus → bronchiole → trachea → nose

e) bronchiole → alveolus → ring of cartilage → nose

Exercise 41

Some chemicals, like tar from cigarettes, can paralyse the cilia in the bronchi. Which of the following may be a consequence of this?

1 Inhaled air would contain less oxygen.

2 More dust could be present in exhaled air.

3 Air would be cooler when it is exhaled.

4 The smoker is more likely to get an infection in their lungs.

a) 1 and 2 only

b) 1 and 3 only

c) 1 and 4 only

d) 2 and 3 only

e) 2 and 4 only

f) 3 and 4 only

g) 1, 2, 3 and 4

What is ventilation?

Ventilation is the process of breathing in (inhaling) and breathing out (exhaling). It allows the air within the respiratory system to be exchanged with the air outside the body.

In vertebrates, ventilation relies on the movement of the ribs and the diaphragm inside the thorax (chest). The ribs surround the lungs and are connected to each other by intercostal muscles. These muscles can contract and relax to change the position of the rib cage. The diaphragm is a sheet of muscle underneath the lungs.

Normal exhalation is called passive exhalation. This uses only the diaphragm and intercostal muscles to expel air.

When more forceful exhalation is required (active exhalation), the muscles of the abdominal wall can also contract.

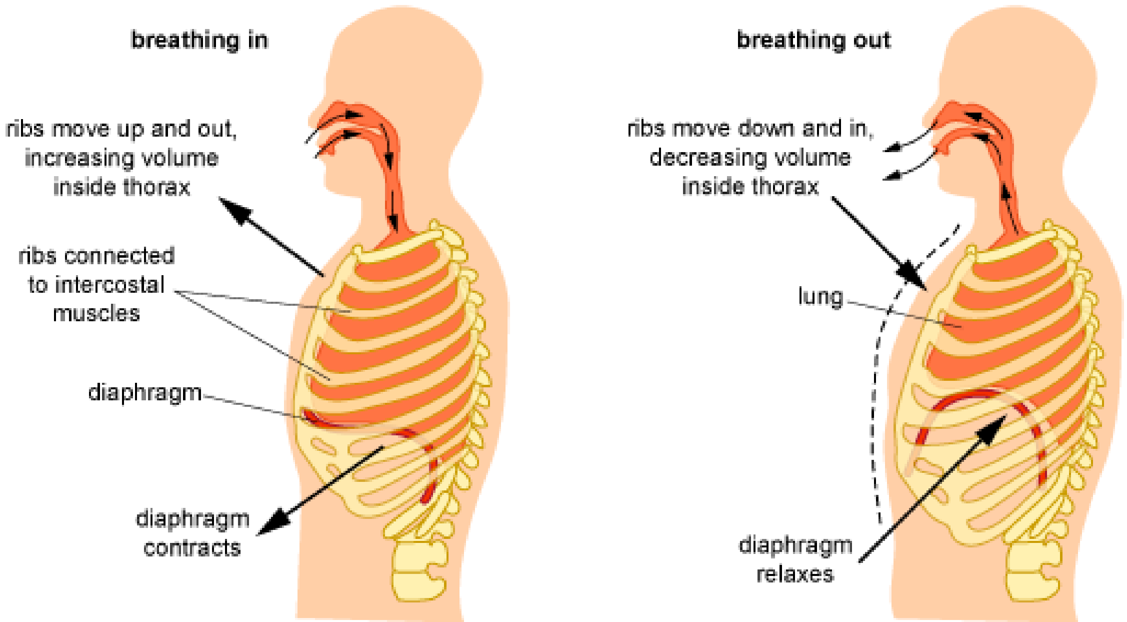
Inhaling – breathing in

- When we inhale, the intercostal muscles contract and pull the ribs up and outwards.
- The diaphragm contracts and flattens downwards (away from the lungs).
- This increases the space (volume) within the thoracic cavity.
- This lowers the air pressure inside the thoracic cavity compared to outside the body.
- Air from outside the body enters the lungs via the trachea and bronchi to equalise the pressure.

Exhaling – breathing out

- When we exhale, the intercostal muscles relax and pull the ribs down and inwards.
- The diaphragm relaxes and becomes domed (moves upwards towards the lungs).
- This decreases the space (volume) within the thoracic cavity.
- This reduced volume increases the air pressure inside the thoracic cavity compared to outside the body.
- Air from inside the lungs is forced out of the body through the bronchi and trachea to equalise the pressure

Breathing in and out



Exercise 42

Which of these are associated with inhaling?

1 The ribs move up and out.
2 The diaphragm becomes domed.
3 The pressure in the thorax decreases.
4 The volume inside the thorax decreases.

a) 1 and 2 only

b) 1 and 3 only

c) 1 and 4 only

d) 2 and 3 only

e) 2 and 4 only

f) 3 and 4 only

Exercise 43

Some of the events that occur during exhalation are shown.

1. The diaphragm becomes domed.
2. The pressure in the thorax increases.
3. Air passes through the trachea.
4. The ribs move down and inwards.
5. Air passes through the bronchi.
6. The volume inside the thorax decreases.

Which of the following is the correct order?

a) 1, 2, 3, 5

b) 2, 1, 4, 6

c) 4, 6, 5, 3

d) 3, 2, 1, 4

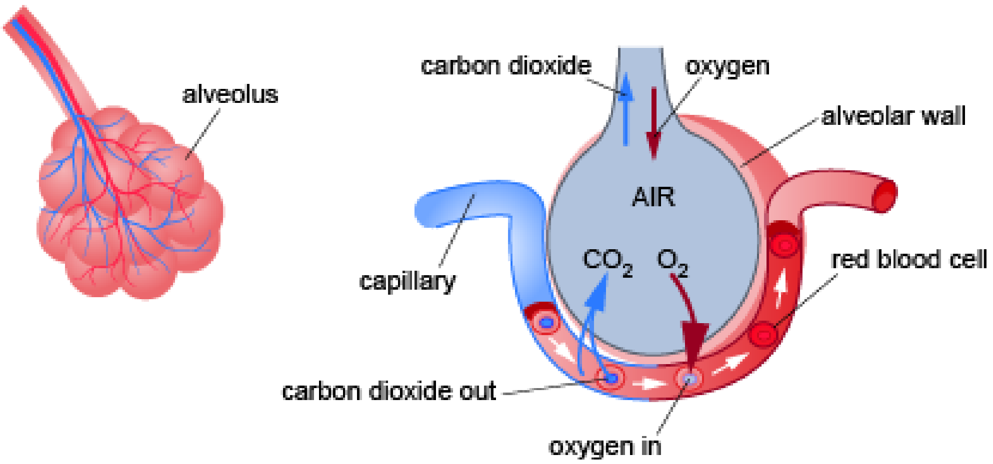
What happens in gas exchange?

Gas exchange occurs when gases diffuse across the capillary and alveolar walls.

Oxygen in inhaled air passes into the body via the mouth or nose. It then moves along the trachea, into a bronchus and then into a bronchiole. This brings it to an alveolus (air sac, plural = alveoli).

Oxygen will then diffuse from the alveolus into the blood capillary and carbon dioxide will diffuse in the opposite direction. Both gases will move from an area of high concentration to one of lower concentration.

Gas exchange in an alveolus



Once oxygen enters the blood, it will bind to a protein called haemoglobin which is found in red blood cells.

Haemoglobin will transport the oxygen around the body to the cells that need it for aerobic respiration.

Carbon dioxide is a waste product from aerobic respiration. It is transported in the blood plasma from the cells to the lungs where it is excreted. It is removed in the air which is exhaled from the lungs.

How is the body adapted to allow efficient gas exchange?

- There are many ways in which the body ensures that the diffusion of oxygen and carbon dioxide occurs rapidly and in the correct directions.
- The alveoli have a large surface area across which diffusion can occur.
- There are thousands of alveoli in each lung, increasing the surface for diffusion further.
- The alveoli and capillary walls are only one cell thick to ensure that the diffusion distance is short.
- The capillaries are wrapped around the alveoli, reducing the distance that the gases must diffuse.
- Blood constantly flows through the capillaries. This maintains the concentration gradients of each gas. This makes sure that both gases diffuse rapidly and in the correct direction.

Exercise 44

Which of the following would increase the rate of diffusion of oxygen and carbon dioxide?

a) Alveoli changing their shape from like a bunch of grapes to a single rounded surface (see diagram below).

b) Tar being deposited on the surface of the alveoli walls.

c) An increase in heart rate.

Exercise 45

Which of these shows the correct path taken by an oxygen molecule from the air as it enters the body?

a) trachea → bronchiole → bronchus → capillary

b) bronchus → trachea → bronchiole → alveolus

c) trachea → bronchiole → alveolus → capillary

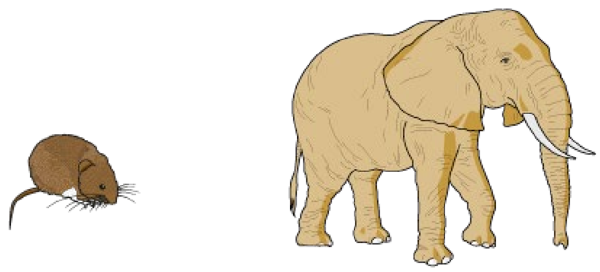
d) trachea → bronchus → bronchiole → alveolus

What does surface area to volume ratio mean?

The surface area to volume ratio tells us about the relative sizes of the surface area of an organism and its volume. A large surface area to volume ratio is one where the surface area is large compared to its volume. An example of this in an organism is a mouse.

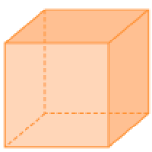
An elephant has a small ratio because it has both a large surface area and a large volume.

Surface area to volume ratio



How do you calculate surface area to volume ratio?

Sometimes a sphere is used as a model to calculate this ratio. However, more often we use a cube. If we use a cube with sides of 3 mm as a model, we can work through the calculation.



The cube has 6 identical sides. Each one is 3 mm by 3 mm.

The area of each face is calculated by multiplying the width by the height: in this case, it is $3 \times 3 = 9$ mm^2. As there are 6 faces, the total surface area is $6 \times 9 = 54$ cm^2.

The volume of the cube is calculated by multiplying the width × height × depth. For this cube this is $3 \times 3 \times 3 = 27$ cm^3.

The surface area to volume ratio is therefore 54 : 27 or 2 : 1.

How and why does surface area to volume ratio affect gas exchange?

Increasing the surface area to volume ratio will increase the rate at which gas exchange by diffusion occurs.

The reason for this is that a large surface area presents a large surface over which diffusion can occur, making it quicker. If you also have a small volume, then the distance that a gas like oxygen has to diffuse before it reaches the centre of an object is small, so it will be quicker. Overall, this will result in a shorter gas exchange time relative to an organism with a larger volume or smaller surface area.

Exercise 46

Which is the correct surface area to volume ratio for a cube with 2.5 cm sides?

a) 1 : 1.2

b) 1 : 2.5

c) 2.4 : 1

d) 5 : 1

B9.2 Organ systems:

c. Circulatory system:

i. Understand the structure and function of the circulatory system, including the heart, heart rate and ECGs, and the blood vessels (arteries, veins and capillaries).

ii. Understand the composition and function of the blood (red blood cells carry oxygen; white blood cells are involved in antibody production and phagocytosis; platelets are involved in blood clotting; and plasma is involved both in the transport of blood components and other dissolved substances including hormones, antibodies, urea and carbon dioxide, and in the distribution of heat).

iii. Understand the relationship with the gaseous exchange system.

iv. Understand the need for exchange surfaces and a transport system in multicellular organisms in terms of surface area: volume ratio.

What is the circulatory system?

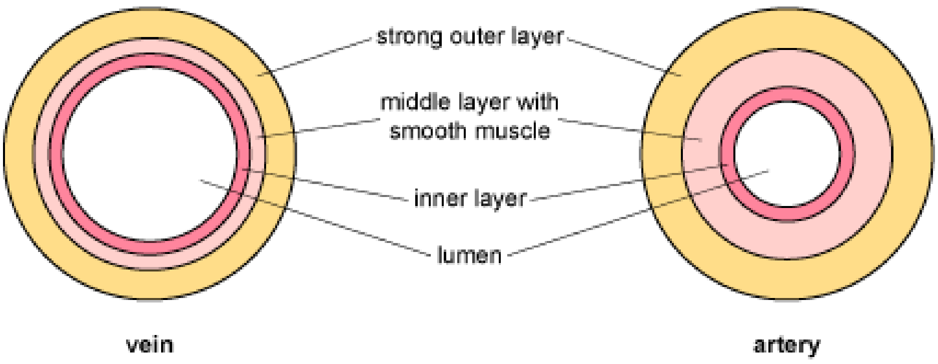
The circulatory system consists of the heart which pumps blood around the body and the blood vessels that are used to transport it. Each organ has a set of blood vessels bringing blood to and from the cells of that organ.

organ	blood vessel names
heart	coronary
lungs	pulmonary
liver	hepatic
kidneys	renal

What are the blood vessels in the system?

The vessels that take blood away from the heart and towards an organ are called arteries. The vessels that return blood from organs to the heart are called veins.

Vein and artery



Vein

- Contains valves along its length to prevent blood flowing backwards.
- Wide lumen (space inside vessel).
- Relatively thin vessel walls with less muscle and elastic tissue.
- Carries blood at lower pressure.
- Usually carries deoxygenated blood (except pulmonary vein).

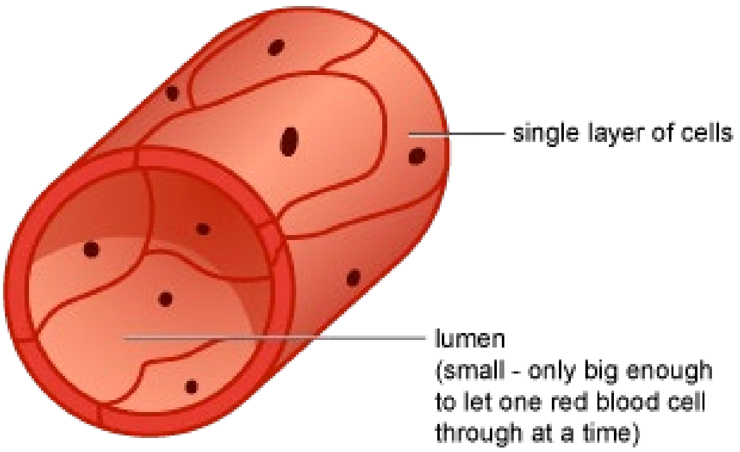
Artery

- No valves along the length of the vessel.
- Narrow lumen (space inside vessel).
- Thick walls made of muscle and elastic tissue to prevent bursting.
- Carries higher pressure blood.
- Usually carries oxygenated blood (except pulmonary artery).

Capillaries

Capillaries are very small vessels with walls made of a single layer of cells. These allow substances to pass easily from the blood into body cells.

Capillary



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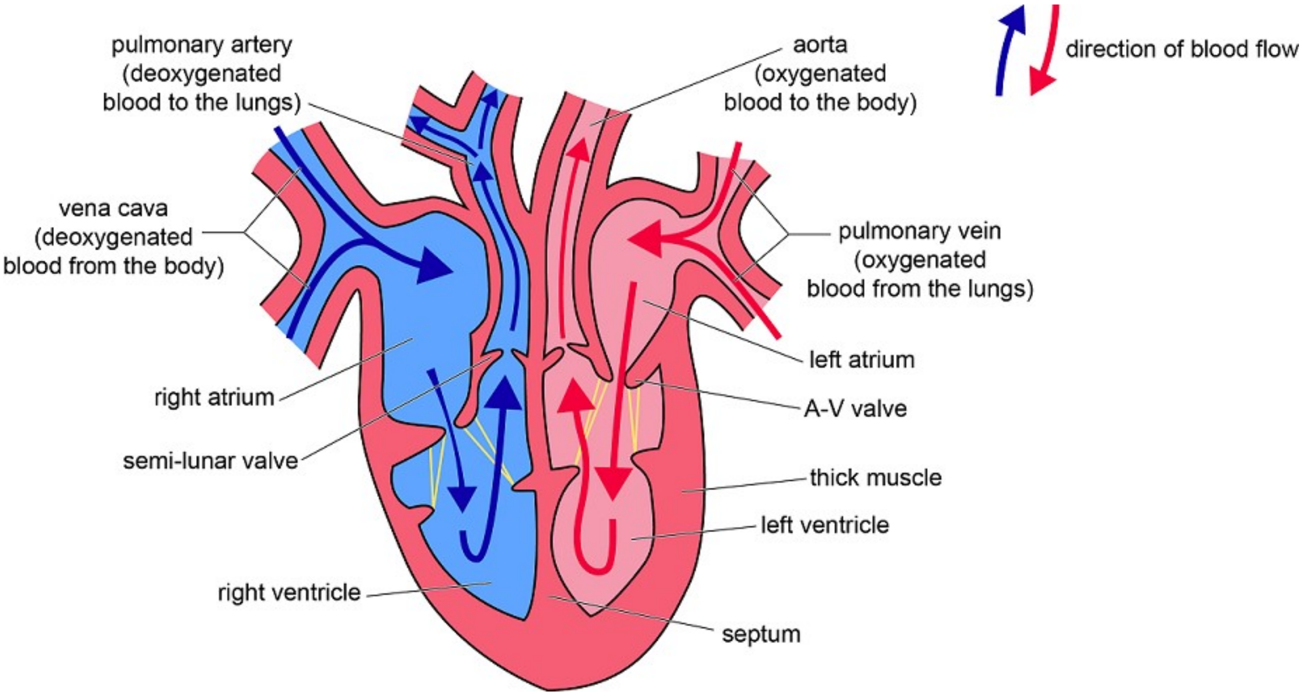
The heart

The heart is the pump that keeps blood flowing in the circulatory system. It consists of a series of chambers, with blood flow between them controlled by valves.

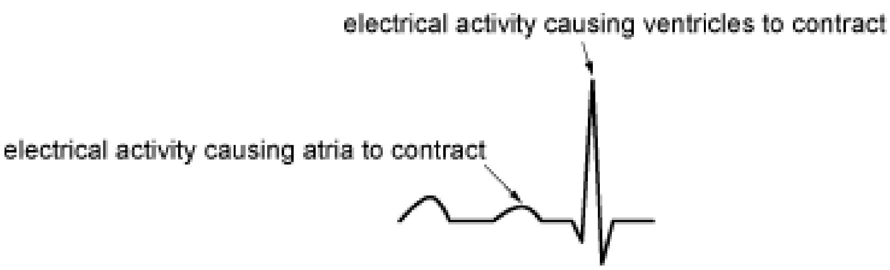
Heart



Deoxygenated blood is pumped from the right side of the heart to the lungs where it gains oxygen and loses carbon dioxide. The oxygenated blood then returns to the left side of the heart so it can be pumped around the body. The heart muscle cells are supplied with blood via the coronary artery.

The contraction of the heart muscle cells is coordinated using electrical impulses which pass between the different regions of the heart. These impulses can be recorded with an electrocardiogram (ECG) which detects the impulses using electrodes placed on the skin. A typical ECG profile showing one complete heart beat is shown below.

Electrocardiogram



The rate at which the electrical activity in the heart changes is related to how fast it beats. This can be monitored using an ECG. Heart rate is affected by lots of factors including exercise and hormones such as adrenaline. These both increase the rate at which the heart beats, allowing blood to circulate faster and delivering more oxygen to muscle cells for aerobic respiration.

Exercise 47

Blood returning to the heart from the body has a partial pressure of oxygen (pO_2) of 40 mm Hg. This is a measure of how much oxygen is found in the blood.

By the time this blood has circulated through the alveoli the pO_2 has risen to 104 mm Hg. When it leaves the heart to pass round the body this has fallen to 95 mm Hg and it remains at this level until it enters the organs of the body.

Which of the following statements are true?

a) The pO_2 in the vena cava is 40 mm Hg.

b) The pO_2 in the hepatic artery is 104 mm Hg.

c) The pO_2 in the pulmonary vein is 40 mm Hg.

d) The pO_2 in the aorta is 104 mm Hg.

e) The pO_2 in the pulmonary artery is 95 mm Hg.

f) The pO_2 in the renal artery is 95 mm Hg.

Exercise 48

The ratio of lumen diameter **:** total blood vessel diameter was calculated for two blood vessels, one artery and one vein. For vessel A, the ratio was 1 **:** 1. For vessel B, the ratio was 1 **:** 4. Both values were expressed to the nearest whole number.

Which vessel must be the artery and which is the vein?

Exercise 49

Look at the graphs below. The scale on the x and y axis is the same for all four graphs.

a) Graph A represents the ECG of a normal heart rate. At which letter on the graph, if any, does the electrical activity of the heart result in events that produce:

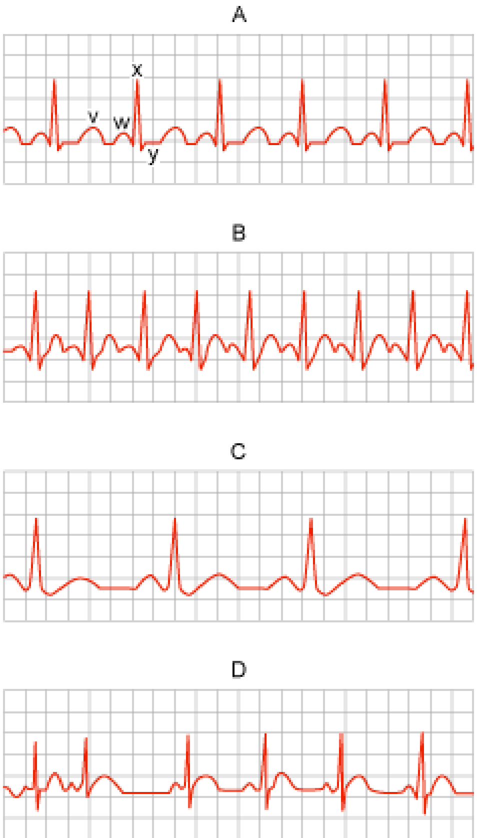
   i. Blood entering the aorta?

   ii. Blood leaving the vena cava?

   iii. Blood leaving the left atrium?

   iv. Blood entering the pulmonary vein?

b) Which graph could show the result of adrenaline release on the heart rate?



There are four major components of blood

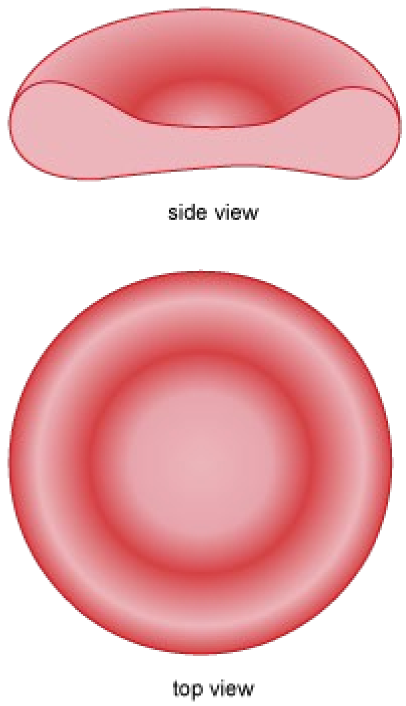
The blood is made of a series of components which are transported within a watery liquid called plasma. These components include red blood cells, white blood cells and platelets. In a healthy person, red blood cells are most numerous and the white blood cells are the least numerous.

Plasma is the liquid in blood

Plasma is the watery liquid that the cells are transported in. It contains dissolved glucose, urea and amino acids, as well as most of the carbon dioxide and some proteins like hormones and antibodies. Plasma makes up 55% of the volume of blood.

Red blood cells transport oxygen

Mature human red blood cells have a specially adapted shape called a biconcave disc. Their function is to transport oxygen around the body. To do this, oxygen binds to the protein haemoglobin in the cytoplasm of the red blood cells. Oxygen can be picked up by red blood cells in the lungs and released into respiring tissues. *Mature red blood cell*



The mature red blood cell:

- has a large surface area for diffusion of oxygen
- contains lots of haemoglobin protein in its cytoplasm
- has no nucleus or other structures to make more room for haemoglobin.

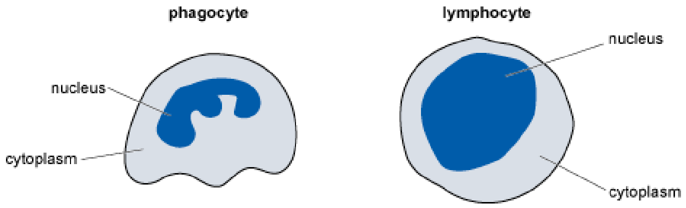
White blood cells help defend us from infections

White blood cells help defend the body from disease. Two types of white blood cell are the lymphocytes and the phagocytes.

Lymphocytes produce antibodies, proteins that target specific markers (antigens) on bacteria and viruses, destroying them. Some lymphocytes form memory cells (which are involved in a secondary immune response).

The phagocytes ingest or engulf (take in) pathogens and digest them using enzymes to prevent damage to body cells.

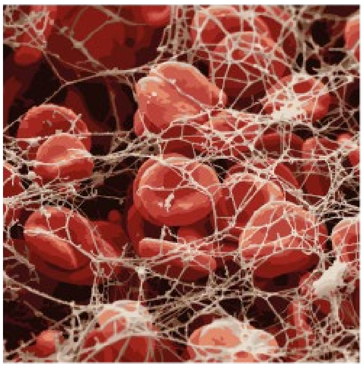
Phagocyte and lymphocyte



Platelets help blood to clot

Platelets are small fragments of cells. They contain no nucleus. Their role in the body is to help blood clot at a wound site. This stops blood loss and prevents microbes from entering the body. Clotting occurs when a series of enzymes convert a soluble protein called fibrinogen into the insoluble fibrin. This creates a mesh of fibres that traps platelets and red blood cells, forming the clot.

Fibrin mesh trapping red blood cells and platelets at a blood clot



Human blood groups

In humans one of the blood group systems is known as the ABO system. The gene for the ABO system codes for a protein found on the cell surface membrane of red blood cells. This protein is called an immunoglobulin (I).

The gene has three alleles but only two are present in any one person. The table below relates to these alleles:

Blood group phenotype	Genotype(s)	Comments
A	I^AI^A (homozygous) or I^AI^O (heterozygous)	The I^A allele is dominant to the I^O allele
B	I^BI^B (homozygous) or I^BI^O (heterozygous)	The I^B allele is dominant to the I^O allele
AB	I^AI^B	Neither the I^A allele nor the I^B allele is dominant to the other. They are co-dominant and so both are expressed.
O	I^OI^O (homozygous)	This combination is homozygous recessive.

Blood transfusions

It is important to know a person's blood group when considering a blood transfusion. This is because in the blood plasma, antibodies may be found as described in the table below:

Blood group phenotype	Antibodies present in blood plasma
A	b
B	a
AB	-
O	a and b

This means that the safe transfusions are:

Blood group phenotype	Can donate blood to people with blood group	Can receive blood from people with blood group
A	A and AB	A and O
B	B and AB	B and O
AB	AB	From any blood group (universal recipient)
O	Donates blood to any blood group (universal donor)	O

Exercise 50

Red blood cells, white blood cells and platelets have different properties. Which of the following statements apply to each cell and which apply to none at all?

a) Contains DNA.

b) Is important during strenuous exercise.

c) Requires proteins in order to perform its function.

d) Possesses a cell wall.

e) Could help protect the body from a bacterial infection.

What is the relationship between the gas exchange and circulatory systems?

The role of the gas exchange system (lungs) is to exchange inhaled oxygen with carbon dioxide in the alveoli.

The role of the circulatory system (heart and blood vessels) is to transport blood all around the body. The heart pumps the blood to all parts of the body including the lungs.

Oxygen is loaded onto the haemoglobin in red blood cells when blood flows through the lungs. This is then pumped around the body so that cells can obtain oxygen for aerobic respiration.

The aerobically respiring cells will also deposit waste carbon dioxide from aerobic respiration into the blood plasma.

This is then transported to the lungs for excretion.

Without the constant movement of the blood through the circulatory system, the cells of the body would not obtain oxygen. The exchange of gases in the alveoli would also stop as the concentration gradients for diffusion were not being maintained.

Why do we need gas exchange and transport systems?

An organism like a bacterium has a large surface area to volume ratio because it consists of a single cell, so it can rely on diffusion for its gas exchange.

Large multicellular organisms, like animals, need to get oxygen (and other substances) to all of their cells. They have a small surface area to volume ratio. If they were to rely on diffusion alone, then oxygen would take a very long time to reach the cells in the centre of the organism.

In order to make the process faster, animals have a transport system which takes the oxygen close to a large number of cells throughout the body. This ensures that their cells are supplied with oxygen more rapidly. They also have specially adapted gas exchange surfaces to ensure that a large volume of oxygen enters the body with each breath.

Exercise 51

Which of the following statements are true?

a) An organism with a small surface area to volume ratio will have rapid diffusion of oxygen from its surface to the cells in its centre.

b) An organism with a large surface area to volume ratio will always need to have blood vessels and a heart to pump blood.

c) A liver cell would have a smaller surface area to volume ratio than a horse.

d) A single-celled fungus will not need a transport system but a multicellular plant will need to have one.

B9.2 Organ systems:

d. Digestive system:

i. Understand the structure and function of the digestive system.

ii. Understand the processes of peristalsis, digestion, absorption and egestion.

The digestive system is the organ system that is involved in:

- the breakdown of large insoluble molecules found in food into their soluble products and
- the absorption of these products of digestion.

Food passes through the digestive system in the following order:

1) mouth

2) oesophagus

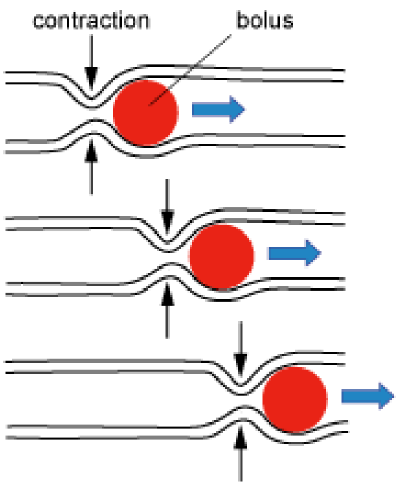
3) stomach

4) small intestine

5) large intestine.

Food is moved through the digestive system (oesophagus and small and large intestines) by peristalsis. Peristalsis is waves of muscular contraction that move the bolus (ball of food) along.

Peristalsis



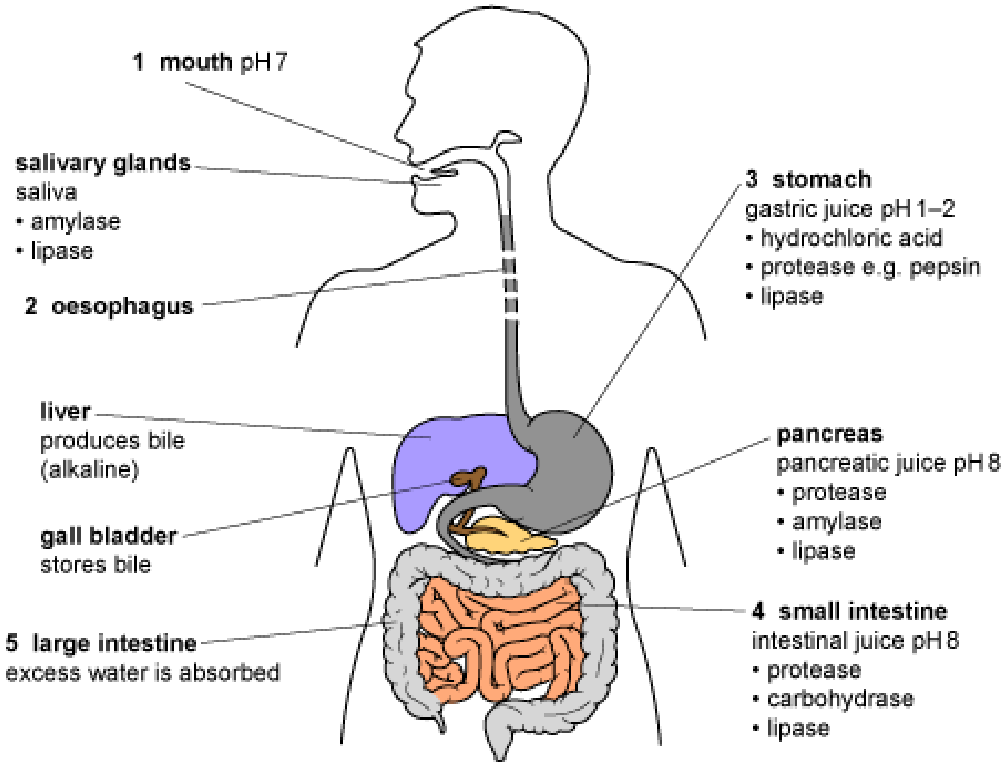
There are two types of digestion:

- mechanical – teeth grinding, stomach churning
- chemical – using bile and enzymes which are produced by specialised cells in glands and tissues in the gut lining.

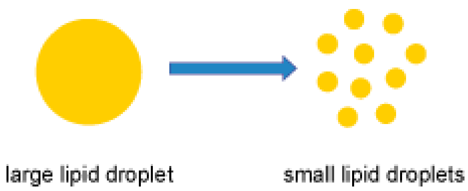
Different enzymes catalyse the breakdown of different food molecules and have their own optimum conditions – so they only work in certain places. For example, pH:

- Hydrochloric acid in the stomach kills bacteria and provides the correct pH for the protease enzyme to digest protein.
- Bile and pancreatic juice contain hydrogen carbonate (bicarbonate) ions to neutralise the stomach acid when it enters the small intestine and provide the alkaline conditions needed by the enzymes present in the small intestine.

The diagram shows the path of nutrients through the different parts of the digestive system, 1–5, and the glands associated with the digestive system.



Bile is made in the liver and stored in the gall bladder. It is released into the small intestine when stomach contents arrive in the small intestine. It emulsifies lipids to increase the surface area for lipases to work on and therefore the rate of digestion is increased.



Food contains many large molecules that need to be digested

Starch, protein, lipids:

- large insoluble molecules – cannot pass through the gut wall.

Extracellular enzymes are secreted into the gut lumen to break down the large insoluble molecules in food by hydrolysis.

Fibre cannot be digested and absorbed in humans as the enzymes required are not present.

Products of digestion

Glucose, amino acids:

- small soluble molecules – pass through the gut wall and are absorbed into the blood.

Glycerol, fatty acids:

- small soluble molecules – pass through the gut wall and into the lymph system before entering the blood.

Food molecules are digested

Digestion can take 12 – 24 hours.

molecules	mouth seconds	stomach 2-4 hours	small intestine 1-5 hours	large intestine
proteins		HCl and protease (pepsin) protein → peptide chains	proteases peptide chains → amino acids	
carbohydrates	salivary amylase starch → shorter carbohydrate chains	HCl inactivates salivary amylase	pancreatic amylase + carbohydrases short chain carbohydrates → monosaccharides	
fats (lipids)	salivary lipase some lipids → fatty acid + monoglycerides	gastric lipase lipids → fatty acids + monoglycerides	bile, pancreatic + intestinal lipase lipids → fatty acids and glycerol	
water		small amounts absorbed by stomach lining	absorbed by small intestine lining	most water absorbed by large intestine
fibre				not absorbed
insoluble				
soluble				

Key

path of molecules through the digestive system

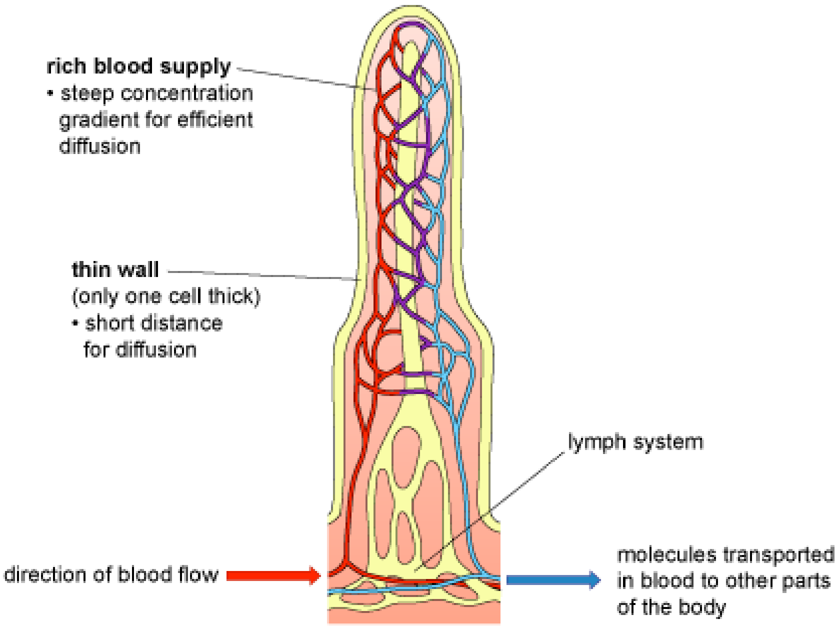
broken arrow indicating digestion

arrow indicating absorption of products of digestion

Small intestine – the main site of absorption

The wall of the small intestine contains millions of finger-like projections called villi that increase the surface area.

Villi contain many blood capillaries so that there is an excellent blood supply to carry away the products of digestion as soon as they have been absorbed. The flow of blood maintains a steep concentration gradient so that diffusion is as rapid and efficient as possible.



Villi lining the wall of the small intestine

How are nutrients absorbed?

- Diffusion – a higher concentration of glucose and amino acids in the gut will diffuse into the blood.
- Active transport – when a lower concentration of nutrients is present in the small intestine than in the blood.

After a meal the concentration of digested products falls over time. Active transport makes sure that none of the digested food is wasted and lost in the faeces.

- Osmosis – water

How the body uses the digested food

Absorbed nutrients are used by body cells:

- to make new macromolecules – carbohydrates, proteins, lipids
- in aerobic respiration.

Enzymes are used to make macromolecules using condensation reactions. Glucose is metabolised by enzymes in aerobic respiration to produce ATP for energy.

Growth, renewal and repair:

- Cells are maintained using amino acids that combine to build different protein structures.
- Cell membranes are produced using lipids.
- Energy is provided by glucose.

Energy storage:

- Excess glucose is converted to glycogen and stored in liver and muscle cells.
- Fatty acids are a concentrated energy store (from dietary fats, conversion of excess amino acids or conversion of glucose).

Not all of the food is digested

All of the digested food products should have been absorbed by the end of the small intestine.

What remains consists of the indigestible components of food, such as cellulose (fibre), from plant-based foods. These materials are then passed on to the large intestine.

The undigested waste matter is called faeces. The brown colour of the faeces is due to bile pigments.

The faeces pass through the large intestine and into the rectum.

They are then expelled through the anus in a process known as egestion.

Exercise 52

Why is it necessary to have an amylase in the mouth and another one secreted by the pancreas?

B9.2 Organ systems:

e. Excretory system:

i. Know and understand the structure and function of the excretory system, including the kidney and the main components of the nephron.

ii. Understand the role of the kidneys in homeostasis.

The structure and function of the excretory system

Excretion is the removal from organisms of toxic materials and substances in excess of requirements. A number of organs in the body are involved in this process, including the liver, lungs, skin and kidneys.

The liver

The body is not able to store proteins or amino acids (the products of protein digestion).

So, any excess amino acids are broken down by the liver in a process called deamination. The nitrogen component is converted to urea. This can be toxic if its level in the blood gets too high, so urea is excreted by the kidneys.

The liver also breaks down haemoglobin from red blood cells. The product is a yellow/green bile pigment called bilirubin. This is excreted with bile into the small intestine. Bilirubin is expelled with faeces.

The lungs

The lungs are excretory organs because they remove carbon dioxide from the body, which is a waste product of aerobic respiration.

The skin

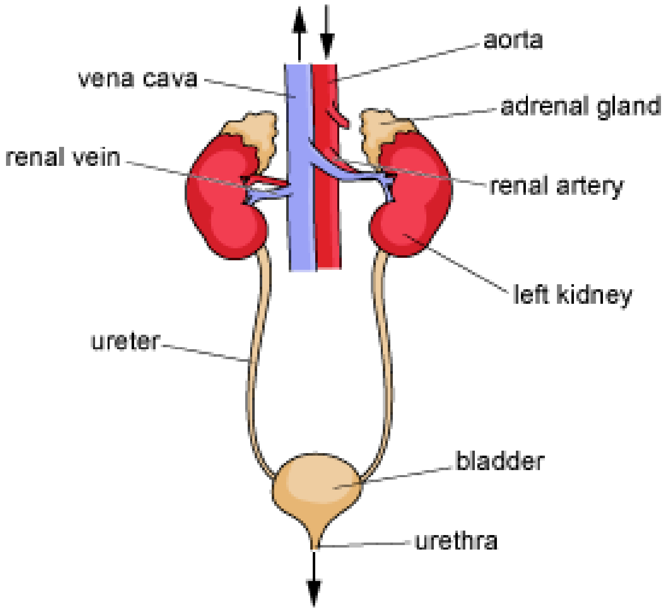
The skin produces sweat, which consists of sodium chloride and traces of urea dissolved in water. Sweating could be considered to be an excretory process, but it is not a response to changes in blood composition so skin is not an excretory organ in the same sense as the lungs or kidneys.

The kidneys

The kidneys have three main roles, which all involve filtration of the blood:

- the removal of urea
- adjustment of the ion content
- adjustment of the water content.

Relationship between the kidneys and associated structures in the body

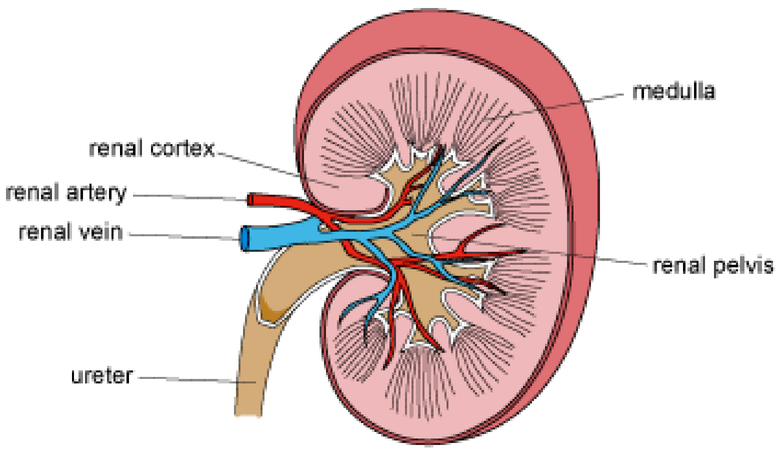


Each kidney receives blood from the aorta via a renal artery. The blood is filtered to remove urea, excess water and salts. The filtered blood is returned to the vena cava via a renal vein.

The mixture of substances removed from the blood plasma (the filtrate) is called urine. It passes down a ureter to the bladder, where it is stored.

A sphincter muscle at the base of the bladder controls the release of urine through the urethra.

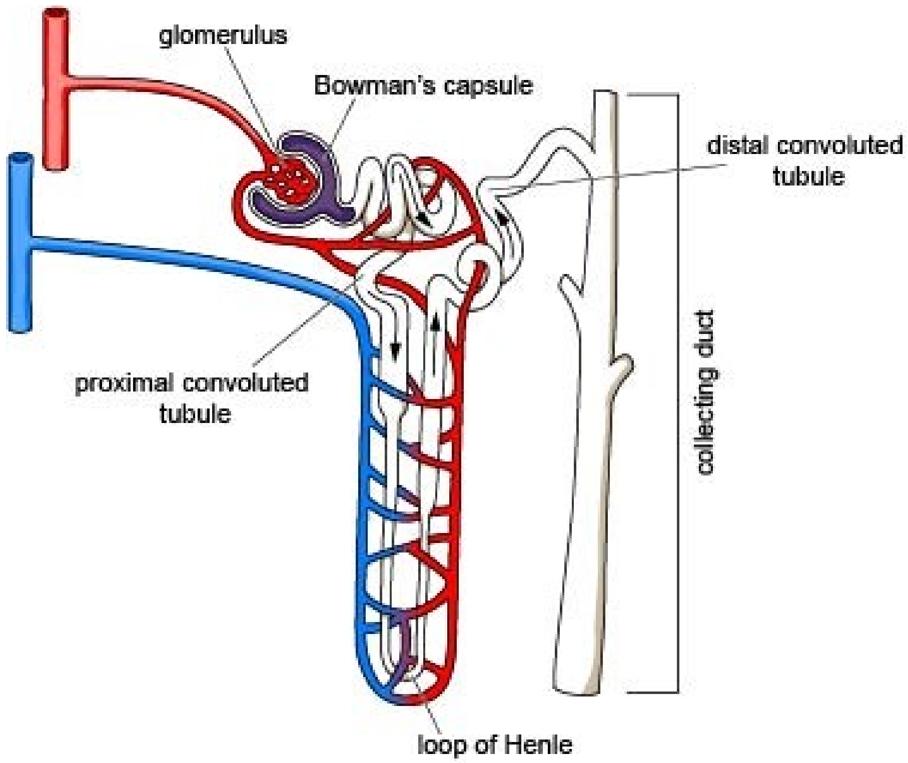
Structure of a kidney, with its associated vessels



The process of ultrafiltration is achieved by microscopic structures called nephrons. There are up to 4 million of these in a kidney.

The diagram below shows part of a nephron, which is the structural and functional unit of a kidney. Each nephron consists of a glomerulus, renal capsule and renal tubule. Capillaries leaving the glomerulus are closely associated with the tubule.

Part of a nephron



A kidney is composed of three main regions: the cortex, medulla and pelvis.

Blood enters a kidney through a renal artery.

This divides into arterioles and capillaries in the cortex.

Each capillary becomes knotted to form a glomerulus, which is surrounded by a Bowman's capsule.

This leads to a convoluted tubule. The proximal convoluted tubule passes down into the medulla, where it forms the loop of Henle, returning to a distal convoluted tubule in the cortex again.

The tubule joins a collecting duct, which passes down through the medulla into the pelvis of the kidney.

How the nephron functions

The wall of the capillary of the glomerulus acts as a filter. As the blood enters the glomerulus, its pressure increases.

Large structures (blood cells) and large molecules, e.g. plasma proteins, are retained within the capillary, but smaller molecules (water, dissolved salts (ions), glucose and urea) are forced out by ultrafiltration. This is filtration under pressure.

The filtrate is collected by the renal capsule and passes into the renal tubule.

As the filtrate passes along the tubule, selective reabsorption takes place into the capillaries surrounding the tubule.

Glucose is reabsorbed by diffusion and active transport.

Water is reabsorbed by osmosis, along with some salts by diffusion and active transport to maintain the correct concentration in the blood.

Salts not needed by the body, along with urea and uric acid, continue along the tubule into a collecting duct in the medulla.

The collecting duct delivers the filtrate to the pelvis of the kidney, where the fluid (urine) passes into a ureter to transfer it to the bladder for storage.

Urine is retained in the bladder by a sphincter muscle at its base.

When the sphincter muscle relaxes, the muscle wall of the bladder contracts to expel the urine (a process called urination) through the urethra.

The role of the kidneys in homeostasis

Homeostasis is the maintenance of a constant internal environment.

The kidneys remove chemicals which might poison enzymes in cells.

All chemical reactions in cells are controlled by enzymes and they are very sensitive to the conditions within the cell. For example, a change in acidity may slow down or stop an enzyme from working. This could prevent an important reaction from taking place in the cell.

The kidneys also control the levels of salts (ions), acids and water in the blood.

Controlling water levels

On a hot day, more sweating occurs to try to maintain a constant body temperature. This means that more water is lost in sweat.

The kidneys respond by producing a smaller volume of more concentrated urine to conserve water in the body.

Without this mechanism, the body could become dehydrated.

On a cold day, less sweating occurs. This means that less water is lost in sweat. The kidneys respond by producing a larger volume of less concentrated urine. Without this mechanism, the body could become over-hydrated.

This could have implications for cells as they would take in the surplus water by osmosis, become swollen and burst.

The regulation of how much water is excreted by the kidneys is under the control of the hormone ADH.

Exercise 53

a) How will the composition of blood leaving a kidney be different from the composition of blood entering it?

b) Distinguish between ureter and urethra.

B9.3 Homeostasis:

a. Know that homeostasis is the maintenance of a constant internal environment, and appreciate its importance in multicellular animals.
b. Understand the concept of negative feedback in the context of homeostasis.
c. Know and understand the regulation of blood glucose levels, including the role of insulin and glucagon.
d. Understand the main features of type 1 and type 2 diabetes, and how type 1 diabetes can be treated.
e. Know and understand the regulation of water content (including the role of ADH) and the regulation of body temperature.

Homeostasis

Homeostasis is the maintenance of a constant internal environment. This involves maintaining internal conditions within set limits. Homeostasis is vital if an organism is going to remain in a good state of health.

Internal conditions that need to be kept steady relate to the composition of tissue fluid and include water content and nutrient concentrations, as well as temperature.

Major fluctuations that are not promptly rectified could result in the death of the organism.

Negative feedback

Homeostasis is maintained by a large number of detectors and effectors. If a specific internal condition changes significantly from its normal level, this change triggers a detector (sensor), which sends information to an effector, which is stimulated to respond (reverse the change).

The response continues until the sensor detects that the level returns to normal. The sensor then sends information to the effector to switch it off and perhaps act in the opposite way (negative feedback).

For example, an increase in core body temperature is detected by the thermoregulatory centre in the brain. Its role is to monitor blood temperature and it also receives information from temperature receptors in the skin.

The rise in body temperature detected by the thermoregulatory centre causes it to send nerve impulses to the skin, which result in effectors (arterioles and sweat glands) responding. The arterioles dilate (a process called vasodilation), and the sweat glands secrete more sweat.

Both of these processes result in the cooling of the skin, which brings down the elevated body core temperature.

As the temperature drops below normal, the thermoregulatory centre detects this and sends nervous impulses to switch off the processes of vasodilation and sweating, as well as triggering other responses, e.g. vasoconstriction and shivering. This is negative feedback.

The regulation of blood glucose levels

The liver is one example of a homeostatic organ as it controls the levels of a number of components of the blood, including glucose.

Responding to an increase in blood glucose levels

After a meal, blood glucose concentrations rise as a result of the digestion of carbohydrates. The glucose is absorbed into the blood stream, causing glucose levels in the blood to rise. If this is not controlled and brought back to normal levels, the individual could lose consciousness and die.

In a healthy adult, excess blood glucose is removed by the liver and converted into the storage carbohydrate glycogen. The mechanism is controlled by the hormone insulin.

When blood glucose levels rise, the islet cells of the pancreas detect the change and secrete insulin in response.

The insulin is transported to the liver in the blood plasma. Once at the liver, insulin stimulates liver cells to take up the glucose from the blood and convert it to glycogen.

Insulin also stimulates other body cells to take up more glucose for use in respiration.

Responding to a decrease in blood glucose levels

If the levels of glucose in the blood fall below normal, e.g. during vigorous exercise or a lengthy period without food, the islet cells in the pancreas are stimulated to release a different hormone – glucagon.

The role of glucagon is the opposite of insulin.

Glucagon is transported by the blood plasma to the liver where it acts on the cells there, causing them to convert stored glycogen back to glucose to raise blood glucose levels.

Summary of the roles of insulin and glucagon

blood glucose levels too high

$$\text{glucose} \underset{\text{glucagon}}{\overset{\text{insulin}}{\rightleftharpoons}} \text{glycogen}$$

blood glucose levels too low

Type 1 and type 2 diabetes

Type 1 diabetes

Type 1 diabetes is a disease that first appears in young people and is caused by an inability of the pancreatic islet cells to secrete enough insulin to control blood glucose correctly. Type 1 diabetes is also known as 'insulin-dependent' diabetes.

The disease can be inherited. It can also be triggered by an event such as a viral infection. The infection causes the body's immune system to attack the islet cells of the pancreas, so they stop producing sufficient insulin.

Type 1 diabetes is an example of an autoimmune disease, when caused by a viral infection.

Symptoms of type 1 diabetes

These include feeling tired, feeling very thirsty, frequent urination and weight loss. There may be glucose present in the urine. Eating a meal high in carbohydrates can result in the diabetic falling into a coma. Similarly, a shortage of food can result in the diabetic falling into a coma.

Control of type 1 diabetes

This can be achieved by the application of a carefully regulated diet to stop blood glucose levels from fluctuating too much. Regular blood tests are needed to monitor blood glucose levels. Regular injections of insulin are also required to control blood glucose levels.

Type 2 diabetes

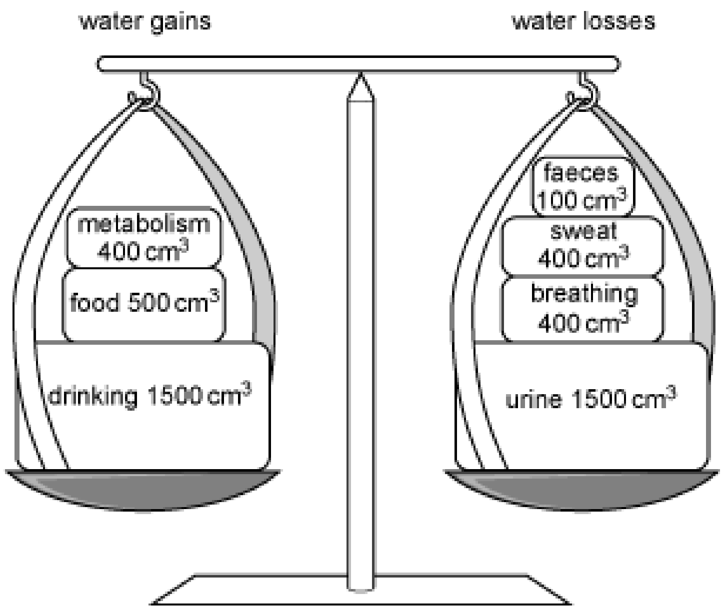
This is the more common form of diabetes (90% of diabetics suffer from type 2 diabetes). It is most common in older people and certain ethnic groups.

Type 2 diabetes can be inherited or a result of obesity, lack of exercise and an unhealthy diet (too much fat and a lack of fibre). These factors can lead to insulin resistance, where the body doesn't use insulin properly.

Regulation of water content

The amount of water in the body has to be carefully controlled. This is called osmoregulation. There are a number of ways by which water enters and leaves the body.

How the water content of the body is balanced



Although the gains and losses of water vary from day to day, a balance needs to be maintained.

For example, on a hot day, sweat production will increase, causing a lower volume of urine to be excreted. The amount of water lost by sweating can also be balanced by drinking more liquids.

Water supplied by metabolism refers to chemical processes that occur in cells. For example, one of the products of aerobic respiration is water.

The amount of water in the blood is monitored by the brain.

The brain signals to the pituitary gland to increase or decrease the amount of ADH (antidiuretic hormone) it secretes.

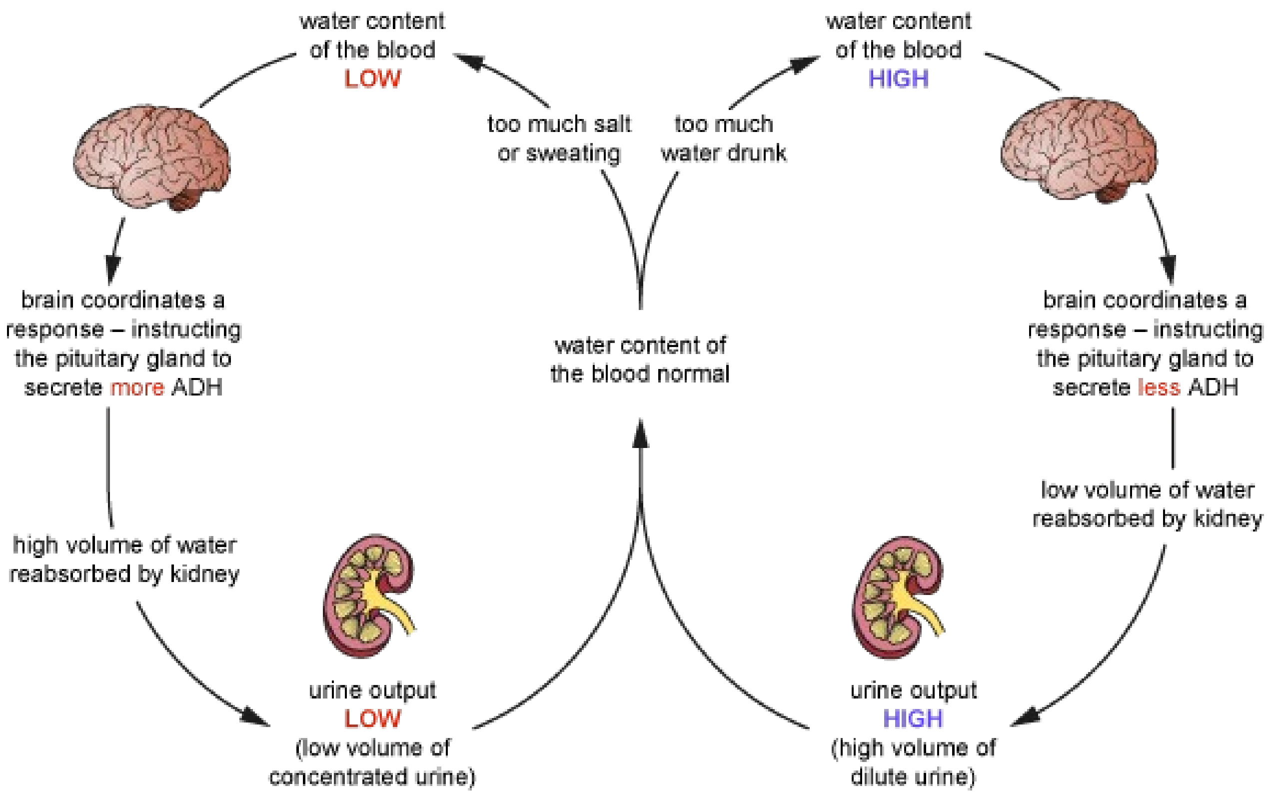
ADH is a hormone, carried in the blood, which signals to the kidneys how much water they should excrete or reabsorb.

High levels of ADH cause the kidneys to reabsorb more water, so less urine is excreted, e.g. on a hot day or during exercise.

The ADH binds to the collecting ducts of the nephrons making them more permeable to water. The water leaves the ducts and re-enters the blood.

Low levels of ADH cause the kidneys to reabsorb less water, so more urine is excreted, e.g. on a cold day or after drinking a lot of liquids.

The water is reabsorbed from the filtrate in the renal tubules of the nephrons of the kidneys, back into the blood plasma of the capillaries, by osmosis.



Regulation of temperature

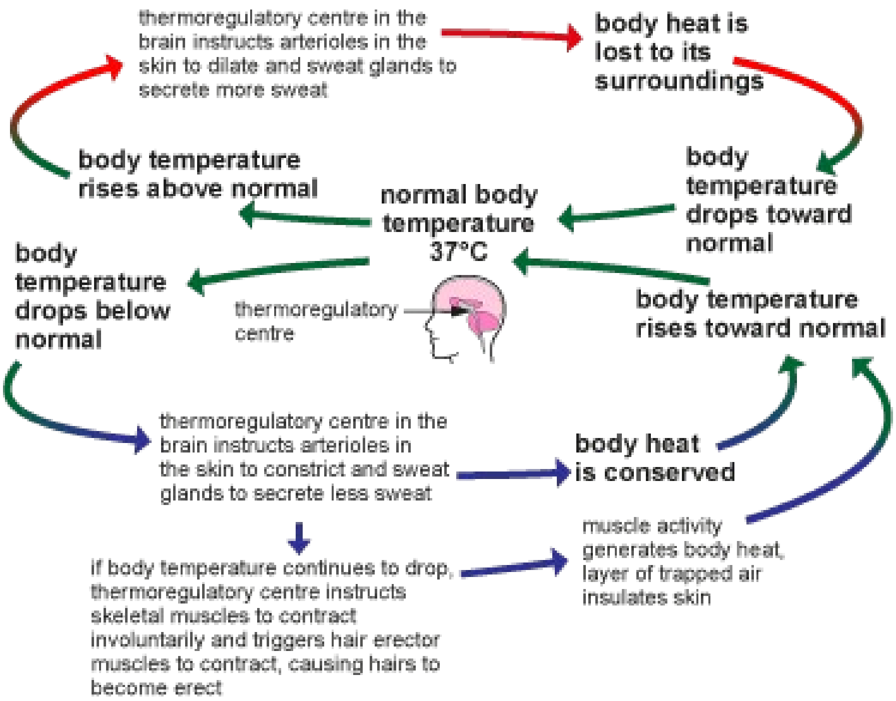
The regulation of body temperature is known as thermoregulation and is a homeostatic mechanism.

An increase in core body temperature is detected by the thermoregulatory centre in the brain. Its role is to monitor core blood temperature and it also receives information from temperature receptors in the skin. The rise in core body temperature is detected by the thermoregulatory centre. It responds by sending nerve impulses to the skin, which result in effectors (arterioles and sweat glands) responding.

The arterioles dilate (a process called vasodilation), and the sweat glands secrete more sweat. Both of these processes result in the cooling of the skin, which brings down the elevated body core temperature.

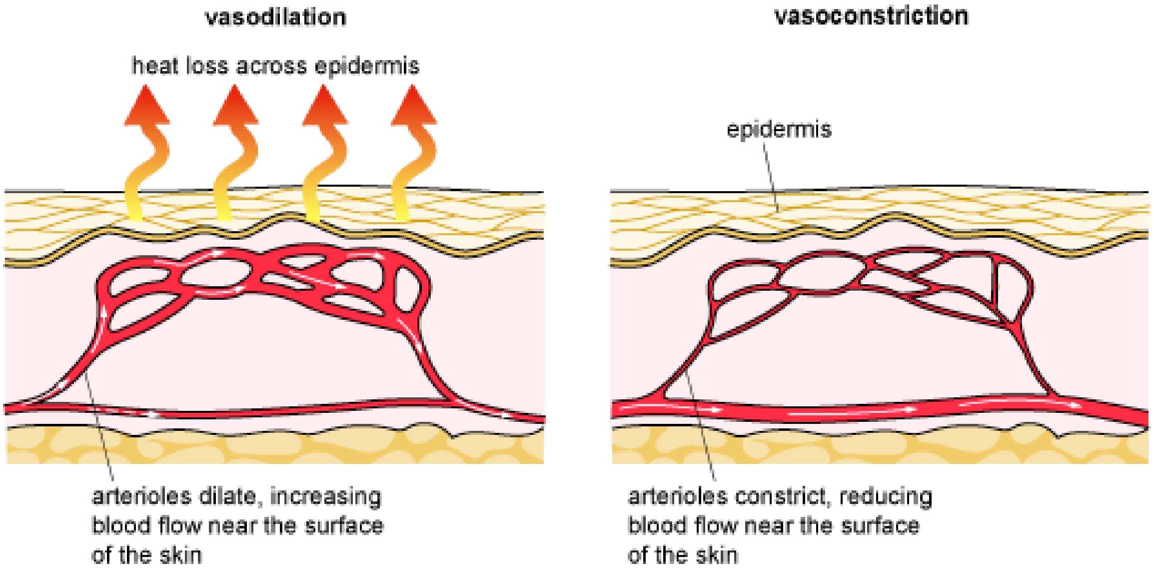
As the core body temperature drops below normal, the thermoregulatory centre detects this and sends nervous impulses to switch off the processes of vasodilation and sweating, as well as triggering other responses, e.g. vasoconstriction, shivering and the erection of hairs on the surface of the skin to trap an insulating layer of air.

Thermoregulation



The diagram below shows how blood vessels in the skin act as effectors in the process of maintaining body temperature.

Note that the blood vessels are arterioles, not capillaries. Capillaries do not have muscles in their walls, so they cannot vasodilate or vasoconstrict.



Exercise 54

a) Measurements were taken of the plasma insulin concentration in a healthy person before, during and after a meal.

Explain why before and after a meal the plasma insulin concentration is 10 units per cm^3, but during a meal it rises to 70 units per cm^3.Distinguish between ureter and urethra.

b) Insulin is a protein. Suggest why insulin is injected by diabetics rather than taken orally in tablet form.

B9.4 Hormones:

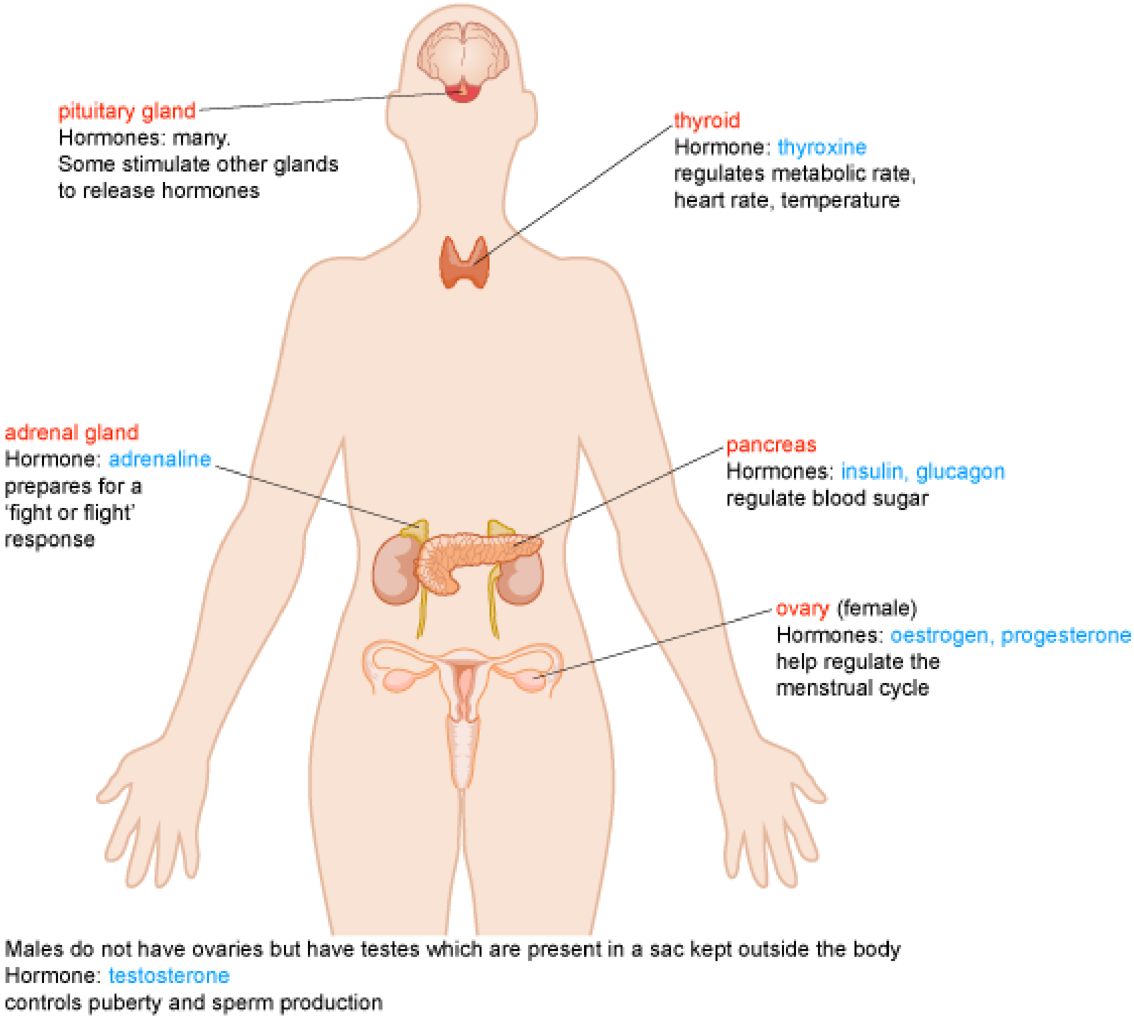
a. Know and understand that hormones are released from specific endocrine glands and travel via the blood to their target structures.

b. Know and understand the main role of adrenaline in the body.

The endocrine system

The endocrine system uses hormones to respond to changes in the environment or changes inside the body. It is made up of endocrine glands.

Endocrine glands produce and secrete specific hormones directly into the blood.



Hormones are chemicals that are carried in the blood plasma to other parts of the body so are relatively slow to act.

Each hormone only affects particular cells in particular organs. These are called target structures.

Hormones tend to have a long-lasting effect.

The endocrine system and the nervous system both respond to change, but there are some important differences:

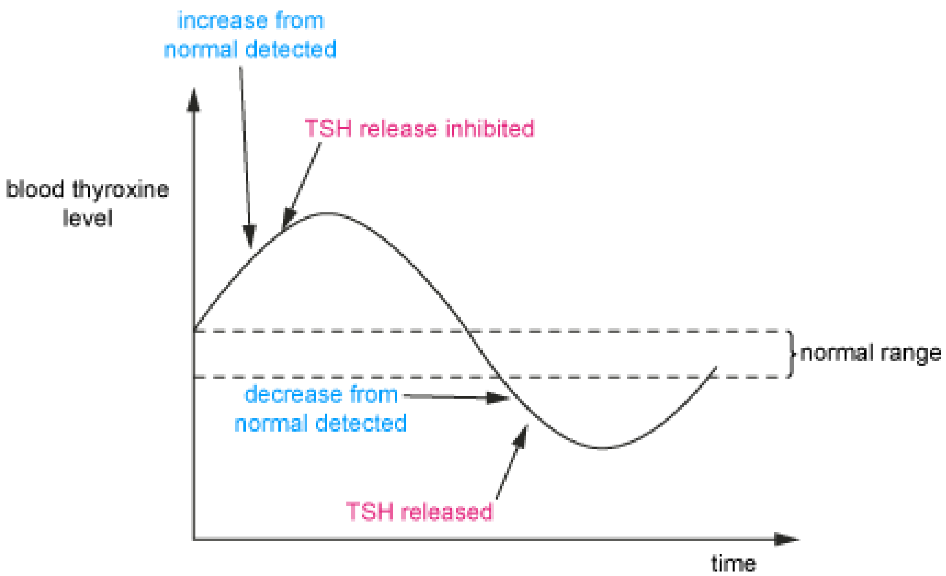
	Nervous system	Endocrine system
Speed of action	very fast	slow
Length of action	short	long
Area of action	very precise	more general

Thyroxine and negative feedback

Thyroxine is released from the thyroid gland. It has an important role in regulating the basal metabolic rate – the speed that chemical reactions take place in the body while it is at rest.

The release of thyroxine is controlled by another hormone which is released from the pituitary gland, thyroid stimulating hormone (TSH).

This keeps the level of thyroxine in the blood within a normal range and is an example of a negative feedback system:



The level of thyroxine in the blood is monitored by the hypothalamus, a gland close to the pituitary gland. When thyroxine in the blood is higher than the normal range, the release of TSH by the pituitary gland is inhibited.

Less thyroxine is released from the thyroid gland.

The level of thyroxine in the blood falls to within the normal range.

When thyroxine in the blood is lower than the normal range, TSH is released by the pituitary gland.

The thyroid gland is stimulated to release more thyroxine.

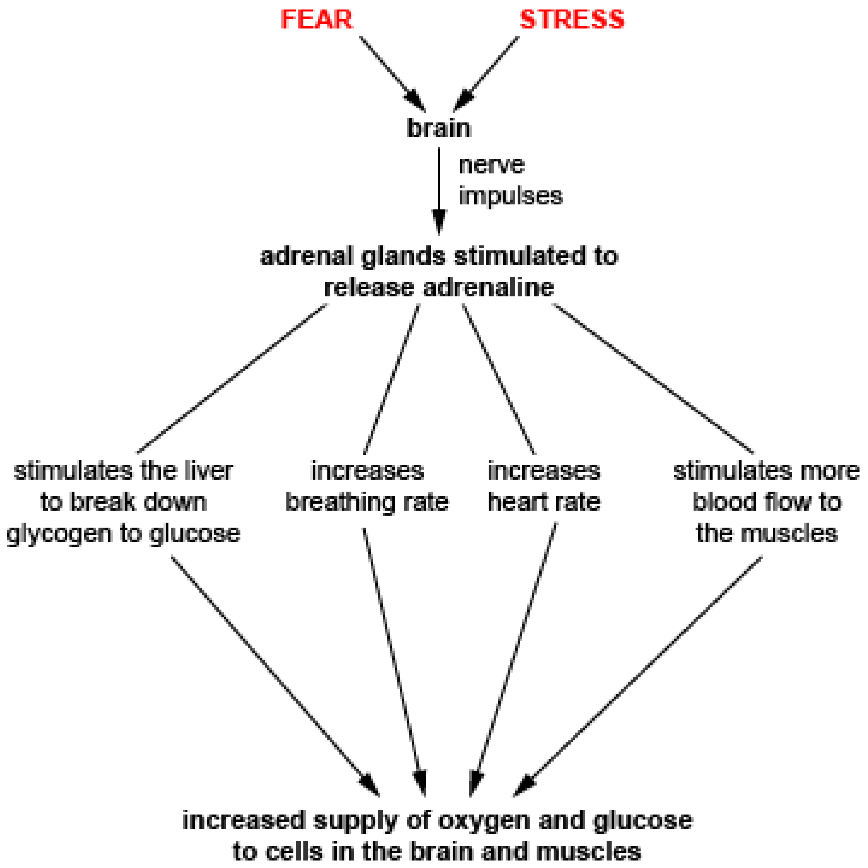
The level of thyroxine in the blood rises to within the normal range.

Exercise 55

Explain why blood thyroxine levels continue to rise after TSH is inhibited.

The role of adrenaline

Adrenaline is released by the adrenal glands in response to stressful or scary situations. It prepares the body for the 'fight or flight' response and has many target structures.



Exercise 56

Why are nervous impulses used to stimulate the adrenal glands to release adrenaline in this case, instead of hormones?

Exercise 57

What is the purpose of increasing the supply of oxygen and glucose to cells in the brain and muscles?

B9.4 Hormones: c. Know and understand the roles of hormones in human reproduction including: i. those involved in the menstrual cycle (FSH, LH, oestrogen and progesterone). ii. those used for contraception, and the differences between hormonal and non-hormonal forms of contraception.

Human reproduction

During puberty reproductive hormones start to be produced and are responsible for the development of secondary sexual characteristics.

Oestrogen is the main female reproductive hormone produced in the ovary.

At puberty, eggs (ova) begin to mature and one is released approximately every 28 days, around day 14, of the menstrual cycle. This is called ovulation.

Testosterone is the main male reproductive hormone produced by the testes and it stimulates sperm production.

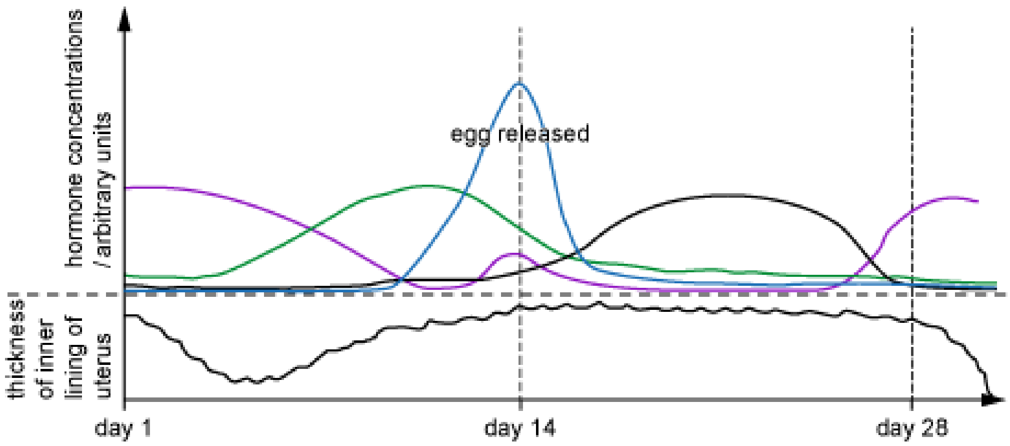
Regulation of the menstrual cycle

Hormones regulate the menstrual cycle in adult females. The menstrual cycle is essential in order for sexual reproduction to occur.

Several hormones are involved in regulating the menstrual cycle:

- FSH – follicle stimulating hormone
- oestrogen
- LH – luteinising hormone
- progesterone.

The graph shows how the hormones interact with each other to regulate the menstrual cycle:



- FSH is produced by the pituitary gland and acts on target structures in the ovaries.
- FSH stimulates an ovary:
  - to develop a follicle containing an egg (ovum maturation)
  - to produce oestrogen.
- Oestrogen is produced by the ovaries
  - stimulates the uterus lining to thicken.
- LH is produced by the pituitary gland and acts on target structures in the ovary
  - stimulates the mature follicle to release the egg/ovum (ovulation) in the middle of the cycle (around day14).
- Progesterone is secreted by the empty follicle in the ovary (the yellow body or corpus luteum)
  - maintains the lining of the uterus during the second half of the cycle so that a fertilised egg may implant.
- Oestrogen and progesterone inhibit the production of LH and FSH.
- Decreasing progesterone levels cause the thickened uterus lining to break down and be discharged(menstruation).

Exercise 58

What would happen if oestrogen did not inhibit the production of FSH?

Contraception

Use of hormones in contraception

The menstrual cycle can be controlled artificially by the administration of the hormones oestrogen and progesterone.

Oestrogen and progesterone prevent ovulation.

- These hormones, taken every day, keeps their blood levels high.
- High levels of oestrogen and progesterone inhibit FSH production and egg/ovum maturation.
- Ovulation cannot take place.

Progesterone also stimulates the production of thick cervical mucus so that sperm are unable to enter the uterus to fertilise an egg. The cervix is the opening to the uterus.

Hormone contraceptives are administered as:

Oral pill – two types:

- combined oestrogen and progesterone
- progesterone only.

Problems with the combined oral contraceptive pill:

- not 100% effective
- side effects are possible (mainly due to oestrogen) – headaches, nausea, irregular menstrual bleeding, fluid retention
- no protection from sexually transmitted diseases (STDs)
- relies on remembering to take it daily.

Other hormonal methods:

- skin patch
  - contains oestrogen and progesterone (same as the combined pill)
  - a small patch stuck to the skin – changed each week.
- implant
  - inserted under the skin of the arm
  - releases a continuous amount of progesterone
  - lasts for up to three years.
- Injection
  - contains progesterone
  - each dose lasts 2 to 3 months.
  -
- intrauterine devices
  - T-shaped devices inserted into the uterus that prevent the implantation of an embryo – plastic IUDs – release progesterone.

Non-hormonal methods of contraception

- barrier methods – stop the sperm from reaching an egg
  - condoms – worn over the penis to prevent sperm from entering the vagina – the only contraceptive device that protects against sexually transmitted diseases
  - diaphragm – a shallow plastic cup that fits over the cervix and is used with a spermicide
  - spermicide – a substance introduced into the vagina to kill sperm or make them inactive – more effective when used with a diaphragm.
- intrauterine devices – T-shaped devices inserted into the uterus that prevent the implantation of an embryo – copper IUDs – prevent sperm from surviving in the uterus.

- surgical methods – permanent sterilization
  cutting or tying structures involved in human reproduction:
  - female: oviducts that connect the ovaries to the uterus
  - male: sperm duct between the testis and the penis
  - very small chance of the structures reconnecting.
- natural methods
  - avoiding sexual intercourse when an egg may be in the oviduct (most fertile time) – not very effective
  - abstinence – no sexual intercourse – 100% effective.

All methods of contraception have their own level of benefit and potential problems.

The most suitable form of contraception will vary according to the individual.

Contraception method	**Effectiveness %**	**Possible side effects**	**Protection from STDs**
Hormonal			
Oral pill	99+	headaches nausea irregular menstrual bleeding fluid retention	no
Other hormonal methods: patch, implant, injection IUD – plastic	99+	irregular bleeding menstruation may stop	no
Non-hormonal			
IUD – copper	99+	heavier/longer menstruation	no
Male condoms	98	none	yes
Diaphragm + spermicide	92–96	none	no
Spermicide	70–80	none	no
Surgical: sterilisation	99.9	none	no
Natural (avoidance when most fertile)	Not very effective – varies	none	no

B9.5 Disease and body defence:

a. Communicable diseases:

i. Know that communicable diseases are caused by pathogenic bacteria, viruses, protists and fungi.

ii. Understand the transmission routes of sexually transmitted infections, including the effect on the immune system of HIV which results in AIDS.

iii. Understand the treatment of disease, including the use of antibiotics, vaccines (role of dead and inactive pathogens, antibody production and formation of memory cells) and techniques to prevent the spread of pathogens including HIV.

iv. Understand the process of discovery and development of new medicines and vaccines, including pre-clinical and clinical testing.

Communicable diseases

These are diseases that are:

- infectious (are caught)

  and
- caused by pathogens.

Pathogens cause disease and include:

1) viruses
2) bacteria
3) protists
4) fungi.

Viral diseases

There are many different communicable diseases caused by viruses, despite viruses not being cells or being alive. Viruses comprise of genetic material and a protein coat. The genetic material is not contained in a nucleus and they lack cytoplasm.

a) AIDS

The human immunodeficiency virus (HIV) is a retrovirus, so it contains RNA as its genetic material and has an enzyme called reverse transcriptase. This enzyme is only found in retroviruses and catalyses the conversion of viral RNA to DNA.

HIV can be passed from one person to another through infected body fluids that contain the virus. It can enter a person across mucous membranes or if the skin of a person is broken. For example, the virus can be passed between people in semen or vaginal fluid so can be considered a sexually transmitted infection/disease. However, it could be transferred in infected blood or breast milk.

Prevention of infection with HIV would be by stopping the transmission of infected body fluids. This can be by:

- using a condom during sexual intercourse
- an HIV-infected mother bottle feeding her baby rather than breast feeding
- screening blood so infected blood is not used in a blood transfusion.

If a person has the virus, they are described as being HIV+. The virus parasitises one type of human white blood cell: a lymphocyte. It causes these cells to make new HIV. HIV is released into the bloodstream by destroying the lymphocyte.

As these lymphocytes are involved in the body's immune system, an HIV+ person may have a reduced white blood cell count which means they have a weakened (compromised) immune system. This leaves the person more susceptible to a range of diseases. When the person reaches this stage, they are said to have AIDS (acquired immune deficiency syndrome).

Currently there is no cure but HIV+ people can be given drugs that stop reverse transcriptase from functioning. With less HIV with functioning reverse transcriptase, new HIV will not be made so the HIV infection can be controlled. These are known as anti-retroviral drugs.

b) Influenza

Influenza (commonly called 'the flu') is caused by the influenza virus.

It is usually spread in airborne droplets of sputum sneezed or coughed out of an infected person and inhaled by an uninfected person. It can also be caught through contact.

Prevention is to contain the virus, such as covering the mouth and nose when sneezing or coughing or wearing a mask if infective, and frequent hand washing to reduce potential transfer from surfaces.

The virus causes a runny nose, fever, sneezing, coughing and a sore throat a few days after infection but these should subside within about a week.

Vaccines using either inactive virus or weakened virus are available to groups at risk such as those with a weakened immune system. Vaccination can help to avoid pandemics.

Antiviral drugs are available to tackle influenza in some circumstances.

Flu can be spread in airborne droplets

c) Measles

Measles (sometimes known as rubeola) is a communicable disease caused by the *Morbillivirus*.

It is spread by direct contact such as touching an infected person. It can also be spread by airborne mucus droplets expelled during sneezing and coughing by an infected person and inhaled by an uninfected person.

The virus that causes measles leads to a reddish blotchy rash that tends to start in the head/neck region, spreads over the face and then can cover the full surface of the skin. Another symptom sometimes seen is a sensitivity to light.

Generally there is no treatment, as the person will make a full recovery. However, it can be prevented by the MMR vaccine which uses live weakened viruses for measles, mumps and rubella (German measles).

Measles

d) Tobacco mosaic disease

The tobacco mosaic virus (TMV) attacks a range of plants including tobacco plants.

The virus can be transmitted from one plant to another by direct contact, or via an insect such as an aphid. The virus can also remain in the soil for some time.

One way to prevent the spread of the infection is to stop viral transmission by removing infected plants, washing hands after touching an infected plant and through crop rotation.

The virus can cause tobacco leaves to have light and dark green areas (mosaic) and they may become wrinkled.

Plants may also be infected with a milder strain of TMV which acts like a vaccine, preventing a more damaging strain.

Another approach is to genetically modify the tobacco plant to make it resistant to the disease.

A leaf with tobacco mosaic disease

Bacterial diseases

Many diseases are caused by bacterial pathogens. In the past, such infections have been successfully treated using antibiotics. These are a diverse range of chemicals that either kill the bacteria or stop them reproducing, giving the body's defence system time to destroy the infection. However, bacteria are increasingly becoming resistant to antibiotics.

Many bacterial diseases can be prevented through vaccinations.

Salmonella food poisoning

One of the most common forms of food poisoning is caused by the salmonella bacterium. This tends to occur when a person ingests food contaminated with the bacterium. The bacterium survives the low pH conditions of the stomach and reproduces in the small intestine where it causes inflammation. This leads to symptoms including diarrhoea, vomiting and fever.

Prevention is by proper food preparation such as washing hands after handling raw meat, making sure that frozen meat is thoroughly defrosted before cooking, and that food is thoroughly cooked.

Most people recover without treatment, but sometimes oral rehydration supplements are given to replace lost electrolytes.

Protist diseases

Protists are single-celled organisms that have a nucleus.

Plasmodium is a protist that causes malaria.

It is spread by mosquitoes infected with the protist. Some varieties of mosquito can bite an infected human, to gain blood. If they take in the protist, then it can be transferred to another human (or a variety of other mammals) at the next bite. These mosquitoes lay their eggs in stagnant water. The eggs hatch into larvae that live in the water for about a week and then become adult flying mosquitoes.

Once a human has the protist, it enters the liver where it matures. It then moves into red blood cells where it reproduces. The red blood cells rupture, releasing the protists which then infect more red blood cells. This reproduction/release can happen in regular cycles leading to the periodic fever associated with malaria.

The disease can be fatal so an understanding of the infection process allows various ways to prevent malaria.

The mosquitoes tend to bite at dusk and in the dark. Infection can be prevented by stopping mosquito bites such as by humans sleeping inside mosquito nets and by the use of skin lotions with chemicals to repel mosquitoes so they cannot be bitten. Taking anti-malarial medication prior to going to malaria-infested areas prevents infection by the protist.

Ways of interrupting the mosquito life cycle include:

- adding fish to the water that eat the larvae
- draining areas of stagnant water.

Insecticides have been used extensively to kill the mosquitoes, but a mutation has occurred, increasingly making mosquito populations resistant to insecticides.

A child sleeping under a mosquito net.
Some nets are impregnated with an insecticide.

Fungal diseases

There are many fungi that can cause diseases including athlete's foot and aspergillosis. These fungi are eukaryotic.

Aspergillosis is a group of diseases caused by the *Aspergillus* fungus. Some of these fungi produce a chemical which is both a toxin and a carcinogen and can contaminate foods such as nuts or starchy foods like bread where the fungus is growing.

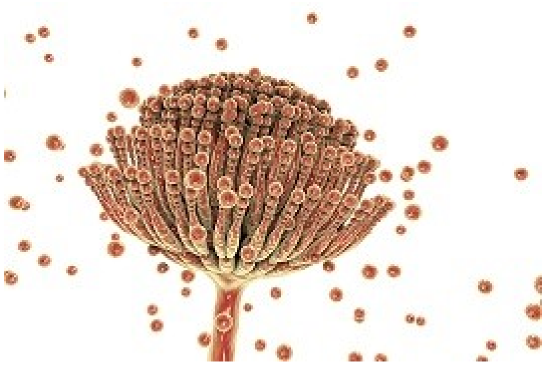
The fungus produces large numbers of spores asexually which disperse into the air and are then breathed in.

Prevention relies on reducing exposure to the growing fungus, such as regulating food storage in dry conditions which prevent fungal growth.

Symptoms include fever, cough, chest pain and breathlessness, usually in humans with a weakened immune system such as those with HIV or asthma.

Treatment uses medication such as steroids or antifungal medication. However, some strains have developed resistance to the medication.

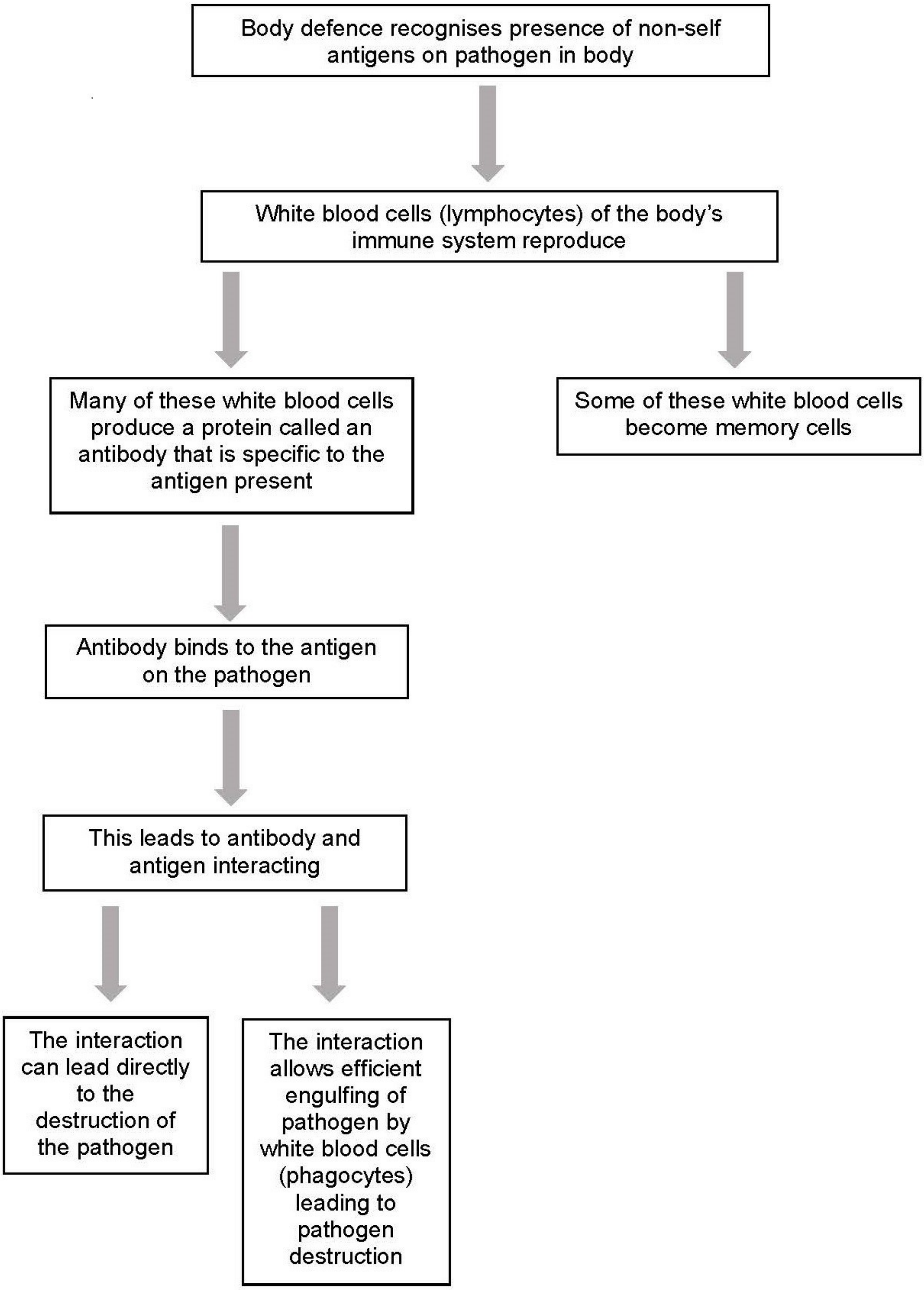
Aspergillus fungus



Vaccinations

Many communicable diseases can be prevented by vaccinations.

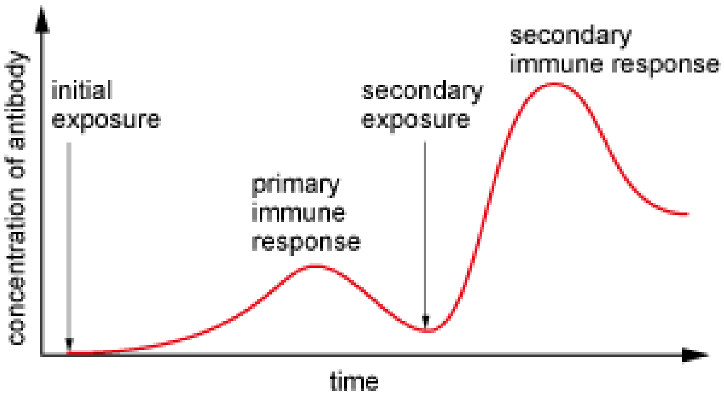
Usually a doctor or nurse gives a person a vaccination. The vaccine that is given can contain a dead pathogen, an inactive pathogen or a weakened virus unable to cause the disease. This means that the pathogen will not cause the person to succumb to the infection and so they will not show any symptoms. However, the pathogen still has markers on its surface that are exclusive to that pathogen. These markers are known as antigens and allow an individual’s immune system to recognise them as non-self. The body responds by producing a primary immune response as shown in the flow diagram below.



The important component of this response is the formation of memory cells that remain in the vaccinated person for a long time.

If the person then comes into contact with the pathogen, with the same antigen, for a second or subsequent time, the memory cells rapidly lead to the production of huge numbers of antibody. The high level of antibodies tends to destroy the pathogen before the symptoms of the disease occur. This is known as the secondary immune response and the person is described as 'immune'.

Below is a graph showing the difference in number of antibodies produced in the primary and secondary response, and speed of antibody production.



Exercise 59

Why would a person vaccinated against measles, mumps and rubella (MMR) not be immune to flu?

Exercise 60

What is the difference between being 'immune' and being 'resistant'?

The discovery and development of new medicines

Many plants produce chemicals that have medicinal properties. Scientists can extract such chemicals.

To become a new medicine, a series of trials are carried out. These can be divided into two sets of tests:

- preclinical tests – do not involve testing on humans
- clinical tests – do involve testing on humans.

The flow diagram below shows the general sequence of events involved and some of the reasons for each event.

General sequence of events	Reasons
Medicine tested on animals.	To make sure it is safe to test on humans.
↓	
Medicine tested on a few healthy people (phase 1).	To make sure it is safe (low numbers decrease risk). To look for obvious side effects
↓	
Medicine tested on a few patients (phase 2).	To make sure it works. Low numbers decrease risk. Look for side effects.
↓	
Medicine tested on many patients. Usually done as a double-blind trial using a placebo (phase 3).	To look for less common side effects. Double-blind to remove any possible bias. Use placebo to compare effect of medicine against placebo effect.

A placebo mimics the medicine being given, such as being an identical-looking tablet, except that it lacks the chemical being studied.

The placebo effect is the positive effect gained from taking the placebo. If the chemical being tested does work, its positive effect should be greater than the placebo effect.

B9.5 Disease and body defence:

b. Non-communicable diseases:

i. Know that the following diseases are caused by the interaction of many factors: cardiovascular disease, many forms of cancer, some lung and liver diseases and diseases influenced by nutrition, including type 2 diabetes.

ii. Know that cardiovascular disease can be treated/managed using lifelong medication (including statins, anti-coagulants and anti-hypertensive drugs), surgical procedures (including stents and bypass for coronary heart disease), and lifestyle changes (including reducing smoking, more exercise and a balanced diet).

Non-communicable diseases

These are diseases that:

- are not infectious – they cannot be passed from one person to another
- are caused by the interaction of many different factors.

Some non-communicable diseases are:

1) cardiovascular disease
2) many forms of cancer
3) some lung diseases
4) some liver diseases
5) nutrition-influenced diseases.

Cardiovascular disease (CVD)

The term CVD covers a range of conditions which are some of the leading causes of death in the UK. CVD includes:

a) coronary heart disease
b) hypertension
c) stroke.

a) Coronary heart disease

The coronary arteries are very narrow blood vessels that supply oxygen and glucose to the heart muscle cells for aerobic respiration. If any of their branches become blocked, then the heart muscle cells after the blockage will not receive oxygen and glucose and begin to carry out anaerobic respiration. If this continues, these cells may die, leading to reduced heart function. The blockage is usually either a fatty deposit called atheroma, or a blood clot.

b) Hypertension

This is when a person has a consistently raised blood pressure (above 140/90 mmHg). It may be due to the narrowing of an artery lumen due to atheroma or hardening of an artery so that it cannot expand when blood flow increases.

c) Stroke

A stroke is when part of the brain is deprived of oxygen-rich and glucose-rich blood, so brain cells die. The reason for the lack of blood is often due to narrowing and/or hardening of arteries supplying the brain tissue.

There are many factors that increase the risk of developing one or more of the above types of CVD. However, they can be split into two groups:

i) those that can be modified, i.e. lifestyle choices

ii) those that cannot be modified.

Some risk factors that can be modified:

- diet – consumption of foods high in fat/cholesterol increase risk of atheroma; and a high salt intake increases the risk of hypertension
- too little exercise
- obesity
- smoking
- excess alcohol intake.

Some risk factors that cannot be modified:

- increasing age
- the sex of the individual
- heredity/a family history of CVD.

Treatment/management of CVD

There are a number of approaches taken to treat/manage CVD. These include:

i) using life-long medication
ii) surgical procedures
iii) lifestyle changes.

i) using life-long medication

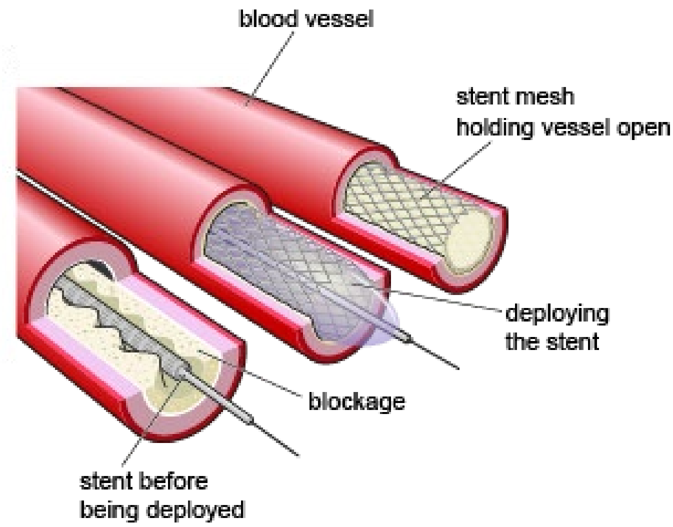
There are a range of medications available as shown in this table.

Medication example	**How it works**
Statins	They reduce the production of cholesterol, which is a component of atheroma. Build-up of atheroma can lead to blocked arteries.
Anti-coagulants	They reduce the likelihood of blood clotting and therefore blocking an artery.
Anti-hypertensive drugs	They can cause blood vessels to relax so their lumen diameter enlarges, reducing blood pressure.

ii) Surgical procedures

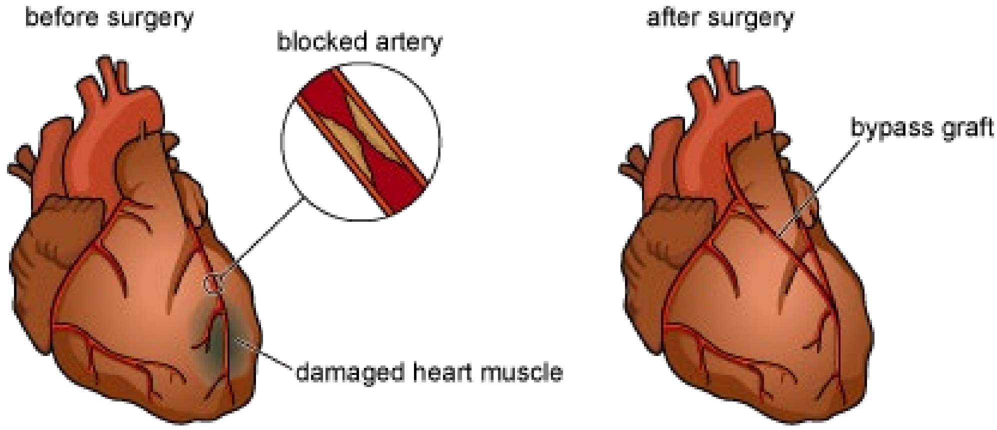
One example of a surgical procedure is to place a mesh tube into a narrowed part of a coronary artery to increase its lumen diameter so there is no restriction in the flow of blood to the cells it supplies. The mesh tube is known as a ‘stent’. A stent can be used in a coronary artery or in a blood vessel supplying brain tissue.

Diagram showing how a stent is placed in a narrowed section of artery and how it enlarges that section



A second surgical example would be a bypass. A small section of blood vessel is removed from another part of the body. It is then used to re-route blood around a blockage in a coronary artery.

The bypass restores blood flow in the coronary artery



iii) Lifestyle changes

As many lifestyle choices have been identified as risk factors of CVD, a change in these would lower the risk. Examples include:

- reducing smoking
- taking more exercise
- eating a balanced diet.

Many forms of cancer

It has been estimated that as many as 40% of cancers are related to lifestyle choices.

The table shows three examples.

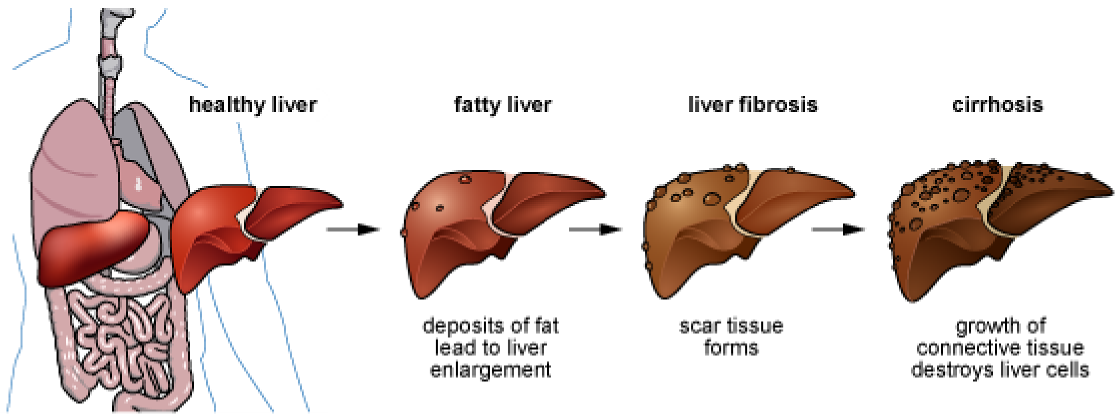
Type of cancer	Some risk factors
prostate cancer	• being overweight • eating a lot of red meat or high-fat dairy products • increasing age • family history of this form of cancer
breast cancer	• being overweight • increasing age • family history of this form of cancer • BRCA 1 or 2 gene mutation
colorectal cancer	• being overweight • a diet low in fibre • increasing age • family history of this form of cancer

Some lung diseases

There is a strong correlation between lung cancer and smoking tobacco. It has been estimated that about 90% of all lung cancers worldwide are tobacco related. This is because smokers inhale chemicals called carcinogens which increase the risk of cancer.

Some liver diseases

Excess alcohol can lead to cirrhosis of the liver; this can be fatal. The diagram shows some stages in developing cirrhosis of the liver.



Nutrition-influenced diseases

Earlier in this section, reference has been made to the effect of a diet high in fatty foods and cholesterol. However, there are many other diseases related to eating an unbalanced diet.

Type 2 diabetes is one such example. This is becoming more prevalent in the UK population and some have calculated that about 1 in 3 adults will get type 2 diabetes in their lifetime.

When a person eats food high in sugar, their blood glucose level will consequently rise and the pancreas responds by releasing insulin. However, if this is done on a regular basis, their body, including muscle cells, become increasingly resistant to the insulin released. Therefore, less insulin may be produced, leading to a persistently raised blood glucose level and the release of more glucose in the urine.

In addition to eating foods high in sugars, other risk factors for type 2 diabetes include being overweight, insufficient exercise and a family history of the disease.

Solutions to Exercises 33 to 60

Exercise 33

a. False. This is a description of the process of breathing. Respiration is a chemical reaction that occurs in cells to release energy.
b. True.
c. False. Glucose and oxygen are needed for aerobic respiration to occur. Carbon dioxide is produced by the process of respiration.
d. False. Anaerobic respiration takes places in the cytoplasm. Aerobic respiration takes place in mitochondria.
e. True.
f. False. The oxygen debt is the extra oxygen taken in during rapid breathing after exercise. It is used to oxidise toxic lactic acid, removing it from the body.

Exercise 34

Statement 1 is not correct. Bacteria do not possess mitochondria and respiration producing carbon dioxide will occur in the cytoplasm.

Statement 2 is correct. Respiration is catalysed by enzymes. An increase in temperature may denature enzymes, slowing the rate of the reaction that they catalyse.

Statement 3 is correct. Anaerobic respiration occurs in the cytoplasm and produces lactic acid. This would lower the pH of the cytoplasm as it is acidic.

The correct answer is therefore g) 2 and 3 only.

Exercise 35

a) is incorrect. The central nervous system is the brain and spinal cord, not the spine.

b) is incorrect Responses from the nervous system are rapid.

c) is correct. Impulses from many nerves are processed and co-ordinated in the brain.

d) is incorrect. Receptors are found throughout the body in the sense organs, like the eyes and skin. They are not in the central nervous system.

Exercise 36

Dendrites allow connections to other neurones, not the cell body or axon. All the other statements are correct for either the axon, the cell body, or both. The answer is d) 1, 2 and 3.

Exercise 37

Motor neurones have myelin sheaths and connect to effectors but they don't connect to receptors and they are not only found in the central nervous system.

Relay neurones have no myelin sheaths, are only found in the central nervous system and connect to other neurones but they don't connect to effectors.

Sensory neurones have myelin sheaths and connect to receptors but they don't connect to effectors and they are not only found in the central nervous system.

The only row with a correct answer in all three columns is **c**.

Exercise 38

a) Movement across a synapse depends on osmosis. This is not true. It requires diffusion.
b) Synapses are often more than 1 mm across. This is not true. Synapses are very small, often only 1 μm in width.
c) Neurotransmitters are electrical impulses. This is not true. Neurotransmitters are chemicals that help produce the electrical impulse in the neurone on the second side of a synapse.
d) Chemicals are needed to pass an impulse across a synapse. This is true and the correct answer. Neurotransmitter chemicals are needed.

Exercise 39

The correct order is receptor, sensory neurone, relay neurone, motor neurone and effector:
c) 3, 2, 4, 1, 5

Exercise 40

Carbon dioxide passes from the blood into the alveolus. From here it moves to the bronchioles and then the bronchi (not included in the list). From here it will enter the trachea which contains rings of cartilage and then pass to the nose or mouth to be exhaled. The correct answer is therefore **b**.

Exercise 41

1 Inhaled air would contain less oxygen. Incorrect. The cilia would have no effect on the air being inhaled.

2 More dust could be present in exhaled air. Correct. Without the cilia to waft away any mucus that has trapped dust, there will eventually be a build-up of particles in the mucus in the bronchi, meaning that it becomes less efficient at trapping new particles. These would then not be removed from the air and so would remain when the air is exhaled.

3 Air would be cooler when it is exhaled. Incorrect. The cilia have no effect on the warming of air when it enters the body.

4 The smoker is more likely to get an infection in their lungs. Correct. If viruses and bacteria are not trapped in the mucus and then removed from the airway, it may lead to more infections within the lung.

The correct answer is therefore e) 2 and 4 only.

Exercise 42

When we inhale, the ribs move up and out and the diaphragm contracts and flattens. This increases the volume inside the thorax and so the air pressure within the lungs decreases. Only statements 1 and 3 are correct for inhaling, therefore the answer is b) 1 and 3 only.

Exercise 43

The ribs move down and inwards while the diaphragm becomes domed. This decreases the volume inside the thorax, resulting in an increase in pressure. As a result of this, air is pushed out of the lungs into the bronchi and then the trachea. The only sequence that reflects these events correctly is c) 4, 6, 5, 3.

Exercise 44

a) The change in shape of the alveoli would result in a reduction in their surface area. This would reduce the surface available for diffusion.
b) Tar being deposited on the surface of the alveolar walls would increase the diffusion distance and slow the rate of diffusion.
c) An increase in heart rate would make the blood flow faster, creating steeper concentration gradients for oxygen and carbon dioxide. This would increase the rate of diffusion.

The answer is c) an increase in heart rate.

Exercise 45

Air enters the body through the nose and mouth. It then passes along the trachea and into one of two bronchi. From here the air enters a series of smaller bronchioles which end in alveoli. From here oxygen will diffuse into the capillaries.

The answer is d) trachea → bronchus → bronchiole → alveolus.

Exercise 46

The surface area is $6 \times (2.5 \times 2.5) = 37.5\ cm^2$. The volume is $2.5 \times 2.5 \times 2.5 = 15.6\ cm^3$.
The ratio is 37.5 : 15.6 or 2.4 : 1, so answer c) is correct.

Exercise 47

a) The pO_2 in the vena cava is 40 mm Hg. True. Blood returning to the heart from the body in the vena cava will be at 40 mm Hg.

b) The pO_2 in the hepatic artery is 104 mm Hg. False. The level of oxygen in the arteries remains at 95 mm Hg after leaving the heart until reaching the organs.

c) The pO_2 in the pulmonary vein is 40 mm Hg. False. The blood in the pulmonary vein has just been through the alveoli and so its level will be 104 mm Hg.

d) The pO_2 in the aorta is 104 mm Hg. False. The level of oxygen in the blood falls to 95 mm Hg by the time it leaves the heart in the aorta.

e) The pO_2 in the pulmonary artery is 95 mm Hg. False. The blood in the pulmonary artery has not been through the lungs yet and so this will have similar oxygen levels to the vena cava, around 40 mm Hg.

f) The pO_2 in the renal artery is 95 mm Hg. True. The levels of oxygen in the arteries remains at 95 mm Hg from leaving the heart until reaching the organs.

Exercise 48

In veins, the walls of the vessel are relatively thin so the diameter across the lumen will be a value close to the diameter of the whole blood vessel. If the numbers are close together the ratio will be 1 : 1. This makes vessel A the vein.

Arteries have a narrow lumen and thick walls. This means that the total diameter of the blood vessel will be much bigger than the much smaller lumen diameter. This means that the ratio will be bigger. With a ratio of 1 : 4, vessel B must be the artery.

Exercise 49

a)

i. Activity x stimulates the ventricles to contract, which will force blood out of the ventricles into the aorta and pulmonary artery.

ii. This is not affected directly by electrical activity in the heart.

iii. Activity w stimulates the atria to contract, forcing blood out of the atria and into the ventricles.

iv. This is not affected directly by electrical activity in the heart.

v. Activity w stimulates the atria to contract, forcing blood out of the atria and into the ventricles.

b) Graph B could show the result of adrenaline release on the heart rate as it shows an increase in the rate at which the heart beats.

Exercise 50

a) White blood cells only, as red blood cells and platelets do not have nuclei.

b) Red blood cells, as they transport oxygen for use in respiration by muscle cells.

c) White blood cells which need antibodies and enzymes, red blood cells which need haemoglobin, and platelets which need fibrinogen/fibrin. All of these are proteins.

d) None of these cells have a cell wall as they are all animal cells.

e) White blood cells and platelets. White blood cells can produce antibodies to kill bacteria or ingest and digest them. Platelets form clots at wound sites to stop bacteria entering and infecting the body.

Exercise 51

A single-celled fungus will have a large surface area to volume ratio and so it does not need a transport system. A multicellular plant will have a smaller surface area to volume ratio and so it will not be able to rely on diffusion alone. It will need to have a transport system to move substances around the plant. Statement d) is true.

An organism with a small surface area to volume ratio will have slow diffusion to its centre so a) is incorrect. An organism with a large surface area to volume ratio may not need a transport system as it could rely on diffusion, for example in bacteria, so b) is incorrect. A liver cell would have a larger surface area to volume ratio than a horse so c) is also incorrect.

Exercise 52

The amylase secreted by the salivary glands works when the pH is close to neutral. When food is swallowed, it travels down the oesophagus to the stomach which has a very acidic pH and so the enzyme is inactivated. To continue the breakdown of starch after it has been through the stomach, another amylase is required that works in the alkaline conditions of the small intestine.

Exercise 53

a) As blood enters a kidney, the pressure increases due to the presence of knotted glomeruli. Ultrafiltration occurs, filtering out smaller molecules and ions. These include water, salts, urea and uric acid. Glucose is also in the filtrate, but it is all reabsorbed into the blood. Water is reabsorbed by osmosis, but the amount taken back into the blood depends on how much excess water there was in the blood. Urea is a waste product of the breakdown of surplus amino acids. Most urea remains in the tubule, along with uric acid, to form part of the urine formed. Some salts are reabsorbed. This happens by diffusion and active transport. So, blood leaving the kidney will contain less water, fewer salts, less urea and less uric acid than blood entering the kidney.

   The cells of the kidney carry out aerobic respiration so will require oxygen and will produce carbon dioxide. Therefore the blood leaving the kidney will have a higher carbon dioxide concentration and a lower oxygen concentration than the blood entering the kidney.

b) The ureter carries urine from the kidney to the bladder. The urethra carries urine from the bladder to be expelled from the body.

Exercise 54

a) The pancreas is only stimulated to secrete insulin when blood glucose levels are raised. Before a meal, these levels would be comparatively low. During a meal, carbohydrates would be digested and the glucose produced would be absorbed through the gut wall into the blood stream. Increasing levels of glucose in the blood plasma are detected by the islet cells in the pancreas. In response, they secrete insulin. This is transported to the liver in blood plasma.

   Once at the liver, the insulin instructs liver cells to absorb glucose and convert it to glycogen. Levels of glucose in the blood plasma then drop back down to the levels recorded before the meal. The pancreas recognises that blood glucose levels have dropped, so the islet cells stop secreting insulin.

b) When a tablet of insulin is swallowed, it would pass down the oesophagus into the stomach. Insulin is a protein so protease enzymes in the stomach would digest the insulin, breaking it down into amino acids. These would have a different molecular structure to the insulin, so would not have any effect on liver cells producing glycogen.

Exercise 55

TSH is released from the pituitary gland directly into the blood where it travels in the blood plasma to the cells in the thyroid gland (the target structures).

When higher than normal blood thyroxine levels are detected the release of TSH is inhibited. However, some TSH would still be present in the blood so the thyroid gland would continue to be stimulated to release thyroxine until TSH blood levels were reduced. As this takes time, the blood thyroxine levels would initially continue to rise.

Exercise 56

Hormones are slow acting so the response would take time to occur, which might put the body in danger.

Exercise 57

So that an increased rate of aerobic respiration is able to take place, supplying the cells with more energy (ATP) to respond appropriately to stress.

Exercise 58

The ovaries would be stimulated to produce many follicles containing ova during the cycle. This could result in many ova being released and being fertilised during sexual reproduction.

Exercise 59

Somebody who has had the MMR vaccine would have been given inactive or weakened measles, mumps and rubella pathogens. Each would have had its own specific antigens which are different to those on the flu virus. Therefore, only antibodies and memory cells specific to the MMR antigens would have been made.

Exercise 60

Being immune means that the person has previously been exposed to a pathogen with its specific antigens and the person has made memory cells. These may protect the individual from the same pathogen for the rest of their life but cannot be passed on to any offspring.

Being resistant means that the individual has either received a gene for resistance from one or both parents, or a mutation has occurred in their DNA leading to resistance. This can be passed on to the next generation.

Photos: Science Photo Library

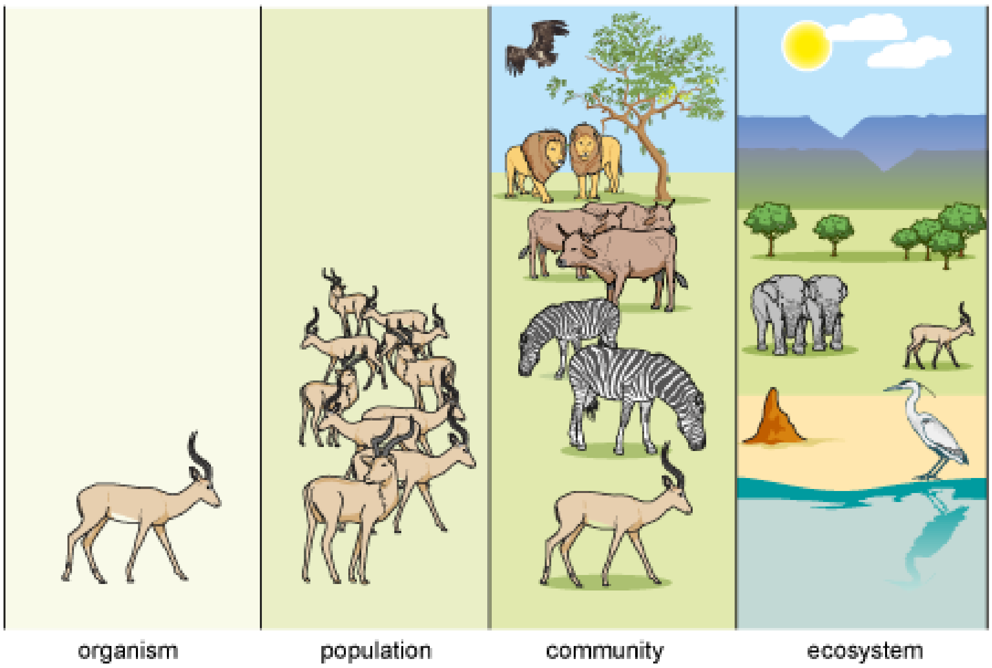
B10. Ecosystems

B10.1 Levels of organisation in an ecosystem:

a. Know and understand the organisation of levels within an ecosystem from individuals through to populations, and from communities through to ecosystems.
b. Know and understand how communities can be affected by abiotic and biotic factors.
c. Know and understand the factors that can cause a population to change in size.
d. Understand the importance of interdependence in ecosystems (relating to predation, mutualism and parasitism) and of competition in a community.
e. Know and understand that photosynthetic organisms are the primary producers of food in an ecosystem, and therefore biomass.

Organisation levels in an ecosystem

An ecosystem consists of living and non-living components. A group of individuals of one species is called a population. The range of populations present represents a community. The place where this community of plants and animals lives is called a habitat. This contains the non-living components on which the individual organisms depend. The diagram below shows the relationship between these key terms.



It is worthwhile learning the definition of each of the key terms:

- An individual is a single living organism.
- A population is a group of organisms of one species, living and interacting in the same area at the same time.
- A community is all of the populations of different species interacting with each other in an ecosystem.
- A habitat is the place where organisms live.
- An ecosystem is a unit containing the community of organisms and their environment, interacting together.

So the ecosystem consists of a living (biotic) component (the communities) and a non-living (abiotic) component (the environment in which the communities live). The environment has distinctive features on which the living organisms depend.

For example, a pond ecosystem provides the following abiotic components:

- Water containing dissolved oxygen and minerals, as well as providing a suitable temperature and pH. The water is transparent, allowing sunlight to penetrate.
- Mud, or another substrate such as sand, which may provide anchorage, a place to hide from predators and a supply of nutrients.

INDIVIDUALS of the same species = **POPULATION**

POPULATION + populations of other species = **COMMUNITY**

non-living part of environment + COMMUNITY = **ECOSYSTEM**

Exercise 61

a) Name a habitat (other than a pond).

b) For your chosen habitat, identify:

   i. three populations living in it

   ii. three abiotic features on which the populations depend and state the importance of each feature.

Abiotic factors, biotic factors and communities

Abiotic factors affecting a community are factors which are non-living.

These include:

- availability of oxygen
- availability of water
- light intensity
- pH (of water or soil)
- pollution
- temperature
- mineral ions.

Changes to any of these factors may affect the numbers of individuals in populations in the community. This can then affect the food web.

Often, a change can have a negative effect (reducing numbers) because the equilibrium becomes unbalanced, but it can also have a positive effect.

For example, an increase in temperature or light intensity can encourage plant growth. This can provide more food for herbivores, or more camouflage, or sites for breeding.

However, increases in water temperature due to global warming are having negative effects on populations of coral in tropical seas. As the corals bleach and die, food chains are destroyed so the whole community in that ecosystem is destabilised.

A thriving community on the coral reef (left) and
a reef which has been affected by rising water temperatures (right)

Seasonal changes can limit the size of animal populations. For example, a cold winter can reduce the populations of small birds and mammals, because they are more prone to hypothermia than larger species.

Biotic factors affecting a community are factors which are living.

These include:

- competition
- disease
- food supply
- predation.

Competition

There are two types of competition: intraspecific competition and interspecific competition.

Intraspecific competition is competition between organisms of the same species for resources such as food, territory, a mate or a nesting site. These factors would have a negative effect on population size if they were in short supply.

Interspecific competition is competition between organisms of different species for resources such as food. In this case, one species is often successful in forcing the other species out of the community.

Disease

Disease can be a particular problem in large populations if it is infectious. It can quickly spread from one individual to another. Epidemics can reduce population sizes very quickly.

Rabbits were first introduced into Australia in the 19th century. However, the rabbits had no natural predators and the rabbit population increased rapidly. They competed with sheep for grass on farmland (an example of interspecific competition). The fatal viral disease Myxomatosis was deliberately introduced in the 1950s to reduce rabbit populations. An epidemic ensued and the result was a severe reduction in the rabbit population.

Food supply

If there is sufficient food for the population, the organisms will be more likely to thrive, survive to breeding age and then breed successfully to produce more offspring. The size of the population will grow.

However, if food is in short supply, there may be an increase in deaths or an increase in migration (emigration) to find new sources of food. The size of the population will be reduced.

Mature female polar bears mate during the warmer months, but the fertilised eggs only implant if the female has taken on enough fat to sustain herself and her cubs during ‘denning’. This is a form of hibernation during which she gives birth and feeds her cubs, but does not take on any nutrition.

A group of polar bears feeding

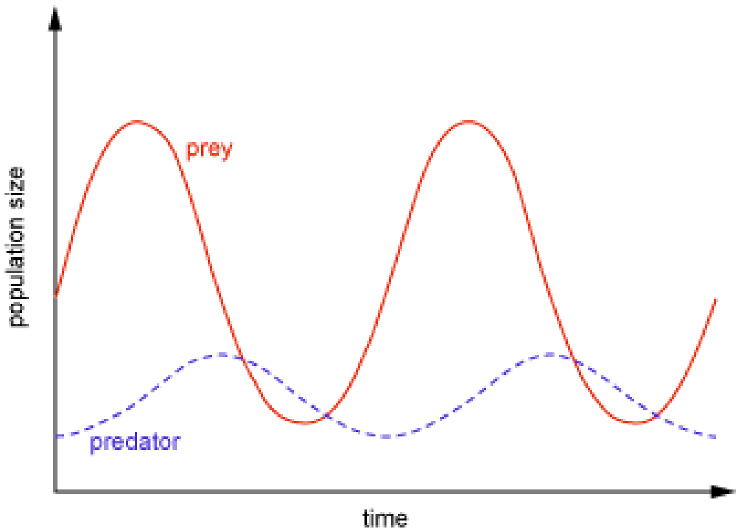
In the case of plants, they make their own food, but they are still dependent on adequate supplies of nutrients, light, water and carbon dioxide. A shortage of any of these factors could reduce their population size.

Predation

In any community there are likely to be predators. If there is heavy predation, the breeding rate of the population may not be enough to replace those eaten, so the number of individuals in the population will drop.

The sizes of populations of prey and predators tend to go in cycles.

Relationship between prey and predator numbers



As the number of prey increases, so does the number of predators, but there will be a time lag because the predator needs to respond to changes in availability of food.

As a result of increased predation, the prey numbers decrease so there is less food for the predators. The number of predators then decreases, and so on. There is always a time lag between changes in prey numbers and changes in predator numbers.

Humans are active predators. For example, uncontrolled fishing can affect fish stocks to the point where species become threatened with extinction.

Tigers have been hunted for various reasons, and dramatic declines in numbers have led to conservation initiatives in recent years. While there were estimated to be 100 000 tigers in the wild in 1900, the World Wide Fund for Nature (WWF) reported that populations fell to a low of around 3200 in 2010, with a modest recovery to over 5500 by September 2023.

Factors that can cause a population to change in size

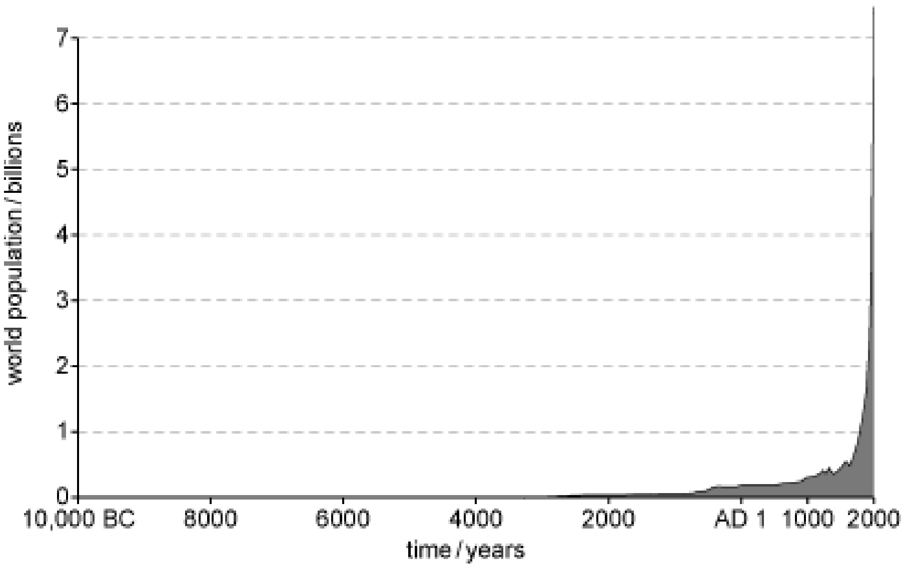
Biologists consider a population of one species to be the total number of organisms of that species to be living in one area.

A population of Emperor penguins in the Antarctic

For a population to grow, the birth rate must be greater than the death rate.

If there are no limiting factors, the size of a population will rise exponentially.

How the human population has increased since the 18th century



Factors that cause the size of the population to change include:

- food supply
- predation
- disease.

These have already been considered earlier in this section. However, human actions can affect the size of a population and include:

- pollution
- climate change.

In addition, if we consider the human population, war is also an important factor.

Pollution

An increase in pollution can reduce the population of a species. For example, the introduction of raw sewage into a water system can reduce the oxygen available to animals, such as fish, in the habitat. They either die because they need oxygen for aerobic respiration, or migrate to water which is not polluted, reducing the population.

Acid rain, caused by combustion of fossil fuels such as coal, kills populations of trees and reduces populations of trout in lakes.

A population of trees killed by acid rain

Climate change

Many populations of organisms cannot cope with sudden changes in climate.

Increases in water temperature due to global warming are having negative effects on populations of coral in tropical seas. As the corals bleach and die, food chains are destroyed so the whole community in that ecosystem is destabilised.

As water warms up, the solubility of oxygen in it decreases.

Most species of aquatic animals rely on oxygen for aerobic respiration.

Populations of the eastern Baltic cod (*Gadus morhua*) have been reduced by a drop in oxygen levels in the coastal waters where they live and breed.

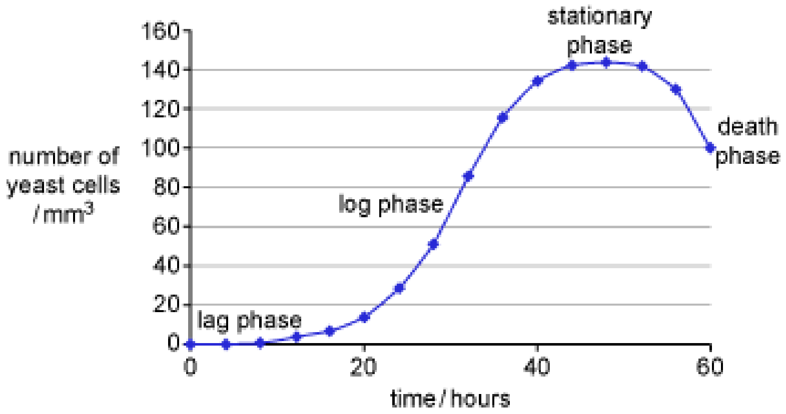
A shoal of cod

In addition, the size of a population can be affected by its relationship with other organisms, if this involves mutualism or parasitism.

Effect of a limiting factor on population growth

If one of the factors affecting the growth of a population is limiting, a sigmoid (S-shaped) curve may be generated when the data is plotted as a graph.

Growth of a population of yeast cells over 60 hours



Four phases can be identified on the graph:

- Lag phase. At this stage the population is very small and takes time to acclimatise to a new environment, become mature and start reproducing. A doubling of small numbers does not have a big impact on the total population size, so the line of the graph only rises slowly with time.
- Log phase (also known as the exponential phase). At this stage there are no limiting factors. Rapid breeding occurs in the population, resulting in significant increases in numbers. There are far more births than deaths.
- Stationary phase. Limiting factors such as shortage of food or a build-up of toxic materials in the environment start to have an effect, slowing down population growth. It gets to the point where the number of deaths equals the number of births, so the line of the graph flattens to form a plateau.
- Death phase. The number of deaths (mortality rate) becomes greater than the number of births so the population numbers start to decrease. This may be due to lack of food, an accumulation of waste materials, disease spreading through the population, or an influx of predators.

Exercise 62

The human population has been described as growing exponentially, although the growth rate is now 1% a year, compared with 20 years ago when it was 2% a year.

a) What factors are causing a rise in population numbers?

b) What factors are likely to be causing a reduction in the growth rate?

Interdependence in ecosystems and competition in a community

Organisms in a community may be subject to a number of different biotic factors, including predation, mutualism and parasitism. Competition between organisms also occurs within a community.

Predation

A predator is a carnivore which kills and eats other animals.

If there is heavy predation of a population, the breeding rate of that population may not be sufficient to produce enough organisms to replace those eaten, so the population will drop in numbers. There tends to be a time lag in population size change for predators and their prey, as described earlier in this section.

Mutualism

This is a close relationship between two organisms of different species where both organisms benefit.

Some hermit crabs place sea anemones on their shells, which then act as a form of protection for the crab, since the anemone has stinging tentacles which ward off potential predators. The anemone benefits because it gains scraps of food as the crab is a messy eater. Normally, anemones are sessile (they stay in one place), but being on the crab's shell provides a means of transport – potentially to fresh sources of food.

A hermit crab with a sea anemone attached to its shell

Many plants are pollinated by insects, resulting in successful reproduction. The insects also benefit because they gain food in the form of nectar and sometimes pollen.

A bee pollinating a flower

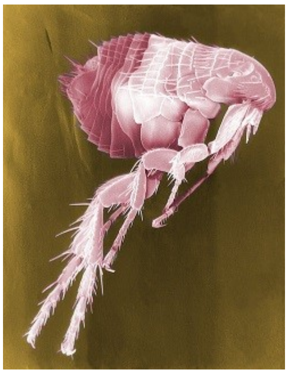
Parasitism

In this relationship, only one of the two organisms involved gains any benefit. The other is harmed.

A parasite is an organism that lives on or in the body of another organism, the host. The parasite gains from the relationship while the host is harmed.

An example of an animal parasite is the flea. It has mouthparts similar to a syringe which can be used to pierce the host's skin to suck blood – the flea's food. In extreme cases where the host (e.g. a kitten) is carrying hundreds of fleas, the amount of blood removed can lead to its death. The fleas can pass to other cats in the community through direct contact or through sharing the same bedding. Fleas can lie in carpets, ready to jump on to a passing host.

A flea



An example of a plant parasite is the fungus which causes Dutch Elm disease. It invades the xylem vessels of Elm trees, blocking them and so preventing the movement of water through the plant. The leaves wilt and go brown and eventually the whole tree dies.

The fungus is carried from tree to tree by elm bark beetles. Once the disease is present in the community, whole populations of Elm trees die, affecting the food webs within the community.

A diseased elm

Competition in a community

As stated previously, there are two types: intraspecific competition and interspecific competition.

Through intraspecific competition, stronger individuals in a population tend to survive and breed, passing their favourable genes to the next generation (survival of the fittest).

Foxes fighting (for territory or a mate), an example of intraspecific competition

In Britain, the red squirrel is in decline because of interspecific competition with grey squirrels. Grey squirrels have been more successful in forcing red squirrels out of their natural habitats because they are bigger, have a greater range of food sources and spread a disease which kills red squirrels but is not usually lethal to greys.

Red squirrels have been forced out of their natural habitats by grey squirrels

Rhododendron plants produce toxins in their roots which are thought to prevent the germination of seeds of other plant species. This prevents interspecific competition for resources such as light, water, space and mineral ions. Toxins are also present in their leaves which reduces grazing by herbivores and being eaten by insects.

Rhododendron bushes growing in a woodland

Photosynthetic organisms as the main producers of food

The sun is the natural source of light energy, about 1% of which is harnessed by photosynthetic plants to make their food. The rest of light is reflected, or is used to evaporate water from leaves (transpiration), or warms up the soil, plants and air.

Photosynthesis is a process whereby plants absorb (trap) the light energy, using pigments such as chlorophyll, and convert it into chemical energy – stored in molecules e.g. carbohydrates, fats and proteins. The food produced and built up in a plant is known as its biomass.

Since all animals ultimately depend on plants for their food, they also depend indirectly on sunlight. As plants are making the food, they are called producers.

Organisms that get their energy from eating other organisms (plants or animals) are called consumers.

A food chain shows the transfer of energy between one organism and the next, beginning with a producer.

The trophic level of an organism is its position in a food chain.

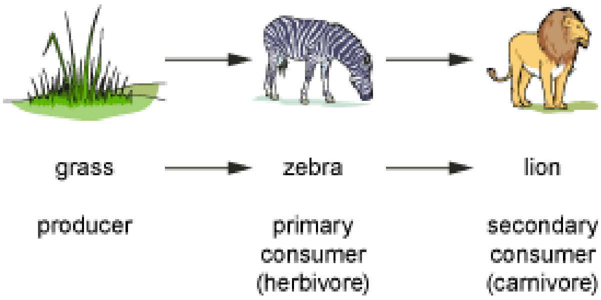
Producers are usually photosynthetic plants.

Primary consumers are herbivores (animals which get their energy from eating plants).

Secondary consumers are carnivores (animals which get their energy by eating other animals).

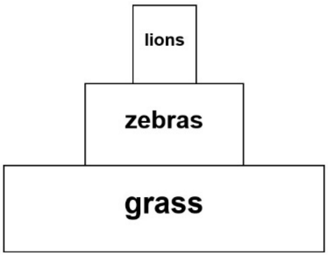
Examples of organisms in a food chain

The food chain involving the organisms in the photograph is:



At each successive stage in a food chain, the amount of biomass decreases. This is because the organisms use some of the food they have obtained for energy to move, respire and maintain their body temperature. Also, some of the material is not digested or even eaten (plant roots in the case of the zebra).

The diagram below shows a pyramid of biomass for the food chain.



The largest bar at the base of the pyramid always represents the producer. The next bar is the primary consumer (herbivore), then the secondary consumer (carnivore) and so on up the food chain. Some food chains, and therefore pyramids of biomass, can have five or more trophic levels, but this is unusual because so little biomass is available near the top to support further trophic levels.

Exercise 63

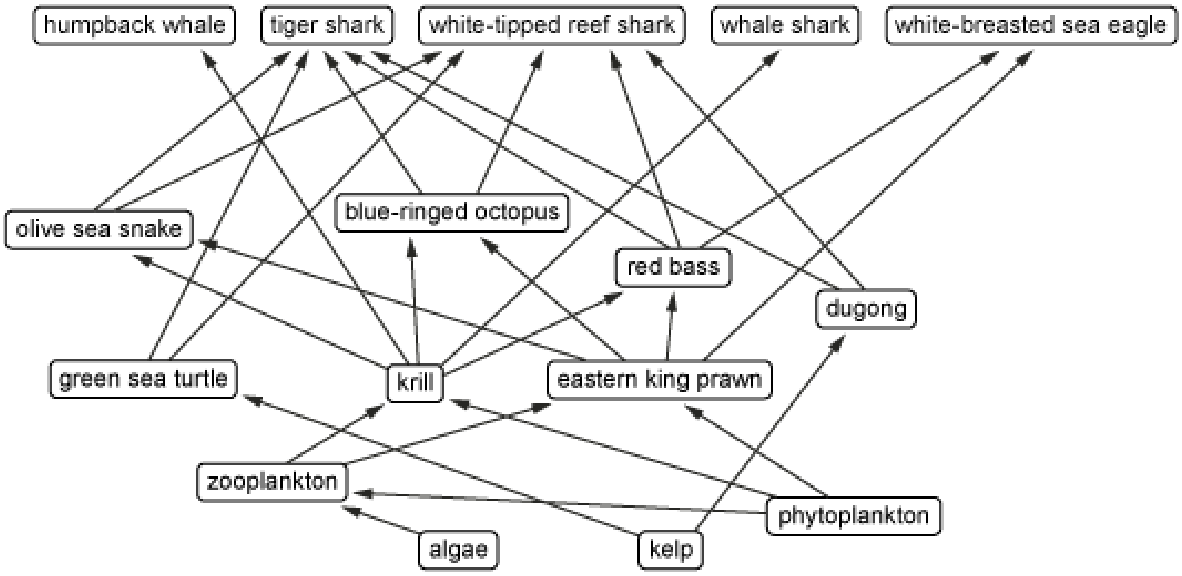
Construct a food chain made up of four trophic levels and label each of the trophic levels

Food chains are not usually as straightforward as the one shown because most animals have more than one type of food.

For example, zebras may graze on a number of different species of grass, as well as tree bark, herbs and shrubs. Lions eat a number of different types of herbivore in addition to zebras, including antelope, wildebeest and even young giraffes.

Food webs show these feeding relationships more accurately.

The diagram shows a food web based on the feeding relationships of organisms living on the Great Barrier Reef in Australia.



Exercise 64

a) Use this food web to name:
   i. the producers shown
   ii. the consumers which feed on the largest number of prey species
   iii. the consumer which is acting as both a primary and secondary consumer
   iv. the organisms that would be most likely to become extinct if one food source was not available.

b) How many different species are present in the longest food chain(s) in this food web?

B10.2 Material cycling:

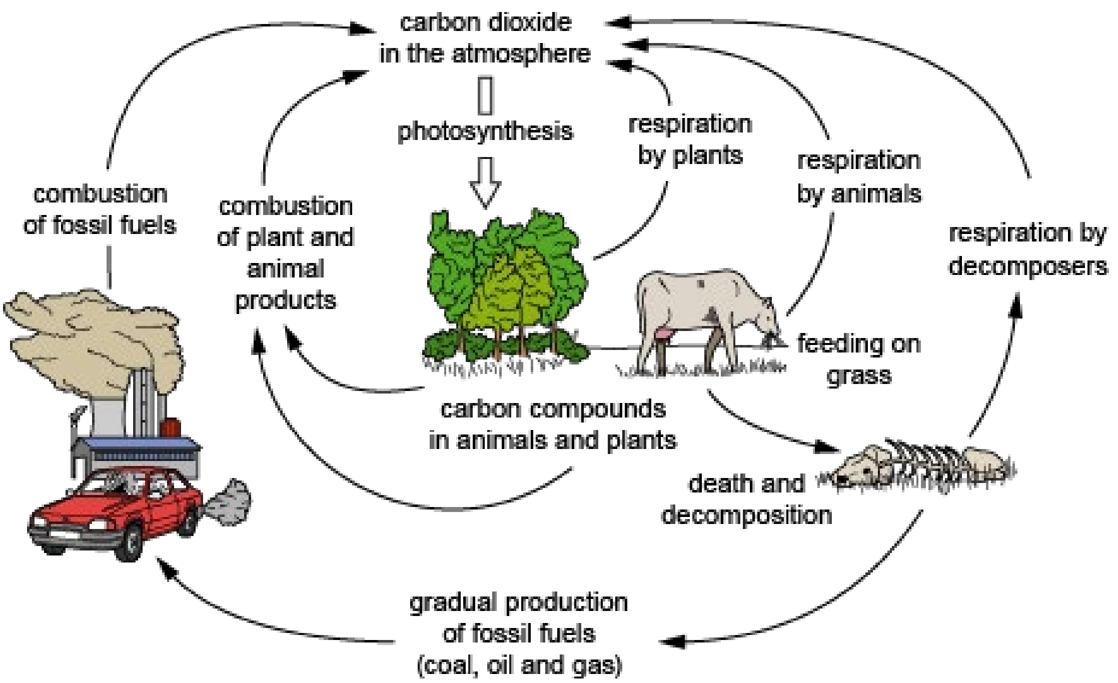
a. Know and understand the carbon cycle, including the importance of the following processes:
    i. photosynthesis
    ii. respiration
    iii. combustion
    iv. decomposition
b. Understand the importance of the water cycle to living organisms.

The importance of the carbon cycle

All living organisms are made up of compounds based on carbon. Processes happening within these organisms, and to them, result in the carbon being recycled.

The key processes are photosynthesis, respiration, combustion and decomposition.

The carbon cycle, showing how carbon flows between living organisms and the environment



Processes involved in the carbon cycle

Photosynthesis

Photosynthesis is a process carried out by green plants and some types of bacteria. They take carbon dioxide from the atmosphere and use energy from sunlight to reduce it to form carbohydrates. This can be described in the following word equation and balanced chemical equation:

$$\underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} \xrightarrow[\text{chlorophyll}]{\text{light}} \underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2}$$

The chlorophyll is present in chloroplasts in leaf cells.

Sugars are formed first and they are converted into starch for storage, or other carbohydrates such as cellulose, or used as the starting material to make fats and proteins. These are all carbon compounds.

Photosynthesis is the only process by which living organisms remove CO_2 from the atmosphere.

When animals (herbivores and omnivores) feed on plants they gain these carbon compounds by digestion. They can become assimilated into the bodies of the consumers. Carnivores gain the carbon compounds when they feed on herbivores. In this way, carbon is transferred along a food chain.

Respiration

All organisms – animals and plants – respire to release energy for metabolic processes. In carrying out aerobic respiration, carbon dioxide is produced as a waste product and released back into the atmosphere.

This can be summarised in the following word and balanced chemical equation:

$$\underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2} \longrightarrow \underset{\text{water}}{6H_2O} + \underset{\text{carbon dioxide}}{6CO_2} + \text{energy}$$

When comparing the equations for photosynthesis and respiration, the two processes have the potential to balance each other, maintaining the concentration of carbon dioxide in the atmosphere. However, if an imbalance is created, for example by mass deforestation or by releasing carbon dioxide into the atmosphere by other processes such as combustion of fossil fuels, the level of carbon dioxide in the atmosphere will increase. This can cause environmental problems such as global warming.

Decomposition

When organisms die, they provide food for detritus feeders (e.g. worms and woodlice, and microorganisms, e.g. fungi and bacteria). Detritus feeders decompose (break down) the organic molecules in the dead plants and animals through the process of respiration to release energy. Again, carbon dioxide is released into the atmosphere.

When this rotting process does not occur, the organic molecules become trapped and can eventually be fossilised – turned into fossil fuels such as coal, oil or gas. This process traps carbon for very long periods of time.

Some animals form shells or exoskeletons from calcium carbonate, using carbon dioxide. These can also become fossilised, trapping the carbon in them.

Combustion

Some plant and animal products, e.g. wood and fossil fuels, are burnt, usually to provide energy. This process also releases carbon dioxide into the atmosphere.

The equation for the complete combustion of carbon is:

$$C + O_2 \rightarrow CO_2$$

Deforestation has a detrimental effect on the amount of carbon dioxide in the air for two reasons: firstly, there are fewer trees photosynthesising, so less carbon dioxide is removed from the air. Secondly, when the trees are cut down, the small branches and foliage are burned, adding more carbon dioxide back into the air.

Exercise 65

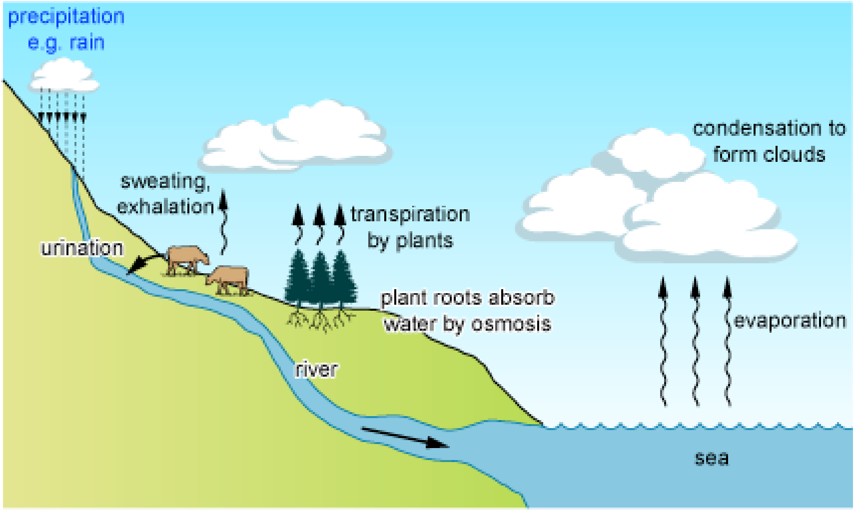
a) Complete the table about processes involved in the carbon cycle (yes/no).

Process	**Requires oxygen?**	**Produces carbon dioxide?**	**Involves the release of heat energy?**
combustion			
decomposition			
photosynthesis			
aerobic respiration			

b) With reference to the equations for photosynthesis and respiration, explain why interaction between the two processes could be considered to be maintaining stable carbon dioxide levels in the atmosphere.

The importance of the water cycle to living organisms

The main features of the water cycle



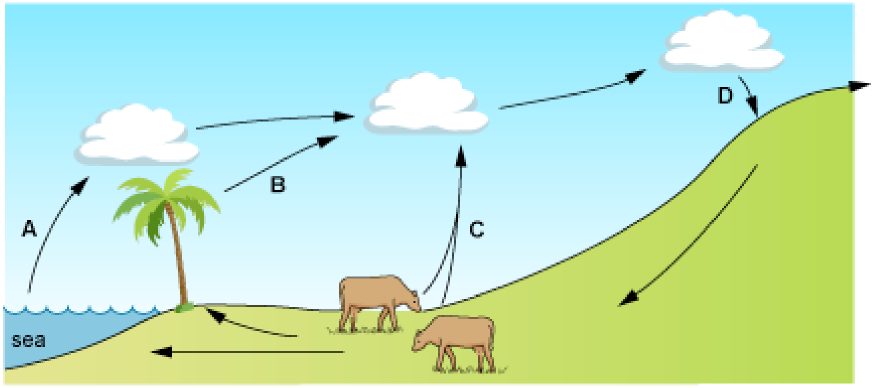
Only a small proportion of water that is recycled passes through living organisms.

Processes in the water cycle include:

- Transpiration – plants release water vapour into the atmosphere, mainly through tiny pores called stomata in the leaves. The water evaporates inside the leaf before it is released.
- Evaporation – occurs from the surface of bodies of water such as rivers, lakes and the sea.
- Condensation – the water vapour in the atmosphere condenses to form clouds.
- Precipitation – water in the clouds forms rain, snow, etc. which falls to the land and drains into water systems.
- Osmosis – the process used by plant roots, bacteria and other organisms to take up water.
- Excretion – from animals. Water is lost from animals in the form of sweat, exhaled air and urine. Faeces (a product of egestion not excretion) also contains some water.

Exercise 66

a) Name the processes A, B, C and D shown in the diagram of the water cycle below.



b)

i. What process is involved in the absorption of water into the tree roots?

ii. Suggest why plants wilt if their roots become soaked in salty water.

B10.3	Biodiversity:

a. Know and understand how quadrats and belt transects are used to investigate the distribution and abundance of organisms in a habitat, and interpret data from their use.
b. Know and understand how to determine the number of organisms in a given area.
c. Know and understand the positive and negative human interactions in an ecosystem, including fish farming, acid rain and eutrophication, and explain their impact on biodiversity.

Biodiversity

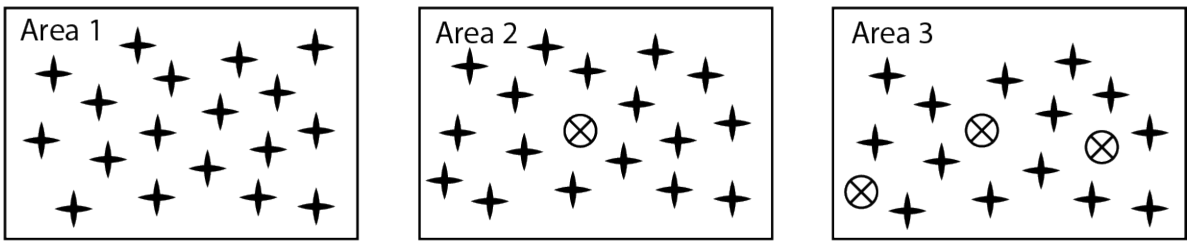
What is biodiversity?

Biodiversity can be used to describe a habitat/area.

Usually two aspects are considered together:

- all the different species present (species richness)
- the number of individuals of each species (abundance)

The diagram below shows three areas of the same size. Each symbol represents an individual plant and each different shape, a different species of plant. The level of plant biodiversity increases from left to right.



Least biodiverse area: a monoculture

Two different plant species are present, but one species is rare in this area

The same two different species are also present but neither species is in low abundance

In the case of area one, a monoculture offers few different food types for herbivores, so there are likely to be less different herbivore species present. This also means there will be fewer different carnivore species that feed on the herbivores. A monoculture, therefore, tends to have a low biodiversity.

Biodiversity, therefore, is a measure of the species richness and abundance of each species present in an area

How to assess the abundance of a species in an area

The area, such as a field, may be large so an estimate has to made. A quadrat is used. This is usually a square of known size. If studying plants, the quadrat may be 0.5 m × 0.5 m (making a quadrat of area 0.25 m^2). If estimating a snail population, a 1.0 m × 1.0 m quadrat may be more suitable.

Here is a method for estimating the population of the banded snail in a grassy field.

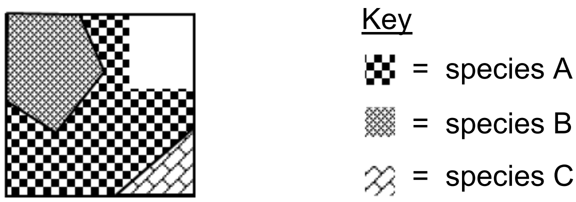
Method Part 1 – Estimating the mean number of snails per metre squared	Comments
1. Place two tape measures at right angles to each other in the area to be studied.	1. The length of the tape measure depends on the size of the area, but a 30 m one is usually a reasonable choice.
2. Produce pairs of random coordinates.	2. The random number generator on a calculator could be used for this.
3. Use the first pair of coordinates to randomly place the quadrat on the ground.	3. If the first pair of coordinates are 10, 24, then one corner (e.g. the bottom left tip) of the quadrat should be placed at the intersection of the two tape measures at 10 m along and 24 m up.
4. Count the number of banded snails present.	4. Only live snails that are within the quadrat boundary are counted.
5. Repeat stages 3 and 4 using the remaining pairs of coordinates. Then calculate a mean for the snails.	5. The numbers can vary greatly, so there are no outliers in the data.
6. If the quadrat is not 1 m^2 in area, calculate the mean number of snails per m^2.	

Method Part 2 – Estimating the banded snail population in the field	Comments
1. Measure the length and width of the field in metres and calculate the area in metres squared.	1. If the field is irregular in shape, perhaps split the field up and calculate the area of each section and then add them together
2. Multiply the field area by the mean number of snails per metre squared.	

There are other ways to assess abundance, particularly if the species is very abundant. One alternative is to estimate the percentage cover of the species within the quadrat.

Exercise 67

The diagram shows a quadrat with three different species present.



a. Estimate the percentage cover for each of species A, B and C.

b. Is it possible to have a percentage cover greater than 100%?

c. Give one natural terrestrial habitat and one natural marine habitat that are very biodiverse.

Remember, that the above technique would need to be applied to all the different species present to find out the biodiversity of the area.

Knowing the biodiversity of an area is important for many reasons:

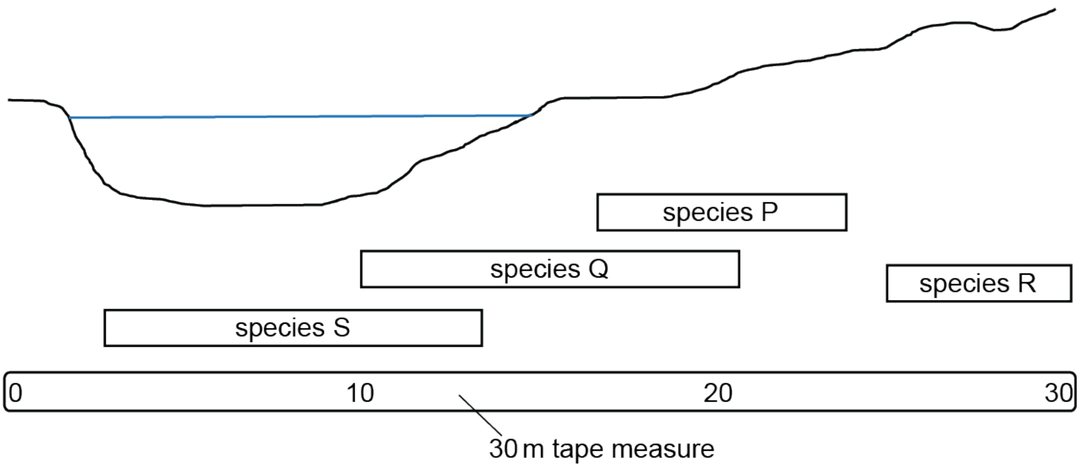
- Diverse ecosystems have a myriad of different species, each adapted to its role and dependent on all the other species present. The loss of one species can negatively affect the whole ecosystem in that habitat. Further, once a species has gone it is very difficult to reintroduce it. The species may become extinct
- Many medicines originate from plants and destroying biodiverse areas may remove plants that have medicinal properties that we do not yet know about
- For conservation purposes, imagine if one of three areas is going to be chosen for flooding to make a new reservoir. The biodiversity of each possible area needs to be considered so an appropriate selection can be made
- A special case may be where there is a rare species identified as present, so this habitat would need to be protected.

To find out the distribution of a species within an area

A species may be distributed unevenly within a habitat for various reasons, such as it prefers a microhabitat within the habitat such as under a rock, or due to a varying soil moisture content in the habitat, or differing pollution levels.

Exercise 68

The diagram shows the profile of a pond and adjacent area. It also shows, via a rectangle, the presence of different species.

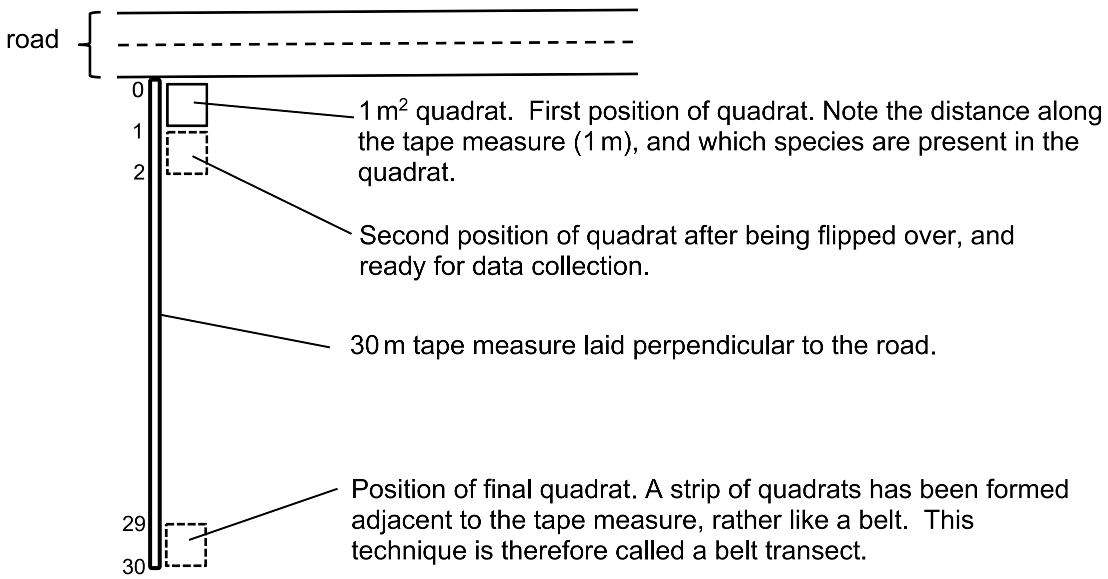


a. Which species
    i. is a fish?
    ii. is least tolerant of damp conditions?

b. Explain why species Q is more likely to be a frog that species P

c. Which species is/are present at 20m?

Below is an annotated diagram of how to study the distribution of plant species in relation to pollution from vehicles.



The table shows the results for the first 10m.

Distance from road edge / m	1	2	3	4	5	6	7	8	9	10
Species J	✗	✗	✗	✓	✓	✓	✓	✓	✓	✓
Species K	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗
Species L	✗	✓	✓	✗	✓	✗	✓	✓	✓	✓
Species M	✗	✗	✗	✗	✗	✗	✗	✗	✓	✓

Key
✓ = species present
✗ = species absent

Interpretation of the results: Assuming that pollution will be highest nearest the road, then species K is the most pollution resistant plant. However, its distribution is very limited, so may be outcompeted by other species when they can tolerate the pollution.

Species L is able to cope with the widest range of pollution levels, whilst species M is the least tolerant of pollution.

Exercise 69

In the above example, why would it be important to record a range of abiotic factors along the belt?

Human interactions in an ecosystem

Positive interactions

- If an area has been found to be biodiverse, it may become subject to protection.
- Humans may manage a habitat to maintain its level of biodiversity. For example, allowing grazing animals in an area which may prevent one plant species from becoming too dominant and reducing the area's biodiversity

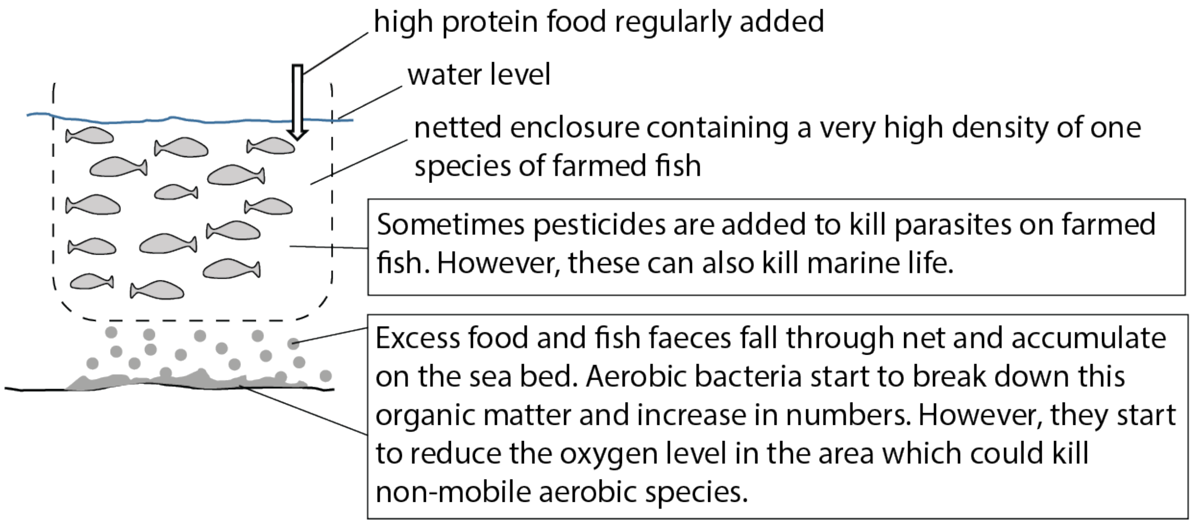
Negative interactions

Some interactions are negative, and ecosystems tend to be harmed. These can include

i. poorly managed intensive fish farming
ii. the effects of acid rain
iii. the process of eutrophication

i. Fish farming
In this process, high value fish, such as salmon, are grown in netted enclosures floating in sea water. The enclosures allow water to flow in and out, but do not let the fish escape, or allow predators to get in.

The diagram shows the process, and the potential harmful effects are identified in the boxes



Once solution is to regularly move the enclosure to a different location to stop the build-up of excess food and faeces. Another solution is to feed the fish little and often so less in wasted and falls through the enclosure.

ii. The effects of acid rain

What is acid rain?

- acid rain can also include acidic snow, etc. as well as rain
- its pH must be ≤ 5.5
- primarily formed due to sulfur dioxide, from combustion of fossil fuels such as coal, dissolving in water vapour forming sulphurous and sulfuric acid

The main effect is harm to some species, which can, therefore, effect other organisms in an ecosystem, as they all interact. Two major examples of the effects of acid rain are given in the table.

Organism affected	Effect(s)
Trees	Acid rain makes the soil more acidic. This causes mineral ions, that the trees need, to become less available, so the trees become mineral deficient. Also the acidic nature of the soil can allow aluminium that is normally bound to clay particles to be released. This aluminium is toxic to trees and can lead to tree death. As a consequence, the herbivore species that feed on the trees may die, and then those animals that feed on the herbivores may die. This reduces the biodiversity of an area.
Lakes & aquatic species	Non-flowing bodies of water are particularly susceptible to a lowering of pH. The released aluminium can be toxic to fish. Whilst some adult fish can survive a pH of 4 to 5, this pH would stop the fish fry from hatching out of eggs leading to a population crash.

Exercise 70

The data shows the lowest pH at which two aquatic species can survive.

Species	*Lowest pH at which the species can survive*
Mayfly	5.5
Frog	4.0

Frogs often eat mayfly. Explain why frogs are susceptible to acid rain at a pH of 5.0.

iii. Eutrophication

Eutrophication is an outcome of water pollution by fertiliser, particularly artificial fertiliser, because this is designed to be very water soluble so can easily run off land into a water course due to rain.

The flow diagram shows the effect of fertiliser once in the water.

Algae in the water take in the fertiliser and grow and reproduce. This can occur to such an extent that an algal bloom forms, and the water surface is covered by the algae.

↓

This can reduce the light intensity reaching aquatic plants below the algal bloom. The plants cannot photosynthesise and die

↓

Dead plants and algae accumulate at the bottom as a source of organic matter.

↓

Decomposer bacteria start to aerobically break down the organic matter, and in the process, they reproduce. The large numbers reduce the oxygen level in the water.

↓

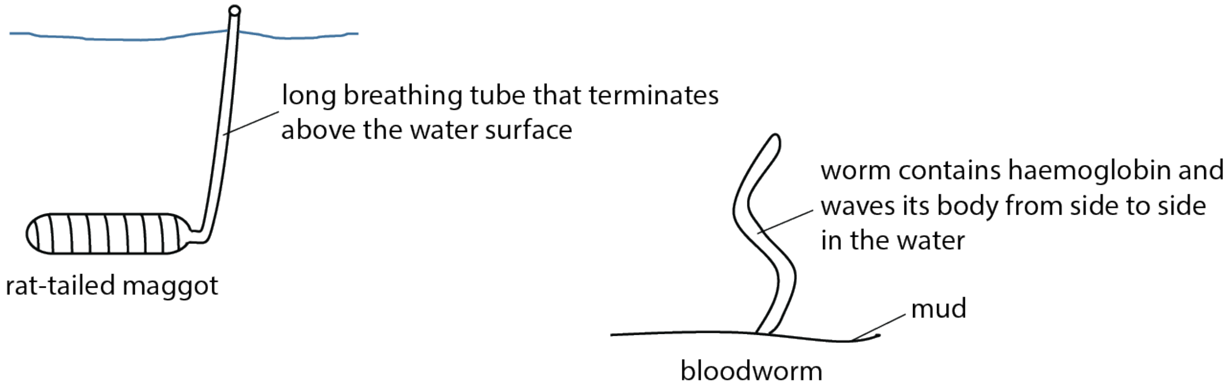
Mobile aerobic species, such as fish, swim away if they can. If not, then like non-mobile aerobic species, they will die. This reduces the biodiversity of the habitat.

↓

The species composition may now become altered in the anaerobic water course. Rat-tailed maggots and bloodworms may become the dominant species

Exercise 71

The diagram shows a rat tailed maggot and a bloodworm.



Using the information provided, explain how the adaptations of each enable them to live in low oxygen conditions.

Solutions to Exercises 61 to 71

Exercise 61

a) Sea rock pool, woodland, sandy seashore, lake, river, forest would all be acceptable answers.

b)

i. Include three groups of different species. An example could be, for a rock pool: named plant species, e.g. seaweed (*Fucus spiralis*), named herbivore, e.g. limpet (*Patella vulgata*), named carnivore, e.g. crab (*Carcinus maenas*).

ii. Include abiotic features which make the habitat special and remember to state the importance of each feature to the organisms living in the habitat.

An example could be, for a rock pool: rock, for anchorage of seaweed and protection of animals from wave action; water, containing oxygen, which the animals need for aerobic respiration and to prevent desiccation of the organisms; low temperature, so oxygen remains available for the organisms.

Exercise 62

a) Factors such as more births than deaths; more efficient food production; lower infant mortality rates; better control of diseases.

Each of the points could be supported with explanations. So, for example, for food production there could be references to: the use of genetic engineering to develop crops that can be grown in otherwise unsuitable environments; development of crops that have higher yields; better control of crop pests (through insecticides or biological control methods); better technology for crop management.

b) Factors such as shortage of food; disease/shortage of medicines; more wars; pollution; natural disasters.

In this situation, where the growth rate is slowing down, there are still more births than deaths. However, explanations would be appropriate for why the rate is slowing down. So, in the case of shortage of food, this may be because: there are distribution problems; cash crops are being grown at the expense of food crops; food crops are being exported, so are not available to the local population; changes in climate are preventing crops being successfully grown.

Exercise 63

You can choose any food chain with which you are familiar. Make sure that the food chain starts with a producer and remember that the arrows always point towards the consumer, indicating the flow of energy through the food chain.

You need to remember the names of the trophic levels and apply these terms to the organisms in the food chain you have constructed.

For example:

seaweed → limpet → crab → cod

producer → primary consumer → secondary consumer → tertiary consumer

Exercise 64

a)

i. Algae, kelp and phytoplankton are all producers because they form the base of the food web and the arrows showing the flow of energy point away from them to their consumers.
ii. The tiger shark and white-tipped reef shark both have five different sources of food.
iii. Krill feed on a producer (phytoplankton) so it is acting as a primary consumer. It also feeds on zooplankton, which are primary consumers, so the krill is acting as a secondary consumer as well.
iv. Organisms with only one food source are most likely to become extinct if the food source is not available. Green sea turtle, dugong, humpback whale and whale shark only have one food source, so are most vulnerable to extinction.

b) Five.

Exercise 65

a)

Process	**Requires oxygen?**	**Produces carbon dioxide?**	**Involves the release of heat energy?**
combustion	yes	yes	yes
decomposition	yes	yes	yes
photosynthesis	no	no	no
aerobic respiration	yes	yes	yes

b) With reference to the equations for photosynthesis and respiration, explain why interaction between the two processes could be considered to be maintaining stable carbon dioxide levels in the atmosphere.

Exercise 66

a)

Process A – water is evaporating from the surface of the sea.

Process B – the leaves of plants lose water by transpiration. This happens by diffusion because there is a lower concentration of water vapour in the atmosphere surrounding the leaves than in the air spaces inside the leaf.

Process C – the animals release water vapour into the atmosphere as they breathe out. The water is formed by respiration and evaporates from the surface of the alveoli in the lungs. Animals may also release water through sweat, urine and faeces.

Process D – precipitation is formed when the water vapour in the clouds condenses into liquid.

b)

i. Osmosis is the movement of water molecules from a higher water concentration to a lower concentration through a partially permeable membrane.
ii. If the plant roots become surrounded by salty water, the water in the vacuoles of root cells will contain a lower concentration of salt than the water surrounding the cells. This will reverse the process of osmosis so water passes out of the cells. The plant loses water, so it starts to wilt.

Exercise 67

a. As it is an estimate, anywhere within this range would be fine. Species A=40-60%, species B= 20-30%, and species C=10-15%.
b. The percentage cover can be greater than 100%, perhaps if one species grows on top of another species.
c. There are many, but rainforests on land and coral reefs in the sea would be examples.

Exercise 68

a. As it is an estimate, anywhere within this range would be fine. Species A=40-60%, species B= 20-30%, and species C=10-15%.
b. The percentage cover can be greater than 100%, perhaps if one species grows on top of another species.
c. There are many, but rainforests on land and coral reefs in the sea would be examples.

Exercise 69

Other factors might be determining the presence/absence of a species. For example, for species L at 4 and 6 metres

Exercise 70

A pH of 5.0 kills the mayfly, so the frogs’ food source is removed. The frogs could starve and die

Exercise 71

Rat-tailed maggot – the maggot can take in atmospheric air which has a high level of oxygen present (≈ 21%) for aerobic respiration, despite the water having little oxygen available.

Bloodworm – the presence of haemoglobin allows it to pick up any oxygen that might be present in this low oxygen environment. Waving its body means that as the oxygen is removed from the water surrounding the worm, this water is mixed with other water that may contain some oxygen.

Photos: CloudVisual - Unsplash/Pixabay/Ptelea/Science Photo Library/SGR - Unsplash

B11. Plant physiology

B11.1 Importance of photosynthesis:

a. Know and understand the process of photosynthesis as an endothermic reaction that uses light energy to react carbon dioxide and water to produce glucose and oxygen.
b. Understand the effect of temperature, light intensity and carbon dioxide concentration as limiting factors on the rate of photosynthesis.

B11.2 Transport systems in plants:

a. Know and understand how the structures of xylem and phloem are adapted to their functions in plants, including the role of:
    i. lignified dead cells in xylem tissue in the transport of water and mineral ions from the roots to the stems and leaves.
    ii. living cells in phloem tissue in the transport of dissolved sugars from the leaves to the rest of the plant for immediate use or storage.
b. Know and understand how water and mineral ions are taken up by plants, and relate the structure of root hair cells to their function in this.
c. Know and understand the processes of transpiration and translocation, including the structure and function of the stomata.
d. Know and understand the effect of environmental factors on the rate of water uptake by a plant, including light intensity, air movement, humidity and temperature.
e. Calculate the rate of transpiration as:

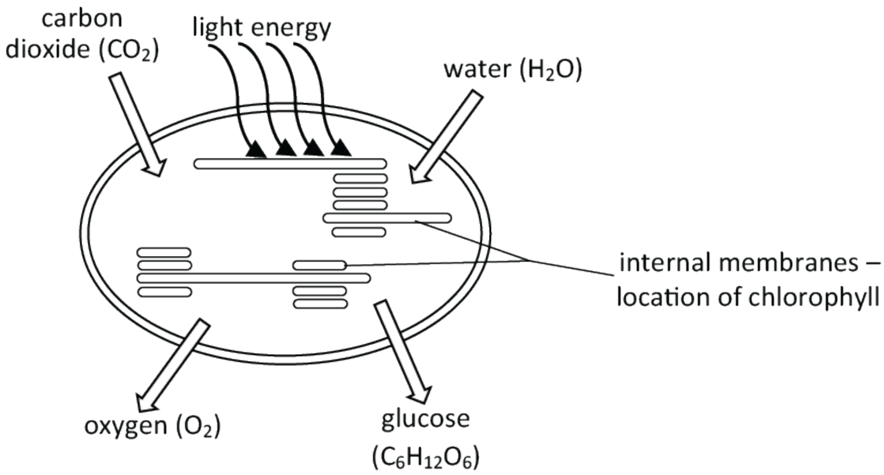
$$\text{rate of transpiration} = \frac{\text{volume of water}}{\text{time taken}}$$

Photosynthesis

Photosynthesis is a chemical process that occurs in the chloroplasts of some plant cells. Chloroplasts contain a pigment called chlorophyll that absorbs certain colours (wavelengths) of light. As light is part of the electromagnetic spectrum, the chlorophyll is absorbing a form of energy. As there is a net energy input, photosynthesis is an endothermic process.

The chloroplasts are able to convert the light energy into chemical energy in the form of glucose.

The diagram shows the reactants a chloroplast absorbs and the products it makes.



The word equation for photosynthesis is: carbon dioxide + water → glucose + oxygen

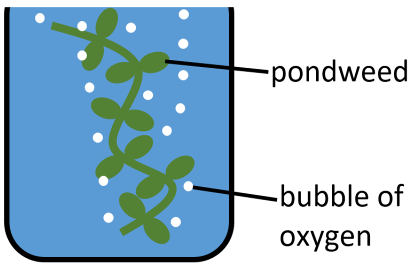
Exercise 72

What might a plant use the glucose it has made for?

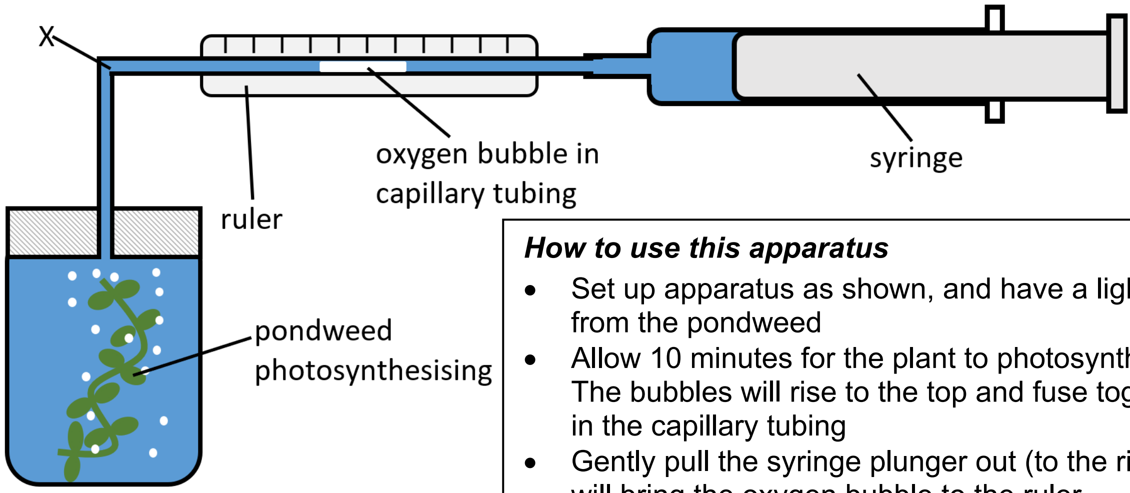
What environmental factors can affect the rate of photosynthesis?

To be able to consider the factors, an understanding of how to assess the rate of photosynthesis is necessary.

One way is to measure the rate of oxygen production. This may seem difficult as it is a colourless gas, but in aquatic plants such as pondweed, bubbles of oxygen are released. These can be counted in a set time.



Bubbles, however, vary in size, so a modification to this apparatus can be used to gain a more accurate result. This is shown below.



How to use this apparatus

- Set up apparatus as shown, and have a light source 30 cm from the pondweed
- Allow 10 minutes for the plant to photosynthesize.
  The bubbles will rise to the top and fuse together at point X in the capillary tubing
- Gently pull the syringe plunger out (to the right) and this will bring the oxygen bubble to the ruler
- The rate of photosynthesis can be calculated by using the formula: $(\pi r^2 h)/\text{time}$, where r is the capillary tubing lumen radius and h is the length of the oxygen bubble (measured using the ruler). Therefore, the rate will be volume ÷ time with units such as mm^3 per minute

Three factors that affect the rate of photosynthesis

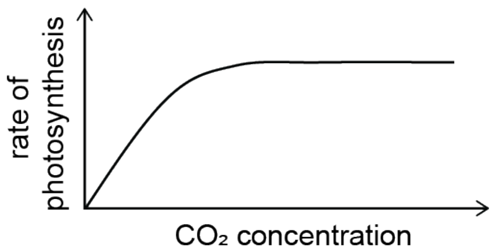
Factor	**Reason it affects the rate of photosynthesis**
CO_2 concentration	CO_2 is one of the reactants
Light intensity	Light is the energy source used in photosynthesis
Temperature	Photosynthesis involves chemical reactions that are catalysed by enzymes

How each factor affects the rate of photosynthesis

1. CO_2 concentration

Practical: The above apparatus can be used. However, to vary the CO_2 concentration, different masses of sodium hydrogen-carbonate can be dissolved in the pondweed water. Leave the pondweed for five minutes at each CO_2 concentration before finding the rate of photosynthesis. This five minutes allows the pondweed to acclimatise to the new CO_2 concentration.

Results:



Explanation:

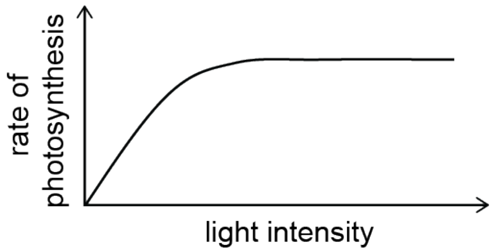
- As the CO_2 concentration increases, so does the rate of photosynthesis initially as CO_2 is limiting the rate.
- Once the plot plateaus, increasing CO_2 concentration has no additional effect on the rate of photosynthesis. This is because some factor, other than CO_2 concentration, is limiting the rate. E.g. the light intensity isn't high enough.

2. light intensity

Practical: The above apparatus can be used. However, to vary the light intensity, the light source should be moved different distances from the pondweed. Remember to leave the pondweed for five minutes at each light intensity before finding the rate of photosynthesis. This five minutes allows the pondweed to acclimatise to the new light intensity. A metre ruler can be used, and it should be noted that

$$\text{light intensity} \propto \frac{1}{(\text{distance between the lamp and pondweed})^2}$$

Results:



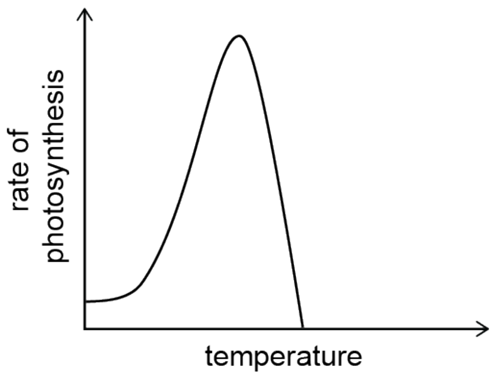
Explanation:

- As the light intensity increases, so does the rate of photosynthesis initially as light intensity is limiting the rate
- Once the plot plateaus, increasing light intensity has no additional effect on the rate of photosynthesis. This is because some factor other than light intensity is limiting the rate. E.g. the temperature is too low.

3. Temperature

Practical: The above apparatus can be used. However, to vary the temperature, the container with the pondweed and water in should be placed in a water bath, and left for five minutes before investigating. This five minutes allows the pondweed to reach the working temperature. Repeat at different temperatures.

Results:



Explanation:

- As the temperature initially increases, so does the rate of photosynthesis as the enzymes and reactants have more kinetic energy, so are more likely to collide and form enzyme-substrate complexes, so will react.
- A point will be reached when the rate of photosynthesis is at its maximum. This is the optimum temperature.
- As the temperature continues to increase, the rate of photosynthesis decreases as the enzymes involved start to denature, so their active site shape changes and enzyme-substrate complexes cannot form as the active site is no longer complementary in shape to the substrate.

Transport systems in plants

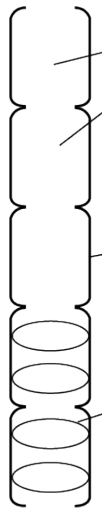
Plants transport a range of materials throughout their body using a vascular system. The two major components are xylem and phloem. Both are found in the roots, stems and in the veins of leaves.

The table shows the main functions of these two components.

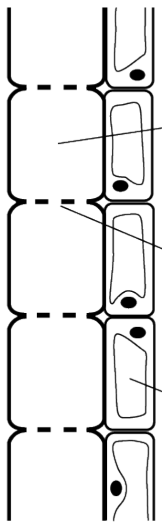
	Main material(s) being transported	Direction of transport
Phloem	Dissolved sugars (such as sucrose)	In all directions from the leaves to wherever the sugar is needed for immediate use (respiration) or for storage (as starch)
Xylem	Water Mineral ions such as nitrates	Up (from roots to stems and leaves)

The two diagrams below show mature xylem and phloem. The labels include the adaptations, and in italics, how they work.

Xylem



Phloem



How are water and mineral ions taken up by plants?

Whilst the obvious answer is by the roots, the majority of a plant root is used to anchor the plant in the ground. Towards the tip of the root are found specialised cells used for uptake: the root hair cells.

The table gives details of the mechanisms used by plants to take up water and mineral ions.

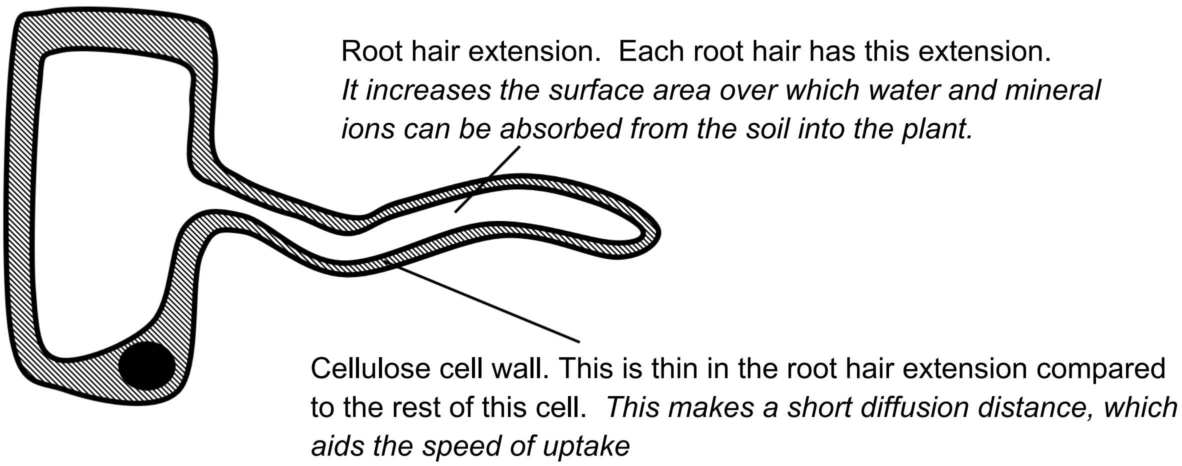
Substance absorbed	**Process**	**Comments**
Water	Osmosis	The water moves from the soil, where it is in high concentration, across the root hair cell membrane, and into the cytoplasm, where the water concentration is lower
Mineral ions	Active transport	Mineral ions tend to be present in lower concentrations in the soil than in plant cells. However, the plant needs to keep taking them up and does so against the mineral ion concentration gradient. To so this, energy is required (from respiration), and carrier proteins that span the width of the root hair cell membrane

Exercise 73

a. What would happen to the uptake of nitrate ions if a metabolic poison was added that reduces the activity of mitochondria?

b. What would happen if the soil became waterlogged?

The root hair cell has adaptations to maximize the uptake of these substances. These are shown in the diagram below. The labels include the adaptations, and in italics, how they work.



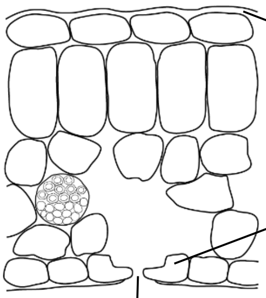
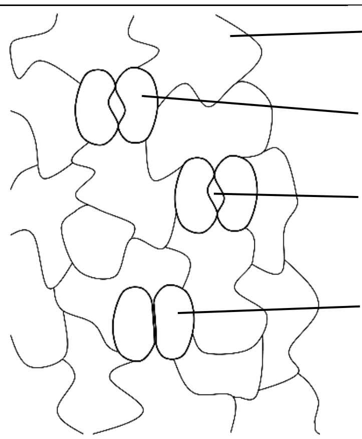
The process of translocation

The sugars enter the phloem at the leaves where they are made. This is an active process so requires energy. The sugars then move to where they are required, and either used or stored. This means there is always a concentration gradient between the site of production and the final destination.

The process of transpiration

Transpiration is the loss of water vapour from a plant, primarily through its leaf stomata.

The diagram below shows the location of most stomata in a leaf; and the structure of the lower epidermal layer.

<table>
<tr><th>Section through a typical broad leaf</th><th>Lower epidermis with three stomata present</th></tr>
<tr><td>
</td><td>
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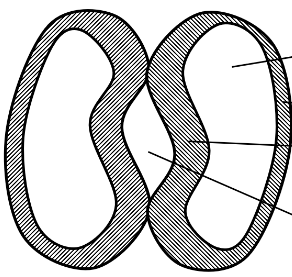
How do the guard-cell stomatal complexes work?

The diagram shows how the cellulose cell wall arrangement of guard cells leads to the opening and closing of a stomatal pore.



Mechanism

1. Stomatal opening
   - Guard cells take in water through osmosis
   - Each cell starts to expand but less so on the side of the thick cellulose cell wall than on the thin side.
   - Each guard cell becomes more ‘bean’ shaped as it expands and a stomatal pore opens
2. Stomatal closing
   - The reverse of the above happens

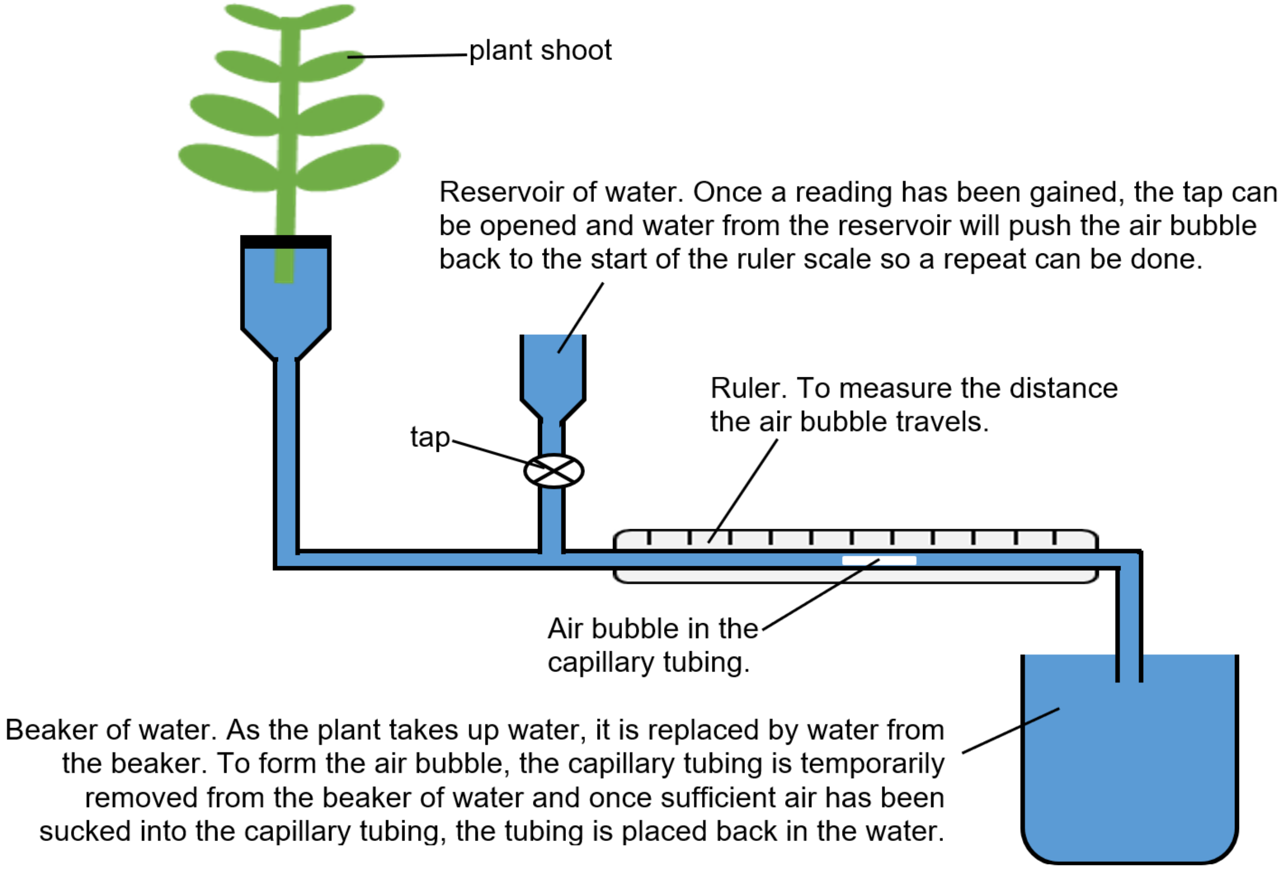
Exercise 74

a. Why do many plants have the majority of their stomata on the lower surface of their leaves?

b. Why do lily pads have their stomata on the upper side of their leaf?

How to measure the uptake of water by a plant

The main way to do this is to use a bubble potometer. This is shown below.



To measure the rate of water uptake, the volume of water taken up per unit time has to be found. The formula is $(\pi r^2 h)/\text{time}$, where r is the radius of the capillary tubing, and h is the distance the bubble has travelled. Typical units would be mm^3 per minute.

Exercise 75

a. Why is it necessary to cut the stem of the shoot under water before placing in the potometer?

b. Explain what would happen to the rate of water uptake if the lower surface of the leaves of a plant in a bubble potometer are covered in a waterproof layer?

What environmental factors can affect the rate of water uptake by a plant?

An important point to note is that one of the main aspects of water uptake is to replace water lost through transpiration. So the environmental factors that affect water uptake also affect transpiration.

Four important environmental factors are:

- Light intensity
- Air movement
- Humidity
- Temperature

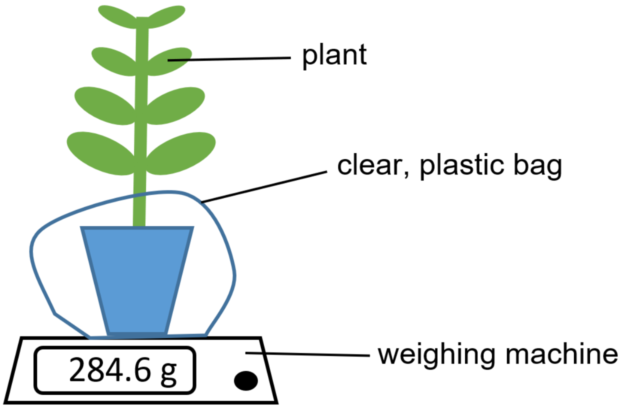
The table describes the effect of each on water uptake and transpiration.

Factor	Effect on water uptake and transpiration	Description of why the factor has this effect
Light intensity	Increasing light intensity, increases water uptake and transpiration.	As light intensity increases, the diameter of the stomatal pores increase, so more water vapour is lost through transpiration, so more water is taken up. N.B. A very high light intensity leads to stomatal pore closure to reduce transpiration
Air movement	Increasing air movement, increases water uptake and transpiration.	The air around a leaf starts to become more humid due to water vapour loss from the stomata. As air movement increases, this humid air is blown away and replaced with less humid air, so more water vapour can enter. This lost water has to be replaced by water uptake.
Humidity	Increasing humidity, decreases water uptake and transpiration.	As air becomes more humid, less water vapour can enter it as the concentration gradient is decreasing.
Temperature	Increasing temperature, increases water uptake and transpiration.	As temperature increases, the air can hold more water vapour, so the concentration gradient increases. The rate of water loss increases, hence the rate of water uptake increases N.B. Very high temperatures lead to stomatal pore closure to reduce transpiration.

The following equipment can be used to measure transpiration:

1. Bubble potometer (see above)

2. Mass potometer



How this works:

- Water a plant and then put the pot in a clear, plastic bag. The bag stops water evaporating from the soil in the pot.
- Find the initial mass of the plant and pot.
- Leave for one week and then find the new mass.
- The conversion from mass of water to volume of water is one gram of water has a volume of one cm^3.
- To work out the rate of transpiration, divide the volume change by the time. To make it so that the rate can be compared with other plants, the change in volume per hour per gram of plant tissue can be calculated.

Please note that an assumption is made: water uptake equals water loss

Exercise 76

Give two reasons why the uptake of water may be higher than the rate of water loss in a plant during the day.

Solutions to Exercises 72 to 76

Exercise 72

for respiration to supply usable energy / ATP
for active transport of mineral ions from the soil into their roots
to allow cell division for growth
to be converted into starch as an energy store
to be converted into cellulose for the plant cell wall

Exercise 73

a. A reduced mitochondrial activity means less aerobic respiration, so less ATP is produced. This means less active transport can occur, so less nitrates would be absorbed

b. Waterlogging means that water fills the air spaces between the grains of soil. As air is absent, there is a shortage of oxygen, so aerobic respiration cannot occur, so again ATP is limiting, and therefore active transport is reduced and the nitrates are not taken up by the root hair cells

Exercise 74

a. It is slightly cooler on the lower surface, so the rate of water vapour loss will be lower.

b. The lower surface of a lily pad is on the water surface, so the stomata have to be on the upper surface so gas exchange can occur with the atmosphere.

Exercise 75

a. So no air bubbles get trapped in the xylem and stop it taking up water.

b. The stomata are on the lower surface of the leaves, so are blocked, so less water vapour is lost through transpiration, so the rate of water uptake will decrease.

Exercise 76

Some water is used in photosynthesis.

If plant has not been well watered beforehand, some water taken up will be used to make the cells turgid.