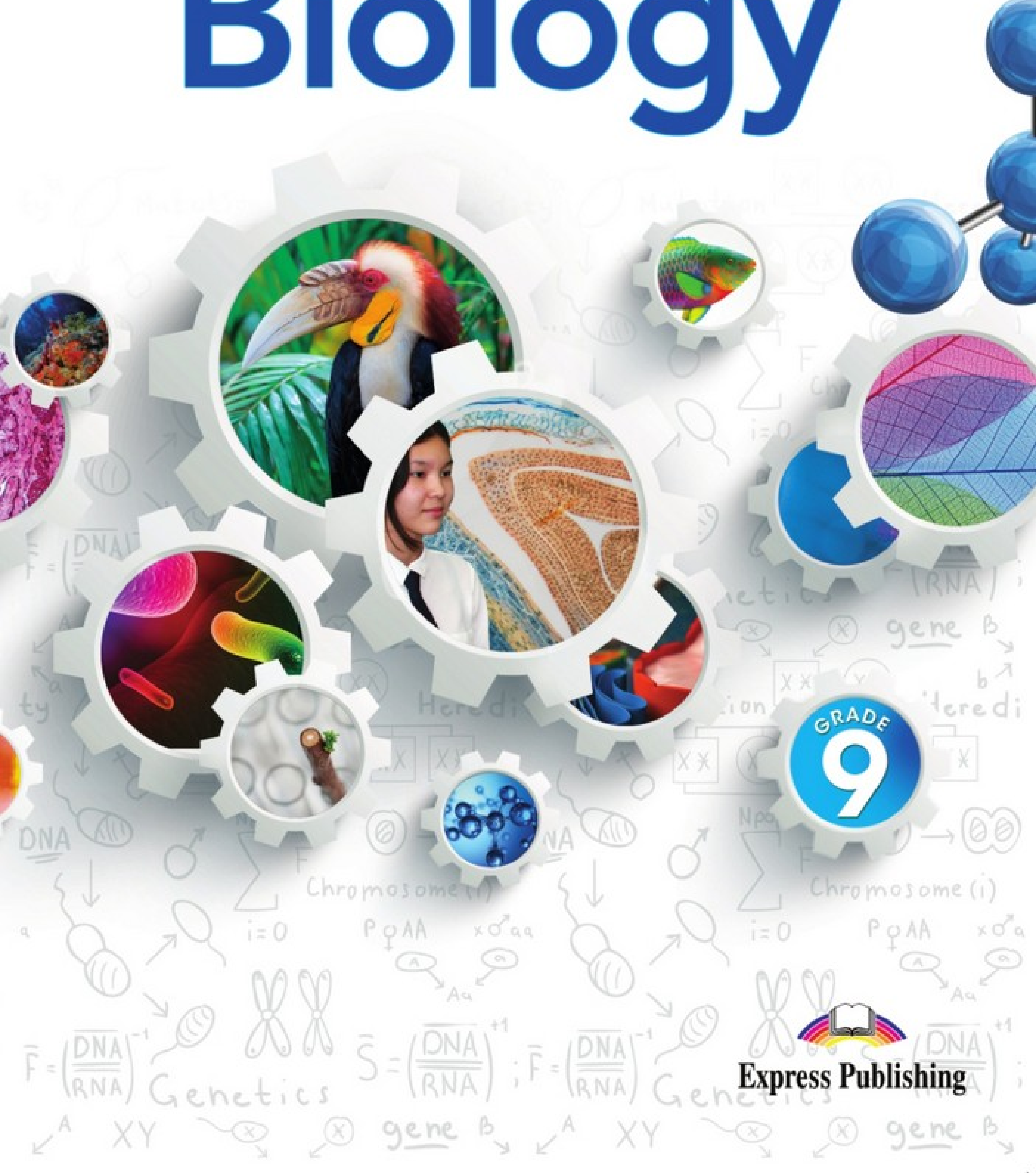
Biology



GRADE 9

Express Publishing

Biology

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Published by Express Publishing

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First published 2018

Printed in Kazakhstan

ISBN 978-1-4715-7525-9

Acknowledgements

We thank EDU Stream for photos of people and translations.

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Contents

Introduction

For the student

Welcome to your new Biology textbook, *Grade 9 Biology*. Your textbook comes with a **Grade 9 Biology Student's Portfolio** and a range of *digital resources*. This book will build on your previous learning of Biology by helping you to understand the world around you. It aims to develop your learning skills in science. You will develop these skills yourself while also learning from your teacher and your fellow students.

Glossary

A comprehensive Glossary for the Textbook and Student's Portfolio book is included at the back of this book.

For the teacher

Written for the new Grade 9 Biology subject programme in Kazakhstan, *Grade 9 Biology* aims to give students a sense of enjoyment and an interest in the learning of science. The book is based on the Grade 9 Learning Objectives in the Grade 7- 9 Biology subject programme document. It develops students' knowledge of and about science through the four content and skills strands described in the Biology subject programme and highlighted throughout the text using four different logos (understanding science, researching and experimenting in science, communicating in science, and science and society).

Understanding U1 | Research R4 | Communicating C3 | Society S2

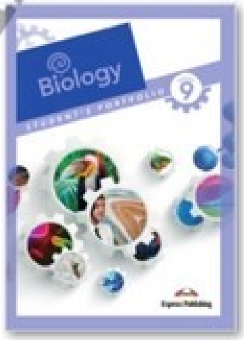
- **Learning outcomes** are stated at the beginning of each module in student-friendly language.
- **Keywords** are listed at the start of each module to allow students to become familiar with important new terms.
- **Activities** allow students to build on their knowledge by completing research.
- **Diagrams** have been fully labelled and are drawn in a simple style so that students can replicate them easily.
- **Questions** are interspersed within the text to offer teachers the opportunity to use different teaching strategies. In particular, there are chances for group work and pair work.
- **Did you know?** boxes feature interesting facts to stimulate students' interest in science.

- The **language** used is clear and simple to allow for use by students of varying reading levels.
- Simple and helpful **logos** are used throughout to enhance student understanding.

Activity — Corresponding page in Student's Portfolio — Key fact

Question — Group work — Research

Student's Portfolio



The Student's Portfolio provides additional material, activities and tasks. The portfolio book enables students to maintain a record of specific activities and reflect on their learning, as well as focusing on key words and key facts, through mind maps and comprehension and recall activities. It also contains templates for self-assessment and peer assessment. This book works in conjunction with the Textbook.

Teacher's Book

The Teacher's Book works in conjunction with the Textbook and the Student's Portfolio book by providing:

- An outline of the Grade 9 content and skills priorities in the subject programme
- Learning outcomes for each module with explanations of how they are incorporated into lessons
- Information on topics, questions and research ideas that can be used to enhance the students' learning
- Answers to all student questions in the Textbook and Student's Portfolio book
- Outlines of digital resources for each module and suggestions for integrating them into classroom work
- Suggestions of ways to assess student activities with assessment templates
- A range of other information and suggestions to support teachers in the delivery of the new course
- Key skills, literacy and numeracy linked to relevant modules
- Guidance for the teacher through the module
- Additional activities and research activities

Digital resources

The *Grade 9 Biology* **digital resources** will further enhance classroom learning. These resources have been designed to integrate with the Textbook and to complement lessons suggested in the Teacher's Book. Following the principles of the new national Biology subject programme, material is provided to suit a range of learner types and to encourage participation and engagement on the part of the student.

A series of **videos** allows students to observe science in action across all modules. These videos reinforce the topic at hand and allow for other perspectives, which may be discussed in class. Similarly, a series of **videos** about **scientist biographies** presents a lively gateway to develop students' interest in science and initiate student-led research.

Further classroom discussion and participation is opened up through **PowerPoint presentations**, including a thematic presentation of information from the Textbook. **Experiment videos** allow for a visual review of activities carried out in the classroom. **Extra assessment material** is provided to support teachers in carrying out a range of oral and written formative and summative assessments.

Guidance for integration of digital resources in the classroom is provided by the **digital resource symbol** used throughout the Textbook, as well as the provision of detailed notes and suggestions in the Teacher's Book.

Laboratory equipment

Laboratory safety rules for pupils

The following rules are enforced to keep you and your classmates safe while in a school laboratory.

1. Do not enter the laboratory without permission.
2. Do not use any equipment unless permitted to do so by your teacher.
3. Make sure you know exactly what you are supposed to do. If in doubt, ask your teacher.
4. Make sure you know the position of all safety equipment in the laboratory, e.g. the fire extinguishers, first aid equipment etc.
5. Always wear eye protection or gloves when instructed to do so.
6. Long hair must be tied back during practical classes.
7. Place your bag and other personal items safely out of the way.
8. Never handle any chemicals with bare hands.
9. Nothing must be eaten, tasted or drunk in the laboratory.
10. Any cut, burn or other accident must be reported at once to your teacher.
11. Always check that the label on the bottle is exactly the same as the material you require. If in doubt, ask your teacher.
12. Any chemical spilled on the skin or clothing must be washed at once with plenty of water and reported to your teacher.
13. Test tubes should never be overfilled. When heating a test tube ensure that the mouth of the test tube is pointed away from you and everyone else.
14. All equipment should be cleaned and put back in its correct place after use.
15. Always wash your hands after practical work.
16. Students should behave in a responsible manner at all times in the laboratory.

Safety labels

The following labels appear on bottles in the laboratory. They also appear on many everyday chemicals such as cleaning products and solvents. These labels indicate chemicals that could be dangerous if not used or handled properly. We use these warning symbols on activities in this book.

Toxic		Substances which can cause death if they are swallowed, breathed in or absorbed through the skin. Example: weedkiller.
Harmful or irritant		Substances which should not be eaten, breathed in or handled without gloves. Though not as dangerous as toxic substances they may cause a rash, sickness or an allergic reaction.
Oxidising		Substances which provide oxygen, allowing other materials to burn more intensely. Example: hair bleach.
Highly flammable		Substances which easily catch fire. Example: petrol.
Corrosive		Substances which attack and destroy living tissue, including skin and eyes. Example: oven cleaner.
Warning sign		This sign is used to draw attention to a warning of danger, hazards and the unexpected.
Safety glasses		Wear safety glasses to protect your eyes.

T

taxonomy The science of classifying organisms.

tendons Strong, flexible, inelastic fibres that connect muscle to bone.

theory A hypothesis that has been supported by many different experiments.

testis (plural: testes) The organ in a male that produces sperm.

threshold The minimum stimulus needed to cause an impulse to be carried in a neuron.

tissue culture The growth of cells in or on a sterile nutrient medium outside an organism.

tissue A group of similar cells that are modified (or adapted) to carry out the same function(s).

transcription The copying of a sequence of genetic bases from DNA onto messenger RNA (mRNA).

transformation The uptake of DNA into a cell.

translation The conversion of a sequence of genetic bases on messenger RNA into a sequence of amino acids.

translocation The movement of sugars produced in the leaves to other regions of the plant.

transpiration The loss (by evaporation) of water vapour from the leaves and other aerial parts of a plant.

triplet (or **codon**) A sequence of three bases in DNA (or RNA) that act as a code for an amino acid.

trophic level A feeding stage in a food chain.

tropism A change in the growth of a plant in response to an external stimulus.

tuning fork A two-pronged steel device which vibrates when struck.

turgor (or **turgor pressure**) The outward pressure of the cytoplasm and vacuole against the cell wall of a plant.

U

ultrasound Sound or other vibrations having an ultrasonic frequency, particularly as used in medical imaging (ultrasound scan in pregnancy).

ultrastructure The detail of a structure as seen using an electron microscope.

umbilical cord A tube connecting the baby (at the navel) to the placenta.

uterus The womb.

V

vaccination The administration (usually by injection) of a non-disease-causing dose of a pathogen (or its toxin) to stimulate the production of antibodies.

vaccine A non disease-causing dose of a pathogen (or its toxin), which triggers the production of antibodies.

vacuoles Membrane-bounded compartments that support the cell and store substances such as food, wastes and water. Mostly found in plant cells.

vagina A muscular tube in females leading to the uterus.

valves Control the direction of blood flow.

variable A factor that may change in an experiment.

variation (within a species) In a group of successfully interbreeding organisms the individual members show different characteristics.

vertebrate An animal that has a backbone or spinal column.

vibration An oscillation of the parts of a fluid or an elastic solid whose equilibrium has been disturbed or of an electromagnetic wave.

virus The smallest type of micro-organism, normally cause a disease.

W

wilt (of a plant, leaf or flower) To become limp through heat, loss of water or disease; to droop.

X

xylem The vascular tissue in plants which conducts water and dissolved nutrients upwards from the root and also helps to form the woody element in the stem.

MODULE 1

Cells and the diversity of living organisms

Learning outcomes

At the end of this module you will be able to:

- Explain the basic functions of the components of plant and animal cells 9.4.2.1
- Calculate a linear increase in cells using microphotography 9.4.2.2
- Recognise and use classification nomenclature when describing different species 9.1.1.1
- Recognise plant and animal species by their different features 9.1.1.2

Keywords

✔ genetics ✔ cell wall ✔ vacuole ✔ cytoplasm ✔ cell membrane ✔ chloroplast ✔ nucleus ✔ mitochondria ✔ magnification ✔ scale bar ✔ inflorescence ✔ noxious weed ✔ cereal ✔ crops ✔ perennial ✔ genus ✔ species ✔ ectoparasite ✔ metamorphosis

Cells

Cells are the basic building blocks of life. The human body alone is believed to be made up of 100 trillion cells, while the simplest organisms such as bacteria, protozoans and some fungi are composed of just a single cell (unicellular).

Animal cells

When viewed under a light microscope, animal cells can be seen to contain a cell membrane, cytoplasm and a nucleus. The nucleus is the control centre of the cell. Animal cells contain many other organelles but these are only visible with an electron microscope.

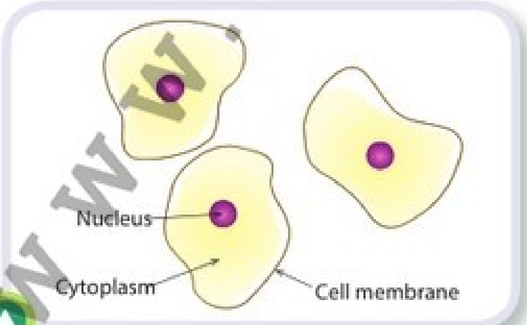


Figure 1.1 *Animal cells*

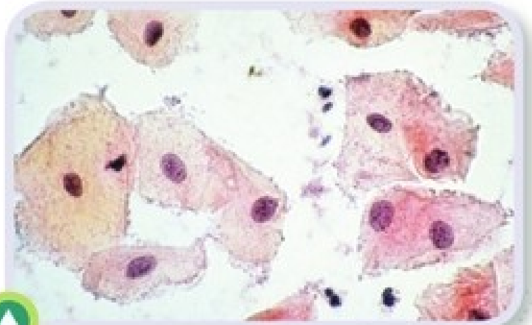


Figure 1.2 *Human cheek cells viewed through a light microscope*

Plant cells

Plant cells have a number of additional features that animal cells do not. Plant cells include a cell wall, a large vacuole and chloroplasts.

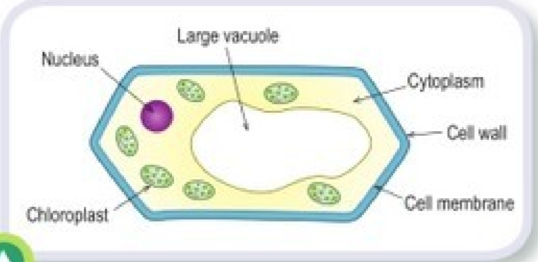


Figure 1.3 *Plant cells*

Figure 1.4 *Plant cells viewed through a light microscope*

Cell structure

Nucleus

Both plant and animal cells have a membrane-bound nucleus which is composed of a substance called chromatin. Chromatin is a mixture of DNA and protein. When a cell begins to divide, the chromatin condenses into structures called chromosomes. Chromosomes contain genetic instructions in the form of genes that control the functions of the cell.

> **Deoxyribonucleic acid (DNA)** is the genetic code that controls cell growth, cell division and cell function.
>
> A **chromosome** is a thread-like structure of DNA and protein found in the nucleus of most living cells and carrying genetic information in the form of genes.

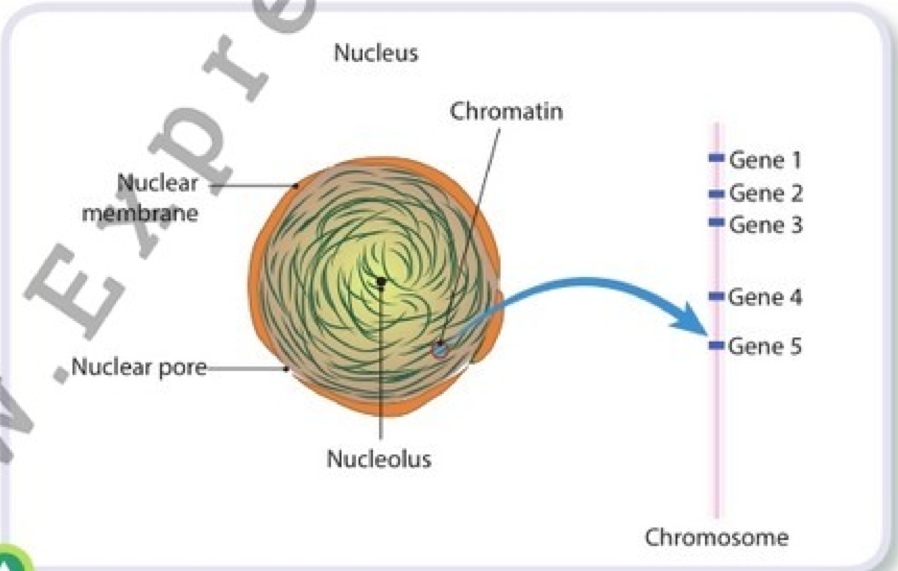


Figure 1.5 *Nucleus and chromosome*

A **eukaryotic cell** is a cell containing a membrane-bound nucleus that holds genetic information, and other membrane-bound organelles (e.g. mitochondria and chloroplasts).

Cell wall and cell membrane

Plant cells have a porous cell wall that surrounds the cell membrane. It is composed of a rigid carbohydrate called cellulose. The cell wall is fully permeable to water, oxygen, carbon dioxide and many other particles. The purpose of the cell wall is to strengthen and protect the plant cell. In addition, the cell wall prevents the overexpansion of plant cells when water enters the plant cell by osmosis. Plants require the mineral calcium for the production of healthy cell walls. Animal cells **do not** have a cell wall.

Both plant and animal cells have a cell membrane. Cell membranes have several functions: they hold the contents of the cell, provide shape and support to the cell and control what substances enter and leave the cell. Cell membranes are **selectively permeable**, allowing some molecules (water and oxygen) to move freely across them. Some larger molecules require energy to move them across the cell membrane.

Did you know?

Cell membranes are also known as plasma membranes.

Cytoplasm

The cytoplasm consists of a watery fluid called cytosol in which all of the cell's organelles are suspended. Many cell activities (protein synthesis) and reactions (glycolysis) take place in the cytoplasm of the cell. The cytoplasm also helps to maintain the shape of the cell.

Mitochondria and chloroplasts

Both plant and animal cells contain mitochondria. Mitochondria are often known as the power houses of the cell because they play a major role in the release of energy from glucose during respiration.

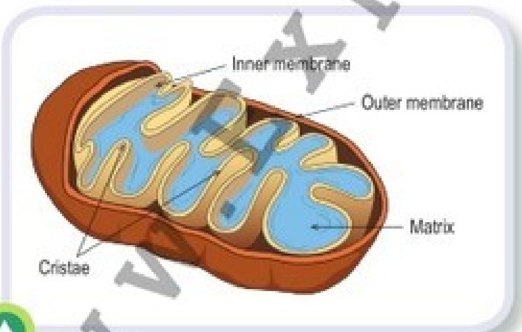


Figure 1.6 *Mitochondria*

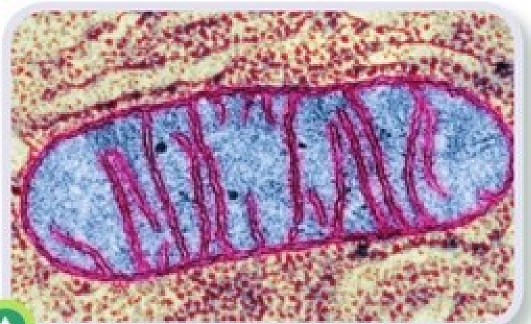


Figure 1.7 *Mitochondria viewed through an electron microscope*

Chloroplasts are found in plant cells only. They contain the pigment chlorophyll and their main function is photosynthesis.

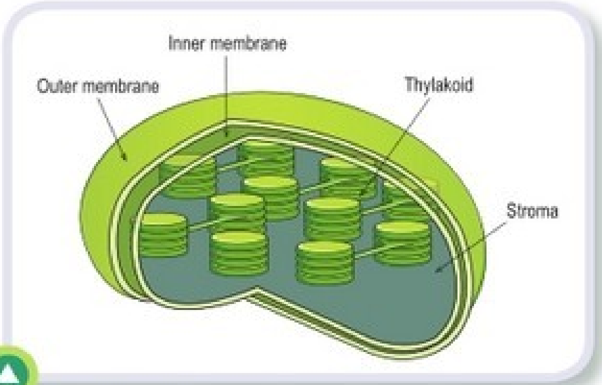


Figure 1.8 *Chloroplasts*

Figure 1.9 *Chloroplasts viewed through an electron microscope*

Both mitochondria and chloroplasts are only visible using an electron microscope. They are both membrane-bound organelles and they both contain their own DNA.

Vacuole

Plant cells have large vacuoles, whereas animal cells have much smaller vacuoles. Vacuoles provide extra support to plant cells and can be used for the storage of sugars and salts.

Ribosomes

There are millions of ribosomes in every cell. They are composed of RNA (ribonucleic acid) and protein. They are involved in the synthesis of protein.

Table 1.1 The functions of cell contents

Structure	Function
Cell wall	Strengthens and protects the plant cell
Cell membrane	Controls the passage of substances into and out of the cell
Nucleus	Controls centre of the cell, cell division; contains DNA
Cytoplasm	Fluid contains cell organelles
Mitochondria	Respiration
Chloroplasts	Contain chlorophyll; photosynthesis occurs here
Large vacuoles	Provide support; used for storage of dissolved substances
Ribosomes	Protein synthesis

Table 1.2 The main differences between plant and animal cells

Plant cells have a cell wall	Animal cells do not have a cell wall
Plant cells have a large vacuole	Animal cells have small vacuoles
Plant cells have chloroplasts for photosynthesis	Animal cells do not have chloroplasts

Q Understanding U4

1.1 The diagram shows the main parts of a plant cell. The cell membrane is already labelled.

- **(a)** Identify parts labelled A, B, C, D and E.
- **(b)** In which part are the chromosomes found?
- **(c)** What is the function of chromosomes?

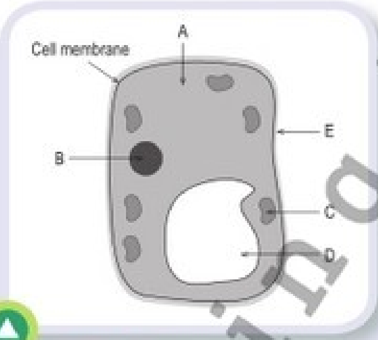


Figure 1.10

1.2 Draw a diagram of a simple animal cell (e.g. cheek cell) as seen under a light microscope. Label any three parts.

1.3 State two differences between plant and animal cells.

1.4 What term is given to cells that have membrane-bound genetic material and organelles?

1.5 Explain the function of each of the following in a plant or animal cell:

- **(a)** Cell wall
- **(b)** Nucleus
- **(c)** Mitochondria
- **(d)** Chloroplasts
- **(e)** Cytoplasm
- **(f)** Vacuole.

Magnification under a microscope

Calculating magnification and size of microscope images

In calculating the size of images seen under the microscope and their magnification we commonly use two units of measurement: the micrometre µm and the nanometre nm.

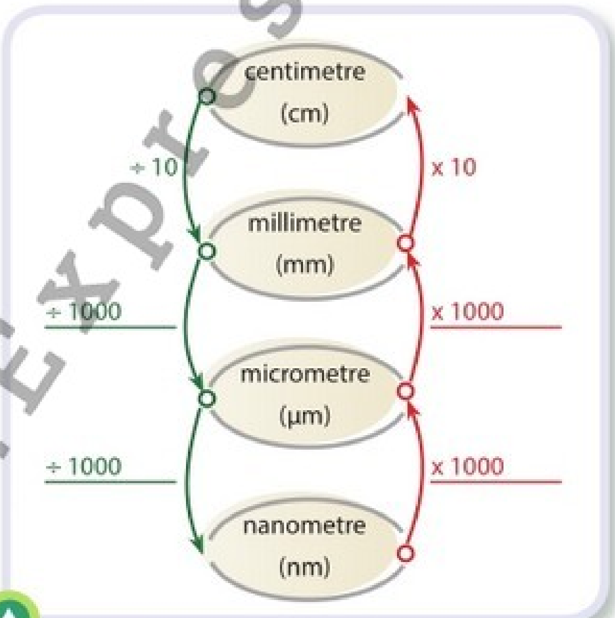


Figure 1.11 *Calculating the size of images using µm and nm units of measurement*

Figure 1.12 represents the relationship between the three terms typically involved in such calculations.

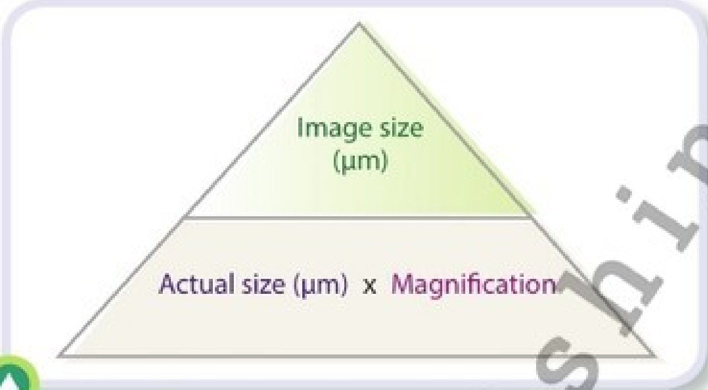


Figure 1.12 Calculating magnification and size of microscope images

image size = actual size x magnification

magnification = image size ÷ actual size

Q Understanding U4 Research R4

1.6 What equation would you use to work out the actual size of something if you were given magnification and image size?

To calculate magnification of an image such as Figure 1.13 you need to follow three basic steps:

Step 1 – Take a ruler and measure the length of the scale bar in mm.

Step 2 – Convert this measurement into the units on the scale bar.

Step 3 – Use these values in the equation.

$$\text{magnification} = \frac{\text{image size}}{\text{actual size}}$$

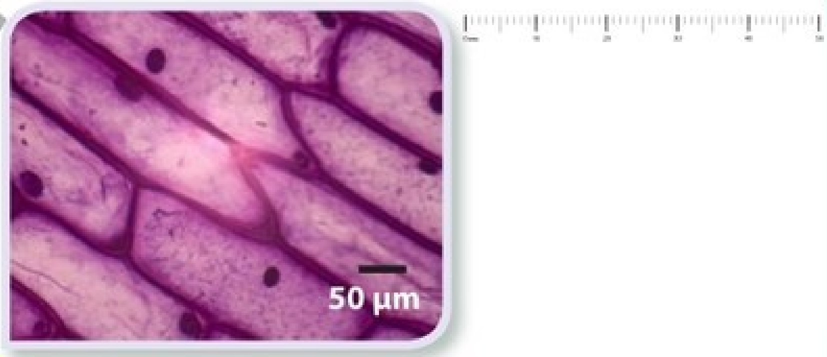


Figure 1.13 Calculating a magnified image using a scale bar

Q U4 R4

1.7 Calculate the actual size of these human cheek cells.

1.8 Calculate the magnification of this image.

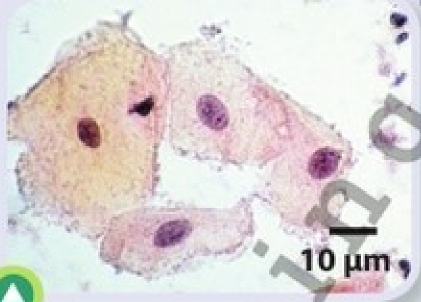


Figure 1.14 *Calculating the size of human cheek cells*

The Plant Kingdom (Plantea)

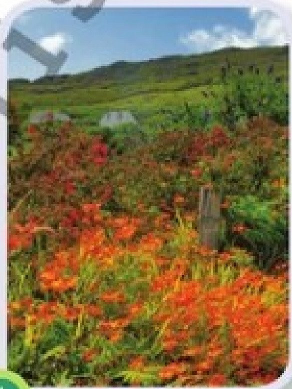


Figure 1.15 *Wildflowers*

It is thought that plants evolved from green algae about 500 million years ago. The evolution of plants allowed life to exist for the first time on land.

The major groups of plants are mosses, ferns and seed-producing plants. The seed-producing plants consist of non-flowering plants such as pine trees and flowering plants such as grasses, cereals, flowers and many trees.

Flowering plants comprise the greatest number of plant species (about 250 000), compared with about 30 000 species for all the other types combined.

The emergence of plants on land provided food for the animals that were to evolve soon after them on land.

Main features of plants

- They are complex, multicellular organisms.
- They are photosynthetic.
- Their cell walls are made of cellulose.
- Their cells often contain large vacuoles.
- They are non-motile.
- They reproduce asexually and sexually.
- They protect the embryo for a time within the structure of the parent plant.

Identifying plant families

Family Gramineae

Gramineae is the most important plant family in agriculture and it is a very large one with an estimated 10,000 species. This family contains productive perennial ryegrass varieties *Lolium perenne* (used for grazing, hay and silage), and cereals such as wheat (*Triticum aestivum*), barley (*Hordeum vulgare*) and maize (*Zea mays*), which are mainly used as animal feeds. All the members of this family are monocots, having one cotyledon in the seed. The part of the grass plant commonly referred to as the flower is composed of many florets (small flowers) contained in a structure called the spikelet. The florets contain the stamens and the carpel. The members of this family can be distinguished from each other on the basis of their inflorescence.

Inflorescence is the fixed arrangement of spikelets on the stem.

Grasses have three main types of inflorescence: **raceme**, **panicle** and **spike**. Each describes how the individual spikelets are attached to a central axis known as the **rachis**. In the raceme and panicle inflorescences, the individual spikelets are attached to small branches that are attached to the rachis. In the spike inflorescence, the spikelets are attached directly to the rachis.

Figure 1.16 *Grass inflorescence*

The inflorescence of perennial ryegrass and Italian ryegrass is a spike. Italian ryegrass can be distinguished from perennial ryegrass by the presence of **awns**.

Wild oats is a noxious weed in tillage crops. It is highly competitive, multiplies rapidly to produce large numbers of seeds, acts as a host for a number of cereal diseases (e.g. barley yellow dwarf virus) and is difficult to control in cereal crops. It has an open-branched panicle inflorescence with spikelets held out on the branches.

Figure 1.17 *Perennial ryegrass*

Figure 1.18 *Italian ryegrass*

Figure 1.19 *Wild oats*

Noxious weeds are unwanted plants that grow aggressively, multiply quickly and are difficult to control. Some noxious weeds are poisonous to livestock, e.g. ragwort.

Annual meadow grass is an annual or short-lived perennial. It is often in flower even at short heights and tends to form small tussocks. Its inflorescence is a branched and spreading panicle with small spikelets. This grass is commonly found on acid soils.

Figure 1.20 *Cocksfoot*

Cocksfoot is a common perennial grass found in permanent grassland. Its inflorescence is a triangular-shaped panicle with green- or purple-tinged spikelets.

Meadow foxtail and timothy have similar inflorescence and are often confused with each other. Both have a compacted panicle that looks like a spike. Meadow foxtail has soft awns along the side of the seed head, making it appear fuzzy like a fox's tail. When comparing the two species side by side, the inflorescence of timothy is roughly twice the length of the inflorescence of meadow foxtail.

Figure 1.21 *Meadow foxtail*

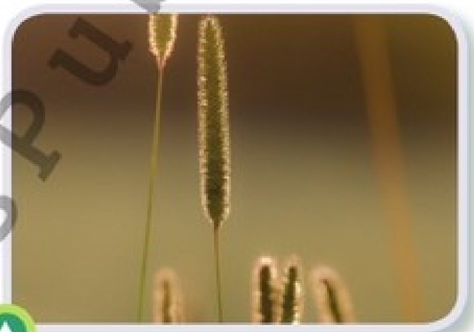


Figure 1.22 *Timothy*

Family Compositae (also known as Family Asteraceae)

This is the largest plant family, containing many grassland weeds (e.g. daisy, dandelion and ragwort) and commercial crops (e.g. sunflowers). The flower heads of these plants are composed of many individual flowers all sharing the same receptacle. The individual flowers are so densely arranged that they resemble a single flower. Members of the Compositae family use wind dispersal to disperse their seeds.

Ragwort is a noxious weed and is poisonous to cattle and horses. Sheep can tolerate some ragwort. It is not usually grazed by livestock; however, care must be taken to ensure that this weed is not incorporated into silage as livestock selectivity is reduced and animals will eat it. Ragwort is a biennial plant. In its first year it can be identified as a rosette: a cluster of leaves in a circular form. In its second year it produces yellow flowers in late spring, which can produce thousands of seeds that are mainly dispersed by wind.

Dandelion is a common perennial plant of permanent grassland. It produces yellow flowers from early summer until October and a single flower head produces an average of 180 seeds. Dandelions can be difficult to remove, since they have a long tap root which has the ability to regenerate if broken. The dandelion plant lives through the winter as a rosette.

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Figure 1.23 *Ragwort flowers*

Figure 1.24 *Ragwort rosette*

Figure 1.25 *Dandelion flowers*

Figure 1.26 *Dandelion rosette*

Spear thistle is also a member of this family and is also listed as a noxious weed. Spear thistle is a biennial and can be a serious problem in grassland and in tillage crops. It can produce large numbers of seeds that are dispersed by wind.

Q Understanding U1

1.9 Identify the plant family to which each of the following belongs:

(a) Ragwort
(b) Wild oats
(c) Italian Ryegrass
(d) Dandelion
(e) Spear thistle

1.10 Grasses are identified by their inflorescence. Explain the term *inflorescence*.

1.11 The common wild oat *(Avena fatua)* is described as a noxious weed.

(a) Give three reasons why this weed is considered noxious.
(b) Name two other noxious weeds.

The animal kingdom [Animalia]

The first animals evolved in the sea about 700 million years ago. Animals later evolved to live in fresh water, and eventually they emerged to live on land.

Animals range from simple sponges and jellyfish, through flatworms, roundworms and segmented worms, to snails, insects and animals with backbones (vertebrates) such as fish, birds and humans.

Trying to define an animal is not easy. There is such a variety of animal species that there is normally an exception to every general animal feature.

Main features of animals

- They are multicellular organisms that take in food (i.e. they do not make their own food)
- They do not have cell walls
- They have a nervous system (to allow fast responses)
- They have a muscular system (to allow movement)
- They normally reproduce sexually
- They have large eggs that cannot move by themselves (i.e. are non-motile)
- They have small sperm that can swim (i.e. are motile) by using a tail or flagellum (plural flagella)

Animal classification

In biological terms, living organisms are classified into one of five **kingdoms**. Each kingdom is further split into smaller groups called **phyla** (singular: phylum). Within a phylum, smaller divisions are created for organisms with common traits – these are called **classes**. Further divisions of classes are called **orders**, which have further subdivisions called **families** and within these families an organism has a generic name called a genus. A genus is given by its Latin name, it is written with a capital letter and is italicised. Members classed together under a genus that can interbreed are known as **species** and are also given a Latin name, which is written after the genus in lower case.

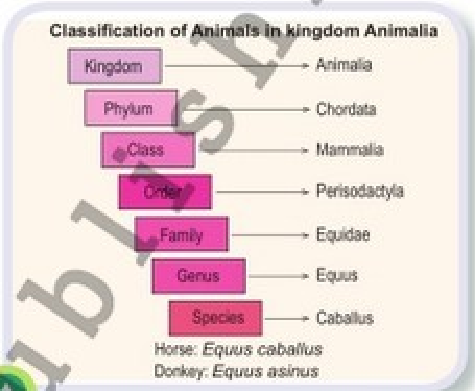

Figure 1.27 *Classification of horse and donkey*

In this module we will just consider the Phylum Arthropoda and some of the different species within it.

Phylum Arthropoda

Over one million species belong to phylum Arthropoda, which includes insects, arachnids and crustaceans. Arthropods are invertebrates: they do not possess a backbone. They have segmented bodies and jointed limbs. They possess an exoskeleton made of chitin, which protects their bodies. They shed this exoskeleton regularly as they mature and this allows them to grow and produce another exoskeleton. This shedding or moulting is known as ecdysis.

There are numerous classes of arthropods. The two classes that are most important in agriculture are class Arachnida (spiders) and class Insecta (insects).

Class Arachnida

Arachnids have several physical characteristics that differentiate them from insects:

- They have eight legs in four pairs.
- They have two main body segments called the cephalothorax and abdomen.
- They do not possess antennae or wings.

Arachnids in agriculture are parasitic by nature. They are **ectoparasites** of both plants and animals and include spiders, ticks and mites.

Figure 1.28 *Arachnid*

An **ectoparasite** is an external parasitic organism that lives on the skin or exterior of the body.

Red spider mite

This plant parasite sucks the sap of many fruit and vegetable plants, including cucumbers, strawberries, apples and even potatoes. Mites cause the stunting and yellowing of leaves. They can be controlled by use of a pesticide or by the introduction of a predator mite.

Mange mite

Mange or scabies is caused by the mange mite and spreads by close contact with infected animals. The female burrows into the skin to lay eggs and this leads to further burrowing when the larvae hatch. The burrowing action of the mites causes itching in the animal. If left untreated, this can lead to open wounds and other infections.

Figure 1.29 *Mange mite*

Ticks

Ticks live on the skin of sheep and cattle, sucking their blood. The sheep tick (*Ixodes ricinus*), a carrier of babesia, causes redwater fever in animals.

Figure 1.30 *Sheep tick*

Class Insecta

- Insects, like all other arthropods, have segmented bodies.
- Their bodies are divided into three parts: head, thorax and abdomen.

- They have six legs (in three pairs), two antennae and compound eyes.
- They normally have two pairs of wings attached to the thorax.

All insects undergo a process of development called metamorphosis. There are two types of metamorphosis: complete metamorphosis and incomplete metamorphosis.

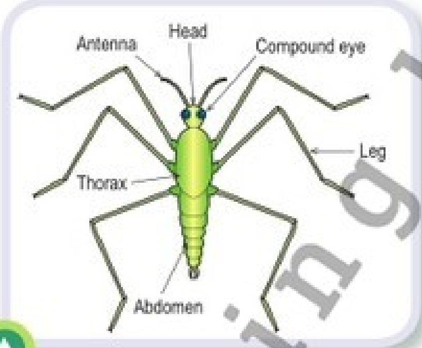

Figure 1.31 *Insect*

Incomplete metamorphosis

In this process of development, the immature insect undergoes a series of moults, shedding its exoskeleton at each stage to allow for growth and development. Immature insects undergoing incomplete metamorphosis are known as nymphs. They are similar in appearance to their adult counterparts, only smaller. Wings do not appear in these insects until they reach adulthood. Aphids, dragonflies and damselflies are examples of insects that undergo incomplete metamorphosis. The life cycle of an insect that undergoes incomplete metamorphosis is shown in Figure 1.32.

Aphids or greenfly cause a lot of damage to plants. They suck sap from the plant, leading to stunted growth and curled, yellowing leaves. They also transmit viruses as they move from plant to plant. Cereals, potatoes and sugar beet are all examples of crops that can suffer from viruses transmitted by aphids. Aphids can be controlled by the use of aphicides and by ladybirds, which are a natural predator of the aphid. Cool, wet, windy weather does not provide favourable conditions for the development of aphids.

Egg → Nymph → Adult

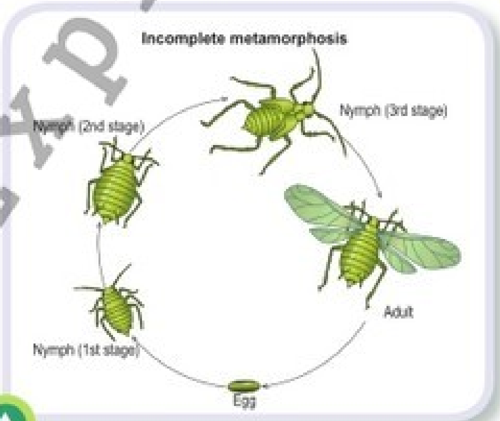

Figure 1.32 *Life cycle of an aphid*

Complete metamorphosis

In this process of development, each stage of the life cycle is physically different from the previous stage. The larval stage is worm-like in appearance and is the feeding stage in the life cycle. The larva develops into a pupa, which is often protected by a cocoon: this is a resting stage and very little movement occurs during this time. The insect undergoes much change in the pupal stage and emerges as an adult insect. Butterflies are the best-known insects that undergo complete metamorphosis.

The life cycle of an insect that undergoes complete metamorphosis is shown in Figure 1.33.

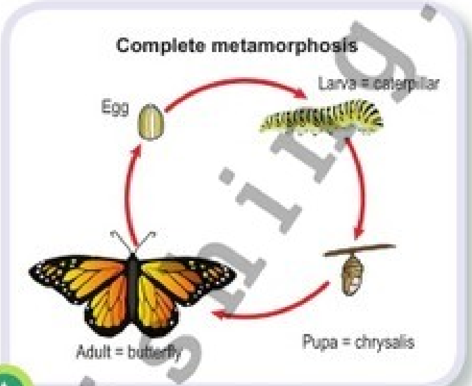

Figure 1.33 *Life cycle of a butterfly*

Egg → Larva → Pupa → Adult

A number of insects are pests in both their larval and adult forms. Examples of these are listed in Table 1.3.

Table 1.3 Insect pests that undergo a complete metamorphosis

Insect	Larval form	Impact in agriculture
Cranefly (Tipulidae)	Leatherjacket	Eat the roots of grasses, cereals, vegetables and strawberries
Clickbeetle (Elateridae)	Wireworm	Feed on the roots of grasses; damage potato tubers

Q U1 Understanding

1.12 Name two characteristics of insects and two characteristics of arachnids.
1.13 To which phylum do insects and arachnids belong?
1.14 Give one example of an insect and one example of an arachnid that are important in agriculture.
1.15 What is the difference between complete and incomplete metamorphosis?
1.16 What is a parasite?
1.17 Name one ectoparasite and one endoparasite.

Species native to Kazakhstan


Figure 1.34


Figure 1.35


Figure 1.36


Figure 1.37


Figure 1.38


Figure 1.39

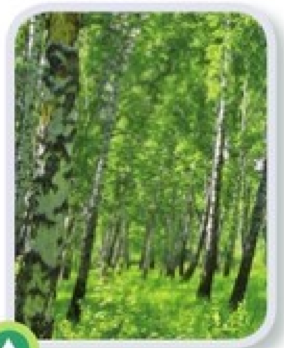
Figure 1.40


Figure 1.41


Figure 1.42

Table 1.4 Species native to Kazakhstan

Figure	Common name	Scientific name
1.34	Red throated loon	*Ranodon sibiricus*
1.35	Snow leopard	*Panthera uncia*
1.36	Northern snakehead	*Gavia stellata*
1.37	Beluga sturgeon	*Betula kirghisorum*
1.38	Wild almond	*Huso huso*
1.39	Steppe eagle	*Aquila nipalensis*
1.40	Birch tree	*Amygdalus bucharica*
1.41	Semirechensk salamander	*Atraphaxis muschketowi*
1.42	Shrubby buckwheat	*Channa argus*

Q Understanding U1 Communicating C1 Communicating C2

1.18 All of these species are native to Kazakhstan. Use the Internet to match the common name to the scientific name in the above table.

1.19 As you research, find a species which is considered to be threatened or endangered and identify three reasons that have led to this species being categorised like this.

1.20 Do you know of any other species native to Kazakhstan?

MODULE 2

The Biosphere and Ecosystems

Learning outcomes

At the end of this module you will be able to:

- Analyse diagrams of exponential and sigmoid curves of population growth 9.3.1.1
- Calculate the efficiency of energy transfer 9.3.1.2
- Compare pyramids of numbers, biomass and energy 9.3.1.3
- Describe the carbon cycle and nitrogen cycle 9.3.1.4
- Explain the impact of the production of oil and other mineral resources on the environment 9.3.2.1
- Explain the impact of pesticides on the environment 9.3.2.2
- Explain the impact of the greenhouse effect on living organisms 9.3.2.3
- Explain the causes and consequences of ozone depletion 9.3.2.4

Keywords

✔ biosphere ✔ ecosystem ✔ energy flow ✔ trophic level ✔ food web ✔ pyramid of numbers ✔ producers ✔ consumers ✔ decomposers ✔ exponential growth ✔ carrying capacity ✔ kilocalorie ✔ pesticides ✔ toxic ✔ resistant ✔ oil refining ✔ ozone depletion

Ecology

Ecology is the study of the interactions between living things (organisms) and between organisms and their environment.

All the external factors that influence an organism are referred to as its **environment**.

Biosphere

The biosphere is one of the four layers that surround the Earth along with the lithosphere (rock), hydrosphere (water) and the atmosphere (air) which extends into the upper reaches of the ozone layer. The biosphere represents the sum of all ecosystems. It thus includes all living things and their interactions with the lithosphere, hydrosphere and atmosphere.

Ecosystem

The entire Earth is itself an ecosystem because no part of it is completely isolated from the rest. This global ecosystem can be said to form the biosphere.

The biosphere consists of many large ecosystems. Conditions such as the climate, soil, plants and animals in each ecosystem are similar, even though they may be located in different regions around the planet.

Ecosystems can be very large. For example, deciduous forests once covered much of Europe. Nowadays, because of pressure on land for agriculture and housing, large areas of forest have been cleared. As a result, forests have been divided up into smaller units called woodlands. Woodlands are clearly distinguished ecosystems, as are grasslands, bogs, lakes, sand dune systems, salt-marshes, rocky seashores and hedgerows.

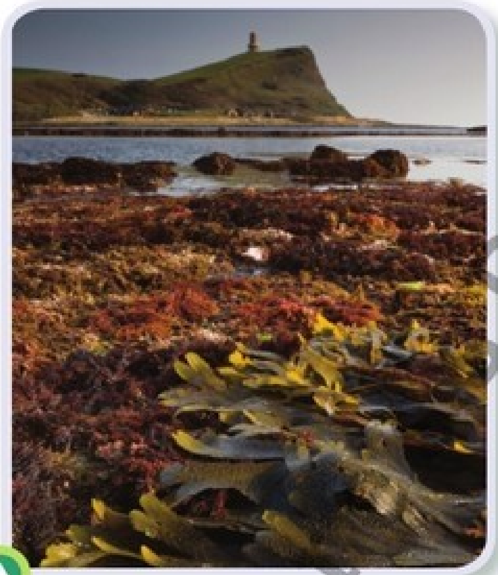

Figure 2.1 *A rocky seashore*

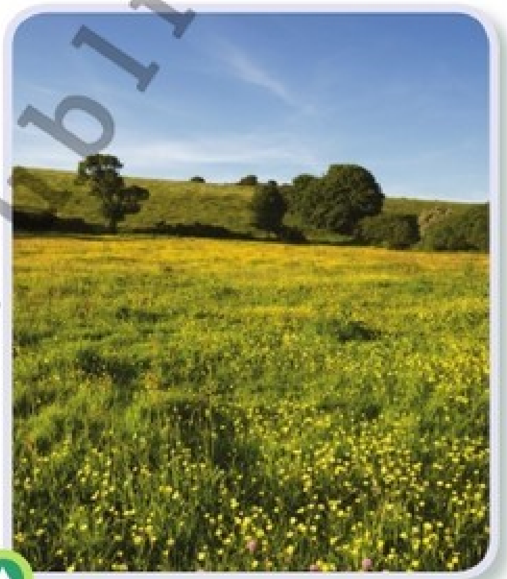

Figure 2.2 *A grassland*

Table 2.1 **Examples of ecosystems**

Ecosystem	Features	Examples
Temperate deciduous forest	Warm summer, rain plentiful	Western Europe, Eastern USA
Desert	Low rainfall	Sahara Desert, Gobi Desert
Tropical rain forest	High temperatures and high rainfall	Brazil, West Africa, parts of South-East Asia
Grassland	Mild temperatures, low rainfall	Steppes of Asia, pampas in South America, prairies in North America
Freshwater	Non-salty water	Rivers, lakes, wetlands
Marine	Salt water	Seashores and oceans

Habitat

A **habitat** is the place where a plant or animal lives.

A habitat is also the place that we study to learn more about an ecosystem. As ecosystems can be very large, it is common to select a number of small, local areas or habitats to study. The study of the local habitat gives a representation of how an ecosystem functions.

A **population** is all the members of the same species living in an area.

We speak of a population of frogs in a pond or a population of primroses in a wood.

A **community** is all the different populations in an area.

For instance, all the plants, animals, fungi and micro-organisms living in a field or bog are a community.

Q Understanding U3

2.1 Explain the difference between (a) the biosphere and ecosystem (b) a community and a population.

2.2 What is the main source of energy for all ecosystems?

2.3 **(a)** Give three examples of ecosystems.

(b) For each example,

(i) state the main factors that define it and

(ii) give a geographical location where it is found.

Energy flow

Every ecosystem requires a constant input of energy from an external source in order to function properly. The **Sun** is the primary source of energy for our planet.

Feeding allows energy to **flow** from one organism to another in an ecosystem.

Producers

Flora includes plants, seaweeds and plankton. All of these are producers. About 1% of sunlight is trapped by green plants and used to make food. The Sun's energy is stored by plants in the chemical bonds of molecules such as glucose and starch.

Plants break down most of these molecules to release energy. This process is called respiration. They use the energy to do work such as making new cells or repairing old ones. However, most of their energy is lost in the form of heat and only a small proportion (about 10%) is passed on to other organisms.

When an animal eats a plant or another animal, the food that is consumed contains energy. Feeding represents a flow of energy. This means that energy moves in one direction, i.e.

- Sun → plant → animal 1 → animal 2 → etc.
- Sun → primary producer → primary consumer → secondary consumer → etc.

Consumers

All animals are consumers.

Primary consumers feed on producers. They include:

- Herbivores (animals that feed on vegetation)
- Decomposers (organisms that feed on dead organic matter such as bacteria and fungi)
- Detritus feeders (organisms that feed on small parts of dead and decomposing plants and animals such as mussels and earthworms).

Figure 2.3 *A caterpillar feeding on a leaf*

Secondary consumers are animals that feed on primary consumers. They include:

- Carnivores (meat-eaters)
- Scavengers (which feed on animals killed by other sources).

Tertiary consumers feed on secondary consumers. They are not always present. If no other organism feeds on them, they are called **top consumers**.

Organisms that feed on both plants and animals are called omnivores. Examples include gulls, blackbirds, badgers and humans.

Food chain

> A grazing **food chain** is a sequence of organisms in which each one is eaten by the next member in the chain.

In a grazing food chain the first organism is a producer or a green plant. An example of a grazing food chain is:

- dandelion → butterfly → thrush → hawk

Trophic level

> A **trophic level** is a feeding stage in a food chain.

Producers form the first trophic level. Primary consumers are the second trophic level and secondary consumers form the third trophic level. Other examples of grazing food chains are given at the top of the opposite page:

Grassland habitat

- grass → rabbit → fox
- buttercup → caterpillar → blackbird → fox

Seashore habitat

- algae → limpet → starfish → gull
- plankton → barnacle → whelk → crab

Scavengers, decomposers or detritus feeders can take food from each trophic level.

Table 2.2 Sample food chains and trophic levels

Trophic level	1st	2nd	3rd	4th
Stage	Producer	Primary consumer	Secondary consumer	Tertiary (or top) consumer
Grassland examples	Buttercup	Caterpillar	Blackbird	Fox
Seashore examples	Plankton	Barnacle	Whelk	Crab

Q Understanding U3

2.4 In the food chain:
dandelion → butterfly → robin → falcon
- (a) What is the initial source of energy for the dandelion?
- (b) How many trophic levels are indicated?
- (c) Which way does energy flow?
- (d) What happens to the energy that does not pass to the next level?
- (e) Draw a pyramid of numbers to represent this food chain.
- (f) If a herbicide is sprayed to kill the dandelion, suggest an effect this might have on the top consumers.

2.5 Construct a grazing food chain containing at least four trophic levels.
In your food chain identify each of the following:
- (a) A predator
- (b) A producer
- (c) A secondary (second order) consumer.
- (d) A primary (first order) consumer.

2.6 Most food chains are limited to about four (or fewer) trophic levels. Explain why this is the case.

2.7 Suggest the effects on a food chain of:
- (a) Increasing the number of producers
- (b) Disease killing off the primary consumers
- (c) An immigration of more top consumers.

Length of food chain

About 10% of the energy in each trophic level is passed on to the next level. The remaining 90% is used by the organisms or is lost as heat, waste or detritus. This means that the amount of energy (food) passing along a food chain **decreases** from one trophic level to the next. This limits the length of a food chain.

In the food chain shown in Figure 2.4, the rabbit does not have to travel too far to get food. The fox must range over a much larger area in order to get its food. If any consumer was to feed on foxes, it would have to use far too much energy hunting for its prey. This is why this food chain finishes with foxes.

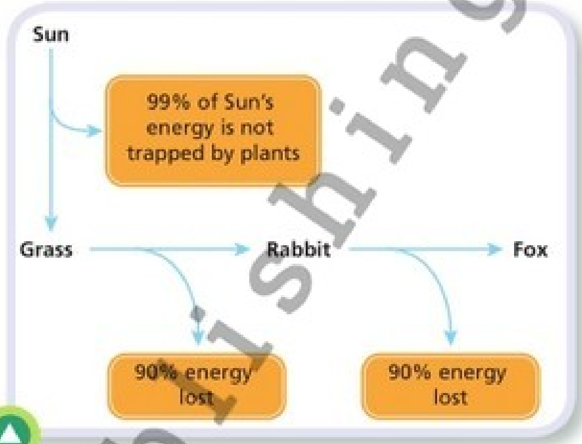

Figure 2.4 *Energy flow in a food chain*

Energy Transfer

The amount of energy transferred from one trophic level to the next is only around 10% The rest of the energy passes out of the food chain in different ways:

- It is converted into metabolic energy the organism uses e.g. in the process of respiration.
- It is used as heat energy.
- It passes out as faeces or the remains of dead animals i.e. it passes on to the decomposers.

The amount of energy passed up the food chain in the form of animal tissue becomes less and less and thus the biomass decreases. This limits the number of levels in a food chain usually to a number less than five. Energy is measured in kilocalories or Kcal.

Q Understanding U1 Communicating C3

2.8 Look at Figure 2.5. If only 10% of the kilocalories from one level is transferred to the next level, find the amount of energy transferred in to b, c and d.

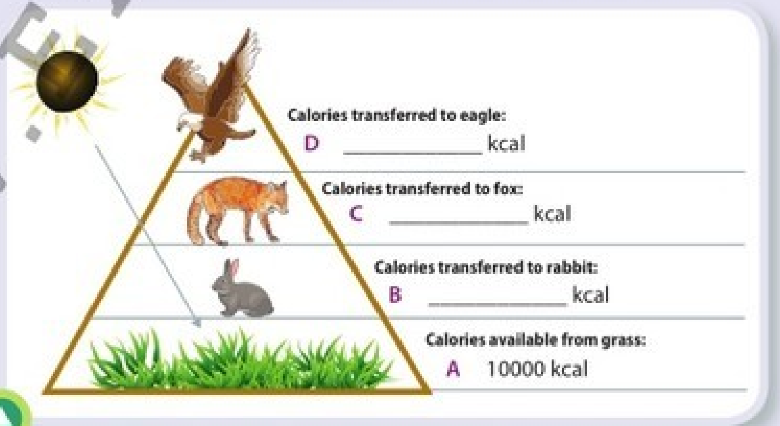

Figure 2.5 *Energy transfer across trophic levels*

2.9 Discuss with another student whether you can make a case for saying that one trophic level is more important than the others.

2.10 What happens to the 90% of energy that does not get to the next trophic level?

Food web

A **food web** consists of two or more interlinked food chains.

Food chains and food webs are attempts to show the feeding inter-relationships in an ecosystem. They show the flow of energy through the ecosystem. A sample food web is shown in Figure 2.6.

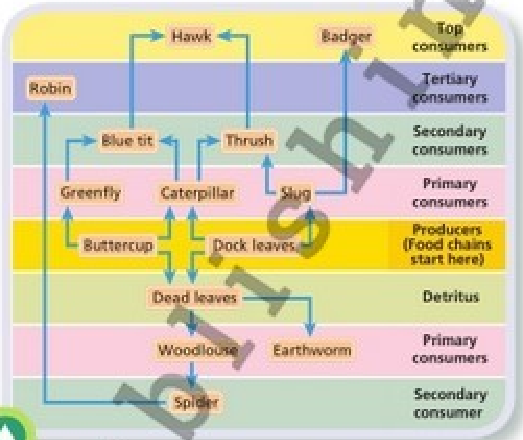

Figure 2.6 *Food web for a grassland*

Pyramid of numbers

The number of organisms at each trophic level in a food chain normally decreases as you move up the food chain. This is because of two factors:

- High energy loss at each trophic level (so there is less energy available to the organisms farther along the food chain)
- The organisms usually increase in size the further they are along the food chain (this is because organisms tend to feed on organisms smaller than themselves).

In the food chain *grass → rabbits → fox* there are many grass plants feeding a smaller number of rabbits, which support very few foxes. The relative number of organisms at each trophic level is shown in Figure 2.7.

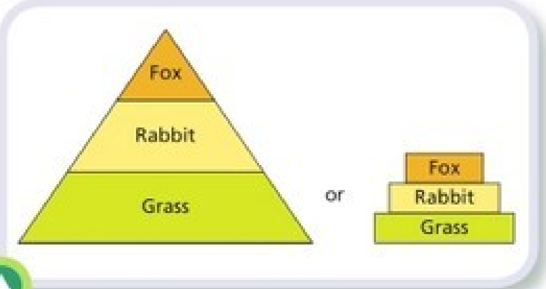

Figure 2.7 *Pyramids of numbers*

Population growth curves

Any population which inhabits a fixed geographic space will pass through three distinct phases in population growth:

- an exponential growth phase
- a transition phase
- a plateau phase

Plotting a graph of such a population gives an S-shaped curve (Figure 2.8) known as the sigmoidal population growth curve.

Figure 2.8 *Sigmoidal population growth curve*

Any population which grows exponentially starts off slowly and then goes through a phase of rapid growth which levels off once the carrying capacity of the area is reached.

Exponential Growth Phase

This phase begins slowly as there are few individuals for reproduction and they are likely to be spread out across the area. Numbers will then start to grow rapidly as abundant resources will mean high birth rates and low death rates.

Transitional Phase

As the population continues to grow a point is reached where an area begins to reach its carrying capacity [K] for the population. The resources available to support a population in an area eventually become limited, which leads to greater competition for survival. More predators will move into the area as the population grows. Greater density of population will lead to the faster spread of disease and ultimately, birth rates slow and death rates rise.

Plateau Phase

Population growth rates eventually become static as having reached the carrying capacity of the area keeps the population in check. This phase is characterised by very small fluctuations in population.

Understanding U3

2.11 What does the carrying capacity line in the Figure 2.8 represent?
2.12 Give two reasons why population growth slows in the transitional phase.
2.13 Which other population is also likely to grow exponentially in an area where an animal is growing quickly in numbers?

2.14 Answer the following questions in relation to the food web shown below.

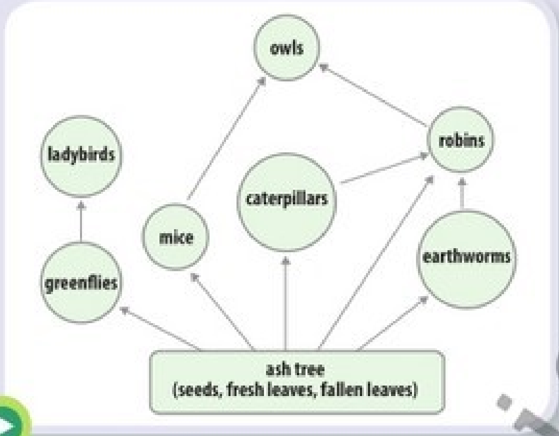

Figure 2.9

(a) Write out a food chain with four organisms in it.
(b) Name the primary producer in the web.
(c) Name two secondary consumers in the web.
(d) Name two herbivores in the web.
(e) Name one omnivore in the web.
(f) Name one carnivore in the web.

Nutrient recycling

Whereas **energy flows** in from the Sun and through the ecosystem, the nutrients that make up the bodies of living things are recycled and used time and time again. Such cycles are called biogeochemical cycles. Although many **nutrients are recycled**, we will focus on two: carbon and nitrogen.

The carbon cycle

The carbon cycle is the process by which carbon from the environment is converted to carbon in living things. The carbon in living things is later released back into the environment.

Carbon is an essential element for living things. It is normally exchanged between living things and their environment in the form of the gas, carbon dioxide.

Plants have been removing carbon dioxide from the atmosphere for millions of years. It is important that this gas is replaced in order to allow photosynthesis to continue.

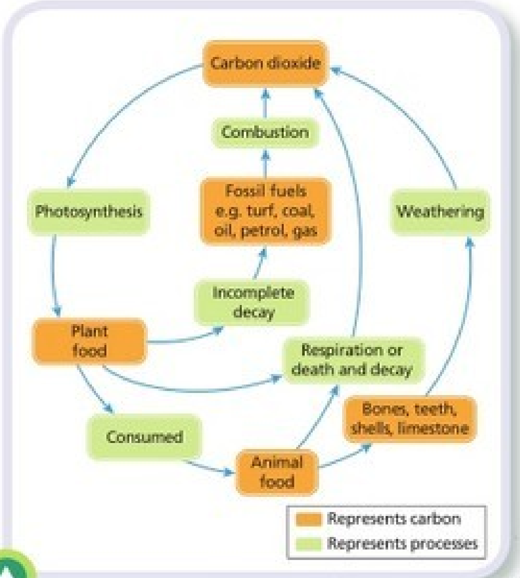

Figure 2.10 *The carbon cycle*

Role of organisms in the carbon cycle

Three groups of organisms have roles to play in the carbon cycle:

- **Plants** remove carbon from the environment by photosynthesis and return it by respiration
- **Animals** obtain their carbon by eating plants; they release carbon dioxide by respiration
- **Micro-organisms** (such as fungi and bacteria) return carbon to the environment when they decompose dead plants and animals.

Global warming

In recent years there has been concern that the concentration of carbon dioxide in the atmosphere is rising. For example, the concentration of carbon dioxide 200 years ago was 0.028%. Now it has risen to 0.039%.

The main causes of the rise in carbon dioxide concentration are thought to be:

- Increased combustion of fossil fuels
- Deforestation

Carbon dioxide is a 'greenhouse gas'. This means it allows heat radiation from the Sun to pass into the Earth's atmosphere, but does not allow reflected heat rays back out. (It is not the only gas that does this.)

Increased levels of carbon dioxide may contribute to global warming, i.e. a rise in the average temperature of the planet. Global warming may cause the following effects:

- Sea levels may rise due to ice melting and the expansion of hot water. This may cause increased flooding.
- Weather patterns may alter (e.g. more stormy weather), which in turn will affect wildlife and agriculture.
- Another major concern is that global warming may cause the Gulf Stream to reverse its direction of flow. This would cause very cold water to flow and would have a huge impact on the climate.

The nitrogen cycle

Nitrogen is needed by living things to make proteins and other biomolecules. However, nitrogen gas in the air cannot be used, as it is unreactive.

The function of the nitrogen cycle is to take nitrogen from the air and make it available for use by living things. The nitrogen in living things is later converted to nitrogen in the air.

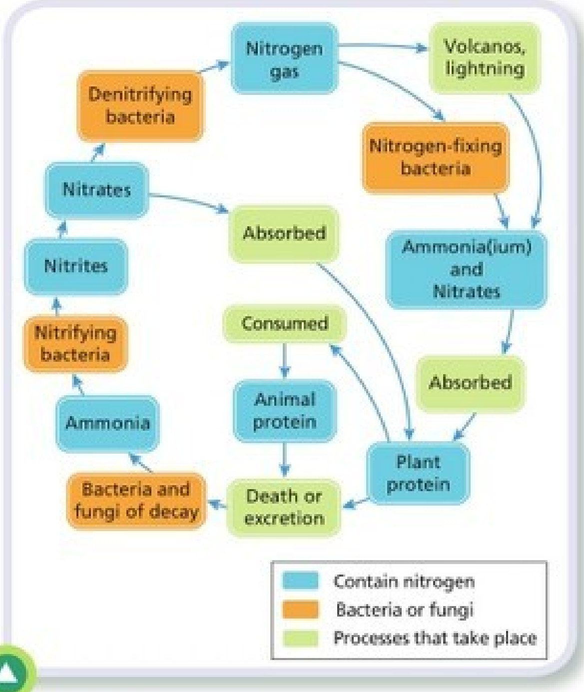

Figure 2.11 *The nitrogen cycle*

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Refer to Figure 2.11 while reading the following account of the nitrogen cycle.

1. Living things need the element nitrogen (to make proteins, DNA, RNA and other biomolecules). Nitrogen gas (N_2) makes up about 79% of the air. However, this form of nitrogen is inert or unreactive and cannot be used by plants and animals.
2. **Nitrogen fixation** is carried out by volcanic action, lightning, industrial processes and by some bacteria. Nitrogen-fixing bacteria can be found free in the soil or they may be associated with the roots of certain plants. The latter group of bacteria live in nodules (swellings) on the roots of a group of plants called legumes. These include clover, soya beans, peas and beans.
   Nitrogen fixation is an anaerobic process (i.e. it does not require oxygen) and the root nodules allow the bacteria to escape from oxygen.
   The relationship between the bacteria and the legume is a form of symbiosis, i.e. two different species living closely together where at least one benefits. In this case both species benefit, because the bacteria get food and the plant gets nitrates, so the arrangement is technically called mutualism (although it is often simply called symbiosis).

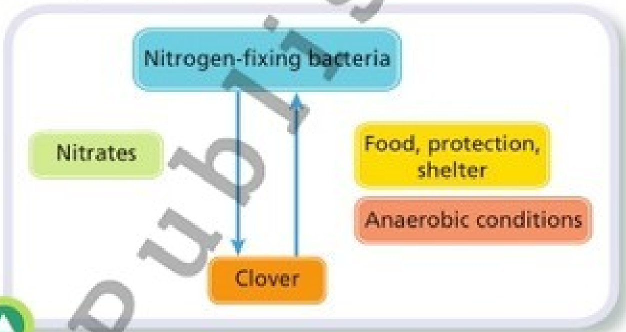

Figure 2.12 *A symbiotic (or mutualistic) relationship*

   Nitrates are converted (assimilated) into plant and animal protein, DNA and RNA.
3. **Decomposition** of dead organisms is carried out by bacteria and fungi of decay, which are mostly found in the soil. These organisms release nitrogenous compounds such as ammonia (NH_3) into the soil.
4. **Nitrification** is carried out by bacteria in the soil, called nitrifying bacteria. Nitrifying bacteria are chemosynthetic, i.e. they make their own food (normally in darkness in the soil) using energy from chemical reactions.
5. Some of the nitrate formed in the soil is absorbed and used by plants.
6. **Denitrification** is carried out by denitrifying bacteria in the soil. Denitrifying bacteria are anaerobic and live in swampy soil or deep down in the soil (where water collects to produce anaerobic conditions).

Role of organisms in the nitrogen cycle

- **Bacteria** play a central role in the nitrogen cycle. The four types of bacteria and their functions are:
  1. Nitrogen-fixing bacteria, which convert atmospheric nitrogen to nitrates.
  2. Bacteria of decay, which convert nitrogen waste to ammonia.
  3. Nitrifying bacteria, which convert ammonia to nitrates.
  4. Denitrifying bacteria, which convert nitrates to nitrogen gas.

- **Fungi** also help to decay dead plants and animals and their wastes into ammonia in the soil.
- **Plants** absorb nitrates from the soil and use the nitrogen to form proteins.
- **Animals** consume plants and use their nitrogen to form animal protein.

Q U3 Understanding

2.15 **(a)** Refer to **Figure 2.13** showing the carbon cycle and name the processes represented by the letters A to H.

(b) Why are the levels of CO_2 thought to be rising worldwide?

(c) Give two possible results of a rise in CO_2 concentrations.

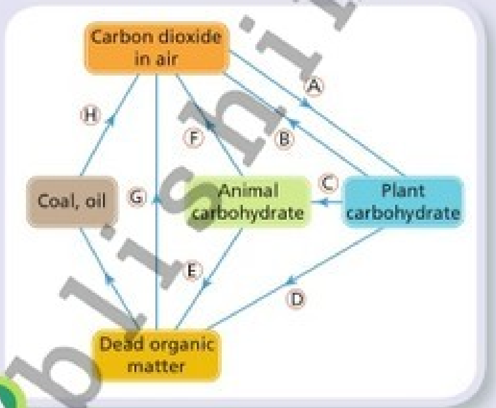

Figure 2.13

2.16 **(a)** Why do plants and animals require nitrogen?

(b) Why do plants not use atmospheric nitrogen?

(c) In what form(s) do plants require nitrogen?

(d) Name two processes that convert nitrogen gas into compounds that plants can use.

Human impact on ecosystems

Fossil evidence discovered to-date suggests that humans emerged on Earth between 200,000 - 300,000 years ago. This is a short period of time in relation to the age of the planet – four and a half billion years (4 500 000 000 years).

In this short time humans have had a huge effect on the Earth's resources and organisms. We will consider three ways that humans affect ecosystems.

Pollution

Most pollution arises from human activities such as dumping, littering, sewage disposal, electricity generation, transport, radioactive processes and noisy activities. Natural pollutants include volcanic emissions and smoke from natural forest fires. Pollution can affect air, fresh water, sea and soil or land.

There are many types of pollution.

- **Domestic pollution** includes household wastes.
- **Agricultural pollution** includes the use of sprays to control pests and weeds, the overuse of fertilisers and disposal of farmyard wastes such as slurry and silage effluent.
- **Industrial pollution** includes smoke that causes acid rain and wastes that may damage streams, rivers and lakes.

Ozone depletion – an example of air pollution

Ozone (O_3) is a gas that forms a protective layer in the upper atmosphere, between 10 and 45 km above the surface of the Earth. It helps to absorb and shield the Earth from incoming ultraviolet radiation.

Ozone depletion (or thinning) was first noted in 1984 as a 'hole' in the ozone layer over Antarctica. Since then a similar, but smaller, 'hole' has developed over the Arctic.

Ozone depletion is caused by a range of manufactured chemical pollutants. These include chlorofluorocarbons (CFCs) used in aerosols, refrigerators (Freon gas), insulating foams (Styrofoam) and industrial detergents.

Some fire extinguishers (halons) and agricultural sprays (fumigants) also destroy ozone, as do emissions from high-flying aircraft.

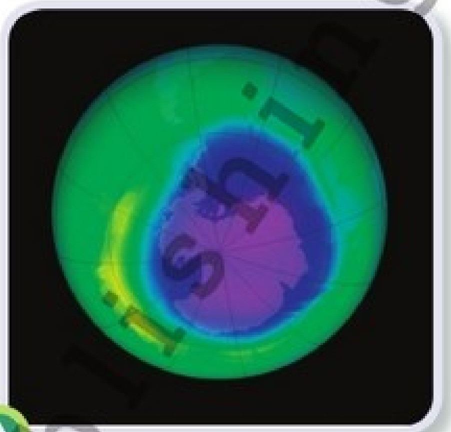

Figure 2.14 *The ozone hole (blue) over Antarctica in 2010*

Effects of ozone depletion

Ozone absorbs ultraviolet rays. Less ozone in the outer layers of the atmosphere allows more ultraviolet radiation to penetrate to the Earth's surface.

Increased ultraviolet levels have a number of effects, such as the following:

- Increased numbers of skin cancers, cataracts (in which the lens in the eye loses transparency) and weakened immunity
- Serious damage to crops and plant life
- Plankton depletion: there is great concern that plankton will be depleted. This would have huge effects on aquatic food chains and, therefore, on fish, penguins, birds, seals and whales. It might even result in less oxygen being produced for organisms to breathe.

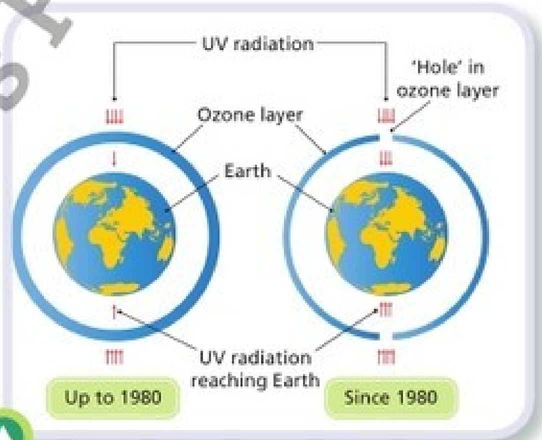

Figure 2.15 *Effects of ozone depletion*

Control of ozone depletion

- A reduction in the use of CFCs will eventually allow the ozone layer to be replenished. Ozone is formed naturally by the reaction of ultraviolet light with oxygen. CFCs are now being replaced with other chemicals such as hydrofluorocarbons (HFCs). These chemicals break down much faster than CFCs. This means they do not reach the upper atmosphere and, therefore, do not cause ozone to break down.

BIOL Gr9 Ss Mod 2.indd 37 7/19/18 5:25 PM

- Sprays or foam products that contain CFCs should not be used.
- Fridges should not be dumped in landfill sites. They should be returned to organisations that will dispose of their CFCs in an environmentally friendly way.

In recent years the hole in the ozone layer has stabilised. It looks like the control methods are allowing ozone to be replenished slowly.

Q Understanding U3

2.17 **(a)** Explain the term pollution.

(b) Pollution may result from domestic, agricultural or industrial sources. Select one of these areas and state an effect that may be produced by a named pollutant.

(c) How may the pollution referred to in (b) be controlled?

2.18 In relation to the incineration of domestic waste, suggest:

(a) an advantage of the process.

(b) a disadvantage of the process.

Environmental impact of petroleum

The recovery, refining, transportation and the range of end uses to which petroleum is put all pose potentially serious hazards for the environment.

Drilling for Oil

The process of drilling for oil involves using drilling rigs to drill deep into the ground or beneath the sea floor to reach oil beds. This can cause oil to spread into gaps between layers of rock and into seas and lakes. The toxicity of crude oil makes it potentially lethal for organisms that come into contact with it. The land in areas where oil is drilled, pumped through pipelines and stored also needs to be cleared and this can have serious impacts on ecosystems.

Refining oil

The refining of oil in most contexts is hugely damaging to local environments and a major contributor to greenhouse gases that increase global warming. Oil refineries pollute the environment in the following ways:

- They produce high levels of toxic air pollutants such as carbon monoxide and sulfur dioxide through practices such as flaring

Figure 2.16 *Oil refinery at night*

- They cause soil and ground water contamination which can cause human and animal health problems and impact on the quality of crops. Such damage is caused by hazardous waste, sludge from treatment processes and coke dust being dumped or spilling into the local environment and working its way into bodies of water such as rivers.

Figure 2.17 *Flaring at an oil refinery.*

Transportation of oil

The nature of the oil industry means that crude oil is often transported across vast distances before it is refined. Accidents such as major oil spills from tankers can devastate marine environments. Perhaps just as important though is the daily spillage of oil from vehicles such as cars, boats and planes that seeps into and accumulates in the environment.

End uses of oil and petrochemicals

As can be seen in Figure 2.18 below petrochemical products are put to a huge range of uses.

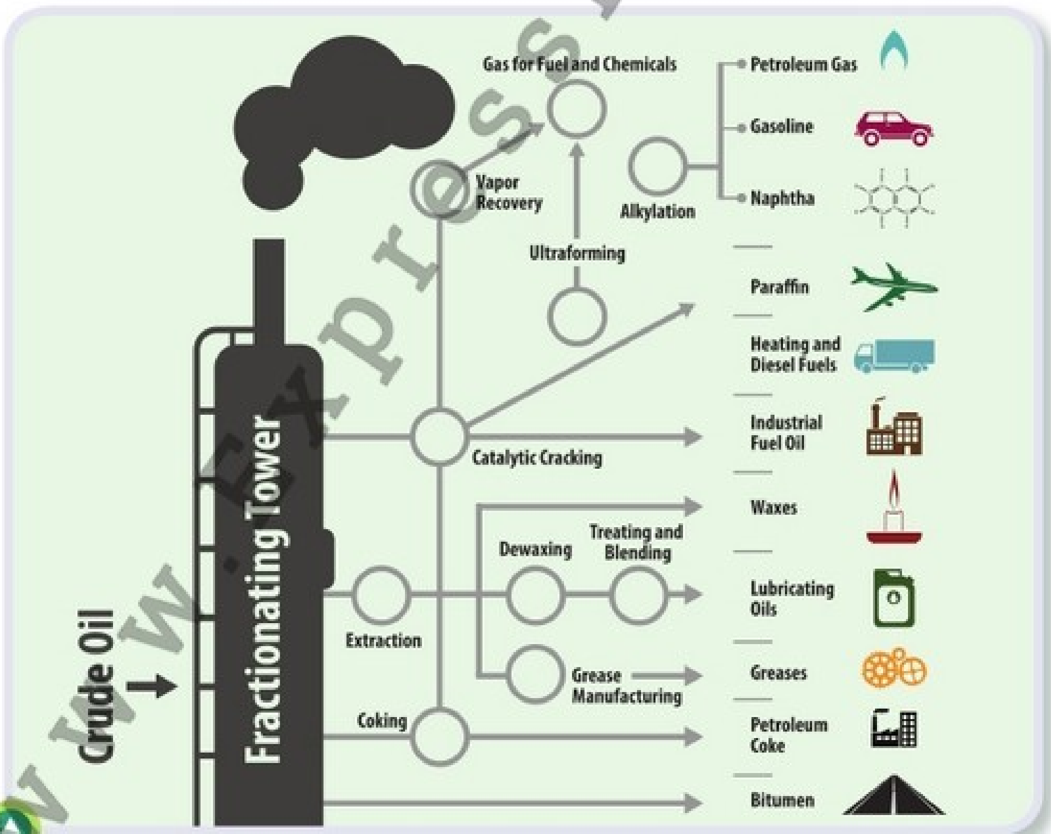

Figure 2.18 *Production and use of petrochemicals*

Communicating C1 Communicating C2

2.19 Research one of the end uses of petrochemical products and prepare a short presentation on its potential environmental impacts.

Understanding U3

2.20 What are the differences in the environmental impact of carbon monoxide and sulfur dioxide?

2.21 Name three ways in which the oil industry can impact the quality of marine environments.

The impact of pesticides on the environment.

Pesticides are chemicals used to kill pests which can be defined as plants or animals that are living in an area where humans do not want them to live.

They are typically used:

- To kill pests that are a health risk to humans or domestic animals
- To reduce pest populations which damage economic activity such as crop growing and crop storage.

Figure 2.19 *Spraying of fungicides and insecticides*

Common examples of the use of pesticides are the spraying of fungicides and insecticides to kill pests in crop and fruit farming and the use of herbicides to kill weeds in crop farming. While there may be immediate economic benefits of chemically controlling pests in such ways, there are many potential environmental hazards associated their use which include:

- they may be toxic to other organisms in the ecosystem
- their persistence in the environment potentially long after their use
- bioaccumulation through food chains: as many pesticides are lipid soluble, they can accumulate in body fat over a period of time. Herbicides and fungicides, for example, can be ingested by insects or earthworms and passed onto birds who feed on them. Pesticides in soil may also leech into waterways.
- organisms through gene mutations can develop resistance to the pesticide which targets them.

Communicating C1 Communicating C2

2.22 Research one instance of the use of pesticides proving harmful in your area/country? Share your findings with another group.

Understanding U3

2.23 Give three ways in which pesticides can affect organisms other than the ones they target in an environment.

2.24 Can you think of how biotechnology might be used as an alternative to pesticides?

MODULE 3

Human nutrition

Learning outcomes

At the end of this module you will be able to:

- Describe in detail the processes of digestion, assimilation, absorption and egestion 9.3.2.1
- Establish the relationship between the organic matter and the corresponding enzyme in the process of food digestion 9.3.2.2
- Investigate the influence of different conditions (temperature, pH) on enzyme activity 9.3.2.3
- Investigate the process of the emulsification of fats by the action of bile 9.3.2.4

Keywords

✔ alimentary canal ✔ salivary glands ✔ ingestion ✔ digestion
✔ absorption ✔ egestion ✔ duct ✔ chime ✔ enzyme
✔ oesophagus ✔ peristalsis ✔ bolus ✔ fibre ✔ bile
✔ duodenum ✔ ileum ✔ villi ✔ lacteal

The need for a digestive system

Some animals, such as sponges and tapeworms, do not have a digestive system. In these animals each cell must have a full range of digestive enzymes.

Most animals do have a digestive system. This allows them to take in large pieces of food and break the food down using structures that need be located in only one place (e.g. teeth in the mouth or enzymes in the small intestine). This means there is no need for every cell in the body to contain all the digestive enzymes.

The tiny particles of digested food are carried to each part of the body, mainly by the blood.

The digestive system

The digestive system (also known as the alimentary canal or gut) is a long tube starting at the mouth and ending at the anus. Attached to the digestive system are the associated glands:

Digestion is the physical and chemical breakdown of food.

Figure 3.1 *The digestive system*

- Salivary glands
- Liver (and gall bladder)
- Pancreas.

Main events in human nutrition

Human nutrition involves the following four processes:

1. **Ingestion** is the taking of food into the digestive system. This happens when food is placed in the mouth.
2. **Digestion** is the breakdown of food. There are two types of digestion.
   - Physical digestion is the mechanical breakdown of food. Physical digestion takes place when we chew food or churn it in the stomach. Physical digestion increases the surface area so that chemical digestion can take place more efficiently.
   - Chemical digestion is the breakdown of food using enzymes.

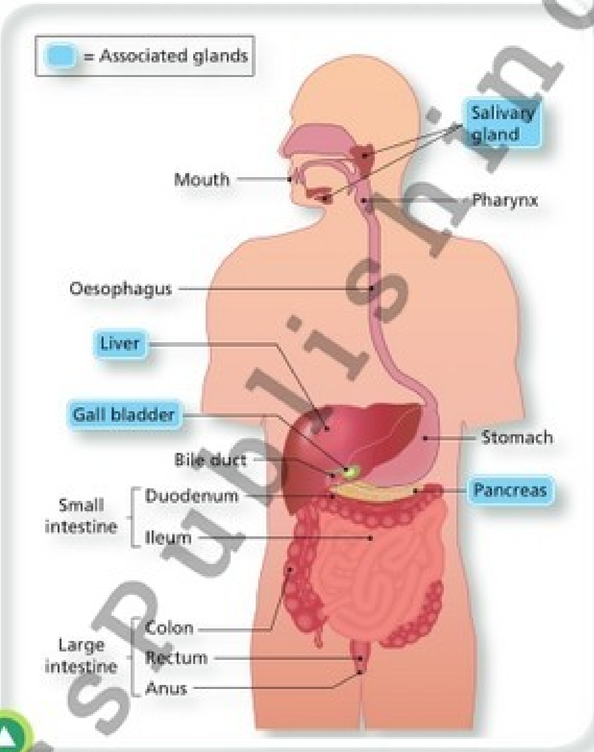

Figure 3.2 *The human digestive system*

3. **Absorption** occurs when the digested food passes from the digestive system and enters into the blood.
4. **Egestion** is the removal of unabsorbed waste from the digestive system.

Q U1 Understanding

3.1 What is the main difference in the cells of animals with a digestive system and animals without one?

3.2 What are the four stages in human nutrition?

3.3 Give the location for each stage.

Stage	Location

3.4 What are the salivary gland, the liver, gall bladder and pancreas called in the digestive process?

Mouth

Types of teeth

- **Incisors** are found at the front of the mouth. They are shaped like chisels and they cut and slice food.
- **Canines** are the long, pointed, fang-like teeth. They are used to grip and tear food.
- **Premolars** have large, flat surfaces and are used to crush and grind food.
- **Molars** are the large teeth located at the back of the jaw. They also crush and grind food.

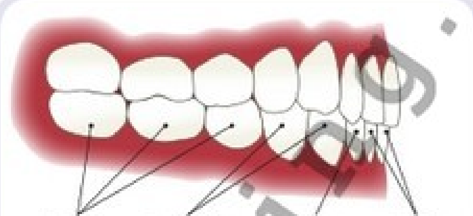

Figure 3.3 *Human jaw, showing the different kinds of teeth*

Dental formula

In the dental formula for an adult human the letters represent the four types of teeth. The upper numbers refer to the number of teeth on one side of the upper jaw. The lower numbers refer to the number of teeth on the lower jaw on the same side. The formula refers to one side of the mouth.

The formula shows that there are 16 teeth on the right-hand side of the mouth and the same number on the left-hand side.

Understanding U1

3.5 Complete the dental formula for adult teeth.

$$2\left(I\frac{2}{\ } \; C\frac{\ }{\ } \; P\frac{\ }{\ } \; M\frac{\ }{\ }\right)$$

3.6 What is the maximum number of teeth an adult human can have?

3.7 State the function for each tooth type.

Understanding U1 Communicating C1 Communicating C2

3.8 Find images of the skeletal jaw and teeth of different types of animals. Discuss in groups what the number and shape of different types of teeth tell you about the diet of these animals.

Digestion in the mouth

- **Mechanical digestion** takes place in the mouth by the chewing and grinding action of teeth on food.
- **Chemical digestion** occurs in the mouth by the action of the enzyme amylase. Amylase is found in saliva, which is a fluid produced by three pairs of salivary glands (located under the tongue, in the cheeks and at the back of the jaws).

Saliva contains water, salts, mucus (or mucin), lysozyme (an enzyme that destroys micro-organisms) and amylase.

Amylase travels through small tubes or ducts into the mouth where it is active. The pH of the mouth is close to 7 and this allows amylase to work. Amylase is inhibited by the acid pH in the stomach.

In the mouth amylase breaks down starch to form maltose:

$$\text{Starch} \xrightarrow{\text{Amylase}} \text{Maltose}$$

Figure 3.4 *The role of amylase*

Did you know?

Humans produce about one litre of saliva every day.

In the mouth, food is formed into a ball, or bolus, and pushed backwards into the pharynx (or throat). The pharynx connects the mouth to the oesophagus. A flap called the **epiglottis** closes over the trachea (or windpipe) and ensures the food passes down the oesophagus.

Q Understanding U1

3.9 What is the difference between mechanical and chemical digestion?

3.10 Why is salivary amylase inactive in the stomach?

Enzyme action

A huge number of **enzymes** are needed to allow the human body (and all living things) to work properly.

> **Enzyme** is a protein that speeds up a reaction without being used up in the reaction.

Along with their role in the digestive system enzymes are also involved in speeding up reactions such as:

- the growth of muscles
- the production of hair
- the formation of blood cells
- the breakdown of poisonous substances such as drugs and alcohol (in the liver).

Each enzyme carries out only one type of reaction. For example, each type of food is broken down by a different enzyme.

Product

The **product** is the substance produced as a result of the action of an enzyme.

For example, in the mouth the enzyme amylase acts on starch. The product of this reaction is called maltose. Amylase only acts on starch. It does not digest other foods such as proteins or fats.

Enzyme	Acts on	Product
Amylase	Starch	Maltose

Substrate

The **substrate** is the substance that an enzyme acts on.

In the mouth the substrate is starch, the enzyme is amylase and the product of the reaction is maltose.

Enzyme	Substrate	Product
Amylase	Starch	Maltose

Activity 3.1

Question

What is the action of salivary amylase on starch?

Equipment needed

Starch solution
Test tubes
Amylase or saliva
Beaker of water at 37°C
Iodine solution
Dropper
Dropping tile
Benedict's solution
Beaker
Bunsen burner
Tripod
Wire gauze

Safety

- Exercise caution when using the Bunsen burner and handling test tubes in the boiling water bath.

Method (phase 1)

1. Dissolve some starch in water to form a starch solution.
2. Add equal amounts of starch solution to each of two test tubes.
3. Add amylase or saliva (which contains the enzyme amylase) to one of the tubes, called tube A. Shake the test tube to mix the contents. Do not add amylase or saliva to tube B. This tube acts as a control.
4. Leave both test tubes for 10 minutes in a water bath at 37°C (this is body temperature and enzymes work best at this temperature).
5. Add a few drops of the solution from each tube to a few drops of iodine solution on a dropping tile.

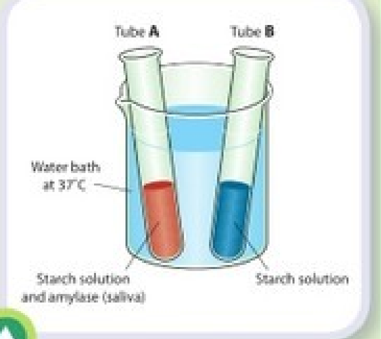

Figure 3.5 *To investigate enzyme action*

Method (phase 2)

At the end of the investigation Benedict's solution can be added to tubes A and B. Both tubes can then be placed in a boiling water bath for a few minutes.

Results

Record your results for each phase of the experiment in the tables below.

Phase 1	Contents	Colour when tested with iodine	Result
Test tube A			
Test tube B			

Phase 2	Contents	Colour when tested with Benedict's solution	Result
Test tube A			
Test tube B			

3.11 Use the internet to find out what the changes in colour with iodine and Benedict's solution show. Use this information to complete the last column of your results table above.

3.12 **(a)** What can you conclude from each phase of the experiment? Explain using the words substrate and product.

(b) Why in phase 2 of the experiment were the tests placed into a bath of boiling water?

3.13 Work in groups. Read the Question and Equipment needed sections of **Activity 3.2** only. Look also at the **Figure 3.6**, but cover the rest of the text about the activity.
Thinking about the question, discuss:

(a) what the role of each item of equipment might be

(b) what the procedure of the experiment might be

(c) what the results might prove.

R2 R3 R4

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Activity 3.2

Question

What is the effect of different pH on the action of salivary amylase on starch?

Equipment needed

2 sets x 3 test tubes
pH tablets of 5, 6.8 and 8
2 beakers
A thermometer
15 ml 1% starch solution + 3 ml 1% NaCl
Saliva solution
3 droppers
Hot plate

Safety

- Exercise caution when using the hot plate.

Method

1. Take a beaker containing 15 ml of 1% starch solution and 3 ml of 1% NaCl solution.
2. Pour the solution equally into three test tubes labelled A, B and C.
3. To test tube A add pH tablet 5, to test tube B pH tablet 6.8 and to test tube C pH tablet 8.
4. Immediately transfer the A, B and C into a beaker containing water and a thermometer for recording temperature. The temperature of this beaker should be maintained at 37°C.
5. Take 3 ml of the saliva solution using a dropper and add 1 ml of solution to each of the three test tubes.
6. Using another dropper, add a few drops from experimental tube A and transfer this into the corresponding test tube of iodine solution. Repeat for the corresponding iodine test tubes for B and C.
7. Record this as the zero minute time reading.
8. At 2-minute intervals add a further drop from each test tube to the iodine test tubes and note any change in the colour of iodine.
9. Repeat the procedure at an interval of every 2 minutes until the colour of the iodine does not change.
10. Note your results.

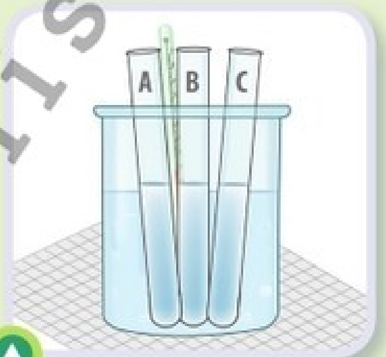

Figure 3.6 *pH of salivary amylase and its effect on starch*

U1 R5

3.14 Did the results support the conclusion you predicted?

Oesophagus

The oesophagus (or foodpipe) carries food to the stomach by an involuntary wave of muscular contraction called **peristalsis**. The process of peristalsis continues throughout the length of the alimentary canal.

Peristalsis

> **Peristalsis** is a wave of muscular action in the walls of the alimentary canal that moves the contents along.

In the stomach, peristalsis helps to break down food mechanically. It also mixes food with the secretions of the stomach and then forces the mixture into the small intestine. In the small intestine, peristalsis forces food forwards and backwards, helping the food to be absorbed. In the large intestine about every 30 minutes strong waves of peristalsis force waste into the rectum.

Figure 3.7 *Peristalsis: note the bolus of food partway down the oesophagus*

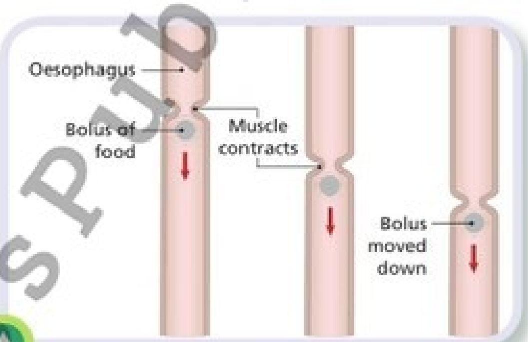

Figure 3.8 *Peristalsis*

Role of fibre

Dietary fibre (also called roughage) is made of cellulose from plant cell walls. Humans cannot digest cellulose. Good sources of fibre in our diet include wholemeal bread, cereals, vegetables and fruit.

Fibre absorbs and stores water. This causes the unabsorbed wastes to expand. The physical increase in the bulk of the waste stimulates the muscles of the intestine to work. In this way **fibre stimulates peristalsis**.

Did you know?

A high-fibre diet is thought to be helpful in reducing the risk of colon cancer. This is because wastes move more rapidly through the colon, which means that cancer-causing chemicals have less time in contact with the colon.

Stomach

The stomach is a muscular bag that holds and digests food. The lining of the stomach (the mucosa) is heavily folded, forming millions of gastric glands. These glands produce a range of secretions, collectively called gastric juice. This consists of mucus, pepsinogen and hydrochloric acid.

Mucus coats the stomach and prevents self-digestion. **Pepsinogen** is an inactive enzyme and therefore does not digest the cells in the stomach lining that produce it. Pepsinogen is converted to the active enzyme pepsin by acid in the stomach. Pepsin converts proteins to smaller peptides. Pepsin is said to be a protease, i.e. it is an enzyme that digests protein.

Hydrochloric acid (HCl) gives the stomach a pH of 1 to 2. The acid kills many bacteria, loosens fibrous and cellular foods, activates pepsinogen and denatures salivary amylase.

Proteins —Pepsin→ Peptides

Figure 3.9 The role of pepsin

The contraction of the stomach walls helps to churn and digest the food mechanically. This turns it into a thick, soupy mixture called chyme. Chyme leaves the stomach in small amounts when a muscle at the base of the stomach opens briefly.

Did you know?

The stomach can hold about 1 litre of food for up to 4 hours. An overproduction of acid in the stomach can lead to heartburn. This occurs when acid rises up the oesophagus, which is not as well covered in mucus as the stomach. It may be controlled by neutralising the acid with alkali, e.g. by taking indigestion tablets.

Q U1 Understanding

3.15 **(a)** What is peristalsis?
(b) State one reason why a low pH is important in the stomach.
(c) Why is fibre important?

3.16 Name the material that makes up the wall of the stomach.

3.17 What enzyme in the stomach digests this substance?

3.18 How does the stomach prevent self-digestion?

3.19 Why does stomach acid not damage the duodenum?

Glands associated with the small intestine

Pancreas

The pancreas secretes the hormone insulin and digestive materials (which form pancreatic juice). Pancreatic juice consists mainly of the salt sodium hydrogen carbonate (or sodium bicarbonate), which neutralises chyme from the stomach, and a range of enzymes such as amylase and lipase. These enzymes enter the duodenum through the pancreatic duct.

Lipase acts on lipids, whereas amylase digests starch. Both enzymes function best at a pH of between 7 and 9, which is the pH of the duodenum.

$$\text{Lipids} \xrightarrow{\text{Lipase}} \text{Fatty acids and glycerol}$$

$$\text{Starch} \xrightarrow{\text{Amylase}} \text{Maltose}$$

Figure 3.10 *The roles of lipase and amylase*

Liver

The liver is a complex organ with many functions. Among the most important functions of the liver are:

- Breaking down red blood cells
- Making bile
- Detoxifying the body, i.e. breaking down poisons such as alcohol and drugs
- Breaking down excess amino acids to form urea
- Converting glucose to glycogen for storage
- Converting excess carbohydrates to fat
- Storing vitamins, such as vitamin D
- Storing minerals (trace elements), such as iron (Fe), copper (Cu) and zinc (Zn)
- Making plasma proteins that are used in blood clotting
- Making cholesterol, which is needed to form many hormones
- Producing heat to warm the blood (and the body).

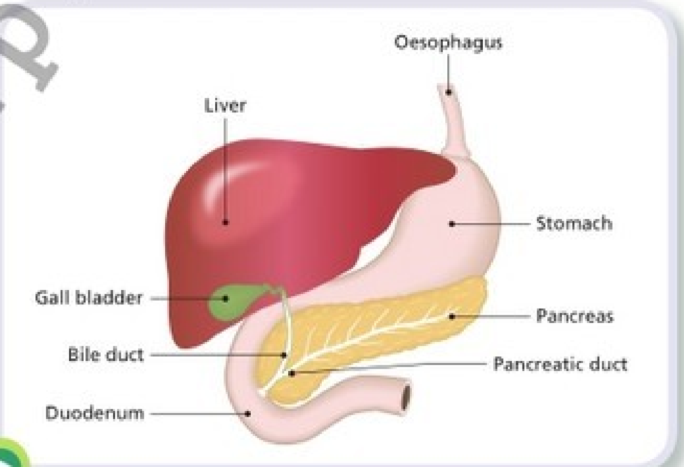

Figure 3.11 *The relationship between the alimentary canal and the liver and pancreas*

Bile

Bile is partly formed from the remains of damaged red blood cells. It is a yellow-green viscous liquid. It consists of water, bile salts and bile pigments (it does not contain any enzymes). Bile is made in the liver and stored in the gall bladder. It enters the duodenum through the bile duct.

Did you know?

Gallstones can form in the bile duct and prevent the release of bile. This often results in severe indigestion, especially after eating fat-rich foods.

Figure 3.12 *Gallstones*

The functions of bile are:

- To emulsify lipids, i.e. to break down large fats and oils into tiny droplets (this increases the surface area for enzyme digestion)
- To neutralise chyme from the stomach (it contains sodium hydrogen carbonate, which is alkaline)
- To excrete pigments (biliverdin and bilirubin), which are made from damaged red blood cells.

Q Understanding U1

3.20 Complete the diagram with the correct letters.

1. ____________ —2. ____________→ 3. ____________ and 4. ____________

5. ____________ —amylase→ 6. ____________

(A) glycerol **(C)** starch **(E)** fatty acids
(B) maltose **(D)** lipids **(F)** lipase

3.21 Which of the following is NOT a function of the liver?

(A) Breaking down red blood cells
(B) Breaking down excess amino acids to form urea
(C) Emulsifying lipids
(D) Making bile
(E) Detoxifying the body, i.e. breaking down poisons such as alcohol and drugs

R2 R3 R4

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Activity 3.3

Question

What is the role of bile in the emulsification of fats?

Equipment needed

3 test tubes
9 ml thick cream
Water
Bile salts
Pancreatic lipase [pancreatin]
water bath
Thermometer
Detergent
Distilled water
pH meter

Safety

- Take care not to spill any of the liquids or cream.

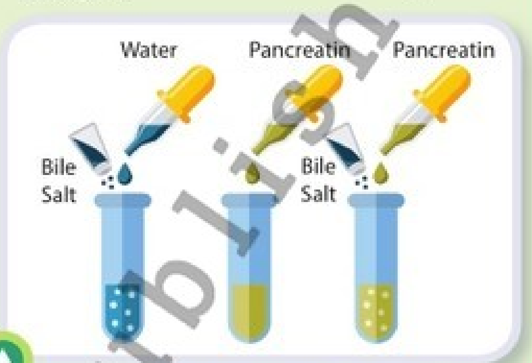

Figure 3.13 *Testing the role of bile in the emulsification of fats*

Procedure

1. Add 3 ml of thick cream to each test tube.
2. Label the test tubes 1, 2 and 3.
3. In test tube 1 add 5 ml of water and a few grains of bile salt.
4. In test tube 2 add 5 ml of pancreatin.
5. In test tube 3 add 5 ml of pancreatin and a few grains of bile salt.
6. Mix the contents of each tube well by shaking.
7. Measure the initial pH of each solution with a pH meter.
8. Between each further measurement clean the pH meter with disinfectant and rinse with distilled water.
9. Place the test tubes into a water bath at 37°C.
10. After 20 minutes, 40 minutes and 60 minutes of incubation take a new pH reading.

Results

Record your results in the following table:

	Test tube 1	Test tube 2	Test tube 3
Initial pH reading			
After 20 minutes			
After 40 minutes			
After 60 minutes			

Q U1 R5

3.22 What did you observe in each test tube?

3.23 What conclusions can you draw about the role of bile in the emulsification of fats?

Small intestine

The small intestine consists of two main parts: the duodenum and the ileum. The duodenum carries out digestion, whereas the ileum is the site of absorption.

Figure 3.14 *Male thorax and abdomen*

Did you know?

The first 25 cm of the small intestine is the duodenum. The remaining 5.5 m comprise the ileum. Food remains in the small intestine for between 1 and 6 hours.

Duodenum

The main function of the duodenum is digestion.

The cells lining the duodenum produce a range of digestive enzymes. In addition, the products of the pancreas and liver enter the duodenum.

The inner lining of the small intestine contains many infoldings called villi (singular: villus). These give the lining a velvety texture. In addition, each villus has many microvilli. The numerous infoldings increase the surface area for either digestion (in the duodenum) or absorption (in the ileum). Intestinal glands between the villi produce a range of enzymes called intestinal juice.

A summary of the digestive process is given in Table 3.1.

Table 3.1 Summary of digestion (enzymes are in bold)

Substance	Made in	Active in	Substrate	Product	Preferred pH
Amylase	Salivary glands	Mouth	Starch	Maltose	7 to 9
Pepsin	Stomach lining	Stomach	Protein	Peptides	2
Hydrochloric acid	Stomach lining	Stomach	Bacteria and fibrous foods	Dead bacteria and softened food	—
Sodium hydrogen carbonate	Pancreas	Duodenum	Acid	Neutralises acid	—
Amylase	Pancreas	Duodenum	Starch	Maltose	7 to 9
Lipase	Pancreas	Duodenum	Lipids	Fatty acids and glycerol	7 to 9
Bile salts	Liver	Duodenum	Lipids	Lipid droplets	—
Sodium hydrogen carbonate	Liver	Duodenum	Acid	Neutralises acid	—

Ileum

The function of the ileum is to absorb nutrients.

Food entering the ileum is almost fully digested. The end products of digestion are given below.

The end products of digestion	
Food	**Digested to**
Carbohydrates	Monosaccharides (e.g. glucose)
Proteins	Amino acids
Lipids	Fatty acids and glycerol

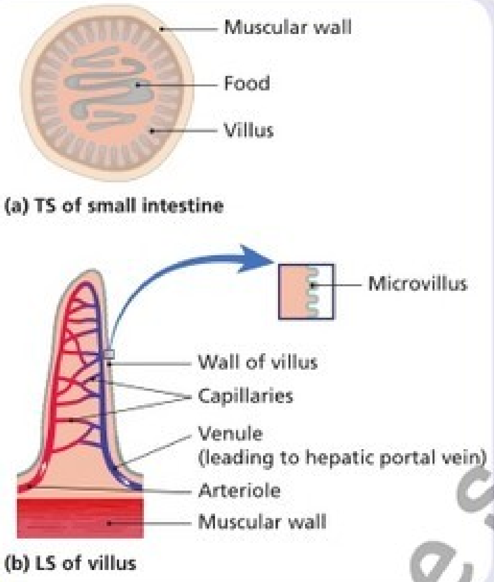

Figure 3.15
(a) Transverse section (TS) of the small intestine
(b) Longitudinal section (LS) of a villus

Villus (plural: villi)

As mentioned earlier, the lining of the duodenum and ileum contains many villi, which increase the surface area for absorption. Food is absorbed by diffusion.

Figure 3.16 *Villi: note the lacteal in the dissected villus*

Adaptations of the villi for absorption

- Large numbers (increase the surface area)
- Large numbers of microvilli (increase the surface area)
- Their walls are only one cell thick
- They have a rich blood supply

The capillaries in each villus absorb water and soluble nutrients such as glucose, amino acids, vitamins and minerals. The capillaries carry the nutrients to the hepatic portal vein, which takes them to the liver. The liver acts as a warehouse, storing some nutrients and releasing others for use throughout the body.

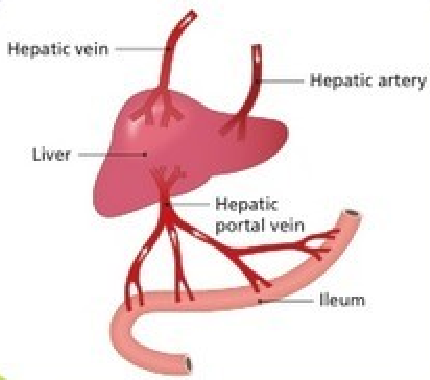

Figure 3.17 *The relationship between the ileum and the liver*

Amino acids cannot be stored in the body (they become toxic). Any amino acids not used by the body are broken down in the liver, forming urea. This process is called **deamination**. Urea and other waste leave the liver in the hepatic vein and eventually pass to the kidneys. Here it forms part of urine, which is then excreted.

Lacteal

Inside each villus is a **lacteal** (see diagram 3.15). Each lacteal contains a liquid called lymph. Fatty acids and glycerol are absorbed into the cells of the villus lining. Here they re-form into fats. These fats are coated with protein and pass into the lymph in the lacteals.

The fats are transported by the lymph, which carries them to the bloodstream in lymph vessels. The protein coat is dissolved in the blood and the fats are absorbed into cells.

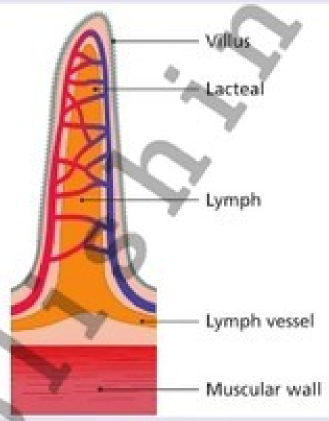

Figure 3.18 *The relationship between the villus and the lacteal*

Did you know?

It takes lymph about 18 hours to pass from the intestine to the bloodstream. Lymph flows into the bloodstream at the subclavian veins near the base of the neck.

Adaptations of the small intestine for absorption

- It is very long
- It has numerous villi and microvilli (which increase the surface area)
- The walls of the villi are very thin
- There is a rich blood supply to carry away water-soluble products
- Each villus has a lymph supply (lacteal) to carry away the fats

Large intestine

The large intestine is only about 1.5 m long (compared with the small intestine, which is about 6 m long). It is called **large** due to its greater diameter (about 6 cm, compared with 3 cm for the small intestine). Food stays in the large intestine for between 10 hours and a few days.

Colon

The function of the colon is to reabsorb water.

The liquid waste that enters the large intestine is converted to semi-solid waste called faeces by the reabsorption of water. Faeces are stored in the rectum before being egested through the anus. (**Note:** Faeces are egested and not excreted. This is because excretion is the removal of the waste products of metabolism from the body. Faeces are not the product of metabolism.)

Figure 3.19 *TS of the colon*

Did you know?

Diarrhoea occurs when unabsorbed material moves too rapidly through the colon. Less water is then reabsorbed and the faeces contain more liquid. Constipation is the reverse. It results from unabsorbed material passing too slowly through the colon so that too much water is reabsorbed. It may be controlled by eating more fibre, which stimulates peristalsis.

Q Understanding U1

3.24 What are the end products of digestion?

3.25 Name the end products of food digestion that are:
- (i) soluble
- (ii) insoluble in water

3.26 Explain what happens to the:
- (i) water-soluble end products
- (ii) water-insoluble end products.

For the questions below choose the best option A,B,C or D.

3.27 Proteins are chemically digested in the:
(a) mouth (b) stomach (c) liver (d) large intestine.

3.28 The role of lacteals is to absorb:
(a) starch (b) amino acids (c) lipids (d) proteins.

3.29 The substance produced by the pancreas to neutralise stomach acid is called:
(a) chyme (b) maltose (c) vitamin D (d) Sodium hydrogen carbonate.

3.30 The stomach has a pH of:
(a) 6 (b) 2 (c) 8 (d) 12.

MODULE 4

Transport in plants

Learning outcomes

At the end of this module you will be able to:

- Compare passive and active transportation 9.1.3.1
- Explain the process of transpiration in plants 9.1.3.2
- Analyse the internal and external factors affecting the process of transpiration 9.1.3.3
- Recognise external factors causing the movement of substances on the phloem 9.1.3.4

Keywords

✔ active transport ✔ passive transport ✔ turgor pressure ✔ root ✔ xylem ✔ phloem ✔ concentration gradient ✔ osmosis ✔ diffusion ✔ wilt ✔ transpiration ✔ humidity ✔ translocation ✔ source ✔ sink

Passive transport

Passive transport is a process that occurs without the cell needing to expend energy to accomplish the movement. In passive transport, substances move from an area of higher concentration to an area of lower concentration. Diffusion and osmosis are both forms of passive transport.

Osmosis and plant cells

The cytoplasm of plant cells contains many dissolved solutes. As a result, the concentration of the cytoplasm of plant cells is far greater than that of pure water. This causes water to move into plant cells by osmosis. When this occurs, the cytoplasm swells and pushes against the rigid cell wall. This causes the build-up of pressure known as **turgor pressure** (see Figure 4.1). If there were no cell wall in plant cells, the continuous movement of water into the plant cell would likely cause the cell to burst.

Figure 4.1 *A wilted plant*

Turgor pressure provides mechanical support to plants, helping the leaves and stems of non-woody plants to remain upright. During hot weather or drought, a plant will start to wilt due to loss of turgor pressure.

Turgor pressure is the pressure that is caused by water passing into the cell by osmosis, resulting in the cytoplasm and vacuole pushing against the cell wall.

If plant cells are placed in a concentrated salt solution, water will move out of the plant cell by osmosis. This causes the cytoplasm and the cell membrane to shrink away from the cell wall, resulting in gaps between the cell wall and the cell membrane. This condition is known as plasmolysis (see Figure 4.2).

Plasmolysis is the shrinking of the cytoplasm and the movement of the cell membrane away from the cell wall due to loss of water by osmosis.

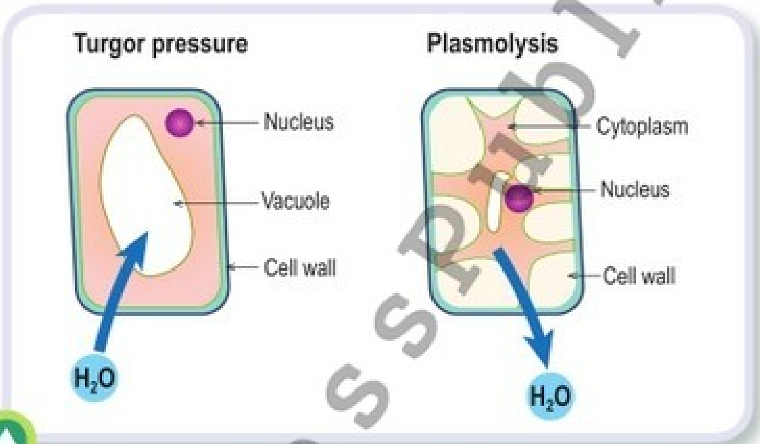

Figure 4.2 *Cells showing turgor pressure and plasmolysis*

Active transport

Active transport is the movement of a substance from an area of low concentration to an area of high concentration against a concentration gradient. Active transport requires energy.

Certain substances are required in large amounts by cells, e.g. glucose and amino acids. This results in the accumulation of these substances in the cell in high concentrations. In order for more glucose or amino acids to move across the cell membrane, energy is required. The movement of these substances is against a concentration gradient (from a low concentration to a high concentration).

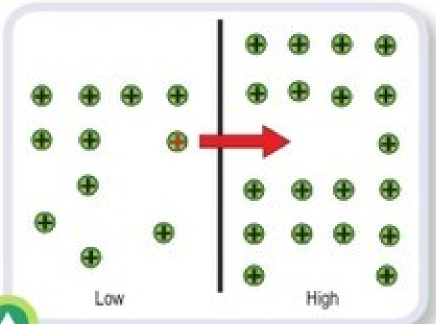

Figure 4.3 *Active transport*

Active transport is required for the movement of important plant nutrients (nitrate and phosphate ions) from the soil solution into the root hairs of plants. These nutrients are dissolved in the soil solution and are absorbed into the plant through the root hairs. The movement of these nutrient ions is from a region of low concentration (soil solution) to a region of high concentration (root hairs) against a concentration gradient.

Q U1 Understanding

4.1 Define the terms 'osmosis' and 'turgor pressure'.

4.2 State two differences between active and passive transport.

4.3 What causes plants to wilt in long periods of dry weather?

4.4 Explain what would happen if you placed a sample of plant tissue in a concentrated salt solution.

The transport of water in the vascular tissue of plants

In plants, xylem tissue is responsible for the transport of water and minerals from the roots to the leaves. Water is an essential ingredient for photosynthesis and it is vital that photosynthesising cells have a plentiful supply. The movement of water from the roots up to the leaves of plants can be explained by root pressure, cohesion-tension and transpiration. As a result, water moves as a continuous column up the xylem tissue from the roots to the leaves. This movement of water in the xylem vessels is known as the transpiration stream.

The **transpiration stream** is the uninterrupted passage of water in the xylem tissue from the roots up to the leaves in plants.

Root pressure

Root pressure is caused by the continuous movement of water by osmosis, from the soil into the root hairs. This causes a build-up of pressure, which forces water into the xylem vessels and tracheids. Root pressure on its own is not sufficient to push water up to the leaves of large plants. Root pressure can be illustrated by cutting a herbaceous plant close to the bottom of the stem. A little bubble of water will form on the top of the cut stem. Root pressure can be responsible for forcing water out of the leaves of grasses and strawberry plants in a process known as guttation.

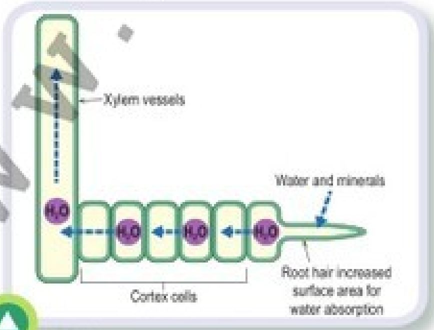

Figure 4.4 *Movement of water into a plant root system*

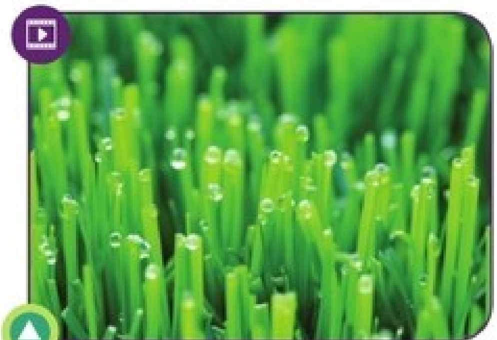

Figure 4.5 *Root pressure forces water out of the leaves of grass*

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Transpiration

Water is constantly lost through the stomata in the leaves by evaporation.

> **Transpiration:** the loss of water by evaporation from the leaves.

As a result, water is drawn out of the xylem vessels to replace the water lost through evaporation. This pulls water up the xylem vessels.

Cohesion–tension model

Water molecules tend to stick together, causing a force known as cohesion. In addition, the loss of water from the leaves by transpiration creates a tension and the combination of these forces together pulls water as a continuous column up the xylem vessels and tracheids.

Factors that affect the rate of transpiration

The rate of transpiration is not constant and is influenced by a number of factors. The factors that affect transpiration are summarised in Table 4.1.

Table 4.1 Factors that affect the rate of transpiration

Factor	Effect
Temperature	Evaporation of water from the leaves of plants helps to keep them cool. On hot days the rate of transpiration increases. The rate of transpiration decreases on cold days.
Wind	On calm days a layer of water vapour builds up around the stomata, increasing the humidity and decreasing the rate of transpiration. On windy days the rate of transpiration increases as air movement across the stomata prevents the build-up of humid air.
Soil water	If plants experience a water shortage, as in the case of droughts, the stomata of the leaves close in an effort to reduce transpiration and conserve water. When soil water is plentiful, plants respire at a higher rate.
Light	Light stimulates the opening of the stomata, increasing the rate of transpiration. Stomata are normally closed at night, reducing the rate of transpiration.
Humidity	If the air is dry and low in water vapour, the rate of transpiration increases. If there is rain or the air is high in water vapour, the rate of transpiration decreases as the air becomes saturated with water vapour and can hold no more water.

Q Understanding U1

4.5 Explain the following terms:

(a) Root pressure
(b) Transpiration
(c) Transpiration stream
(d) Cohesion

4.6 (a) How does increasing relative humidity affect the rate of transpiration?
(b) List 3 other factors that affect the rate of transpiration.

4.7 Briefly describe the movement of water from the roots to the leaves of plants.

4.8 How do plants react at times of drought?

R2 R3 R4

Activity 4.1

Question

How can we measure the rate of transpiration?

Equipment needed

Scalpel or safety blade
Leafy shoot (use a plant that has a thin, waxy cuticle, e.g. beech or lilac)
Potometer
Large basin (or sink)
Beaker
Vaseline
Lamp

Safety

- Take care when using the scalpel.

Conducting the activity

1. Cut a leafy shoot at an angle under water.

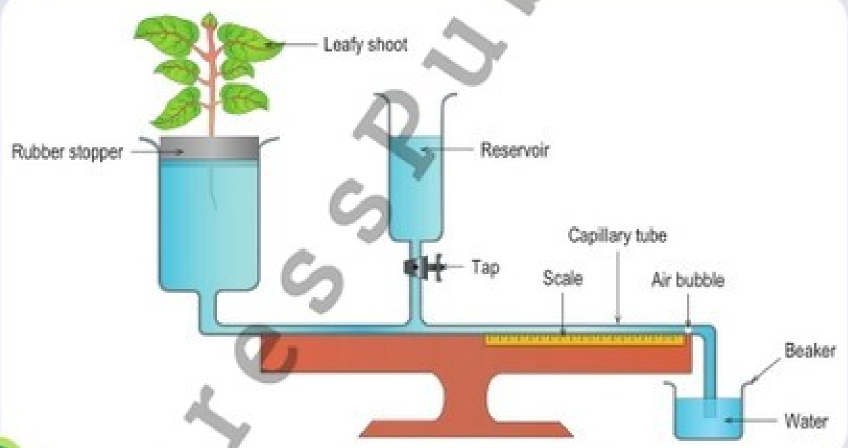

Figure 4.6 *Measuring the rate of transpiration using a potometer*

2. Immerse the potometer under water. (Note: If air gets into the xylem vessels it can form an air lock, interfering with transpiration.)
3. Place the leafy shoot into the potometer.
4. Use Vaseline to seal all the joints of the potometer and prevent air entering.
5. Place the potometer in front of a lamp.
6. Remove the capillary tube from the beaker of water and allow an air bubble to enter the capillary tube.
7. Re-immerse the capillary tube in the beaker of water.
8. Using the scale, note the start position of the bubble.
9. Leave the potometer for two hours.
10. Measure the position of the bubble after two hours and calculate the distance travelled by the air bubble.
11. The rate of transpiration is calculated by dividing the distance moved by the air bubble by the time taken. Units for transpiration cm/min.

Record your results.

This activity can be repeated using a fan or hairdryer to investigate the effect of wind on the rate of transpiration.

Q U1 R1 R5

4.9 Why is it important to avoid air getting into the xylem vessels in this experiment?

4.10 What did you observe about the air bubble in the capillary tube?

4.11 What can you conclude from your results?

R2 R3 R4

Activity 4.2

Question

How can we demonstrate the production of water during transpiration?

Equipment needed

Geranium or busy Lizzie	Plastic bag	Anhydrous copper Sulfate
	Bell jar	

Safety

- Be careful when handling the bell jar as it could break and cause injury.

Conducting the activity

1. Ensure the plant is well watered before the start of the experiment.
2. Wrap the bag around the base of the plant to enclose the pot and the surface of the soil. This is to prevent water evaporating from the soil.
3. Place the plant under the bell jar.
4. Leave in a sunny location for a few days.
5. Condensation will build up on the inside of the bell jar.
6. Heat hydrated copper sulfate over a Bunsen burner to remove the water from the compound. When the copper sulfate changes from a blue colour to white, all the water has evaporated and it is now anhydrous.
7. Use anhydrous copper sulfate to test for the presence of water. Add a few drops of the liquid that has condensed on the inside of the bell jar to the anhydrous copper sulfate.

Figure 4.7 Condensation on the inside of the bell jar is due to transpiration

Q Understanding U1 Research R1 Research R5

4.12 What variable did you try to eliminate in this experiment?

4.13 What happened when you added some drops of the condensed liquid to the copper sulfate?

4.14 What did this test prove?

Translocation

Translocation is the movement of sugars produced in the leaves (sources or sites of photosynthesis) to other regions of the plant for storage or use (sinks).

Phloem sap is primarily water with sugars and plant hormones dissolved in it. The movement of the phloem sap can occur up and down the phloem sieve tubes from sites of sugar production, known as **sources** (sites of photosynthesis) to regions where sugars are required or stored; these regions are known as **sinks**. Important sinks for the storage and use of sugars include roots, flowers, fruits and stems. Plants store their sugars as starch.

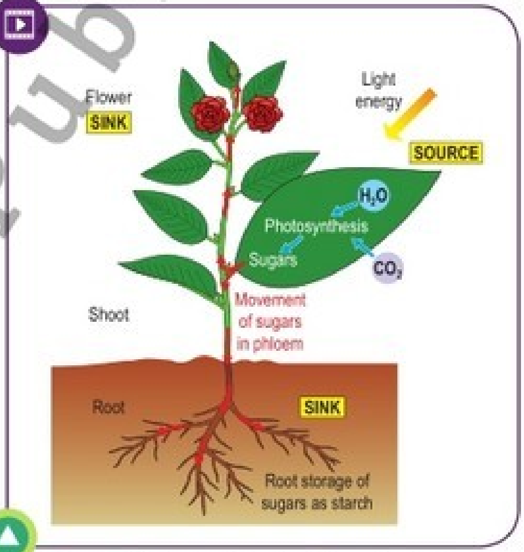

Figure 4.8 *Translocation in a flowering plant*

The mechanism by which phloem sap moves is best described as the **pressure-flow hypothesis**. In photosynthesising leaves (sources), sugars are moved into phloem tissue by active transport. This increases the concentration of sugars inside in the phloem tissue. As a result, water moves into the phloem cells by osmosis. Since the walls of the phloem cells are rigid, pressure builds up. In non-photosynthesising regions (sinks), sugars are constantly being removed for storage or use. As a result, water also exits phloem tissue by osmosis, causing a decrease in pressure. This produces a pressure gradient between the source and the sink, which causes phloem sap to flow from source to sink.

Q Understanding U1

4.15 Translocation is the movement of sugars from **sources** to **sinks**. Explain what is meant by the highlighted terms.

4.16 Explain the difference between transpiration and translocation.

MODULE 5

Respiration and Excretion

Learning outcomes

At the end of this module you will be able to:

- Compare the processes of aerobic and anaerobic respiration and their chemical equations 9.1.4.1
- Consider the relationship between muscle fatigue and the processes of aerobic and anaerobic respiration 9.1.4.2
- Describe the structure and the function of the nephron 9.1.5.1
- Describe the processes of the filtering and formation of urine 9.1.5.2
- Describe factors that affect the functioning of the kidneys 9.1.5.3
- Explain measures of prevention of kidney and urinary tract diseases 9.1.5.4
- Identify a link between habitat and end products of metabolism in different organisms 9.1.5.5

Keywords

✔ aerobic respiration ✔ anaerobic respiration ✔ glycolysis
✔ lactic acid ✔ nephron ✔ arteriole ✔ reabsorption
✔ filtrate ✔ diuretic ✔ kidney stone ✔ nitrogenous wastes

Aerobic respiration

Living things need energy to allow them to move, grow, stay warm and repair damaged parts. They get their energy from food in a process called respiration.

The majority of living things need oxygen for respiration. This type of respiration is called aerobic respiration. Aerobic respiration needs oxygen to release energy from food.

To allow aerobic respiration to take place all cells need a supply of glucose and oxygen.

- Glucose is carried by the blood from the small intestine to all the cells of the body.
- Oxygen is carried by the blood from the lungs to all the cells of the body.
- In all living cells glucose combines with oxygen to release energy and the waste products carbon dioxide and water vapour.

- Some of the energy is used by the cells while some is lost as heat.
- The waste products are carried by the blood to the lungs from where they pass out of the body.

Respiration is the release of energy from food.

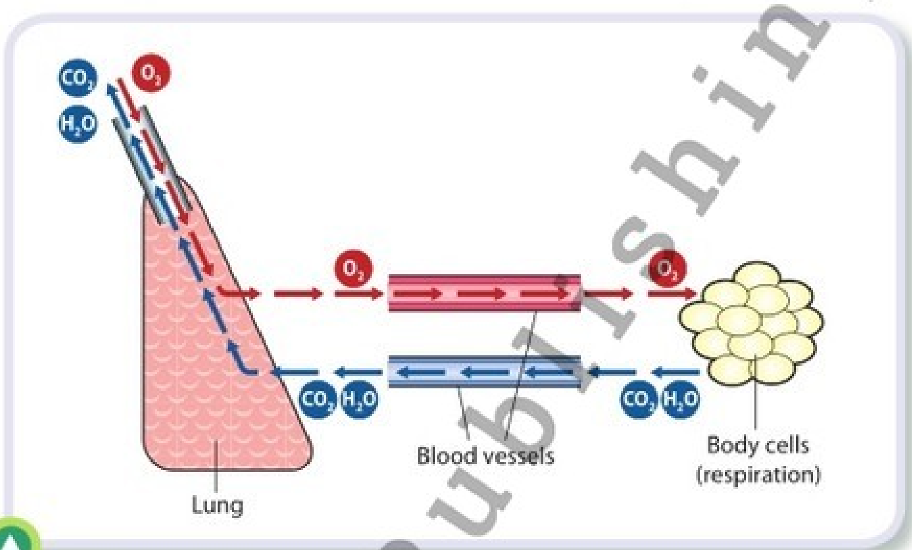

Figure 5.1 *Gas exchange in the lungs and body cells*

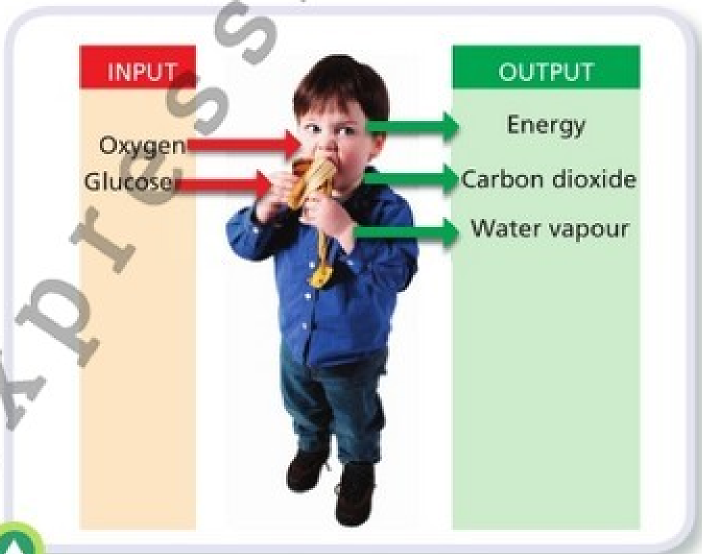

Figure 5.2 *The process of aerobic respiration*

Both plant and animal cells obtain their energy by aerobic respiration. The products of aerobic respiration are carbon dioxide, water and energy in the form of ATP (adenosine triphosphate). ATP is the energy source used by cells.

Aerobic respiration is the controlled release of energy from glucose in the presence of oxygen.

The overall balanced chemical equation for the reaction is:

$$\text{Glucose + Oxygen} \rightarrow \text{Carbon dioxide + Water + Energy}$$
$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy}$$

The first stage of aerobic respiration, glycolysis, takes place in the cytosol. This stage does not require oxygen and releases only a small amount of energy. During this stage, glucose is broken down into two molecules of pyruvic acid.

If oxygen is available, the pyruvic acid passes into the mitochondria and goes through a series of chemical reactions which result in the pyruvic acid completely breaking down into carbon dioxide and water. This process produces a large amount of energy.

Q U1 Understanding

5.1 Define **aerobic respiration**. Write a balanced chemical equation to show the products of aerobic respiration.

$C_6H_{12}O_6 + 6O_2 \rightarrow +$ ________________________________

5.2 Aerobic respiration occurs in two stages in plant and animal cells.

(a) Name the first stage of aerobic respiration and identify the location in the cell where this stage occurs.

(b) Name the organelle where the second stage of aerobic respiration occurs.

Anaerobic respiration

Anaerobic respiration differs from aerobic respiration in that it occurs in the absence of oxygen. Like aerobic respiration, it also uses glucose and produces energy, but less energy because no oxygen is present.

Anaerobic respiration occurs in tissues which have a high energy demand, at times when there is insufficient oxygen for the energy needed to be produced through aerobic respiration alone, such as when muscles are worked during vigorous exercise. Anaerobic respiration takes place in the cell cytoplasm and produces lactic acid.

$$\text{Glucose} \rightarrow \text{Lactic acid + Energy}$$
$$C_6H_{12}O_6 \rightarrow 2C_3H_6O_3 + \text{Energy}$$

Lactic acid accumulates during strenuous exercise and this causes muscles to feel sore, begin to twitch and eventually reach a point where they can no longer contract. Following anaerobic respiration, the lactic acid needs to be oxidised so it can turn into carbon dioxide and water, and this is why we say that after anaerobic respiration there is an 'oxygen debt' in the cell. Think of an athlete after a workout breathing heavily, taking in the oxygen needed to breakdown the lactic acid.

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Understanding U1

5.3 Under what conditions do humans respire anaerobically?

5.4 What is the end product of this process?

5.5 What is the effect of this product on muscles?

5.6 Give the word equation to represent anaerobic respiration in human muscle.

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Activity 5.1

Question

How can we show that muscles working harder will tire sooner?

Figure 5.3 *Opening and closing hands*

Equipment needed

1 set of workout weights per group

Conducting the activity

Procedure 1

1. Sit in a chair and rest your elbow on the desk.
2. Open and close the hand of your stronger arm at the rate of once every three seconds.
3. Record the time it takes to feel muscle fatigue (the point at which it becomes too painful to continue the action).
4. Rest your hand for two minutes.
5. Repeat steps 1 to 4 at a faster speeds opening and closing your hand every 2 seconds and then every second. Record your results.

Procedure 2

1. Stand with legs at shoulder length apart.
2. Perform a bicep curl (see Figure 5.4) every three seconds. Use your stronger arm or both arms.
3. Record the time it takes to feel fatigued (the point at which it becomes too painful to continue the action).
4. Rest your arm for two minutes.
5. Repeat steps 1 to 4 using faster speeds of bicep curl.

Figure 5.4 *Bicep curl*

Understanding U1 Research R5

5.7 What did your results show? Were they conclusive?

5.8 How would you describe the physical effects of such exercise?

5.9 What can you conclude from the experiment?

The kidney

The main function of the kidney in the body is the production of urine. It is also responsible for the removal of wastes from the blood such as excess water, salt and urea.

Kidneys occur in pairs and are located in the abdominal cavity just below the diaphragm. The left kidney sits higher than the right kidney due to the presence of the liver on the right-hand side of the abdomen. Kidneys are bean-shaped and are surrounded by two layers of fat for protection. The kidneys form an important part of the urinary system.

The urinary system

- **Kidney:** site where urine is produced
- **Ureter:** duct that connects the kidney to the bladder, carrying urine to the bladder for storage
- **Bladder:** site where urine is stored until it is expelled from the body
- **Urethra:** duct through which urine is expelled from the body
- **Renal artery:** supplies oxygenated blood to the kidney from the dorsal aorta; this blood also carries wastes to be filtered from the blood
- **Renal vein:** carries blood away from the kidney, after it has been filtered.

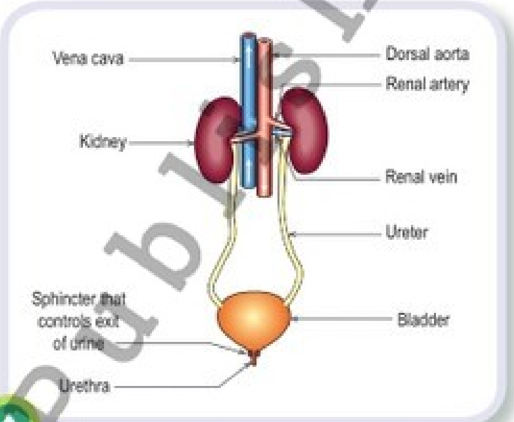


Figure 5.5 *Urinary system*

Structure of the kidney

The kidney consists of approximately one million tubules called nephrons. The function of the nephron is to produce urine. Nephrons are located in the cortex, but extend into the medulla. Each nephron consists of several parts. A diagram of a nephron is shown in Figure 5.6.

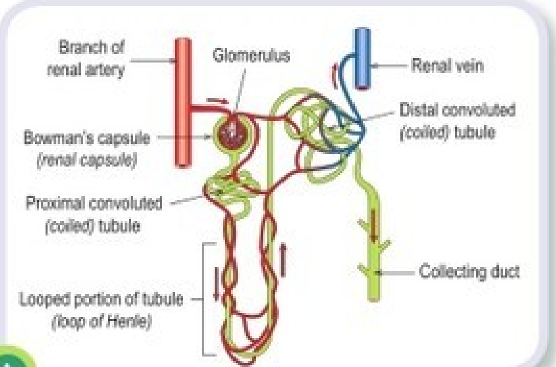


Figure 5.6 *The nephron*

The C-shaped structure on the upper end of the nephron is called Bowman's capsule. The nephron extends to form a tubule called the proximal convoluted tubule, which in turn bends to form a U-shaped tube called the loop of Henle. The loop of Henle ascends into the distal convoluted tubule, which in turn leads into a collecting duct.

Each nephron has its own blood supply. A branch of the renal artery enters the Bowman's capsule, which divides to form a number of capillaries. This cluster of capillaries is called a glomerulus. This part of the nephron is located in the cortex of the kidney and it is the concentration of glomeruli that gives the cortex its dark-red colour. The capillaries drain into an arteriole, which loops around the nephron. The capillaries lead to venules, which in turn lead to the renal vein.

Q Understanding U1

5.10 What are the main functions of the kidney?
5.11 What is the function of the nephron?
5.12 What happens in the Bowman's capsule?

Production of urine

Blood enters the glomerulus and is filtered under high pressure. Blood cells are too big to be filtered but glucose, salts and waste filter from the glomerulus through the walls of the Bowman's capsule. The filtered blood leaves the glomerulus through the arteriole. However, if glucose, salts and water were to be continually removed from the blood through filtration the body would soon become dehydrated and starved of nutrients. Selective reabsorption of nutrients prevents this from happening.

Selective reabsorption: a process where the body reabsorbs certain molecules for use in the body by active transport. The molecules include glucose, amino acids, vitamins and water (which were removed in the filtration process).

Selective reabsorption

Selective reabsorption takes place in the proximal convoluted tubule. A low sodium concentration is maintained in the walls of the proximal convoluted tubule by pumping sodium out of the wall by active transport. The filtrate moves from Bowman's capsule to the proximal convoluted tubule. Na+ ions then pass from the glomerular filtrate into the wall of the proximal convoluted tubule due to the low concentration gradient. This process takes place by passive diffusion. Cl– ions are also reabsorbed. Water is also reabsorbed and passes through the wall of the proximal convoluted tubule by osmosis. Other toxins accumulated by the body are added to the waste fluid as it passes through the distal convoluted tubule.

Did you know?

A **diuretic** is a substance that causes the increased passing of urine.
An **anti-diuretic** is a substance that supresses the formation of urine.

The amount of water that is reabsorbed is controlled by a hormone called anti-diuretic hormone (ADH), which is produced in the pituitary gland. ADH increases the permeability of the collecting duct, allowing water to be absorbed. The more water that is reabsorbed, the smaller the volume of urine produced. If the osmotic pressure of the blood falls, ADH is not produced by the pituitary gland. The collecting duct ceases to be permeable and water is not reabsorbed. A greater volume of urine is produced.

Q Understanding U1

5.13 What is selective reabsorption?
5.14 Where does reabsorption take place?
5.15 What does ADH stand for and where is it produced in the body?

Factors affecting kidney function

The role of the kidneys is to filter and return around 200 litres of fluid to the bloodstream every day. About two litres are removed from the body in the form of urine, and about 198 litres are recovered.

There are numerous factors that can affect the condition and functioning of the kidneys but the main ones are:

- Poor diet can increase the risk of kidney disease by causing higher blood pressure and cholesterol levels. Obesity is associated with poor kidney function as are diets which are high in salt content. It is recommended that people limit their salt intake to 6g a day as more than this is likely to lead to higher blood pressure.
- Smoking is another key factor linked to poor kidney function because it leads to cardiovascular disease which is associated with kidney disease.
- Taking exercise helps kidney function as it helps reduce blood pressure.
- Alcohol can cause changes in the function of the kidneys and make them less able to filter your blood. It can also affect the ability of the kidney to maintain the right amount of water in the body.
- Patients suffering from a range of conditions such as tonsillitis and hypothermia will also need their kidney function closely monitored as kidney failure can be linked to these illnesses.

Kidney diseases

CKD

Chronic kidney disease is defined as having some type of kidney abnormality, or 'marker', such as protein in the urine and having limited kidney function for a period of three months or longer. The two conditions most closely associated with CKD are diabetes and high blood pressure. Diabetes occurs when the body does not make enough insulin or cannot use normal amounts of insulin properly. This results in a high blood sugar level and is the leading cause of kidney disease. High blood pressure occurs when the force of blood against your artery walls increases.

Polycystic kidney disease

Polycystic kidney disease is the most common inherited kidney disease. In this condition kidney cysts form that enlarge over time and may cause serious kidney damage and even kidney failure.

Kidney stones

Kidney stones are one of the most common conditions associated with the kidneys. Their causes range from an inherited disorder that causes too much calcium to be absorbed from foods to infections or obstructions of the urinary tract.

Patients with kidney stones can experience severe pain in the back and side when the stones pass. In cases where stones are too large to pass naturally, patients can have stones removed or a treatment to break them down into small pieces that can pass out of the body.

Figure 5.7 *kidney stones*

Urinary tract infections

Urinary tract infections occur when germs enter the urinary tract and cause symptoms such as pain or a burning sensation during urination and result in a more frequent need to urinate. These infections most often affect the bladder, but they sometimes spread to the kidneys, and they may cause fever and pain in your back. In women most infections are caused by bacteria from the bowel that reach the urethra and bladder. In men, most infections are the result of problems that restrict normal urine flow, such as an enlarged prostate.

Figure 5.8 *Urine samples in a lab*

Excretion in the animal kingdom

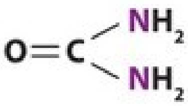
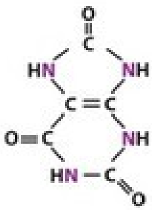
We have defined excretion as the removal from the body of the waste products of metabolic activity. We have seen that one of the basic functions of excretion is the removal of nitrogenous wastes that would be toxic if built up in the body.

How different types of animal in the animal kingdom excrete such nitrogenous wastes and the forms in which they excrete them are linked to the evolutionary development of an animal and the habitat in which it lives.

Most animals that live in aquatic habitats eliminate nitrogenous wastes as ammonia. Ammonia is highly toxic but also very water soluble and hence can be effectively flushed by animals in aquatic habitats.

Land animals, with more limited access to water, need to excrete nitrogenous waste in less toxic forms. In the case of mammals, nitrogenous wastes are excreted in the form of urea. This is less toxic than ammonia and can, therefore, be stored in higher concentrations. In the cases of reptiles and birds, wastes are excreted in the form of uric acid - in the form of a semi-solid paste. Although this requires more metabolic energy to produce, it requires very little water to flush which means less weight to carry around.

Table 5.1 **Nitrogenous wastes**

A	B	C
		
NH_3 Ammonia	 Urea	 Uric acid
Figure 5.9 *Most aquatic animals*	Figure 5.10 *Mammals and amphibians*	Figure 5.11 *Reptiles, birds, insects*

Q U1 Understanding

5.16 Which of the following are the main functions of your kidneys?

(A) to support healthy bones and tissues

(B) to keep your blood pressure normal

(C) to clean the blood

(D) all the above

5.17 Name the nitrogenous waste product of:

(a) a cat

(b) a lizard

(c) a fish.

5.18 Give two common symptoms of a kidney infection.

5.19 What is a common cause of a urinary tract infection in

(a) women

(b) men?

5.20 Name two conditions which can cause chronic kidney failure?

MODULE 6

Regulation and Response

Learning outcomes

At the end of this module you will be able to:

- Establish the connection between the function and structure of nerve cells 9.1.7.1
- Describe the functions of nerve tissue and its components 9.1.7.2
- Describe the origin and conduction of nerve impulses 9.1.7.3
- Explain the mechanism of neurohumoral regulation 9.1.7.4
- Explain the mechanism for maintaining constancy of the internal environment of the organism 9.1.7.5
- Identify the effects of growth regulators on plant life 9.1.7.6

Keywords

✔ homeostasis ✔ internal environment ✔ response ✔ stimulus ✔ nerve impulse
✔ neuron ✔ dendrite ✔ axon ✔ synapse ✔ repolarisation ✔ depolarisation
✔ hormone ✔ gland ✔ tropism ✔ phototropic ✔ growth regulator

External and Internal environments

The term 'external environment' refers to the surroundings in which an organism lives. The external environment for **amoeba** is fresh water; for humans it is the air around us. Most organisms (apart from humans) have relatively little ability to control their external environment.

The term 'internal environment' refers to the surroundings of the cells in a multicellular organism. The internal environment of humans is tissue fluid (or intercellular fluid). Tissue fluid surrounds every cell in the human body. All organisms have the ability to control their internal environment, or their cell conditions, to some extent.

Homeostasis

Homeostasis involves a combination of many processes acting together to control the internal environment of an organism. Examples of homeostasis in humans include:

- Maintaining body temperatures very close to 37°C, despite widespread changes in external temperatures

- Keeping the pH of the blood and tissue fluid very close to pH 7.4
- Preventing the build-up of toxic chemicals in the body
- Maintaining sufficient levels of oxygen in the body
- Regulating the level of glucose in the blood plasma so that it stays close to 0.1%.

The control of features such as those listed above requires the involvement of many organs and organ systems. For example:

- Body temperature is controlled mainly by the skin
- Blood plasma pH and, consequently, tissue fluid pH, is controlled by the kidneys
- Prevention of the build-up of toxic wastes is controlled by the liver and kidneys
- Oxygen concentrations are controlled by the respiratory system
- The level of glucose is controlled by the hormone insulin produced by the endocrine system.

Figure 6.1 *Body temperature in hot (left) and cold (right) temperatures: red is 37°C and dark blue is 25°C*

The brain co-ordinates the activities of these organs and systems in humans. To allow this to happen, the brain must be continuously informed of conditions, both inside and outside the body, so that it can cause the relevant change(s) to be made.

Homeostasis requires exchange

In many cases, homeostasis is dependent on an organism exchanging materials with its environment by diffusion, osmosis and active transport. Diffusion and osmosis do not require energy, but active transport does. For example, materials such as gases, nutrients and toxic wastes have to be exchanged between cells and their external environment.

The rate and efficiency at which exchange can take place depends on the amount of material to be exchanged and the surface area available for diffusion.

- For small, single-celled organisms (such as amoeba), special organs are not required for exchange. This is because there is a large surface area over which a relatively small amount of material can be exchanged.
- In larger, multicellular organisms, such as plants and animals, the problems of exchange are overcome by a range of methods. Some of these methods require the development of exchange systems such as respiratory and excretory systems, as outlined below.

Methods used to improve exchange

- The organ or organism may be flattened, as is the case in the leaves of a plant. This reduces the distance between the two surfaces and allows sufficient materials to be exchanged by diffusion.
- Respiratory systems provide increased surface area for the exchange of gases by diffusion. This is seen in the development of alveoli in the human lungs.
- Respiratory and excretory systems take materials to the body surface. This happens in humans where gases pass in and out of the lungs and waste products are excreted from the body (e.g. when salts and water are removed from the body in the form of sweat).

Figure 6.2 *Alveoli have a large surface area for gas exchange*

In addition to the methods outlined above, large organisms have another problem. Exchange is only effective over short distances (about 0.5 mm). Therefore, large active animals such as humans have to develop a circulatory system.

A circulatory system transports materials such as gases, nutrients and toxic wastes over long distances. For example, gases are transported by the blood circulatory system from all over the body to and from the lungs. In addition, waste products from all parts of the body are taken to the kidneys in the bloodstream.

The need for homeostasis

Homeostasis allows organisms to function efficiently

Homeostasis controls the environment surrounding the cells. This allows the cells to maintain constant conditions, thus enabling them to function under the most suitable (optimal) conditions. If the cells operate under ideal conditions then the organism will function most efficiently. For example:

- If the temperature of the cells in the human body falls below 37°C, the reactions in the cells will slow down (because the rate of enzyme reactions slows down). This will result in the metabolism of the person slowing down.
- If the temperature of human cells rises above 37°C, the reactions will also slow down (because human enzymes begin to lose their shape and work less efficiently at high temperatures). Each human cell (and as a consequence the human body) works most efficiently at 37°C.

Homeostasis allows organisms to function independently of their external environment

Homeostasis allows organisms to function most efficiently in adverse or unsuitable external conditions.

- For example, humans can continue to function when the external temperature drops in winter because they can control their internal temperature.
- However, frogs, for example, cannot control their internal temperature. Their temperature rises and falls with the temperature of their external environment.
- As a result, low temperatures cause frogs to slow down their metabolism. In order to avoid slowing down (and dying) in the cold of winter, frogs are forced to hibernate in order to conserve energy.

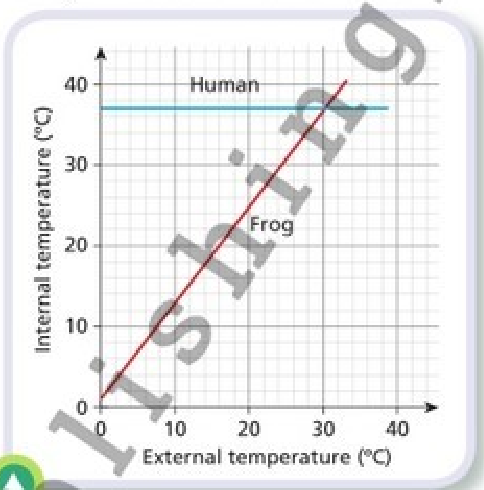


Figure 6.3 *The relationship between body temperature and external temperature*

Homeostasis allows slight changes in internal environments

It is important to realise that conditions in the internal environment of any organism have to be allowed to change or fluctuate **slightly**. For example:

- Human body temperature falls (by about 1°C) at night when we sleep
- Human body temperature rises when we get an infection (this is called a fever and is an attempt by the body to destroy whatever is causing the infection)

Figure 6.4 *A high temperature indicates infection*

- The internal environment of the body changes due to hormonal changes during:
  - The menstrual cycle
  - Puberty
  - Menopause.

In the short term, homeostasis maintains a relatively constant internal environment. However, homeostasis can be adapted to allow for the changing requirements of the body over longer periods of time.

Q U1 Understanding

6.1 What is homeostasis? Note one reason why it is important in the human body.

6.2 Why are circulatory systems found in large animals but not in small ones?

6.3 Suggest one method by which an organism without a circulatory system might transport materials.

6.4 State one way in which each of the following contributes to homeostasis.

(a) Liver (b) Lungs (c) Nephrons of kidneys

6.5 'Homeostatic mechanisms allow for temporary changes in the internal environment.' Give two examples in support of this statement.

The nervous system

All animals have the ability to respond to a stimulus. Animals use their skeleton, muscles, brain, nerves and hormones to respond to stimuli. The brain, nervous system and hormones (endocrine system) control the behaviour and actions of animals in a rapid response to a stimulus.

The nervous system in vertebrate animals consists of two parts: the central nervous system (CNS) and the peripheral nervous system (PNS).

The central nervous system (CNS)

The central nervous system consists of the brain and the spinal cord. The brain is protected by the skull and the spinal cord is protected by the vertebrae. The brain and spinal cord receive sensory information (sight, smell, touch, taste, sound) through nerves called the cranial nerves.

The brain has a number of different regions, each with its own function.

- **Cerebral hemispheres:** Each lobe of the cerebrum Figure 6.5 makes up part of the cerebral hemispheres. They are used for reasoning, memory, hearing and the other senses.
- **Corpus callosum:** These nerve fibres connect the left and right hemispheres.
- **Cerebellum:** This regulates balance, movement and muscle coordination.
- **Pituitary gland:** This secretes hormones.
- **Pons:** This connects the cerebrum with the cerebellum.
- **Medulla oblongata:** This controls automatic functions such as breathing and heartbeat.
- **Spinal cord:** These nerve fibres connect the brain to the peripheral nervous system (PNS).

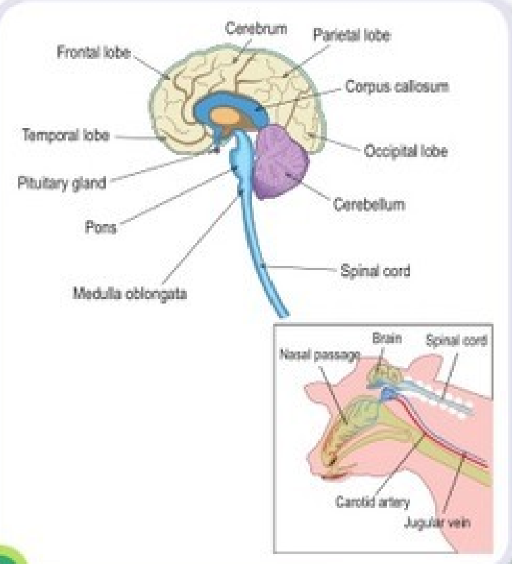


Figure 6.5 *The brain*

The peripheral nervous system (PNS)

The peripheral nervous system consists of sensory nerves and motor nerves. The sensory nerves include the cranial nerves, which bring sensory information to the brain and spinal cord from sensory organs such as the ear or skin. Motor nerves carry messages from the CNS to the muscles and glands.

Other internal organs such as the lungs, heart and digestive system are monitored by the automatic nervous system and are not under the conscious control of the animal.

Nerves

A nerve cell is called a neuron.

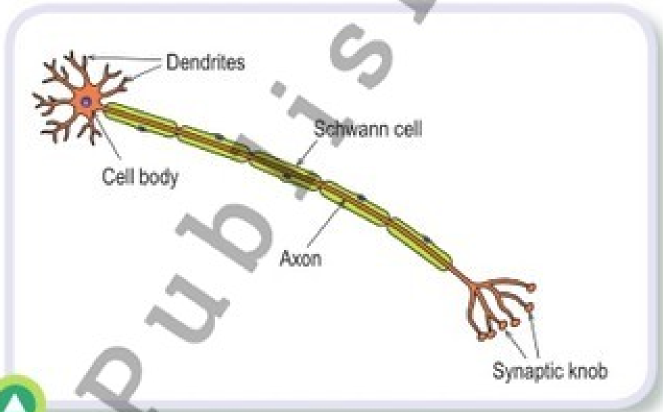


Figure 6.6 *A motor neuron*

Dendrite: This contains receptors that accept impulses from other neurons.

Cell body: This controls activity within the neuron.

Axon: This is a nerve fibre running the length of the neuron. Impulses are transmitted over axons.

Schwann cell: This surrounds the axon and provides insulation.

Synaptic knob: This transmits the impulse to the dendrites of the next neuron, aided by a chemical transmitter. The space between the synaptic knob of one neuron and the dendrites of the next is known as a synapse.

Generation and Transmission of nerve impulses

A nerve impulse is generated when the stimulus is strong. The stimulus triggers both electrical and chemical changes in the neuron. There are different ions on either side of the cell membrane. The exterior side has sodium ions that are positively charged and are more in number. The interior side of the cell is negatively charged with more potassium ions. Due to this difference in the charges, there is an electrochemical difference.

The generation of a nerve impulse causes a change in the permeability of the cell membrane. The sodium ions flow inside and potassium ions flow outside, causing a reversal of charges. The cell is now depolarised. This depolarisation results in an action potential which causes the nerve impulse to move along the length of the axon. This depolarisation of the membrane occurs along the nerve. A series of reactions occur where the potassium ions flow back into the cell and sodium ions move out of the cell. This whole process again results in the cell becoming polarised as the charges are restored.

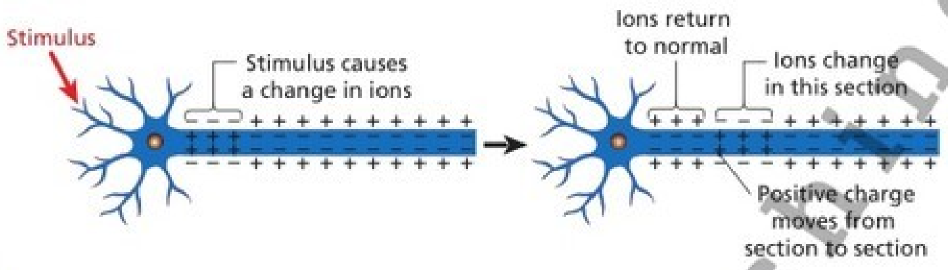


Figure 6.7 *Transmission of nerve impulses*

When the nerve impulse reaches the end of the axon, the neurotransmitters release chemicals which diffuse across the synaptic gap - the small space present between the axon and the receptors. Nerve impulses can be transmitted either by the electrical synapse or the chemical synapse.

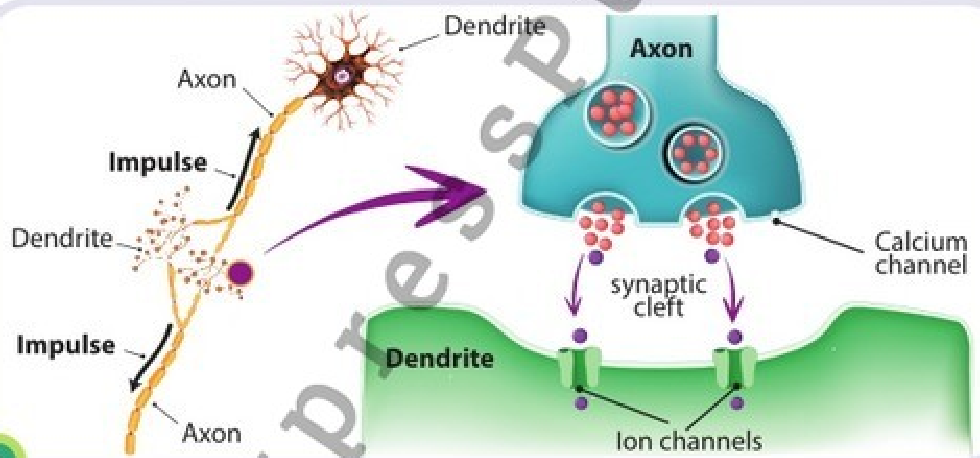


Figure 6.8 *Transmission across the synaptic cleft*

Q Understanding U1

6.6 Name the two parts of the nervous system.

6.7 What two parts of the body make up the central nervous system?

6.8 What is the function of the dendrites and Schwann cell in a neuron?

6.9 Which two types of ion create the opposite charge characteristic of a neuron's membrane?

6.10 The sodium channels close during repolarisation. How does this affect the neuron?

6.11 An action potential is created when there are sufficient stimuli to create sodium ion changes along the whole axon. True or False?

The endocrine system

Endocrine glands

Endocrine glands secrete hormones. However, unlike the circulatory system or lymphatic system, these hormones are not transported around the body in specialised ducts. The glands secrete hormones into the bloodstream. Hormones are produced in very small quantities and are transported by the circulatory system to specific parts of the body, where they can stimulate or inhibit actions in the target organ or tissue.

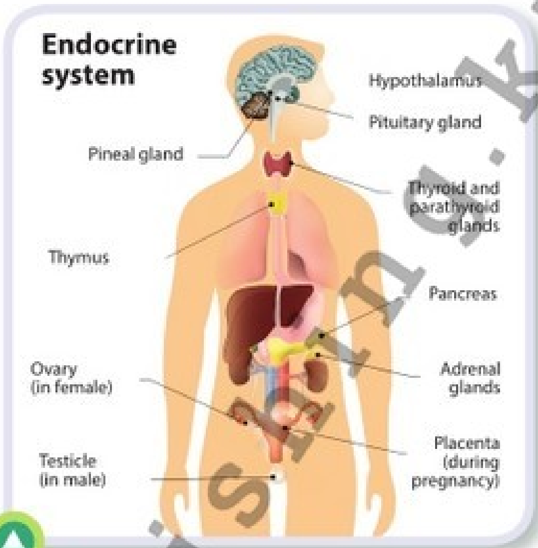


Figure 6.9 *The endocrine system*

There are a number of endocrine glands in the body Figure 6.9. Each gland secretes a different hormone which controls a different response in the body.

Pituitary gland

The pituitary gland is located at the base of the brain below the hypothalamus. The hypothalamus is part of the fore-brain and controls the pituitary gland. The hypothalamus secretes chemicals that stimulate or inhibit hormone production in the pituitary gland. This has an important knock-on effect for the rest of the body, since the pituitary gland is responsible for the control of several other endocrine glands in the body. The brain sends information to the pituitary gland via the hypothalamus.

The pituitary gland is split into two parts: the anterior lobe and the posterior lobe. Each is responsible for specific functions and production of specific hormones within the endocrine system.

Anterior lobe

Two of the most important hormones produced by the anterior lobe are growth hormone and prolactin.

- **Growth hormone** is responsible for regulating growth of bone and other tissues.
- **Prolactin** is responsible for production of milk in mammals.
- **Luteinising hormone (LH)** in females stimulates ovulation and development of the corpus luteum, and in males stimulates the production of testosterone (a hormone).
- **Follicle stimulating hormone (FSH)** in females promotes the development of a follicle that produces oestrogen, and in males promotes the development of the testes and sperm production.

The anterior lobe is also responsible for regulation of the activity within the thyroid, adrenal and reproductive glands.

Posterior lobe

The posterior lobe is responsible for the secretion of oxytocin and anti-diuretic hormone (ADH).

Oxytocin is responsible for contractions in the uterine wall during birth and, subsequently, milk let-down after the birth. The production of oxytocin is stimulated by suckling in mammals, when a signal is sent from the mammary glands to the brain. The message is relayed to the posterior pituitary gland and oxytocin is secreted. This causes the milk ducts to contract and let-down the milk to the young mammal.

Anti-diuretic hormone (ADH): One of the most important functions of ADH is to regulate water retention in the body. This function is carried out in the kidneys, where water is reabsorbed through the collecting ducts. Salt levels in the body can also be regulated by the reabsorption of sodium and chloride ions in the kidney. ADH also has a role in raising blood pressure.

Thyroid glands

The thyroid glands are some of the largest glands in the endocrine system. They are located in the neck just below the larynx. The main hormone secreted by the thyroid glands is thyroxine, which contains iodine. Thyroxine regulates metabolism in the body and is also responsible for growth. A lack of thyroxine due to insufficient iodine can lead to goitre. Goitre is enlargement of the thyroid glands as they try to produce more thyroxine. This condition is more common in humans than animals. Lambs or calves born with congenital goitre are often born very weak or are stillborn. This can be avoided by giving the mother an iodine supplement in her diet prior to the birth.

Pancreas

The pancreas is a leaf-shaped organ that lies above the duodenum. The pancreas produces digestive enzymes that are secreted into the small intestines. The pancreas is also involved in the secretion of the hormone insulin into the bloodstream. The islets of Langerhans produce insulin. This is secreted when there are high glucose levels in the body. Fatty tissue, liver and muscle cells are stimulated to take up the glucose. The liver and muscle then store the glucose as glycogen. Insulin also restricts the use of fat as an energy source.

The most common disease caused by a lack of insulin is diabetes mellitus. A common symptom is glucose in the urine, which indicates a high level of glucose in the body. When this occurs, the kidneys excrete glucose, which means that glucose is not being stored as glycogen in the liver. The body is also unable to metabolise it.

Adrenal glands

The adrenal glands are located above the kidneys. The adrenal glands consist of two parts: the adrenal cortex and adrenal medulla. Hormones are produced by the adrenal glands when the body is under stress.

The adrenal cortex produces a large number of hormones which are responsible for salt and water regulation and for maintaining blood pressure.

The adrenal medulla is responsible for producing adrenaline. This increases heart rate and blood pressure when the body is under stress and in survival mode.

Gonads

Gonads are the organs that produce gametes. The term *gonads* can be used to refer to the testes in the male or the ovaries in the female. The hormones that are produced in the gonads are involved in reproduction.

Testes

The testes secrete hormones known as androgens. Androgens are hormones that are responsible for the development of male characteristics. Their production leads to growth of muscle mass and strength and development of sex organs. The best-known androgen is testosterone.

Ovaries

The ovaries secrete the hormone progesterone. Progesterone has a variety of functions, which include: supporting pregnancy by allowing the uterus to grow during gestation, development of the mammary glands, inhibition of lactation prior to birth, labour, and also the inhibition of the immune response to the embryo.

The ovary also secretes oestrogen. This promotes the secondary sex characteristics in the female, including the development and growth of mammary glands.

Q Understanding U1

6.12 Which hormone is needed for respiration?

6.13 Name one symptom of diabetes.

6.14 What is the purpose of adrenaline?

6.15 Where is the pituitary gland located?

6.16 Animal hormones are blood-borne messengers that regulate the actions of different parts of an organism.

- **(a)** Name two reproductive hormones in animals.
- **(b)** Give one function for each of them.
- **(c)** Name the hormone involved in 'milk let-down' in animals.
- **(d)** Where in the body is the pituitary gland?

Neural responses

The kinds of stimuli that cause the endocrine glands to produce and release hormones are of three distinct types: **hormonal**, **humoral** and **neural**. Hormonal responses are those such as the secretion of the slower-acting hormones: FSH, LH and GH involved in sexual reproduction and growth functions of the body. Humoral responses are responses to a change in the level of ions or nutrients in the blood such as the secretion of PTH or insulin. Neural responses are those that involve fast-acting nerve fibres within the sympathetic nervous system stimulating the release of hormones into the bloodstream.

Commonly known as the fright/flight/fight mechanism, the sympathetic nervous system activates the adrenal medulla – part of the adrenal gland – to release adrenaline which causes the body to tense and become more alert as more energy is made available to the muscles and heart rate increases.

The body is thus tensed through the action of fast-acting neurons to better deal with a stressor in the external environment. Related effects of this response are that systems such as the immune system and digestion are suspended to a degree while energy is focused on dealing with the threat.

Responses in flowering plants

Growth regulation

The growth of flowering plants can be controlled by external and internal factors. Normally the external factors operate by causing, or controlling, the production of internal factors.

External factors

- **Light** affects plant growth by providing the energy needed for photosynthesis. This in turn supplies the energy-rich molecules needed by plants for growth. In addition, light is needed to produce chlorophyll, fully formed chloroplasts, normal-sized leaves and strong stems.
- **Day length** plays a very significant role in causing plants to flower. It may also have a role in fruit and seed formation, dormancy, leaf loss and germination of some seeds.
- **Gravity** can cause roots to grow down into the soil, while shoots grow upwards, away from gravity.
- **Temperature** affects the growth of plants mainly by affecting the rate of enzyme reactions. As a result, plants grow faster at higher temperatures. In addition, some plants will only produce flowers if they are exposed to low temperatures for a number of days or weeks.

Internal factors

Plants produce a range of chemicals called growth regulators. These growth regulators are produced in the meristematic regions of the plant, such as in the root tip or shoot tip regions.

Tropisms

A **tropism** is a change in the growth of a plant in response to an external stimulus.
A **positive tropism** occurs when the growth is towards the stimulus.
A **negative tropism** occurs when the growth is away from the stimulus.

The main advantage of tropisms is that they allow plants to obtain more favourable growing conditions. For example:

- Stems grow towards light so they can produce more food by photosynthesis
- Roots grow towards gravity so they can penetrate deeper into the soil for better anchorage and absorption.

Two main types of tropisms are outlined below.

Phototropism

Phototropism is the change in growth of a plant in response to light, usually from one direction (i.e. unidirectional light).

Stems are positively phototropic (i.e. they grow towards light). This allows the stem (and the leaves) to get more light. In this way they can carry out more photosynthesis and produce more food.

Figure 6.10 *Phototropism: a stem growing towards light*

Many roots are negatively phototropic. This is clearly seen in the roots of climbing plants such as ivy, where the roots grow away from light and towards the wall or surface to which they are attached.

Geotropism

Roots usually grow towards gravity (positively geotropic) and stems grow away from gravity (negatively geotropic).

Geotropism (or gravitropism) is the change in growth of a plant in response to gravity.

Figure 6.11 *Geotropism: a stem growing away from gravity*

If the roots grow towards gravity they can anchor the plant more efficiently in the soil. In addition they can absorb more water and minerals. By growing away from gravity, stems grow towards the light.

This allows plants to produce more food.

Growth regulators

A **growth regulator** is a chemical that controls the growth of a plant.

Most growth regulators are produced in small amounts in one part of a plant (mainly in meristems) and transported to another part where they cause an effect. For this reason they are often called hormones. The exact way that growth regulators are transported is not known. Most, however, are transported in the vascular tissues (xylem and phloem).

It is difficult to establish the exact role of plant regulators. This is due to the following reasons:

- They are active in very small amounts.
- Their effects depend on their concentration. This means the same regulator can have opposite effects at high or low concentrations.
- Their effects depend on the location in the plant in which they are acting. For example, the same concentration of plant regulator can have opposite effects in the stem and root.
- Different regulators interact in different ways. Some regulators support each other to produce a greater effect. Others interfere with each other and the combination may have no effect.

Growth regulators can act as growth promoters or growth inhibitors.

Growth promoters

Auxins are examples of growth promoters in plants.

Auxin as an example of a growth regulator

Auxins and IAA

There are a number of auxins, the most important of which is indoleacetic acid (IAA). IAA, which is often simply called auxin, is made in shoot tips, young leaves and seeds. It moves down the stem by an unknown mechanism. Auxins cause stem and root growth and stimulate fruit formation (at certain concentrations).

Production sites

Auxin is produced in the meristematic tissue in the tips of shoots. It is also produced in young leaves and in developing seeds.

Functions of auxin

The functions of auxin include:

- Stimulating stem elongation
- Stimulating root growth
- Causing cells to form into different structures (e.g. in the zone of differentiation in the root)
- Developing fruit
- Inhibiting side branching in stems
- Causing phototropism
- Causing geotropism.

Figure 6.12 *Apical dominance: the plant on the right has had its growth tip removed and shows more side branching*

Effects of auxins

Tropisms

Auxins cause cell elongation and growth or bending.

Apical dominance

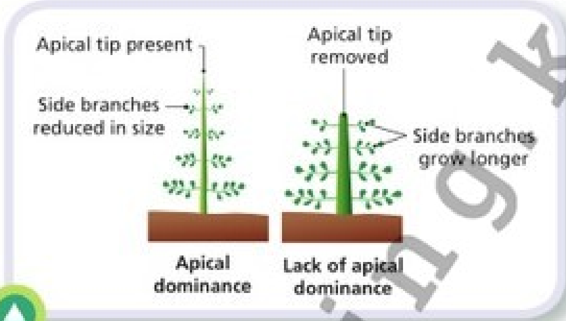


Figure 6.13 *Effect of apical tip on plant growth*

The apex is the tip (top) of the plant. If the apical bud is intact, auxin produced in the tip will pass down the stem and inhibit (prevent the growth of) lateral buds and any side branching. This form of growth is clearly seen in cacti (which have very few side branches) and conifers (where the inhibition decreases down the stem, allowing lower branches to grow more strongly). If the apical tip is removed side branches are allowed to develop. The plant will then develop as a low, bushy form.

Did you know?

In some places, farmers often cut down hedges to stimulate side branching and form a barrier farm animals cannot cross.

Fruit formation

IAA is made in developing seeds. It stimulates food to form in the fruit that surrounds the seed(s).

Root growth

At low concentrations, IAA causes roots to grow (whereas at higher concentrations IAA causes stems to grow). IAA can be applied artificially to stimulate rooting. However, commercially prepared growth promoters (i.e. synthetic ones) are more efficient at this process.

The mechanism of a plant response to light (i.e. mechanism of phototropism)

Auxin and cell elongation

Auxin loosens cell walls, which allows them to expand. Cell elongation is essential for normal growth and tropisms.

Role of auxin (IAA) in phototropism

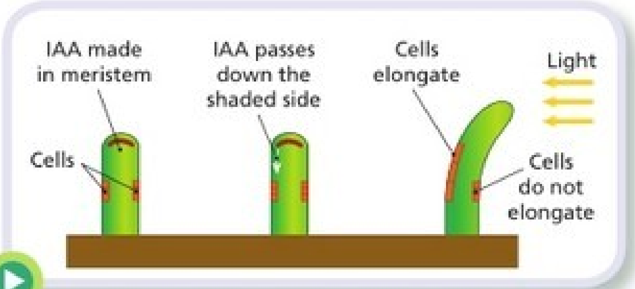


Figure 6.14 *Role of IAA in phototropism*

1. IAA is produced in the growth tips (meristems) of the stem.
2. If the stem is exposed to light from one side IAA will diffuse down the shaded side (i.e. the side furthest from the light source).
3. The concentration of IAA present in the shaded cells causes them to elongate more than the cells on the bright side of the stem.
4. As a result of the uneven elongation, the stem bends towards the light (phototropism will result).

Q Understanding U1

6.17 Name two external factors that control growth in plants.

6.18 (a) What is a tropism?

(b) Distinguish between positive and negative tropisms.

(c) What is the significance of tropisms for plants?

6.19 (a) Name one positive tropism in each case that affects:

(i) Shoots (ii) Roots.

6.20 Outline one benefit to a plant in each case of:

(a) Phototropism (b) Geotropism.

6.21 Some oat seedlings were grown in the dark and then treated as follows:

Group A: no treatment given, left intact

Group B: tips of seedlings covered with metal foil

Group C: tips of seedlings cut off.

The seedlings were then exposed to light from one side as shown in diagram:

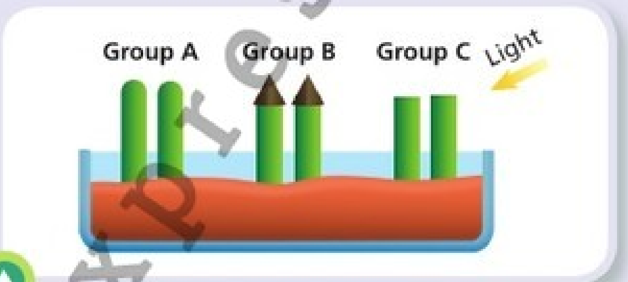


Figure 6.15 *Role of IAA in phototropism*

(a) Which group of seedlings will respond to the light?

(b) Explain why the other groups will not respond.

(c) Name the response that is produced.

(d) What is the value of this response to a plant?

(e) Name the substance causing the response.

6.22 With regard to auxin, state:

(a) A precise location where it is produced.

(b) Two ways in which it acts as a growth regulator.

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Research R2 Research R3 Research R4 Portfolio 45

Activity 6.1

Question

How can we show the effects of phototropism?

Equipment needed

3 small cups full of soil	3 sticky notes	Aluminium foil
Tape	Medium-sized box such as a shoe-box	A straw
A marker	12 corn seeds	Water

Conducting the activity

1. Plant four corn seeds in each of the soil cups. Space evenly and plant the seeds 2.5.cm in the soil.
2. Label the three cups using the sticky notes:
   (a) Control **(b)** Tip **(c)** Base
3. Water the cups and place them on a sheet of aluminium foil to prevent water soaking through.
4. Place inside the box with one side open to the light coming in from an angle. Place in a windowsill, with the open side facing the sun.
5. Make four of each type of light-exclusion device:

For shoots

6. A small cap of aluminium foil to cover tips. Form each one over the straw.

For base sleeve

7. A small strip of aluminium foil to wrap around the base.
8. Check the cups each day. Once a shoot grows to 2.5cm high, place either a shoot cap (on tip seedlings) or a base sleeve (on base seedlings) around them, depending on which cup they are in. The control cup will get neither of the light exclusion devices.
9. Continue to water the seedlings as needed.
10. Check the seedlings after a week.

Q Understanding U1

6.23 What did you notice about the control seedlings compared to the seedlings with caps and the seedlings with base sleeves?

6.24 What can you conclude from these results?

MODULE 7

Molecular Biology and the Cell Cycle

Learning outcomes

At the end of this module you will be able to:

- Explain the mechanism of the action of the enzyme 9.4.1.1
- Describe the structure of the double helix of the DNA molecule 9.4.1.2
- Make a model of DNA based on the principles of its structure 9.4.1.3
- Explain the processes occurring in the interphase of the cell cycle 9.2.2.1
- Describe the phases of mitosis 9.2.2.2
- Describe the phases of meiosis 9.2.2.3
- Compare the processes of mitosis and meiosis 9.2.2.4

Keywords

✔ catalyst ✔ active site ✔ substrate ✔ optimum ✔ denaturation
✔ chromosome ✔ nucleotide ✔ strand ✔ complementary
✔ homologous ✔ chromatin cell ✔ division ✔ meiosis ✔ mitosis

Molecular Biology

Enzymes

Enzymes are catalysts made of protein and are therefore sometimes called biological or organic catalysts. Their function is to speed up chemical reactions and to allow these reactions to proceed at normal cell temperatures.

Enzymes are made of chains of amino acids which are then folded into a three dimensional (3-D) shape. The 3-D shape of an enzyme means that it will fit neatly and react only with a substance of a shape that matches the shape of the active site of enzyme.

Active site

The active site is the part of an enzyme that combines with the substrate. The active site is not a rigid shape. Instead it is a depression or pocket on the surface of the enzyme. The enzyme itself is a protein that has a complex three-dimensional (3-D) shape, as has the active site. Many enzymes are composed of two or more globular sections, called domains, joined together.

Very often the active site is larger than the substrate to which it combines. Each active site is specific to the substrate that it acts upon.

The substrate causes (or induces) the active site to change shape slightly when they come in contact. The active site then fits more precisely around the substrate. This process is called the **induced fit model** or the **active site** theory of enzyme action (see Figure 7.2).

The induced fit model of enzyme action can be compared to the way a bean bag, with a large hollow in it, will change shape to fit snugly around our body shape when we sit in it.

Figure 7.1 *A computer graphic of an enzyme (blue) with the substrate (yellow) attached to the active site*

Mechanism of enzyme action – The induced fit model

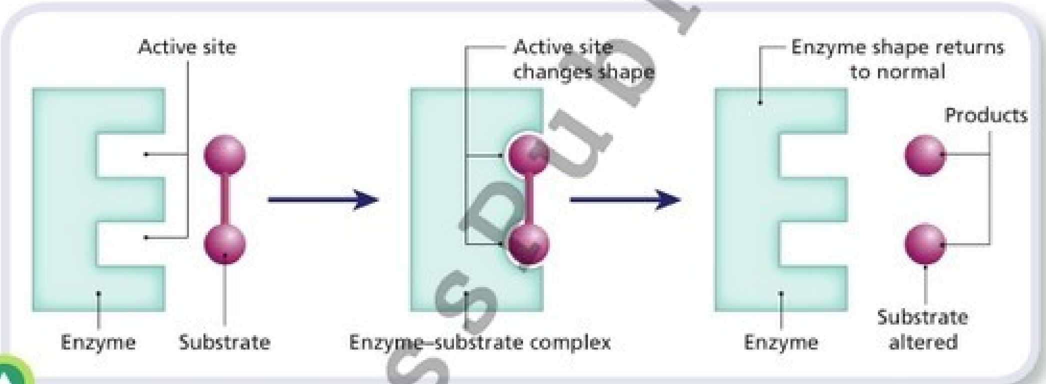


Figure 7.2 *The induced fit model*

1. The substrate combines with the 3-D active site of the enzyme.
2. The active site is induced or caused to change shape slightly by the substrate.
3. The substrate and enzyme form an enzyme-substrate complex. The bonds in the substrate are altered so that the substrate changes into the product(s).
4. The products leave the active site.
5. The active site returns to its original shape and can now accept a new substrate molecule.

These five steps happen very quickly. In some enzymes they take place more than 1000 times every second. For this reason, and because the enzyme is unchanged in the process, a small amount of enzyme can process a large number of substrate molecules in a short space of time.

Enzyme specificity

Most enzymes are said to be specific to a single substrate. This means that an enzyme will react with only one particular substrate. The reason for this is that each active site will fit or react with only a single substrate. Anything that alters the shape of the active site will reduce the ability of the enzyme to work effectively.

Optimum pH

The shape of the active site is particularly sensitive to pH. Each enzyme is adapted to have the correct shape at a particular pH value (e.g. pH 2 for pepsin and pH 6 to 8 for most other enzymes).

If the pH is unsuitable, then the enzyme changes shape and the active site will no longer accept a substrate molecule. Enzymes are said to have their optimum activity at specific pH values.

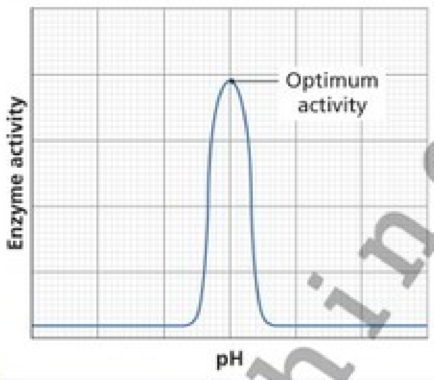


Figure 7.3 *Graph of optimum pH for enzyme activity*

Enzymes and Temperature

Enzymes are less sensitive to temperature changes than they are to changes in pH. An increase in temperature causes increased molecular movement. As a result, substrate molecules collide more frequently with enzymes. This means that reaction rates rise as temperatures rise.

However, each enzyme and active site starts to change its shape and lose its efficiency above a certain temperature. This temperature is between 20°C and 30°C for most plant enzymes and 37°C for human enzymes.

An enzyme's **optimum pH** means the pH value at which the enzyme works best.

Denaturation

Caused by

- High temperatures
- pH values outside the enzyme's optimum pH
- Some chemicals or radiation.

Explanation

When most proteins are heated above 40°C (or subjected to unsuitable pH values or treated with certain chemicals or radiation), they gradually lose their 3-D shape.

In the case of an enzyme, this means that the active site will lose its ability to react with its substrate.

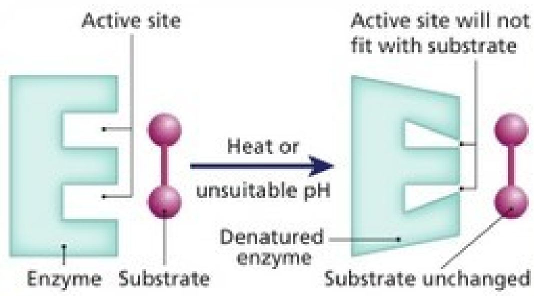


Figure 7.4 *Denaturing an enzyme*

Such a change in shape and loss of biological activity is called **denaturation**. It is normally a permanent, or irreversible, process.

Did you know?

High temperatures or fever in a human can be very serious, as they can affect the shape and the efficiency of enzyme reactions.

Q Understanding U4

7.1 What does the active site have to do with the specificity of enzymes?

7.2 What is meant by an enzyme's optimum pH?

7.3 What is a denatured enzyme?

7.4 Suggest two reasons why a small amount of enzyme can speed up a reaction dramatically.

The cell cycle

Chromosomes

The nucleus of the cell contains the genetic information in the form of DNA (deoxyribonucleic acid). When viewing cells under a light microscope, the nucleus appears as a dark mass composed of a material known as chromatin. This is a mixture of DNA and protein. However, when the cell is about to divide, the chromatin forms structures called chromosomes.

> **Chromosomes** are composed of DNA and protein and are visible only during cell division. A **gene** is a part of a chromosome that contains information to produce a protein.

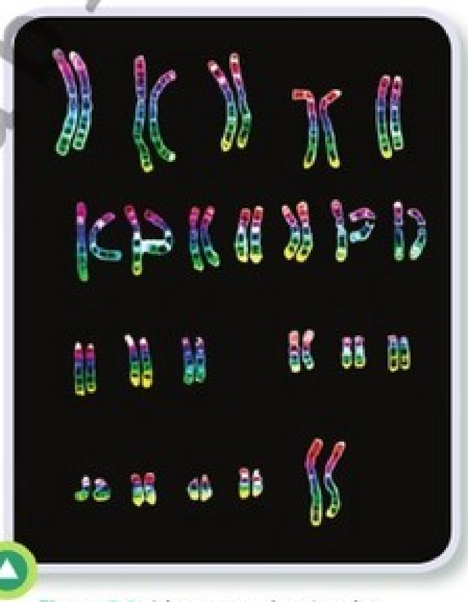


Figure 7.5 *A karyotype showing the chromosome pairs in a human cell*

Structure of DNA

The basic units of DNA are nucleotides, each nucleotide consists of a deoxyribose sugar, phosphate and base. It is the base element that changes in different nucleotides. Deoxyribose is a pentose sugar, meaning that it is a five carbon sugar.

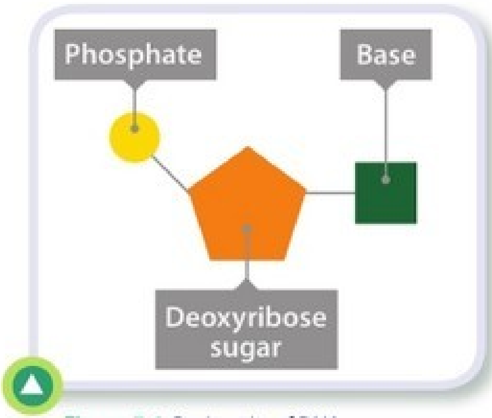


Figure 7.6 *Basic units of DNA*

Nucleotides bond to form strands: a strong covalent bond is formed between the deoxyribose sugar of one nucleotide and the phosphate of another. These bonds form what is called the sugar-phosphate backbone of the DNA molecule as shown in Figure 7.7.

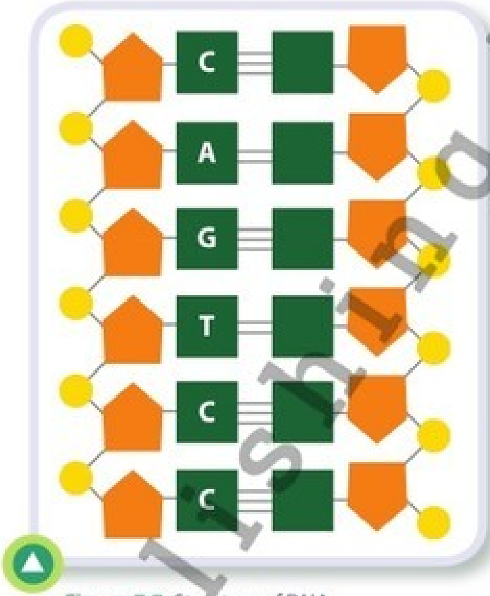


Figure 7.7 *Structure of DNA*

Four different chemicals make the 'bases' that form DNA. Each base is known by the first letter of its name:

Adenine (A)
Thymine (T)
Guanine (G)
Cytosine (C).

Each of the four bases can only join or bond with one other base

A joins with T
G joins with C

and these pairings are known as complementary base pairs.

It was two scientists from Cambridge University, James Watson and Francis Crick, who first identified the structure of DNA, namely that bases occurred in pairs and that there were two chains wound into a double helix.

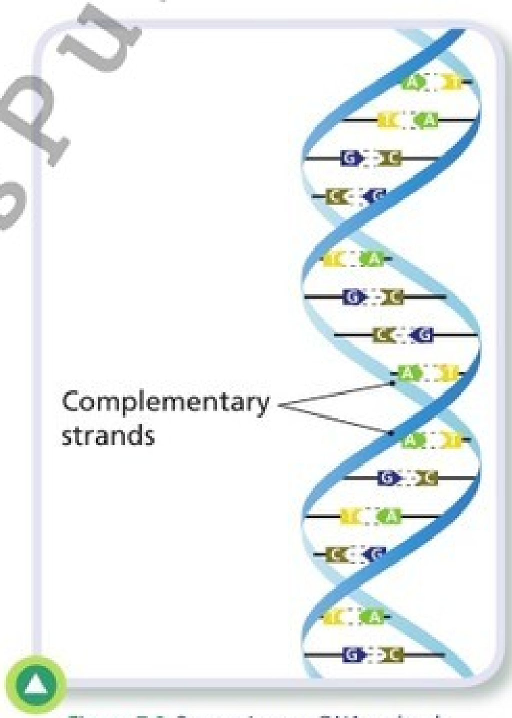


Figure 7.8 *Base pairs on a DNA molecule*

A double helix

The pairs of bases, A/T and G/C, are said to be complementary base pairs. The pattern of complementary base pairing means that if one strand of a DNA molecule has the sequence TAGCAT, then the sequence on the partner strand must be ATCGTA.

Activity 7.1

Question

How can we model the structure of a strand of DNA?

Equipment needed

Pipe cleaners (2 different colours)

Beads (6 different colours)

Safety

- Be careful when cutting and twisting pipe cleaners into shape because of any sharp ends.

Conducting the activity

1. Take two pipe cleaners of the same colour and cut them into strips of about 8 cm long. Use these to string your pairs of bases. Each of the four chemicals should be represented by a different colour.
2. Bead the other pipe cleaners with different coloured beads to represent the sugar and phosphate groups. Think about how these will match up in the double helix model.
3. Attach the base strands to the backbone strands by wrapping round the ends of the base strands.
4. Show your model to another group and check their model for inconsistencies.

7.5 What is the pentose sugar found in DNA?

7.6 What is the meaning of the term complimentary base?

7.7 What is the complimentary base of thymine?

7.8 What is the shape of the DNA molecule known as?

7.9 If one strand of a DNA molecule has the sequence CGTAGC, what is the sequence of the partner strand?

In order to understand how chromosomes work, it is helpful to think of chromosomes being like a dictionary. A dictionary contains thousands of words; similarly, chromosomes contain thousands of genes. Each word has a meaning or explanation, in the same way that a gene contains a specific instruction in its sequence of DNA.

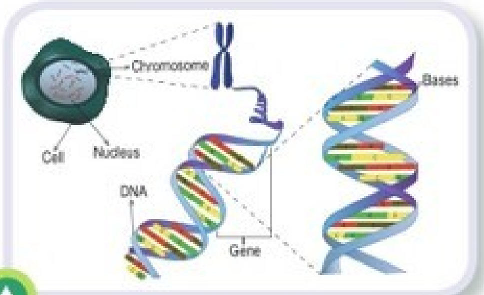


Figure 7.9 *Genes are composed of DNA. A section of a chromosome that codes for a protein is known as a gene. Each chromosome contains thousands of genes.*

Proteins are made up of amino acids. Genes determine the sequence of amino acids required to produce many different types of proteins. These proteins have wide-ranging functions including structural proteins (keratin), hormones (insulin), antibodies, enzymes (amylase) and transport proteins (haemoglobin in red blood cells).

Chromosomes occur in pairs, known as homologous chromosomes, and for this reason a cell with a complete set of chromosomes is known as diploid or 2n. Every species has its own chromosome number. Humans have a total of 46 chromosomes (or 23 pairs) in their body cells.

Homologous chromosomes are a pair of chromosomes of the same size that have the same gene sequence.
A cell is **diploid** or **2n** when it has a full set of chromosomes.

Table 7.1 Chromosome number in agricultural animals

Animal	Diploid number
Cattle	60
Sheep	54
Pig	38
Chicken	78

Cell division must occur in order for animals and plants to grow, to repair and replace dead and worn-out cells and to reproduce. There are two types of cell division: mitosis and meiosis. Mitosis occurs in normal body cells (referred to as somatic cells) and meiosis occurs in the testes and ovaries to produce gametes.

Somatic cells: all the body cells of an organism, apart from sperm and egg cells. Somatic cells contain a full set of chromosomes.

Cell division

Interphase

Before cell division commences, the cell prepares itself for mitosis by gradually getting bigger and producing additional cell organelles such as mitochondria. This phase is called **interphase** and normal somatic cells spend the majority of the **cell cycle** in this phase.

During interphase the nuclear membrane is present and the chromatin has not yet formed chromosomes. It is important to remember that when a cell is in interphase the cell is **not** dividing.

Interphase can be broken down into three distinct phases known as G1, S and G2 as shown in Figure 7.10. The sections of the diagram represent an approximation of the comparative lengths of each phase with interphase lasting approximately between 12 and 24 hours in mammals.

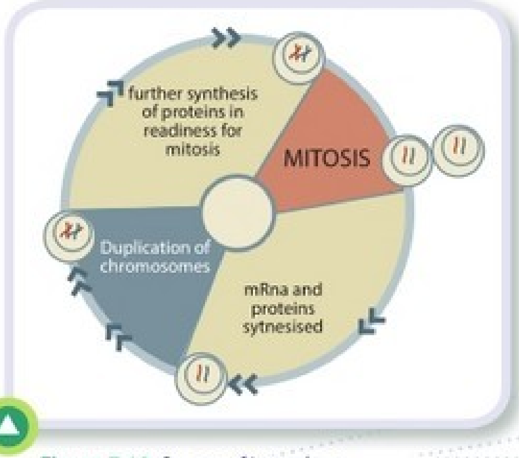


Figure 7.10 *Stages of interphase*

Gap 1 (G1) is the stage in which cells increase in size. During this phase cells produce mRNA and synthesise protein. A process known as the G1 checkpoint is activated in this phase to check that cells are ready for the subsequent phases.

S phase is the stage in which DNA replication occurs as the chromosomes duplicate.

Gap 2 (G2) is the final phase before mitosis during which cells continue to produce new proteins and grow and a further checkpoint mechanism is activated (G2 checkpoint) to check that DNA replication was successful.

Cell cycle: the cycle of growth and division of a eukaryotic cell.

Once cell division commences, it can be divided into four main stages: prophase, metaphase, anaphase and telophase. Prophase is the first stage of mitosis. During prophase, the chromosomes become visible in the cell. Each chromosome duplicates itself, so that the chromosomes appear as two strands (called sister chromatids) joined in the centre by the centromere. The old chromosome is attached to an identical copy of itself.

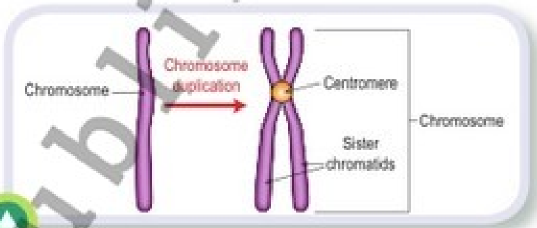
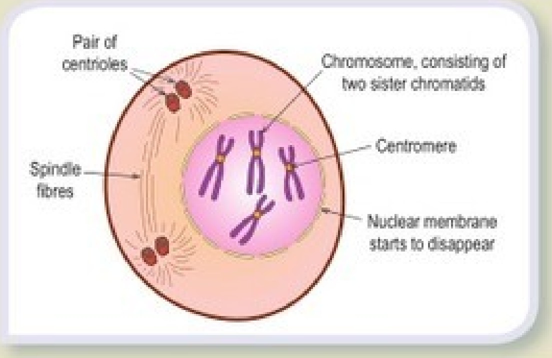
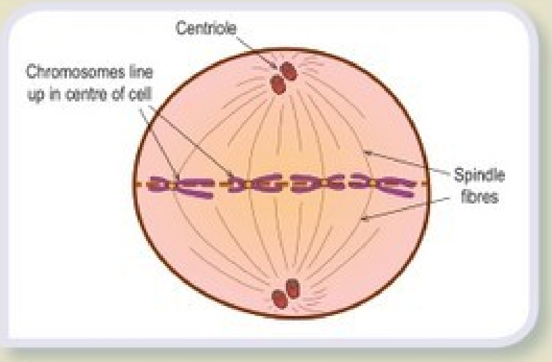
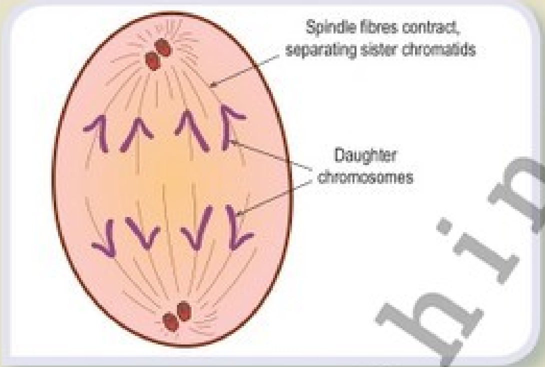
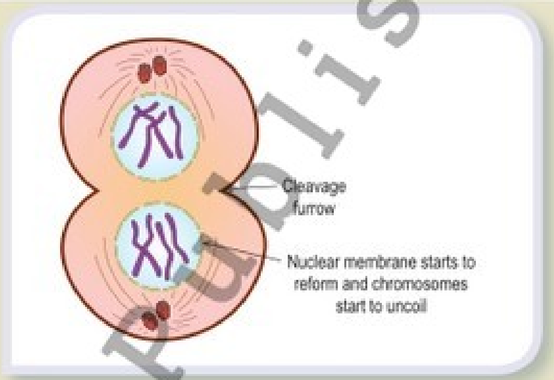


Figure 7.11 *A chromosome duplicating itself to become two chromatids.*

Stages of mitosis

Table 7.2 Stages of mitosis

Stages of mitosis	
1. Prophase • Chromosomes become visible and duplicate themselves. • The nuclear membrane and other cell organelles disappear. • Spindle fibres start to form.	
2. Metaphase • The chromosomes line up in the centre of the cell. • The spindle fibres attach themselves to the centromere of the chromosome.	

Stages of mitosis	
3. Anaphase • The spindle fibres contract, separating the duplicated chromosome from its copy. • The chromosomes are pulled to opposite poles of the cell.	
4. Telophase • This is the final stage of mitosis. • The chromosomes begin to uncoil to form chromatin. • The spindle fibres break down. • The nuclear membrane reforms. • At the end of telophase, the cytoplasm divides to form two cells. • Division of the cytoplasm is known as cytokinesis.	

Telophase in plant cells

In plant cells, a cell plate grows between the two new cells and from this a new cell wall develops, thus separating the two cells.

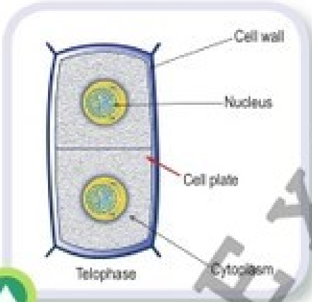


Figure 7.12 *Telophase in a plant cell*


Figure 7.13 *Plant cells in interphase*


Figure 7.14 *A plant cell at prophase*


Figure 7.15 *A plant cell (centre) at metaphase*


Figure 7.16 *A plant cell (centre) at anaphase*

Locations of mitosis

In plants, cell division by mitosis is continuously occurring in the tips of shoots and roots. Meristematic tissue (also known as meristem) in these locations is constantly producing new cells by mitosis to allow for plant growth. Cambium tissue, between the phloem and xylem in vascular bundles of dicot stems, is also meristematic tissue. In animals, mitosis is continuously occurring in the bone marrow to produce new red blood cells, the cells lining the digestive tract and skin cells. Mitosis occurs very rapidly in the development of a zygote into an embryo in animals. Mitosis also occurs during metamorphosis in insects.

Significance of mitosis

- Mitosis produces two identical daughter cells that have the same number of chromosomes.
- Genetic information on the chromosomes is identical.
- Mitosis is important for growth and repair of dead and worn-out cells.
- Some organisms can reproduce asexually by mitosis, e.g. yeast cells reproduce by budding.

Research R2 Research R3 Research R4

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Activity 7.2

Question

How can we measure the rate of mitosis in onion root tips?

Equipment needed

Small fresh onion
Small jars or beakers
Toothpicks
Muriatic acid (10% HCl)
Latex gloves
Tweezers
Distilled water
Pipette
Paper towels
Scalpel
2 needles
0.5% Toluidine blue
Cover slides
Light microscope

Safety

Wear latex gloves and goggles when using acid during this experiment

Conducting the activity

1. Insert 3-4 toothpicks around the sides of the onion and place the onion root side down in a jar of water. Keep the onion submerged in the water for a few days until the roots grow.
2. Remove the onion from the water and with a scalpel slice about 5 mm off the tips of the roots. Place these root tips into a different small beaker and pour in muriatic acid to cover the root tips.

Figure 7.17 *Onion root cells mitosis*

3. After 20 minutes remove the root tips from the acid and pour the acid away.
4. Place the root tips on a microscope slide and rinse well using a pipette and distilled water.
5. With the scalpel trim the root tips to 2 mm long. Keep the tips. Use a needle to carefully slice the root tips into 2 length-wise sections. You may wish to do this with a magnifying lens.
6. Coat the dissected root tips in Toluidine blue using a pipette. Leave for two minutes and then place a coverslip over the tip of the slide and pipette distilled water onto it.
7. Remove excessive dye with a paper towel. Prepare multiple slides with two root tips per slide.
8. Place a slide on the microscope. Observe on the lowest magnification first. Focus the image until you can clearly distinguish the tip of the root. Move up slightly from the tip and focus on the area just above it where the cells will be replicating.
9. Change the microscope objective until you can easily identify the stages of mitosis within the area of cell replication. Make a sketch of each stage and compare these to images in this book.
10. Record the number of cells you observe in each stage with a tally chart. Try to avoid counting cells twice.
11. When you have counted around 1000 cells convert your tally chart to a bar graph.

Q Research R5

7.10 How similar were your bar charts and sketches to those of other members of your class?

7.11 Which stage of mitosis takes the longest amount of time?

Meiosis

Meiosis, also known as reduction division, occurs in the testes and ovaries of animals and produces four non-identical cells that have half the number of chromosomes of the parent. These cells are called gametes or sex cells (egg and sperm). Since these cells have only half a set of chromosomes, they are called haploid or n.

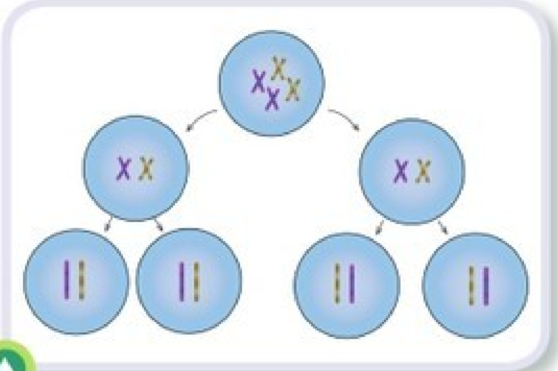

Figure 7.18 *In order to decrease the chromosome number by half, meiosis involves two stages of cell division. This produces four haploid daughter cells.*

A cell is **haploid** or **n** when it has half a set of chromosomes. Gametes are haploid.

During meiosis, **crossing over** can occur between a pair of homologous chromosomes. During this process the pair of chromosomes will swap DNA. This process brings about variation in the combination of genes on the resulting chromosomes and consequently in the gametes produced.

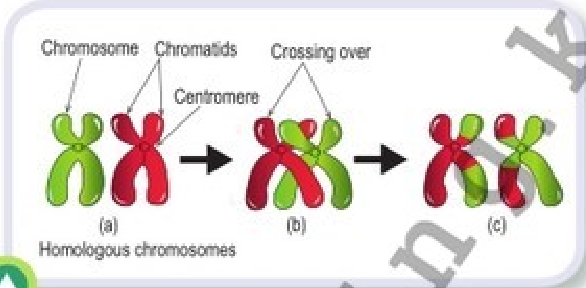

Figure 7.19 *When chromatids exchange genetic information during crossing over, this leads to genetic variation.*

Remember that chromosomes occur in pairs and, as a result of meiosis, each gamete has one chromosome from each pair. In humans, the gametes have 23 chromosomes. On fertilisation the diploid number of chromosomes is restored in the zygote. If meiosis did not occur, the offspring would have double the number of chromosomes the parent had.

> **Crossing over** is the process where homologous chromosomes exchange genetic information. This process occurs only during meiosis and results in genetic variation in the offspring.

In plants, meiosis takes place in the anther during the production of pollen grains and also in the ovule in order to produce the egg cell and the two polar nuclei cells.

Significance of meiosis

- Meiosis reduces the chromosome number in the cell by half.
- The chromosome diploid number is restored on fertilisation.
- Crossing over during meiosis produces new combinations of genes, which leads to new variations in the offspring.

Table 7.3 **Summary of mitosis and meiosis**

	Mitosis	Meiosis
Chromosome number	Same as parent cell	Reduced by half
Importance	Growth, repair and asexual reproduction in some organisms	Production of gametes
Genetic information	Identical to parent cell	Different, new combination of genes due to crossing over between pairs of chromosomes
Location of cell division	Somatic cells	Reproductive organs
Produces	Two diploid daughter cells	Four haploid daughter cells

Understanding U2 Communicating C2

7.12 Make posters of each stage of mitosis to hang in your classroom. Use pipe cleaners or plasticine as chromosomes to demonstrate the stages of mitosis and crossing over in meiosis.

Understanding U2

7.13 What is chromatin made of?

7.14 When does chromatin change to form chromosomes?

7.15 Explain the following terms:

(a) gene **(b)** diploid **(c)** chromosome.

7.16 Where are chromosomes found in a cell?

7.17 Figure 7.20 shows the four stages of mitosis in a random order.

(a) Put the stages A–D in the correct order.

(b) Why is mitosis important in the growth of animals and plants?

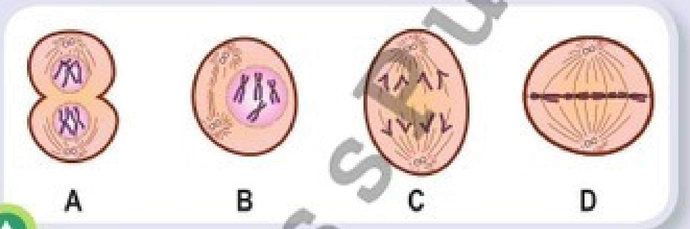

Figure 7.20

Understanding U2

7.18 The Figure 7.21 shows the metaphase stage of mitosis. Name the parts labelled L and M.

7.19 A sheep has a diploid number of 54 chromosomes. How many chromosomes will be present in:

(a) an egg cell

(b) a zygote?

7.20 Where in an animal's body does meiosis occur?

7.21 Identify one location in a plant where meiosis occurs.

7.22 If meiosis did not occur during gamete formation, what consequence would this have on the number of chromosomes that the offspring would have in comparison to the parents?

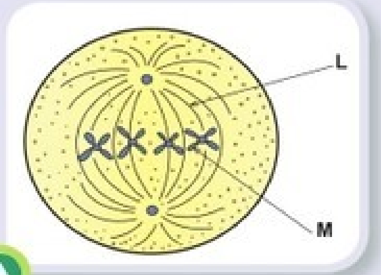

Figure 7.21 *Question 7.18*

MODULE 8

Heredity and Variation

Learning outcomes

At the end of this module you will be able to:

- Assess the role of Mendel's research in genetics 9.2.4.1
- Justify the cytological bases of and solve problems associated with dihybrid crossing 9.2.4.3
- Compare complete and incomplete dominance 9.2.4.4
- Evaluate the significance of test crosses 9.2.4.5
- Describe the theory of sex determination 9.2.4.6
- Explain the role of chromosomes in sex determination 9.2.4.7
- Explain the mechanism for the determination and inheritance of human blood groups 9.2.4.8
- Describe various methods for studying human genetics 9.2.4.9
- Create a genealogical tree 9.2.4.10
- Describe how the use of modern agricultural technology impacts regional crop yields 9.2.4.11

Keywords

✔ genetics ✔ variation ✔ gene ✔ allele ✔ dominant ✔ recessive ✔ genotype ✔ phenotype ✔ incomplete dominance ✔ monohybrid ✔ dihybrid ✔ homozygous ✔ heterozygous ✔ genetic modification ✔ transgenic species

What is genetics?

Genetics is the study of how we inherit traits or characteristics from our parents. Individuals within a species are not all identical; there is considerable variation within a population. However, some of these variations are more desirable than others. These variations can be passed on to the offspring of the individuals. For centuries, farmers have recognised this and have artificially selected animals and plants with desirable characteristics. These animals are mated or crossed to produce offspring with these desirable traits. Farmers artificially select for characteristics such as good milk production, high milk solids and good fertility in dairy cattle, resistance to disease and high crop yields in plants and good conformation and fast growth rates in beef animals.

> **Genetics** is the study of inheritance.
> **Variations** are differences that exist among individuals of the same population.

Figure 8.1 *Aberdeen Angus are naturally polled*

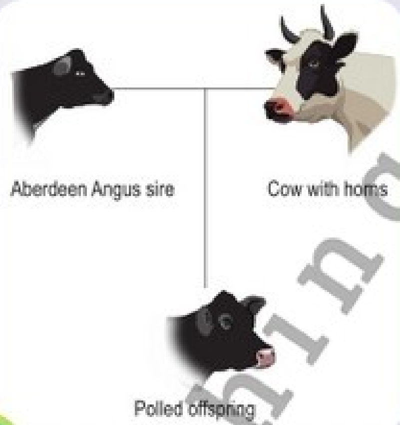

Figure 8.2 *The inheritance of the polled characteristic in cattle*

Gene: A section of a chromosome that contains information to produce a protein.
Allele: Alternative forms of the same gene.

Figure 8.2 can be explained if we use letters to represent the genes. In Figure 8.2 the polled (hornless) condition is represented by a capital **P**, since this is the dominant trait. The horned condition is represented by a lower case **p**, since this is the recessive trait. Normally, every characteristic is controlled by a gene that has a **pair of alleles** and this is known as an organism's **genotype**. The **phenotype** is the outward appearance of the organism. If we look at Figure 8.2 and represent it using the genotypes in the cross below, we can explain why all the offspring are polled. The following is known as a **monohybrid** cross, since it looks at the inheritance of **one** characteristic.

Dominant: Expressed in the phenotype when present in the genotype and is normally represented by a capital letter, e.g. T.
Recessive: Expressed only when an individual has no dominant allele present and is usually represented with a lower case letter, e.g. t.
Genotype: The genes present in the organism, whether they are expressed or not, e.g. Tt.
Phenotype: The outward appearance of the organism.
Monohybrid cross: Looks at the inheritance of a characteristic (trait) that has two alleles.

Parents:	PP	x	pp
Gametes:	P Ⓟ		p Ⓟ

Genotype of F1:	Pp
Phenotype of F1:	polled

Note: In the above cross, F1 stands for the first filial generation, which is also known as the first-generation offspring

Figure 8.3 *Inheritance of the polled characteristic in cattle, using letters to represent alleles*

Some important things to note in the above cross are that the parents have two alleles present for the gene; however, the gametes have only one allele present. When an organism produces **gametes or sex cells**, pairs of alleles are separated during meiosis so that only one allele occurs in the gamete. This is illustrated in Figure 8.4. On fertilisation, the male and female gametes fuse and the offspring again have a pair of alleles for a given gene, one from each parent.

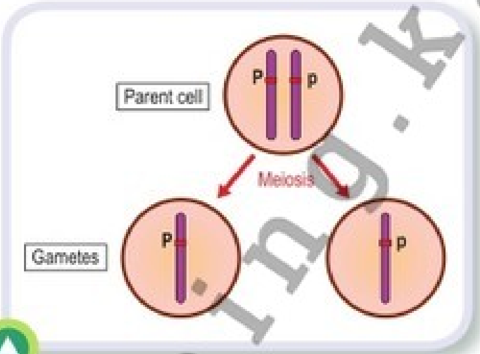

Figure 8.4 *Gamete formation*

This separation of alleles when gametes are formed is known as **segregation** and it follows **Mendel's Law of Segregation**.

> **Mendel's Law of Segregation** states that when gametes are formed only one allele from a pair of alleles is carried in the gamete.

Gregor Mendel (1822–84)

Gregor Mendel was a scientist and an Augustinian monk with an interest in the inheritance of characteristics in the garden pea plant. He chose seven different characteristics to study, each characteristic existing in two alternative forms (alleles) which were controlled by what Mendel called 'factors'. Today these factors are called genes. Mendel performed several thousand crosses over the course of about two years. He kept accurate records of the results of these crosses and performed statistical analysis on his results. From his results he identified patterns of inheritance. Table 8.1 shows some of the characteristics Mendel studied and their alleles. In each case, one of the alleles is dominant and the other is recessive.

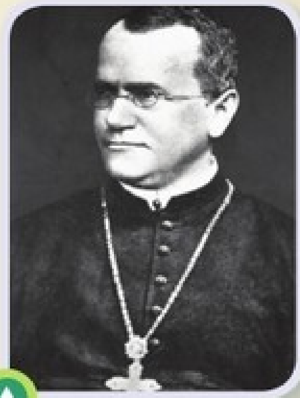

Figure 8.5 *Gregor Mendel*

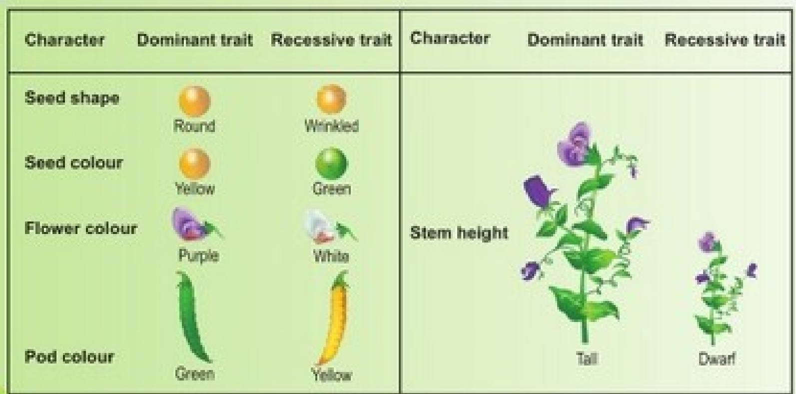

Figure 8.6 *The genetic traits in pea plants studied by Gregor Mendel*

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Table 8.1 Genetic traits in pea plant

Characteristic (gene)	Dominant allele	Recessive allele
Shape of seed	Round	Wrinkled
Colour of seed	Yellow	Green
Length of stem	Tall	Dwarf
Flower colour	Purple	White
Pod colour	Green	Yellow

Mendel's study of pea plants

Mendel chose peas as the subject for his inheritance studies for a number of reasons:

- The traits he chose had easily distinguishable alternatives (alleles).
- He concentrated on the inheritance of one characteristic at a time.
- He controlled pollination of pea plants, crossing plants with alternative traits by hand.
- Peas are easy to grow.
- Pea plants produce large numbers of seeds.

In Figure 8.3 you will notice that there are three possible genotypes for the polled characteristic: PP, Pp and pp. The genotypes PP and pp are **homozygous**: the alleles present in the genotype are the same. The genotype PP is **homozygous dominant**: there are two dominant alleles present. The genotype pp is **homozygous recessive**: two recessive alleles are present. The genotype Pp is **heterozygous**: the alleles present in the genotype are different. When an organism has a heterozygous genotype, it is often referred to as a **hybrid**. Plants and animals that are produced from genetically different parents often display **hybrid vigour**. Table 8.2 summarises this.

Homozygous: The alleles present in the genotype are the same, e.g. PP or pp.
Heterozygous: The alleles present in the genotype are not the same, e.g. Pp.
Heterozygous genotypes are often referred to as hybrids and they have one dominant and one recessive allele.
Hybrid vigour or heterosis: The increased productivity displayed by offspring from genetically different parents.

Table 8.2 Summary of genetic genotypes and their phenotypes

	Genotype	Phenotype
Homozygous dominant	PP	Polled
Homozygous recessive	pp	Horns present
Heterozygous	Pp	Polled

Q U2 Understanding

8.1 Distinguish between each of the following pairs of terms:

(a) Homozygous and heterozygous
(b) Dominant and recessive
(c) Genotype and phenotype

8.2 Give three reasons why Mendel used pea plants in his study of genetics.

What happens if two **heterozygous polled** cattle are crossed? In this case, both of the parents are **Pp** for the characteristic. They both carry a recessive allele for the horned condition but this is hidden by the presence of the dominant allele P for polled.

Parents:	Pp	x	Pp
Gametes:	(P) (p)		(P) (p)

Since each parent is heterozygous for the trait, they will produce two different types of gametes: half will carry a **P** and half will carry a **p**. Both types of gametes are shown under each parent's genotype. To identify the gametes, separate the alleles in the parents and put a circle around them. The formation of gametes here follows Mendel's Law of Segregation.

Genotype of F1: Punnett square

	(P)	(p)
(P)	PP	Pp
(p)	Pp	pp

Note: To identify all the possible offspring produced by a cross, a Punnett square is drawn. The first parent's gametes are placed down the side of the Punnett square, one gamete next to each box; the other parent's gametes are placed along the top, one above each box.

Genotypes		**Phenotypes**	
25%	PP	75%	Polled
50%	Pp		
25%	pp	25%	Horned

Ratio: 3 Polled : 1 Horned

The Punnett square is completed by combining one allele from the left with one allele from the top of each square. The genotypes, their percentages and their matching phenotypes are then written underneath the Punnett square. Both **PP** and **Pp** genotypes will give the same phenotype – polled. Only the genotype **pp** will give the horned condition.

Note: The final ratio of polled cattle to cattle with horns in the example above is 3:1, a typical Mendelian ratio. This ratio always occurs in monohybrid crosses that involve two parents whose genotype is heterozygous for the characteristic.

Question

In peas, the allele for round seed (R) is dominant over the allele for wrinkled seed (r). Outline the cross between a heterozygous round seeded plant and a wrinkled seeded plant. In your answer show the gametes produced and the genotypes and the phenotypes of the offspring.

Answer

In the question, the second parent has the wrinkled seed characteristic expressed in its phenotype. As the gene for wrinkled seed is recessive, this parent must have both recessive genes in order for this characteristic to be expressed. The other parent is heterozygous: they have both the dominant and recessive gene present in their genotype.

Parents: Rr x rr

Gametes: (R) (r) (r)

F1 Punnett square

Gametes	(R)	(r)
(r)	Rr	rr

Genotype of F1: 50% Rr and 50% rr
Phenotype of F1: 50% Round and 50% Wrinkled
Ratio: 1 Round : 1 Wrinkled

Q U2 Understanding

8.3 Complete the cross by filling in the spaces to show the possible gametes, genotypes and phenotype.
The genotypes of the parents (FF) × (Ff).
- **(a)** The gametes produced by (____) × (____) (____) each parent.
- **(b)** The genotype of the offspring (____) (____)
- **(c)** The phenotype of the offspring ________________________________

8.4 In pea plants, round seeds (R) are dominant over wrinkled seeds (r). Answer the questions below using the following genotypes: RR, Rr, rr .
- **(a)** What genotype is homozygous dominant?
- **(b)** What genotype will produce wrinkled seeds?
- **(c)** Which two genotypes will produce round seeds?
- **(d)** What genotype is homozygous recessive?
- **(e)** What genotype is heterozygous?

8.5 In sheep, a white fleece (W) is dominant to a black fleece (w). A heterozygous white fleece sheep was crossed with a black-fleece ram. Outline the cross showing the gametes, genotype and phenotype of the F1 that may result from this cross.

Q R1 S2

8.6 Read the text and then in groups of 6-8 plan how you would carry out a reliable survey. Record your results and present your results and conclusions to other groups.

R2 R3

Activity 8.1

A good way of demonstrating variation within the human population is to carry out a survey to calculate the proportion of your class who can taste the compound phenylthiocarbamide or PTC. PTC is either very bitter or is virtually tasteless depending on the genetic makeup of the taster. Tasting PTC is controlled by a gene that codes for a taste receptor for PTC on the tongue. There are two common alleles of the PTC gene. One allele is the tasting form and the other allele is the non-tasting. The ability to taste PTC is a dominant allele. Therefore, a person only requires one copy of the tasting allele (T) in order to taste PTC. Individuals who are homozygous dominant (TT) for tasting experience a more intense bitterness than those who are heterozygous (Tt). Non-tasters are homozygous recessive for the non-tasting allele (tt).

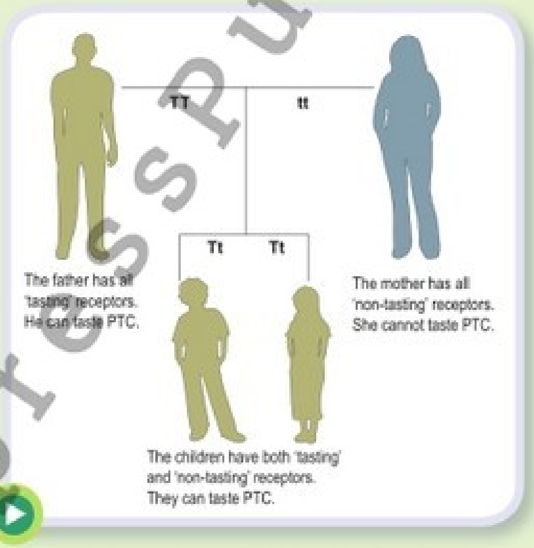


Figure 8.7 *Inheritance of PTC receptors in humans*

Compounds similar to PTC are found in cucumbers, cabbage, Brussels sprouts and broccoli. People who taste PTC do not usually like these vegetables: they taste bitter to them.

Q R4 R5

8.7 Were your results clear?

8.8 What did you conclude from your investigation and those of other groups?

Incomplete dominance

In all of Mendel's crosses, one allele for a particular characteristic was dominant over the other allele. However, this is not always the case. In Shorthorn cattle, red-coated cattle are RR and white-coated cattle are rr. When a red bull is crossed with a white cow all the offspring are Rr and have a **roan coat** (with patches of both red and white hair). This is an example of incomplete dominance. In this case, neither the allele for red coat nor the allele for white coat is dominant. Thus, when both alleles occur together in the offspring, a blending occurs in the phenotype.

> **Incomplete dominance** occurs when two alleles are equally dominant. When both occur together in the genotype, the resulting phenotype is a blend of the two.

When two roan Shorthorn F1s are crossed (Rr × Rr) there is a 50% chance that the F2 (second generation of offspring) will be roan and a 25% chance that the offspring will be red-coated or white-coated.

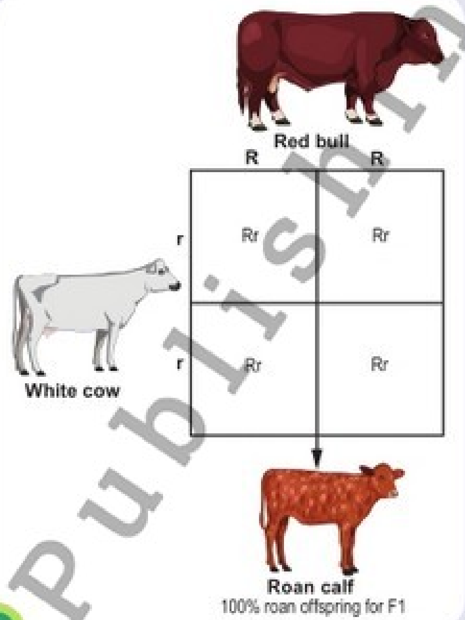
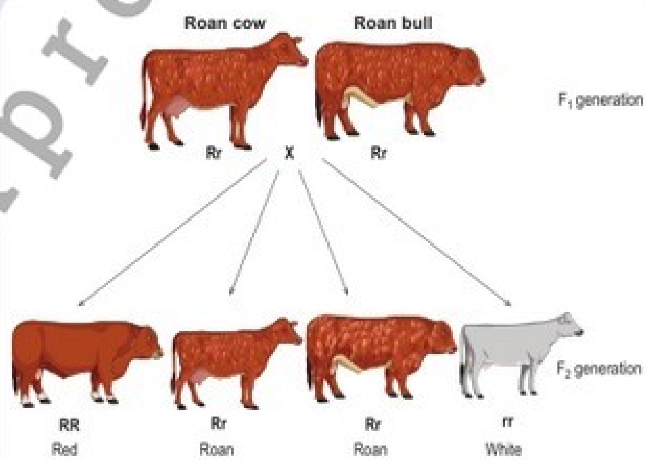


Figure 8.8 A red-coated Shorthorn crossed with a white-coated Shorthorn produces all roan calves



	R	r
R	RR	Rr
r	Rr	rr

Figure 8.9 The offspring that result from crossing two roan animals

Incomplete dominance can also be seen in snapdragons. The red flowers are homozygous (RR) and the white flowers are homozygous (rr). When crossed, the offspring are all heterozygous (Rr) and are pink in colour.

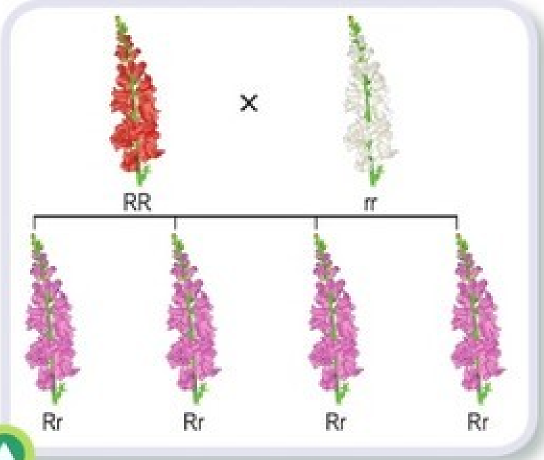


Figure 8.10 *Incomplete dominance in snapdragon*

Figure 8.11 *Pink snapdragon flower*

Question

In cereal trials for oats, the pure-breeding variety Barra, with a straw length of approximately 500 mm, was crossed with the pure-breeding variety Evita, with a straw length of approximately 800 mm. The resulting hybrid had an approximate straw length of 650 mm.

(a) Using B to represent the '500 mm' gene and E to represent the '800 mm' gene, show how this result arose.

(b) Using a Punnett square or other suitable method, show the genotypes and **matching** phenotypes resulting from a cross between two of the new hybrids.

Answer

(a) This cross is another example of incomplete dominance:

Parent's genotype:	BB	x	EE
Parent's phenotype:	500 mm		800 mm
Gametes:	Ⓑ		Ⓔ
F1 Genotype:	100% BE		
F1 Phenotype:	650 mm straw length		

(b) Cross between two of the hybrids BE:

F1 x F1:	BE	x	BE
Gametes:	Ⓑ Ⓔ		Ⓑ Ⓔ
F2, Punnett square			

Gametes	B	E
B	BB	BE
E	BE	EE

F2 Genotypes			**Phenotypes**
25%	BB	→	500 mm
50%	BE	→	650 mm
25%	EE	→	800 mm

Q Understanding U2

8.9 In sweet peas, a cross between a red-petalled plant and a white-petalled plant produces pink-petalled flowers in the progeny. Explain why this happens and then show the cross using a diagram.

8.10 Coat colour in Shorthorn cattle is controlled by two alleles that show incomplete dominance.

(a) Explain the meaning of the term incomplete dominance.

(b) A red-coated (RR) bull was crossed with a white-coated cow (rr) and the F1 were roan-coated. Write down the genotype of the F1.

(c) Another roan-coated bull was crossed with the female from the F1. Show by means of a cross: the gametes produced, the genotype and the phenotype of the F2.

Multiple alleles

In all of the characteristics we have examined so far, a characteristic or trait has been controlled by the presence of two alternative alleles. However, some characteristics are controlled by more than two alleles. When this occurs, the characteristic is said to have multiple alleles.

When a characteristic is controlled by two or more alleles, the alleles are known as **multiple alleles**.

For example, blood groups in humans are controlled by three alleles: A, B and O. The alleles A and B are equally dominant or **co-dominant**, while the allele for O is recessive. The presence of the three different alleles within the human population means that there are four possible blood groups, depending on the alleles present in the individual. However, an individual can only have two of the alleles present in their genotype. Table 8.3 lists the genotype and phenotypes of the four blood types.

Co-dominant: Both alleles of a gene are equally dominant and both are expressed equally in the phenotype when they occur together in the genotype.

Table 8.3 **Genotypes and resulting phenotypes in humans**

Genotype	Phenotype (Blood Group)
AA and AO	Blood type A
BB and BO	Blood type B
AB	Blood type AB
OO	Blood type O

Q U2 S2

8.11 If one parent is blood type A and the other is type B, which of the following blood types could their offspring be?

(a) AB **(b)** A or B **(c)** O **(d)** any

8.12 Which of these statements is true? In determining the phenotype for the ABO blood system:

(a) O is dominant over B **(b)** O is recessive **(c)** B is dominant over A

Dihybrid crosses and independent assortment

A dihybrid cross involves a cross between individuals with alleles for two characteristics. Gregor Mendel carried out a number of genetic crosses where he investigated the inheritance of two different traits in pea plants. During his studies of dihybrid crosses, Mendel formulated his second law of inheritance: the Law of Independent Assortment. This law states that during gamete formation, meiosis causes pairs of alleles to separate and move into the gametes (egg and sperm cells) independently of any other pair of alleles.

Dihybrid crosses involve the inheritance of two characteristics.

The **Law of Independent Assortment** states that during gamete formation, members of a pair of alleles segregate and move into the gametes independently of any other pair of alleles.

In order to understand how independent assortment occurs, examine Figures 8.12 and 8.13.

- The first cell is diploid (2n) in Figure 8.12. Chromosome pair number 1 contains a pair of genes for plant height, with one chromosome carrying the allele for tall (T) and the other chromosome carrying the allele for dwarf (t).
- Chromosome pair number 2 carries a pair of genes for the shape of the seed. One chromosome carries the allele for round seed (R), while the other chromosome carries the allele for wrinkled seed (r).

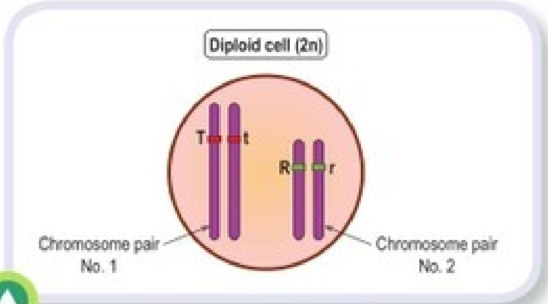


Figure 8.12 *Alleles present in diploid cell*

During the first stage of meiosis, one chromosome from each pair must pass into the gamete, therefore reducing the chromosome number from four in the diploid cell to two chromosomes in the gametes. As a result, only one allele for each characteristic will be present in each gamete.

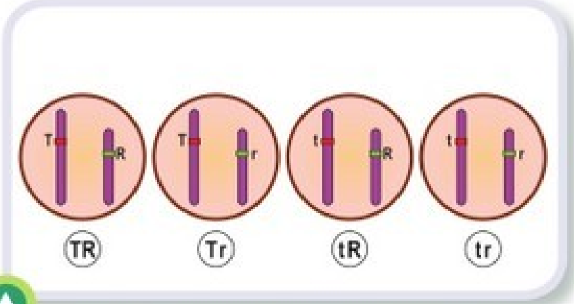


Figure 8.13 *Gametes formed from diploid cell*

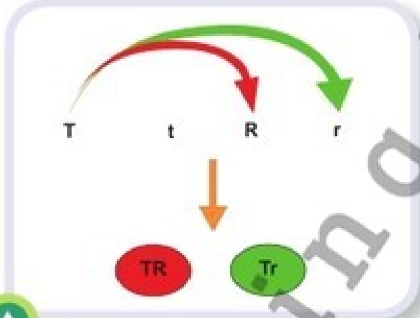


Figure 8.14 *Identification of gametes*

Taking one chromosome from each pair, count the number of combinations of alleles produced from the diploid cell in Figure 8.12. Keep in mind that each gamete must have one allele from each pair of alleles (one for height and one for seed shape).

Examine Figure 8.13 to see these combinations. Since the alleles are on separate chromosomes, they can travel independently into the gamete.

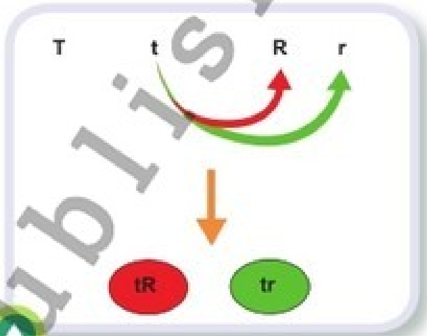


Figure 8.15 *Identification of gametes*

An easy way to represent Mendel's Law of Independent Assortment when identifying alleles present in the gametes from a parent's genotype is to use arrows (see Figures 8.14 and 8.15). First, draw an arrow from the **first allele** to the third and fourth allele in the genotype of the parent.

This provides the first two gametes (Figure 8.14). The process is repeated, drawing arrows from the **second allele** to the third and fourth allele, giving the final two gametes (Figure 8.15).

Examples of dihybrid crosses

The following is an example of a typical cross that Mendel would have completed.

Question

In plants the allele for tall (T) is dominant to the allele for dwarf (t), and the allele for round seeds (R) is dominant to the allele for wrinkled seeds (r). If pollen from a homozygous tall plant with round seeds pollinated a dwarf plant with wrinkled seeds:

(a) State the genotype of the seeds formed.

(b) Describe the phenotypes of the F1 plants.

(c) What ratio of offspring phenotypes could result from a cross between two F1 plants?

Answer

(a) and (b)

Note: The first parent is homozygous tall and round; therefore, it must have two dominant alleles for each characteristic, TTRR. The second parent has the recessive characteristics expressed; therefore, it must be homozygous recessive for both characteristic, ttrr.

Parents: TTRR x ttrr
Gametes: (TR) x (tr)

The gametes contain one allele from each gene pair present. Since the parents are homozygous for both characteristics, they will only produce one type of gamete.

Genotype of F1: TtRr
Phenotype of F1: Tall and round

All of the offspring in the F1 are tall and round, since they all have a dominant allele and they are heterozygous for both characteristics. The recessive alleles do not appear in the phenotype.

(c)

F1 x F1 TtRr x TtRr

Gametes: (TR) (Tr) (tR) (tr) x (TR) (Tr) (tR) (tr)

Since both F1 parents are heterozygous for both characteristics, each F1 parent will produce four different types of gametes.

Punnett square of F2

One parent's gametes are placed across the top of the punnet square and the other parent's gametes are placed down the side.

Gametes	TR	Tr	tR	tr
TR	TTRR	TTRr	TtRR	TtRr
Tr	TTRr	TTrr	TtRr	Ttrr
tR	TtRR	TtRr	ttRR	ttRr
tr	TtRr	Ttrr	ttRr	ttrr

Genotypes with matching phenotypes

Genotypes of F2	Phenotype of F2
1/16 TTRR 2/16 TTRr 2/16 TtRR 4/16 TtRr	9 tall with round seeds
1/16 TTrr 2/16 Ttrr	3 tall with wrinkled seeds

1/16 ttRR
2/16 ttRr → 3 dwarf with round seeds

1/16 ttrr → 1 dwarf with wrinkled seeds

Identical genotypes are grouped together. In order to keep track of the identical genotypes, tick them off as you go through the Punnett square. Count the number of genotypes that give the same phenotype and record this.

Ratio: 9:3:3:1

Question

A maize plant, heterozygous for the recessive alleles hairless tassel (h) and short anther (l), is self-fertilised and the seeds are collected. The genes for tassel type and anther length are **not linked**. Use a cross to illustrate what proportion of the offspring you would expect to show:

(a) Hairy tassel

(b) Short anther

(c) Hairy tassel **and** short anther.

Answer

In the question, we are told that the maize plant is 'self-fertilised'; therefore, the maize plant is crossed with itself. It can be said that the plants are 'selfed'. Also, the question gives us the recessive allele as h and l. Therefore, the dominant alleles must be **H** for hairy and **L** for long.

Parents: HhLl x HhLl

Gametes: (HL) (Hl) (hL) (hl) x (HL) (Hl) (hL) (hl)

The gametes are identified using the method from Figure 13 and Figure 14.

F1

Gametes	HL	Hl	hL	hl
HL	HHLL	HHLl	HhLL	HhLl
Hl	HHLl	HHll	HhLl	Hhll
hL	HhLL	HhLl	hhLL	hhLl
hl	HhLl	Hhll	hhLl	hhll

Genotypes of F2 | **Phenotype of F2**

1/16 HHLL
2/16 HHLl
2/16 HhLL
4/16 HhLl → 9 hairy tassel and long anther

1/16 HHll
2/16 Hhll → 3 hairy tassel and short anther

1/16 hhLL
2/16 hhLl → 3 hairless tassel and long anther

1/16 hhll → 1 hairless tassel and short anther

Genotypes that give the same phenotypes are grouped together. The genotype is then linked to its corresponding phenotype..

What proportion of offspring will have:

(a) Hairy tassel: Only those with Hh or HH in their genotype will give hairy tassels. Using the results above, 12/16 will have hairy tassels.
(b) Short anther: Only those with ll in their genotype will give short anthers: 4/16 will have short anthers.
(c) Hairy tassel and short anther: Only those with the genotype HHll or Hhll will have hairy tassel and short anther in their phenotype: 3/16 will have this phenotype.

The use of the phrase **'not linked'** in the above question refers to the fact that the genes for hairless tassel and short anther occur on different chromosomes and, therefore, follow Mendel's Law of Independent Assortment. It could also be said that these genes are 'located on non-homologous chromosomes'.

Q Understanding U2

8.13 In potato plants, the allele for purple stems (P) is dominant to the allele for green stems (p), and the allele for red fruit (R) is dominant to the allele for yellow fruit (r). A potato plant heterozygous for purple stem and red fruit colour is crossed with a potato plant with green stems and yellow fruit.
(a) What are the genotypes of the parents?
(b) State the genotypes and the phenotypes of the F1.

8.14 In pea plants, purple flowers (P) is dominant to white flowers (p), and tall plants (T) is dominant to dwarf plants (t). A homozygous tall plant with purple flowers is crossed with a dwarf plant with white flowers. State the genotype and phenotype of the F1 plants produced by this cross. Two of the F1 offspring were crossed. State what proportion of the F2 offspring will be tall with white flowers.
(a) State the genotype and phenotype of the F1 plants produced by this cross.
(b) Two of the F1 offspring were crossed.
(c) What proportion of the F2 offspring will be tall with white flowers?
(d) What proportion of the F2 will be dwarf with white flowers?
(e) What proportion of the F2 plants will have purple flowers?

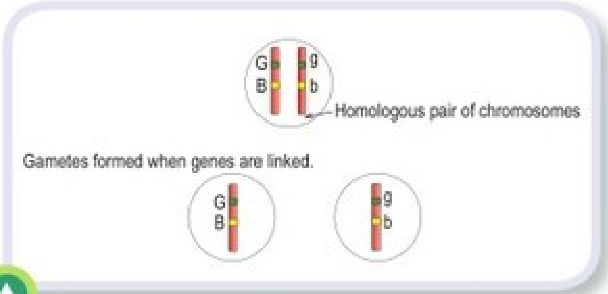


Figure 8.16 *Linked genes*

Linked genes

In the examples seen thus far, the genes involved in the dihybrid cross have occurred on separate chromosomes. If the genes were linked, they would both occur on the same chromosome. In Figure 8.16 the alleles G and B and the alleles g and b are linked. As a result, independent assortment cannot occur and there is a high probability of these linked genes going into the gametes together. Crossing over (which occurs during meiosis, when homologous chromosomes swap genes) separates linked genes.

> **Linked genes** are genes that are located on the same chromosome and tend to be transmitted together into the gamete.

The following is an example of a dihybrid cross where one of the characteristics demonstrates incomplete dominance.

Question

In broiler hens, white plumage (W) is dominant to red (w). Comb length on the head is controlled by two alleles: long-comb (L) and short-comb (S). An intermediate condition, medium-comb, occurs when a pure-breeding long-comb bird is crossed with a short-comb bird.

(a) State the genotype of a red and medium-comb chick.

(b) State the genotype of a red and short-comb chick.

(c) If a red and long-comb cock is crossed with a purebred white and short-comb hen, state the expected genotype and phenotype of the F1 generation.

(d) If two F1 siblings are then mated, what is the probability that an F2 chick will have

- **(i)** White plumage and medium-comb?
- **(ii)** Red plumage and medium-comb?
- **(iii)** Red plumage and short-comb? What ratio of offspring phenotypes could result from a cross between two F1 plants?

Answer

(a) Red and medium-comb chick: wwLS. Since red is recessive, the chick must be homozygous ww for this characteristic to be expressed in the phenotype. Since comb length demonstrates incomplete dominance, the chick must be heterozygous (LS) for comb length.

(b) Red and short-comb chick: wwSS. Red is recessive, so the chick must be homozygous ww for this characteristic to show in the phenotype. For the chick to have a short-comb it must be homozygous SS (purebred).

(c) The best way to determine the answer here is to do out a cross.

Parents' Phenotype	Red and long-comb	x	White and short-comb
Parents' genotype	wwLL	x	WWSS
Gametes	(wL)	x	(WS)

F1 Genotype: WwLS
F1 Phenotype: white plumage and medium-comb

(d) Two of the F1 chicks must be crossed to answer part (d).

F1 Genotype	WwLS	x	WwLS
Gametes	(WL) (WS) (wL) (wS)	x	(WL) (WS) (wL) (wS)

Punnett square of F2

Gametes	WL	WS	wL	wS
WL	WWLL	WWLS	WwLL	WwLS
WS	WWLS	WWSS	WwLS	WwSS
wL	WwLL	WwLS	wwLL	wwLS
wS	WwLS	WwSS	wwLS	wwSS

Since the alleles L and S demonstrate incomplete dominance, two LL will produce long-comb, two SS will produce short-comb and LS will produce medium-comb in the phenotype.

(i) White plumage and medium-comb: Both WW and Ww will produce white plumage but only the genotype of LS will produce a medium-comb. Therefore, the genotypes highlighted in red above will produce that phenotype: 6/16 chicks will have white plumage and medium-comb.

(ii) Red plumage and medium-comb: In order for a chick to have red plumage, the chick must be ww (since red is recessive). The chick must also be LS to have a medium-comb. Therefore, only the genotypes highlighted in blue will have that phenotype: 2/16 chicks will have red plumage and medium-comb.

(iii) Red plumage and short-comb: The chick must have the genotype wwSS to have red plumage and short-comb. The only genotype that will produce that phenotype is highlighted in yellow. 1/16 chicks will have red plumage and short-comb.

Sex determination

Humans have 23 pairs of chromosomes; 22 pairs are known as autosomes and one pair of chromosomes is known as the sex chromosomes (X and Y). The sex chromosomes determine the sex of an individual. Females have two X chromosomes and males have an X and a Y chromosome. Examine Figure 8.17: what observation can you make about the Y chromosome?

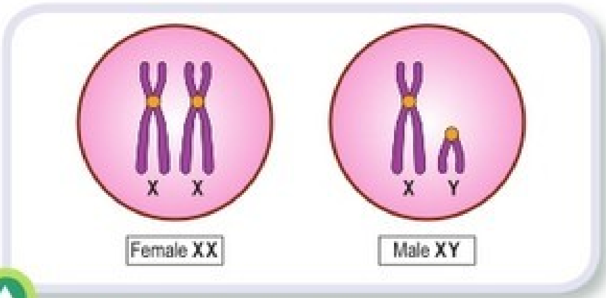


Figure 8.17 *Male and female sex chromosomes*

Sex chromosome: a chromosome that determines the sex of an organism.

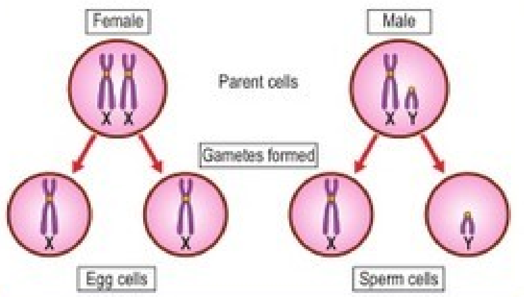


Figure 8.18 *Sex chromosomes and the gametes produced*

The Y chromosome is much smaller than the X chromosome. Therefore, we can conclude that the Y chromosome doesn't have the same amount of information on it as the X chromosome. This has important consequences when we examine some of the genes that are carried on these sex chromosomes. Since males have two different sex chromosomes, X and Y, they are responsible for sex determination of their offspring. When meiosis occurs, females produce gametes that all contain an X chromosome; however, half of the male's gametes contain the X chromosome and half carry the Y chromosome (see Figure 8.18).

On fertilisation, the egg cell contributes an X chromosome, while the male sperm determine the sex of the offspring. If an X sperm cell fertilises the egg, the offspring will be female; if a Y sperm cell fertilises the egg, the offspring will be male. This is shown in the following Punnett square. Role of organisms in the carbon cycle . Three groups of organisms have roles to play in the carbon cycle:

Male gametes

Female		X	Y
	X	XX	XY
	X	XX	XY

F1 Genotype: 50% XX and 50% XY
Phenotype: 50% female and 50% male

Every time a male and female are mated, there is a 50% chance that the offspring will be female and a 50% chance that the offspring will be male. This probability has particular consequences in the dairy industry, where female calves are often preferred over male calves.

For this reason, scientists involved in cattle breeding have determined a way of separating sperm carrying X chromosomes from sperm carrying Y chromosomes in order to produce semen samples that have been sexed.

In mammals, it is the male that determines the sex of the offspring. In birds, it is the female that determines the sex of the offspring. In birds, the sex chromosomes are called Z and W, with the Z chromosome being the larger and having more genes than the W chromosome. Female birds are ZW and male birds are ZZ.

Figure 8.19 *Sex determination is controlled by the ZW chromosomes of females in poultry*

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Sex linkage

In 1907 Thomas Hunt Morgan conducted genetic crosses with the fruit fly *Drosophila melanogaster*.

Initially, Morgan intended to use these fruit flies to reproduce Mendel's monohybrid crosses. Fruit flies usually have red eyes; however, Morgan noticed a white-eyed male in one of his crosses.

Figure 8.20 *T.H. Morgan*

Morgan crossed this white-eyed male with a red-eyed female and all of the F1 produced had red eyes. Naturally, he presumed that red eyes were dominant and white eyes were recessive. He continued his investigation and crossed an F1 male with an F1 female. He presumed that he would get a Mendelian ratio of 3 red-eyed flies to 1 white-eyed fly in the F2 generation. On examination of the results of the cross, Morgan recorded that all the F2 females and 50 per cent of the males had red eyes, while the remaining 50 per cent of the males had white eyes. Morgan concluded that the inheritance of eye colour in the fruit flies was related to the sex of the offspring. What Morgan had discovered was that the gene for determining eye colour in fruit flies is located on the sex chromosomes.

The X chromosome carries a number of genes that are not related to sex determination. For example, in fruit flies the gene for eye colour is located on the X chromosome and in humans the gene for blood clotting and colour vision are carried on the X chromosome. These genes are known as sex-linked genes or X-linked genes, since they are only found on the X chromosome and there is no gene for these characteristics on the Y chromosome.

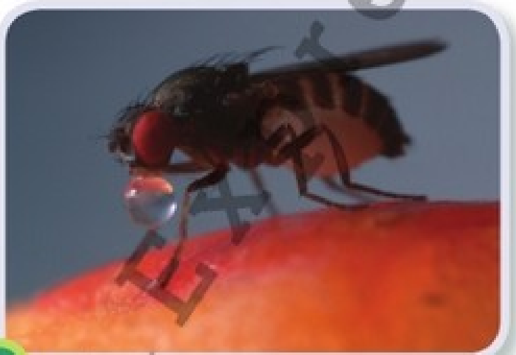


Figure 8.21 *Red-eyed fruit fly*

Figure 8.22 *White-eyed fruit fly*

Sex-linkage or **X-linkage** is a gene that is found on the X chromosome but there is no copy on the Y chromosome.

White eye, haemophilia and colour blindness are all caused by recessive genes. Normally, the inheritance of two recessive genes is required for these characteristics to be expressed in the phenotype. However, since these genes are carried on the X chromosome and males have only one X chromosome, and therefore only one copy of the gene, these sex-linked disorders occur more commonly in males than in females. In order for a female to be affected by a sex-linked characteristic, she would have to inherit two copies of the recessive gene: her mother would have to be a carrier of the sex-linked characteristic and her father would have the sex-linked condition.

Figure 8.23 shows the inheritance of white eye colour in male fruit flies.

Genotype of parents $X^R X^R$ x X^rY

Gametes (X^R) (X^R) x (X^r) (Y)

A homozygous red-eyed female is crossed with white-eyed male. The male is white-eyed because he has only one gene and the recessive one is expressed.

In the gametes, the X chromosomes carry the gene and the Y is left blank to show that it does not have a gene for eye colour.

Gametes	X^r	Y
X^R	X^RX^r	X^RY
X^R	X^RX^r	X^RY

F1 Genotype and phenotype: Both males and females have red eyes. The males and females inherited the red-eye gene from their mother. However, the females have inherited the white-eye gene from their father but it is not expressed, since the gene for red eyes is dominant. In this case the females are called carriers.

If an F1 female is crossed with an F1 male the following cross is produced.

F1 cross: $X^R X^R$ x X^RY

Gametes: (X^R) (X^r) x (X^R) (Y)

F2

Gametes	X^R	Y
X^R	X^RX^R	X^RY
X^r	X^RX^r	X^rY

In the second cross, notice how the female produces two different types of X gametes. One gamete is carrying the normal gene for red eye and the other is carrying the gamete for white eye.

The only flies that have white eyes in the phenotype are those with genotype XrY. Since there is no gene for eye colour on the Y chromosome, the white-eye gene on the X chromosome is expressed.

F2 Genotype: X^RX^R, X^RX^r, X^RY and X^rY

Phenotype: All females have red eyes, 50% of males have red eyes and 50% of males have white eyes.

Figure 8.23 *Inheritance of white eyes in fruit flies*

Sex-linked genes in agriculture

There is a very rare sex-linked characteristic in Holstein cattle. Male calves can be born with very little hair and with no incisors. This is more likely to happen if closely related animals are crossed.

Use of fruit flies in genetics

There are many advantages of using fruit flies when studying genetics:

- Fruit flies are easy to keep.
- They produce large numbers of offspring, which is good for statistical analysis.
- They produce a new generation every two weeks.
- They have only four pairs of chromosomes.
- They have well documented mutations, e.g. inheritance of white eyes in male fruit flies.

Q Understanding U2

8.15 The gender of offspring is determined by the male parent in mammals. Illustrate this statement in terms of chromosomes.

8.16 (a) Distinguish between the following pairs of terms:

(i) Sex-linked genes and linked genes.

(ii) XX and XY.

(b) How are linked genes separated?

(c) How does the X chromosome differ from the Y chromosome in mammals?

(d) Explain, using examples, why some recessive disorders carried on the X chromosome appear more commonly in males than in females.

8.17 Suggest reasons why the fruit fly [Drosophila] is suitable for genetic experiments.

Genetic modification of plants

Genetic modification (GM) describes an organism whose DNA has been altered for the purpose of improvement or to correct a defect in the organism.

Genetic engineering allows scientists to insert beneficial genes into the chromosomes of plants and animals. Plants and animals that are produced by genetic engineering are called **genetically modified organisms**. In some cases, a gene from one organism (e.g. bacteria) can be placed into a completely unrelated organism (e.g. plant). Such organisms are known as **transgenic species**.

Transgenic species: any organism that has had part of the DNA of another species (animal, plant, microorganism, etc.) transferred into its own DNA by genetic engineering.

Genetically modified maize contains a gene from a bacterium called *Bacillus thuringiensis* that codes for a toxin. This toxin is poisonous to insect pests and, in particular, to the corn borer caterpillar. As a result, the plant can produce its own pesticide so that the caterpillars die when they eat the plant. This reduces the need to spray crops with pesticides.

Some varieties of maize can be genetically modified so that they can tolerate herbicides such as Roundup. This allows farmers to spray crops with herbicides to kill competing weeds without killing the maize crop.

However, not all genetically modified organisms have to be transgenic. Genetic information can be transferred between two varieties of the same crop or genus. This is referred to as **cisgenesis**.

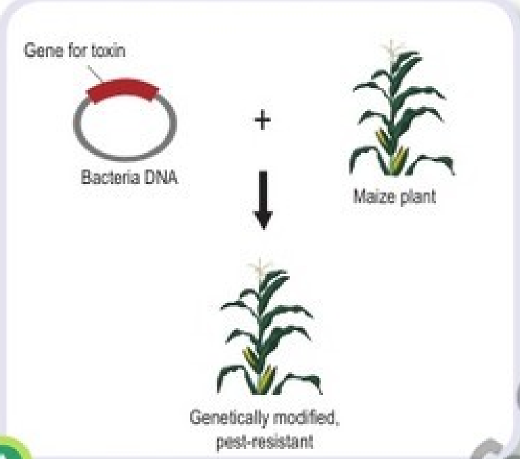


Figure 8.24 *Genetically modified maize*

Figure 8.25 *Tomato purée made from genetically modified tomatoes*

> Varietal approval is a variety of plant that has been approved by an authority (e.g. a Food Safety Authority) for commercial production and sale.

One of the benefits of using genetic engineering is that it can accelerate the breeding process of a crop. Using traditional methods of plant breeding, it could take 40 years to breed the blight-resistant variety of potatoes from the wild potato varieties. Using genetic engineering, the new blight-resistant GM variety could be produced in a laboratory within 18 weeks and could achieve varietal approval within 3-5 years.

Other benefits of GM crops include the potential to preserve crop yields in the presence of a disease or drought conditions. In medicine, bacteria and yeast are genetically modified so that they produce insulin, which is used to treat diabetics.

Many of the concerns surrounding the use of GM organisms stem from a lack of understanding of the technology. One concern is that GM crops may cause allergies in the people consuming them. Any plant or animal containing genetically modified traits would have to be assessed to identify any potential allergy that might arise. Another fear is that herbicide-resistant genes could escape into other plants by cross-fertilisation to produce 'super weeds', which would then be resistant to herbicides.

Herbicidal-resistant GM crops have been grown for many years in parts of the United States and Canada. Here the farmers continually sprayed their herbicide-tolerant soybean crop with the same herbicide in order to control weeds. As a result, weeds started to demonstrate resistance to the herbicide being used. The use of the herbicide-resistant soybean made many farmers complacent in their crop management. Instead of practising crop rotation and other methods of weed control, they had in fact encouraged the development of herbicidal resistance in the weeds associated with the GM soybean by continually using the same herbicide.

Risk assessment studies have been carried out on GM organisms over the past ten years and these studies are ongoing. To date, no health issue has been identified. A study of GM potatoes for example might study whether they have a positive or a negative impact on insects, pollinators and soil microbes.

Q Understanding U2 Society S2

8.18 What is a transgenic organism? How are transgenic organisms produced?

8.19 What are the benefits of using genetically modified organisms?

Communicating C1 Communicating C2

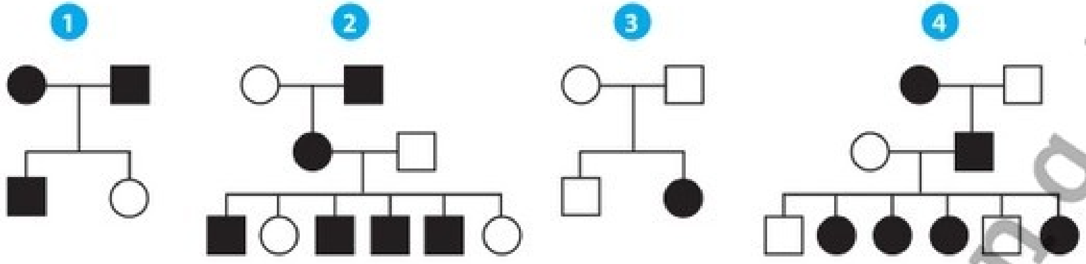
8.20 Research what methods in your local region are used for increasing crop yields: *GM*, *crossbreeding of plants*, *use of pesticides* or others. Prepare a short presentation for the rest of the class.

Methods of studying human genetics

Pedigree charts

A pedigree chart is a diagram showing the genetic history of a group of related individuals. Doctors can use charts to show genetic disorders are inherited in a family. From analysis of such charts it is possible to work out the probability of someone in a family inheriting a certain condition. In the chart:

□ = male | ○ = female | Shaded shapes show individuals afflicted with a certain trait.



U2 C2 S2

8.21 Match the trait shown in the pedigree charts above to the inheritance pattern.

(a) X-linked dominant ______
(b) X-linked recessive ______
(c) autosomal dominant ______
(d) autosomal recessive ______

8.22 Look at the charts above. Draw your own genealogical chart starting with your grandparents or great-grandparents. Can you indicate any inherited traits such as: *eye colour*, *colour blindness*, *dimples* or others?

Twins in the family are indicated like this:

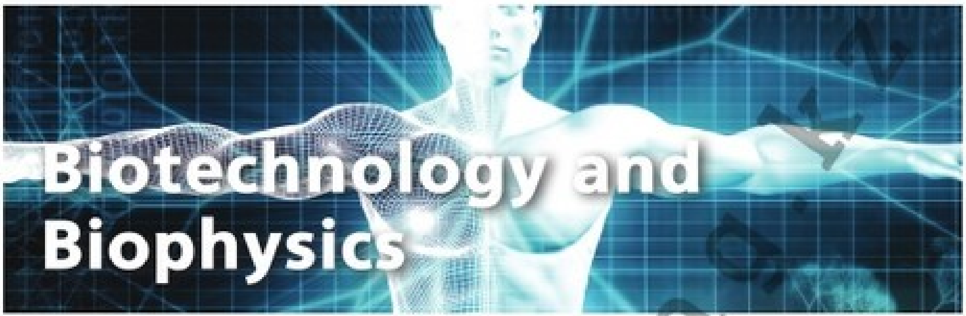
Twin studies

Another method of studying genetics is through twin studies which allow researchers to examine the overall role of genes in the development of a trait or disorder. The methodology in such studies is usually comparisons between monozygotic (MZ or identical) twins and dizygotic (DZ or fraternal) twins where researchers assess the degree of genetic and environmental influence on a specific trait being studied. MZ twins are the same sex and share 100% of their genes. DZ twins can be either the same–or opposite–sex and ,on average, will share 50% of their genes.

U2 C2 S2

8.23 Research another method of studying genetics. Prepare a short presentation to present to the class.

MODULE 9



Biotechnology and Biophysics

Learning outcomes

At the end of this module you will be able to:

- Describe biotechnological processes with particular reference to the production of insulin 9.4.3.1
- Give examples of products produced in continuous and batch cultures 9.4.3.2
- Give examples of electrical processes in living organisms 9.4.4.1
- Describe characteristics of brain- computer interfaces (BCIs) 9.4.4.2

Keywords

✔ micro-organism ✔ harvest ✔ pump ✔ plasmid ✔ recombinant
✔ batch fermentation ✔ immobilise ✔ millivolts
✔ paralysis ✔ prosthetic ✔ decode

Biotechnology

Biotechnology is the use of living things and parts of living things to produce useful products that have a wide range of uses in manufacturing, food production and medicine. Organisms used in biotechnology include plants, animals and micro-organisms such as bacteria and fungi. Most recent developments involve altering micro-organisms by adding genes from which different products can be harvested. Below we will consider how insulin, which is important in diabetes treatment, is produced.

Insulin

Insulin is a vital hormone, because it is the only hormone that reduces blood glucose levels. It causes cells, especially muscle and fat cells, to absorb glucose from the blood. The absorbed glucose is either used in respiration or converted to glycogen. Glycogen is mostly stored in the liver and muscles.

Low insulin production, or an inability of cells to take up insulin, results in a disorder called diabetes. If this develops in young people, it is normally caused by the failure of the islets of Langerhans in the pancreas to work properly. The symptoms of diabetes are: high glucose concentration in the blood and urine, the production of large amounts of urine, severe thirst, loss of weight and tiredness.

Patients suffering from severe diabetes have to constantly monitor and maintain their insulin levels either through injections or by using an insulin pump.

Did you know?

People with severe diabetes have to inject themselves with insulin up to four times a day.

Up until the 1980's insulin was harvested from the pancreas of cows and pigs, purified and used in treating human diabetes patients. Today, however, as a result of developments in gene technology, it is possible to insert a human gene into the genetic material of a common bacterium, E-coli and produce the protein encoded in the human gene. In the case of the production of insulin, the process works as follows:

Figure 9.1 *Insulin pump*

Step 1

The human gene responsible for the production of insulin is isolated.

Step 2

The plasmid (the bacteria loop of DNA) is isolated and cut with an enzyme.

Step 3

The gene is inserted into the plasmid and sealed using enzymes.

Step 4

The recombinant DNA (rDNA) is then inserted into the host bacteria cell.

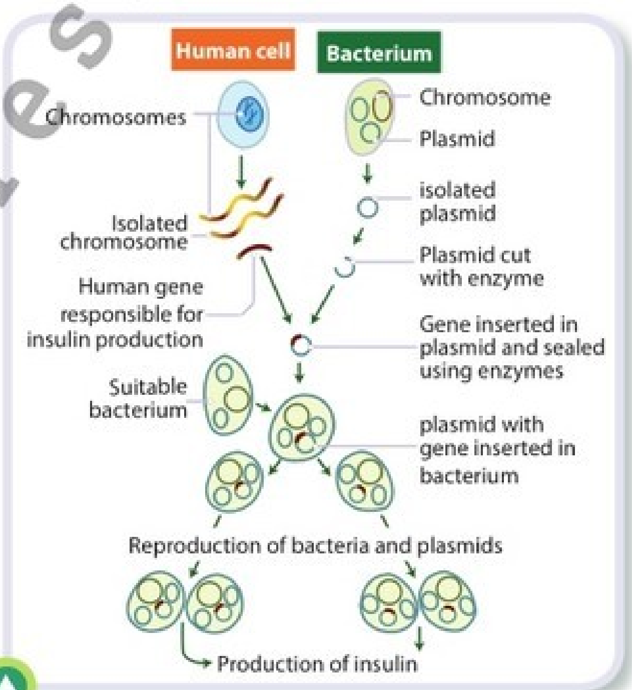


Figure 9.2 *The production of insulin*

Step 5

Bacteria cells are then kept in fermentation tanks – conditions which encourage them to multiply.

Step 6

The insulin is harvested and purified for use.

This process is considered to have several advantages over the harvesting of insulin from animals:

- reduced production costs compared to costs of feeding and sheltering animals
- ability to create greater quantities of insulin
- synthetic insulin is less likely to cause adverse reactions
- no animal welfare or ethical concerns with the synthesising process.

Figure 9.3. *Fermentation tank*

Batch and Continuous cultures

There are two different forms of fermentation culture used in biotechnology: **batch culture** as in the production of insulin and **continuous culture** as in the production of citric acid from the fungi Aspergillus niger.

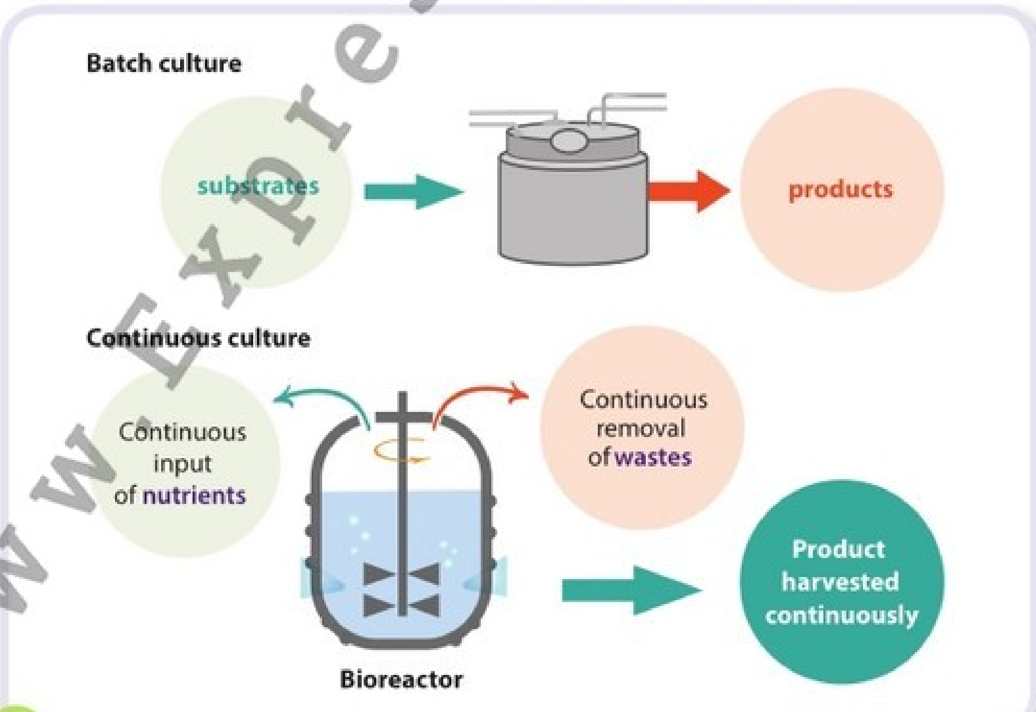


Figure 9.5 *Differences between batch and continuous culture*

Table 9.1

Batch culture	Continuous culture
closed fermentation process	open fermentation process
micro-organisms and nutrients left for a set amount of time	continuous reaction with no time limit
nutrient stock is depleted during process	The way in which living things produce
final harvesting of product	product harvested in ongoing way

Batch culture has the advantage that fermenting machinery can be used to produce different kinds of product, whereas continuous culture is more efficient due to time and cost savings. Penicillin is an example of another product made in batch cultures; ammonia an example of a product made in a continuous batch process.

Q U4 Understanding

9.1 What is the function of the hormone insulin in the endocrine system?

9.2 Name two advantages of using biotechnology to produce human insulin rather than using animals.

9.3 Can you think of a reason why products involving the use of E-coli are made in batch culture rather than continuous culture processes?

9.4 Explain what the letter 'r' stands for in 'rDNA'?

Bioelectricity

Bioelectricity is the study of the electrical phenomenon of life processes, that is to say, the electric current and potentials which are found in living organisms. The cell is the basic unit of such potentials as it can be polarised by certain processes in the organism using energy. A bioelectric current involves the flow of ions across types of cell in an organism that have electrically excitable membranes. In the human body, these include neurons and muscle cells [see Module 6 and Module 10]. We have seen that muscle- and nerve-cell membranes are slightly permeable to positive potassium ions. These ions can diffuse out of the cell, leaving a net negative charge within it.

Figure 9.6 *Electric eel*

Figure 9.7 *Electric ray*

Did you know?

In the electric eel, currents at one ampere in excess of 600 volts can be generated, but in most organisms the range of bioelectric potentials is from 1 to several hundred millivolts.

Certain types of fish such as the electric eel and electric ray have extremely powerful bioelectric organs which they use as a self-defence mechanism or to immobilise prey.

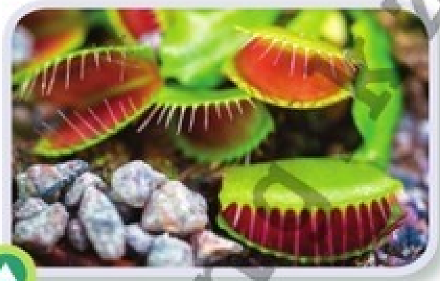


Figure 9.8 *Venus flytrap*

Plants, unlike animals, do not have a nervous system but they do use electrical signals to control individual cells, as well as to carry messages between different parts of the plant. The Venus flytrap is a well-known example of this. Its mechanism for snapping shut is activated by an electrical impulse. The bioelectric potential of plants is also evident in the process of photosynthesis. Plants divide water molecules into hydrogen and oxygen through photosynthesis, and electrons which are generated during this division are used by the plants to create sugar they need to grow and reproduce.

9.5 Name an organism in nature that generates electricity to immobilise prey.

9.6 Name two types of cell in the human body that have electrically excitable membranes.

9.7 Identify an ion that these membranes are permeable to.

9.8 What is produced when water molecules are divided into hydrogen and oxygen in photosynthesis?

Activity 9.1

Question

Can a potato be used to generate electricity?

Equipment needed

Potatoes	Copper Electrode	Multimeter	A small LED
1 Lemon	Zinc Electrode	Alligator clips/ Leads	

Safety

- Be careful when handling the alligator clips.

Conducting the activity

1. Set up the apparatus as show in Figure 9.9.
2. Measure the current. The voltage and current can be increased by using two or more potatoes connected 'in series'.
3. Replace one potato with a lemon and see if there is any difference in current and voltage.
4. Record your results.

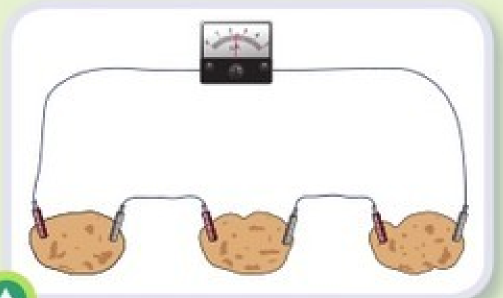


Figure 9.9 *Using a potato to generate electricity*

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Q U4 R5

9.9 What were your results?

9.10 Can you explain how the potato acted as a battery in this experiment?

Clinical instruments

In modern clinical practice a range of instruments are used to measure bioelectric potentials: the ECG for the heart and the EEG for brain activity.

U4 C2

9.11 Find out what each of these tests measures.

9.12 Identify two conditions that each of these tests can diagnose.

Biophysics

The brain-computer interface (BCI) describes the connection between a brain and an external device which can read signals from the brain to control an external activity. The most typical applications of this technology to-date have been in enabling people suffering from paralysis to regain some control of their limbs or prosthetic limbs or to perform actions such as directing a keyboard.

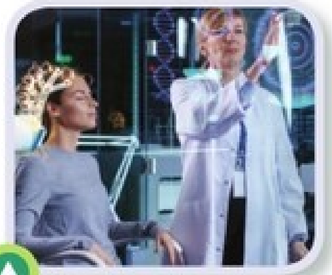


Figure 9.10 *Computer interface*

We have seen in Module 6 that different parts of the body have different control centres in the brain responsible for co-ordinating different movements. Scientists are able to measure brain activity and locate the type of signal that is generated from such centres, so BCIs can detect signals that relate to specific body movements. As these centres of the brain can be activated just by thinking about a movement rather than performing it, BCIs have huge potential in helping people perform actions where neuromuscular pathways have been damaged.

Similarly, signals relating to mental activity in the brain such as counting forwards or backwards can also be detected and these can be decoded by BCIs to allow someone with paralysis to control a device such as a computer mouse or menu on a screen.

U4 C2

9.13 Research a type of BCI which is used for medical, assistive purposes or for a more general use and prepare a short presentation for the class explaining how it works.

MODULE 10

Muscles and Movement

Learning outcomes

At the end of this module you will be able to:

- Investigate the strength and endurance of muscles in the hand 9.1.6.1
- Describe the dependency of muscle work on the frequency of contractions 9.1.6.2

Keywords

✔ wrist ✔ thumb ✔ tendon ✔ dominant ✔ non-dominant
✔ forearm ✔ flexor ✔ extensor ✔ palm ✔ power grip
✔ precision grip ✔ contraction

Hand muscles

The complex structure of the hand allows us to perform a great range of movements with precision. The muscles in the forearm, wrist and hand can be seen to work together in highly complex ways to achieve the variety of movement that allows us to complete the wide range of tasks we perform with our hands. Most people prefer to use one hand for more delicate, complex tasks such as writing, cutting and drawing. This hand is called the dominant hand and the other the non-dominant hand.

Did you know?

About a quarter of all the bones in the human body are found in the hand and the hand has more than 30 muscles.

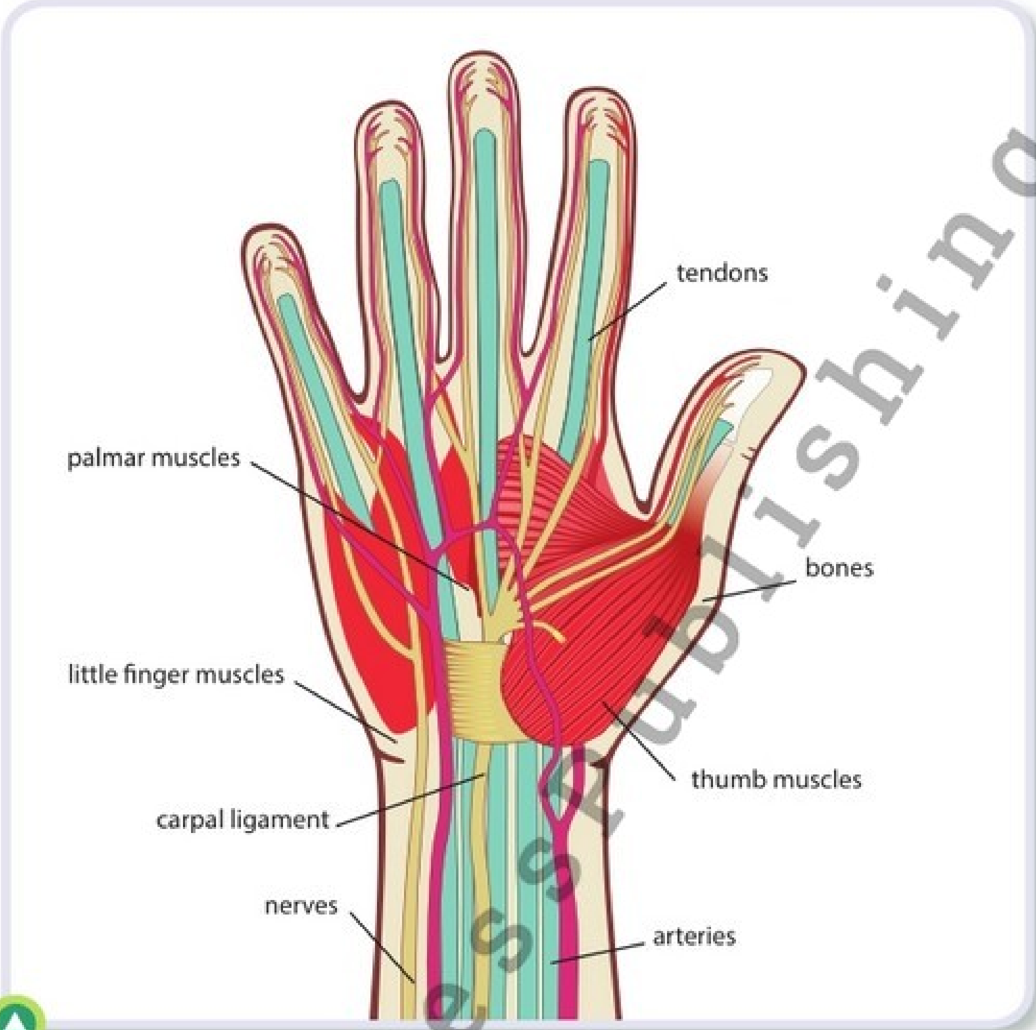


Figure 10.1 *Hand anatomy*

Long forearm muscles

Most movements of the hand are controlled by muscles in the forearm. The extensor tendons of the muscles allowing the hand to extend run through the back of the hand (see Figure 10.1) to the fingertips. The flexor tendons run through the palm of the hand to the fingers.

Short hand muscles

Another set of muscles are found between the individual metacarpal bones. These muscles support a variety of movement, allowing fingers to spread out and close together and to extend and flex.

Little finger and Thumb muscles

The thumb and little finger muscles (see Figure 10.2) are powerful muscles that are important in allowing the hand to grip objects. They allow the thumb, for example, the movement of opposition whereby it can touch all other fingers. Consider how important this is in holding your pen in a position that allows you to write.

Power grip and Precision grip

There are essentially two ways that we use the hand to hold or move objects depending on the power or precision needed to perform the action.

Power grip

This involves closing the fingers around an object with the thumb working in opposition to the fingers. In this way, an object such as a door handle or a heavy box can be gripped tightly and moved. The amount of strength that is needed to hold and move such objects depends on their weight and the smoothness of their surface.

Figure 10.2 *Power grip*

Precision grip

In this type of grip the thumb works in opposition to the tip of the index finger or other fingers to grip smaller objects such as a paintbrush or a sewing needle. This kind of grip permits the hand muscles to perform a range of finer and more delicate movements.

Figure 10.3 *Precision grip*

Muscle fatigue

Fatigue in skeletal muscle results from a reduction in muscle tension which is caused by repeated muscle contraction activity. As we have seen in Module 5, muscle contraction requires energy in the form of ATP which is produced aerobically when oxygen levels are high and anaerobically when oxygen levels are low. Muscle fatigue occurs when levels of lactic acid build up and limit muscle function. In the activity below we investigate such reactions in relation to a repeated action using both the dominant and non-dominant hand.

Research R2 Research R3 Research R4

Portfolio 69

Activity 10.1

Question

How can we investigate the endurance of hand muscles?

Figure 10.4 *Hand gripping a clothes peg*

Equipment needed

A stopwatch

A clothes peg

Safety

- Be careful when using the peg to avoid injury.

Conducting the activity

1. Work in pairs, one is the subject and the other the recorder.
2. The subject holds a peg in their dominant hand and extends their arm out straight in front of them.
3. The recorder presses the start button on the stopwatch.
4. The subject opens and closes the peg [gripped between thumb and fingers] as many times as possible in 60 seconds with arm extended.
5. Leave the stopwatch running and allow the subject to rest for 60 seconds. Record results.
6. Subject then repeats the task with same hand.
7. Allow 60 seconds rest.
8. Subject holds the peg in their non-dominant hand and performs task for 60 seconds. Record results.
9. Allow sixty seconds rest and then subject repeats task with non-dominant hand.
10. Students swap roles and repeat activity.
11. Record the number of times each subject opened and closed the peg in each of the 4 stages of the activity.

Q Understanding U1 Research R5

10.1 What physical observations were made by each student during the activity?

10.2 What conclusions did you reach about the endurance and recovery times of hand muscles in the dominant and non-dominant hand?

10.3 How can you explain these conclusions?

Research R1 Understanding U1

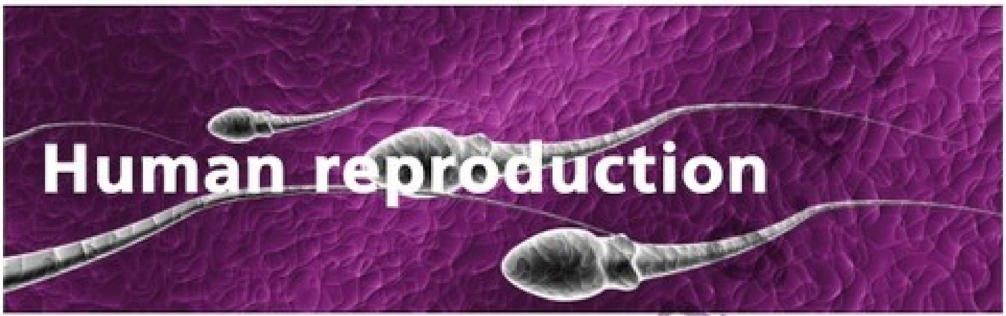
10.4 The above experiment involved testing the endurance of each hand in performing a repeated movement. Work in small groups to design and run an experiment that tests the ability of each hand to grip an object with maximum strength for a sustained period.

Q Understanding U1

10.5 What is the main function of thumb muscles in the precision grip and power grip of the hand?

10.6 Where are the muscles that primarily control the movement of the middle three fingers on the hand located?

MODULE 11



Human reproduction

Learning outcomes

At the end of this module you will be able to:

- Describe the structure of the human sexual system 9.2.1.1
- Investigate features of the structure of male and female gametes 9.2.1.2
- Describe the development of secondary sexual characteristics during puberty 9.2.1.3
- Describe the menstrual cycle and the role of oestrogen and progesterone 9.2.1.4
- Explain the meaning of and types of contraception 9.2.1.5
- Explain the consequences of sexually transmitted diseases and prevention measures 9.2.1.6
- Compare the development of the embryo and the foetus 9.2.11.2
- Explain the consequences of smoking, alcohol and other drugs on the development of the human embryo 9.2.11.3

Keywords

✔ gametes ✔ testis ✔ puberty ✔ sperm ✔ scrotum ✔ penis ✔ ovary ✔ fallopian tube ✔ uterus ✔ cervix ✔ vagina ✔ menstrual cycle ✔ menstruation ✔ ovulation ✔ fertile period ✔ intercourse ✔ fertilisation ✔ implantation ✔ pregnancy ✔ amnion ✔ amniotic fluid ✔ placenta ✔ umbilical cord ✔ contraception ✔ STI

Introduction

The human reproductive systems (male and female) are composed of three structural levels of organisation:

1. A pair of structures in both males and females to produce sex cells (gametes):
   - The testes produce the male sex cells called sperm
   - The ovaries produce the female gametes called eggs or ova (the singular is ovum).
2. A series of transport tubes.
3. A number of glands to secrete hormones that control human reproduction.

The male reproductive system

What are the functions of the parts of the male reproductive system?

Testis

The testis (plural *testes*) makes **sperm**. The testes start to make sperm between the ages of 12 and 14. This is the age of sexual maturity (or **puberty**) in boys.

A few weeks before birth they descend out of the body cavity into a pouch called the scrotum. The temperature in the scrotum is maintained at 35°C. At this temperature meiosis can occur, producing sperm. (Meiosis does not take place properly in males at normal body temperature, i.e. 37°C).

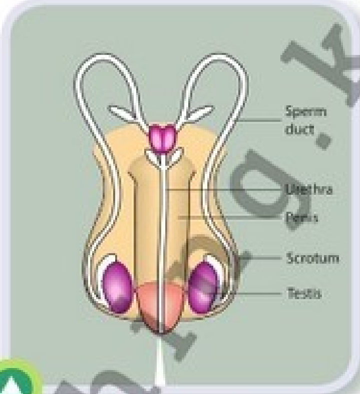


Figure 11.1 *The male reproductive system*

Sperm

Sperm are produced by **meiosis**. Sperm-producing cells are diploid, i.e. they contain 46 chromosomes. They divide by meiosis to form sperm cells. Meiosis halves the number of chromosomes and so sperm cells (spermatozoa) are haploid, i.e. they contain only 23 chromosomes.

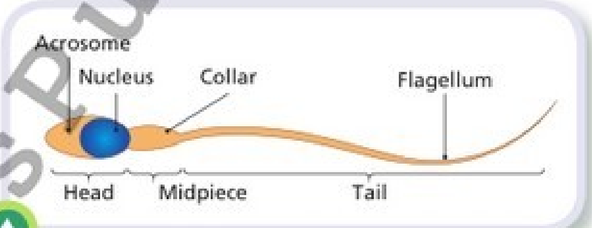


Figure 11.2 *Structure of sperm cell*

Each sperm cell contains:

- An acrosome (a region containing enzymes that can digest the membrane of the egg)
- A nucleus (containing 23 chromosomes)
- A midpiece (containing many mitochondria)
- A tail (to allow the sperm to swim).

Puberty is the beginning of sexual maturity.

Sperm are formed continually throughout a man's lifetime.


Figure 11.3 *Sperm cells (scanning electron micrograph, or SEM)*

Scrotum

The scrotum is a sac in which the testes are held. The scrotum holds the testes outside the body, allowing them to be kept at a temperature just lower than body temperature. This allows sperm to be made successfully.

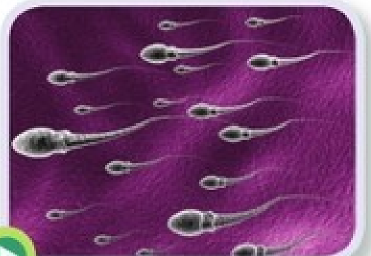


Figure 11.4 *Sperm cells*

Sperm ducts

Two sperm ducts carry sperm from the testes to the penis.

A number of glands are located beside the sperm ducts. These glands produce a liquid called seminal fluid. The mixture of sperm and seminal fluid is called semen.

Penis

The sperm ducts join a tube called the **urethra**. Sperm pass through this tube, which is located in the centre of the penis.

The penis allows semen (or sperm) to pass out of the male body and into the body of the female.

Testosterone

Androgens are male hormones. Testosterone is the main androgen. It is produced in small amounts by the testes before puberty (and by the female ovaries throughout life). Testosterone causes the primary male sex characteristics early in life, i.e. the growth of the penis and other male reproductive parts and the descent of the testes into the scrotum.

The production of testosterone increases enormously at puberty, causing the enlargement of the penis, testes and other reproductive parts. Testosterone also causes the secondary male characteristics.

Secondary male characteristics

- Growth of pubic, underarm, facial and body hair
- Enlargement of the larynx, causing the voice to break and deepen
- Increased muscular and bone development
- Widening of the shoulders
- Growth spurt (body weight may double)
- Increased secretion of sebum in the skin

Secondary sexual characteristics are those features that distinguish males from females, apart from the sex organs themselves.

Q Understanding U2

11.1 Rewrite the words below in the correct order to describe the path taken by sperm cells:

sperm duct penis testis

(1) ______________ **(2)** ______________ **(3)** ______________

11.2 Name the structure in males responsible for each of the following:

(a) Making sperm

(b) Controlling the temperature at which sperm are produced

(c) Transferring sperm to the female

(d) Carrying sperm from the testes to the penis.

11.3 **(a)** Draw a diagram of a sperm and label four major parts.
(b) Give one function for each part named.
11.4 **(a)** Distinguish between primary and secondary male traits.
(b) Name the hormone responsible for these traits in males.
11.5 Make a sentence connecting these four terms
(a) 35°C **(b)** testes **(c)** scrotum **(d)** 37°C

The female reproductive system

What are the functions of the parts of the female reproductive system?

Ovary

The ovaries produce eggs. The ovaries start to make eggs at puberty. This occurs between the ages of 10 and 13 years. Other changes taking place in the girl's body at puberty include:

- The maturing and enlargement of the breasts
- Widening of the pelvis (to allow for birth)
- Increased body fat
- Growth of pubic and underarm hair
- Growth spurt (which is also stimulated by testosterone produced by the adrenal glands).

Figure 11.5 *The female reproductive system*

These are known as the **secondary female characteristics.**

Eggs are the female sex cells or gametes. Each egg is much larger than a sperm cell.

Normally, one egg is formed each month in the female body. Egg production starts at puberty. Beyond the age of 35 the number of eggs in each ovary falls dramatically. Egg production usually stops between 45 and 55 years of age. This stage, where the ovaries have run out of eggs, is called the **menopause** (or the 'change of life').

Fallopian tube

The fallopian tube collects the egg from the ovary and carries it to the uterus.

If sperm are present, one of them may join (or fuse) with the egg in the fallopian tube. If there are no sperm present, the egg dies within two days.

Figure 11.6 *Sperm about to fertilise an egg*

Uterus

The uterus or womb is the place in which a baby (or embryo) will develop.

Cervix

The cervix is the opening or neck of the uterus. Sperm pass through the cervix in order to reach an egg.

Vagina

The vagina is a muscular tube into which the penis releases sperm. It forms the **birth canal** when the baby passes down the vagina at childbirth.

Q Understanding U2

11.6 Name the structures in males and females that produce gametes.

11.7 Outline the differences between sperms and eggs in terms of:

(a) Size **(b)** Numbers formed **(c)** Structure.

11.8 In order to prevent pregnancy some women have their fallopian tubes closed by surgery. How does this prevent pregnancy?

Communicating C1

11.9 Research the name given to a similar procedure as that in question 11.8 for males, where the sperm ducts are cut or sealed.

What is the menstrual cycle?

In females, one menstrual cycle takes place about every twenty-eight days between puberty and the menopause. The menstrual cycle does not take place during pregnancy (i.e. when a baby is developing in the uterus).

The main events in the menstrual cycle are outlined below. The times given in this account are average times. These timings can be different in different females and during different months.

The menstrual cycle

The menstrual cycle (*mensis* is the Latin for 'month') begins at puberty and continues until the **menopause**, which is the end of a woman's reproductive life (usually between the ages of 45 and 55).

The **menstrual cycle** is a series of events that occurs every 28 days on average in the female if fertilisation has not taken place.

The **menopause** is when ovulation and menstruation stop happening in a female.

The events of a typical menstrual cycle can be summarised as follows:

Days 1–5

- The old lining of the uterus (the endometrium) breaks down and is shed from the body. The loss of this blood and tissue through the vagina is called menstruation (or a period).
- Meiosis occurs in an ovary to produce a new egg. The new egg is surrounded by the Graafian follicle.

Days 6-14

- The developing Graafian follicle produces the hormone **oestrogen**. This hormone causes the endometrium to thicken again.
- Oestrogen also prevents new eggs from developing, so that normally only one Graafian follicle develops during each menstrual cycle.

Day 14

- Ovulation occurs when the Graafian follicle bursts to release the egg from the ovary. The egg passes into the abdomen of the female and on into the funnel of the Fallopian tube. The egg is then moved along the Fallopian tube.
- The egg is normally only available for fertilisation for up to 48 hours after ovulation.

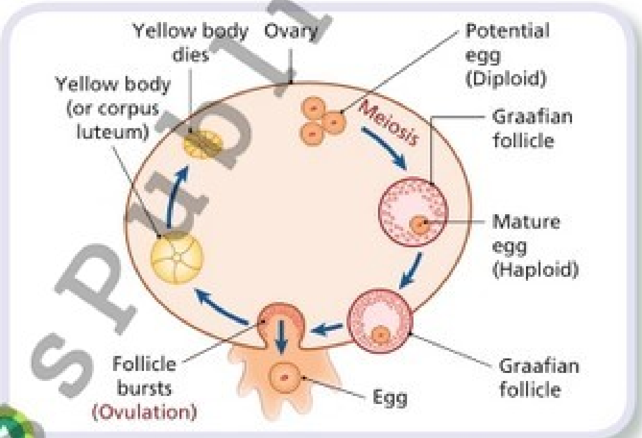


Figure 11.7 *Changes in the ovary each month*

Days 14-28

- The remains of the Graafian follicle develop into the corpus luteum (yellow body).
- The yellow body makes the hormone **progesterone** (and some oestrogen), which causes the endometrium to thicken even more.
- Progesterone also prevents new eggs from forming. The egg that was released will die by day 16 if it is not fertilised.
- If fertilisation has not taken place, the yellow body (corpus luteum) starts to degenerate around day 22. This results in a reduction in progesterone levels, which causes the lining of the uterus to break down on day 28.
- On day 28 the spongy, nutritive lining of the uterus breaks down and is released from the body through the vagina. This bleeding is called menstruation or 'a period'. The bleeding lasts for about 5 days. The onset of bleeding marks the start of a new monthly (menstrual) cycle.

Menstruation is the discharge of the lining of the uterus (the endometrium) and the unfertilised egg.

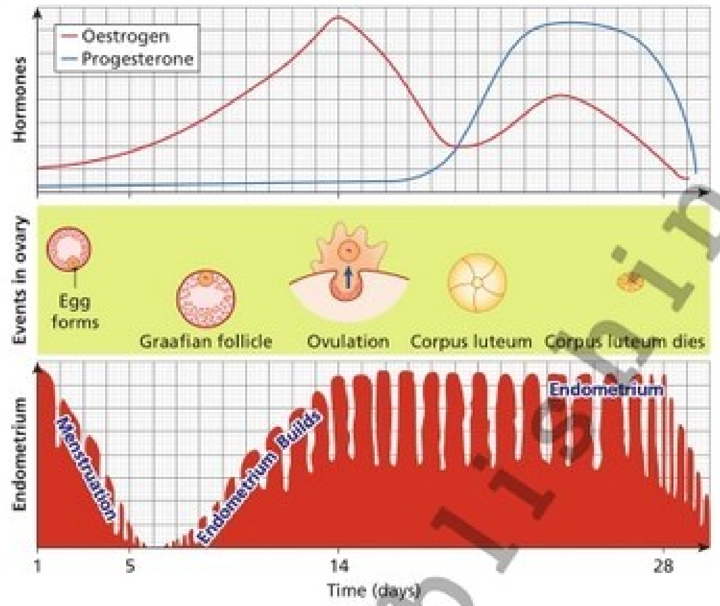


Figure 11.8 *Events during a single menstrual cycle*

Functions of oestrogen and progesterone

- Oestrogen causes the endometrium to thicken in the first half of the cycle.
- Progesterone continues this process in the second 14 days.
- Both hormones prevent (inhibit) eggs from developing. For this reason they are used in contraceptive pills.

The high levels of oestrogen produced at puberty cause the primary female sexual characteristics. These are the growth of the sex organs. The combination of oestrogen and progesterone at puberty causes the secondary female characteristics.

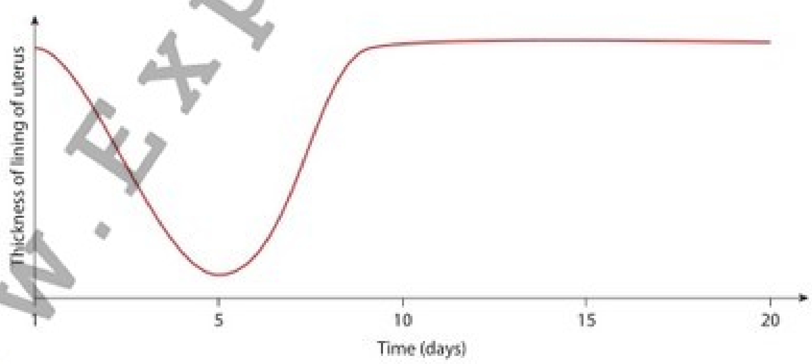


Figure 11.9 *The changes in thickness of the lining of the uterus over part of the menstrual cycle*

Q U2 Understanding

11.10 Figure 11.9 shows what happened to the thickness of the uterus lining over part of a menstrual cycle. Refer to this figure to answer some of the following questions.

(a) What is menstruation?

(b) On what day did menstruation finish?

(c) Why does the lining of the uterus thicken?

(d) On what day would you expect the lining to decrease in thickness again as it did on day 1?

(e) What is ovulation?

(f) On what day in a normal menstrual cycle does ovulation normally occur?

11.11 State one important event that occurs on the following days in a typical cycle:

(i) Day 1 (ii) Day 14 (iii) Day 28.

11.12 Name a hormone associated with:

(i) Days 5 to 14 (ii) Days 14 to 28

11.13 Which hormone(s) is/are associated with primary and secondary female characteristics?

The fertile period

The fertile period is the time during the menstrual cycle when a female is most likely to become pregnant if she has sexual intercourse.

- Sperm can survive in the female reproductive system for five to seven days. They survive for such a long time because the female system nourishes the sperm.
- The egg can stay alive for two days.
- The fertile period is the time in the menstrual cycle when pregnancy is most likely to take place. For a twenty-eight-day cycle this is normally from day 9 to 16.
- The fertile period may be different in every female or in every month because menstrual cycles are not always twenty-eight days long. In some females the fertile period could start before day 9 and last beyond day 16.

Did you know?

There is effectively **no** time within the menstrual cycle during which a female cannot get pregnant if she has sexual intercourse..

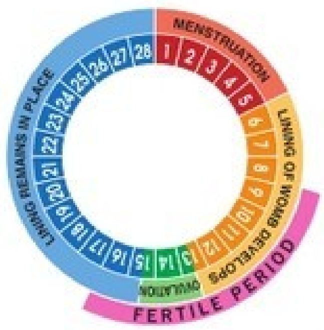


Figure 11.10 *The menstrual cycle and the fertile period*

What is sexual intercourse?

Sexual intercourse (which is also called **copulation**) takes place when the erect penis of the male is placed in the vagina of the female.

The movement of the penis in the vagina causes semen to be released from the penis.

What happens to sperm in the vagina?

Normally, millions of sperm are released into the vagina. The sperm move through the cervix and into the uterus. They then move from the uterus towards a fallopian tube.

After ovulation, the egg is pushed along the fallopian tube by tiny hairs. Many sperm swarm around the egg in the fallopian tube. Soon the head of one of the sperm will enter the egg.

If there is no egg present in the fallopian tube, the sperm die, normally within five days.

Q Understanding U2

11.14 How do the sperm know which ovary has released the egg?

What is fertilisation?

Fertilisation takes place when the nucleus of a sperm joins or fuses with the nucleus of an egg. This takes place in the fallopian tube.

The fertilised egg forms a single cell called a **zygote**.

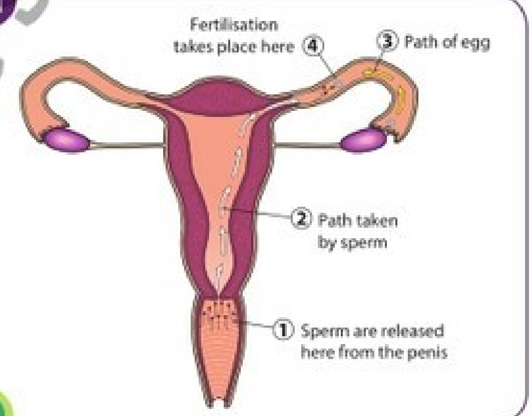


Figure 11.11 *Path of sperm and egg leading to fertilisation*

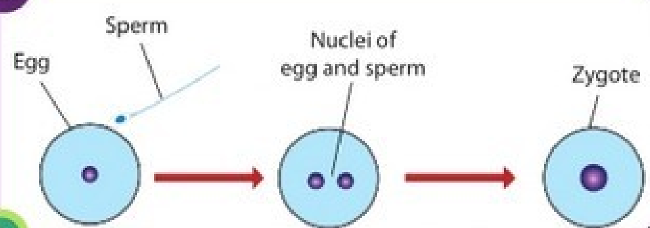


Figure 11.12 *The process of fertilisation*

Understanding U2

11.15 Figure 11.13 represents sexual reproduction in humans.

(a) Name the structures represented by the letters A and C.

(b) Name the cells represented by B and D.

(c) Name the process E.

(d) Name the cell F.

(e) In what part of the female reproductive system does process E normally occur?

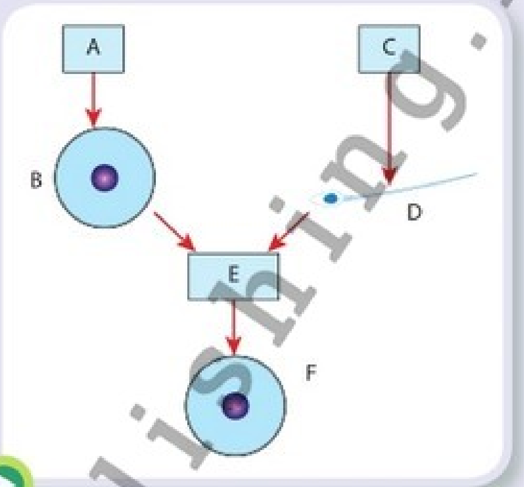


Figure 11.13 Representation of sexual reproduction in humans

Communication C1 Society S2

11.16 How are identical twins formed?

11.17 In what way is the formation of non-identical twins different to the formation of identical twins?

Pregnancy

Once the zygote has formed it goes through many cell divisions to form a ball of cells. These cells then form an embryo. Within a few days of fertilisation, the embryo becomes attached to the lining of the uterus. This attachment is called **implantation**.

Soon after this, the embryo becomes surrounded by a membrane called the **amnion**. This membrane fills up with a liquid called **amniotic fluid**. Amniotic fluid acts as a shock absorber to protect the embryo (or baby) during pregnancy.

After eight weeks, the embryo can be recognised as a human. At this stage, it is called a **foetus**.

Figure 11.14 A three-day-old embryo on the tip of a pin

Pregnancy normally lasts from implantation until birth. A normal pregnancy lasts around forty weeks (about nine months).

Video
Cell division

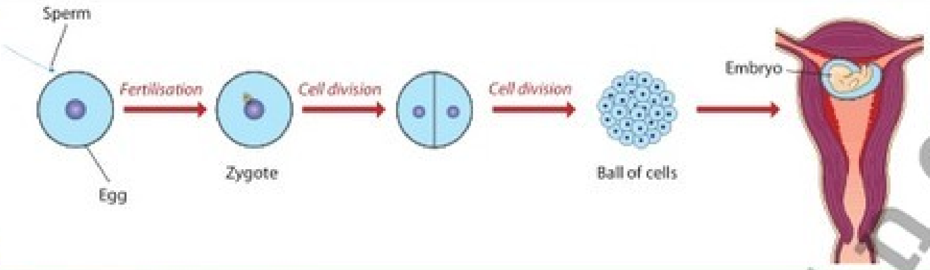


Figure 11.15 *Sexual reproduction*

Figure 11.16 *Embryo at seven weeks*

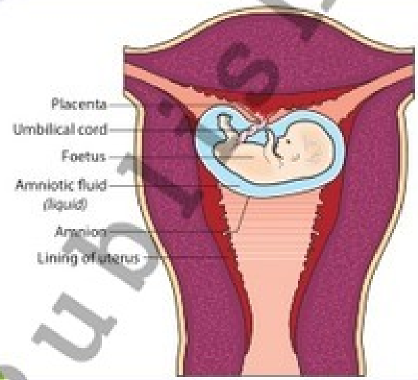


Figure 11.17 *Foetus in uterus*

Q Understanding U2

11.18 Rewrite the following in the order in which they normally take place:

implantation	amnion forms	intercourse	zygote forms.
gamete formation	fertilisation	embryo forms	

(1) ______________ (4) ______________ (6) ______________

(2) ______________ (5) ______________ (7) ______________

(3) ______________

What is the placenta?

A structure called the placenta forms early in pregnancy. The baby's blood passes through the **umbilical cord** to and from the placenta. The placenta attaches to the lining of the uterus. The umbilical cord attaches to the baby at the navel (belly button).

The functions of the placenta

The function of the placenta is to allow materials to pass between the mother and the baby in the uterus:

- Food and oxygen pass from the mother's blood into the baby's blood.
- Waste products (such as carbon dioxide and salts) pass from the baby to the mother.
- Along with these useful functions the placenta also allows harmful substances, e.g. alcohol, smoke and drugs, to pass into the baby.

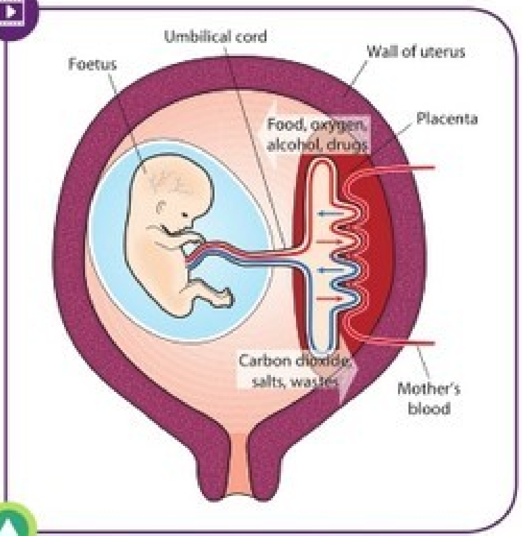


Figure 11.18 *Essential and harmful substances can pass between mother and baby*

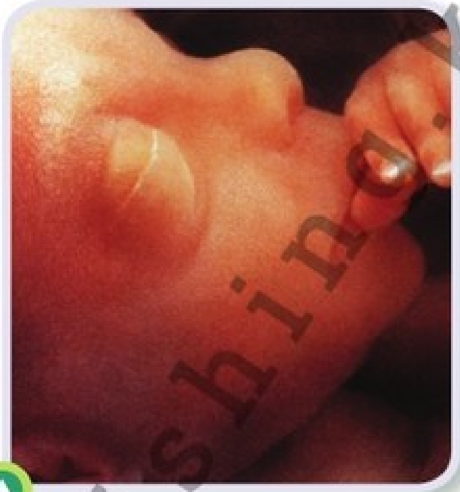


Figure 11.19 *Foetus aged twelve weeks*

Embryonic development

Embryonic development up to 8 weeks

The heart forms and starts to beat in the embryo in the first 4 weeks after fertilisation. The brain develops and the umbilical cord forms. By the fifth week, the internal organs and the limbs have started to form. By the sixth week, the eyes are visible and the mouth, nose and ears are forming.

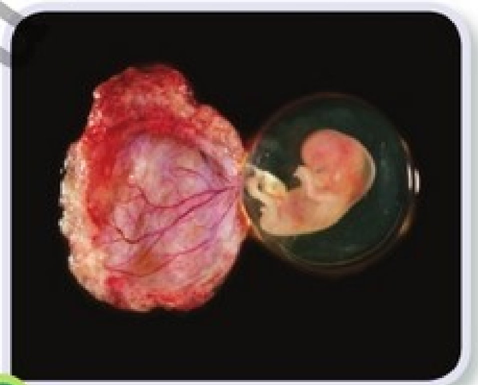


Figure 11.20 *An 8-week-old foetus in its sack of amniotic fluid (right) with the placenta (pink, left)*

By the eighth week, the tail has diminished. The face is human and the major body organs are formed. Ovaries or testes are distinguishable. Bone is beginning to replace cartilage. At this stage the embryo is recognisably human and is called a **foetus**.

Embryonic development up to 3 weeks

From the eighth week onwards the foetus grows and refines the structures already formed. During the remainder of the pregnancy the foetus does not produce any more organs. The last 7 months of the pregnancy involve the growth of the foetus (along with the enlargement of the mother's uterus and abdomen).

Figure 11.21 *A foetus (12 weeks old) and umbilical cord*

By the end of the third month (12 weeks) the eyes are low in the face and are widely spaced. Bones grow to replace cartilage (called ossification). The nerves and muscles become coordinated, allowing the arms and legs to move. The foetus sucks its thumb, kicks and forms milk teeth beneath the gums.

Although it is exchanging gases and excreting waste through the placenta, the foetus is seen to take amniotic fluid in and out of its mouth. It even urinates and releases faeces into the amniotic fluid. At this stage the external sex organs have formed and the gender of the foetus can be seen in scans.

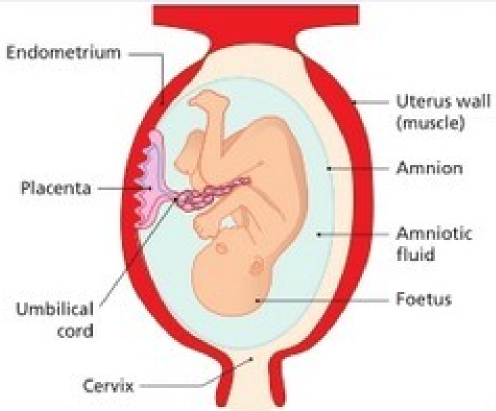


Figure 11.22 *Foetus in the uterus*

Did you know?

The embryo and foetus are particularly sensitive to radiation and drugs (including alcohol and smoke) in the first 3 months of development. This is due to the formation of tissues, organs and systems in this time.

Gestation

In humans gestation lasts 266 days (38 weeks, or 9 months) from the date of fertilisation.

Gestation is the length of time spent in the uterus from fertilisation to birth.

11.19 Figure 11.23 represents the links between a mother and her foetus during pregnancy.

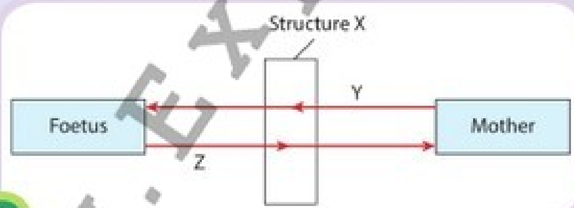


Figure 11.23 *Representation of childbirth*

(a) Name the structure shown as X.
(b) Name a gas that passes in the direction of arrow Y.
(c) Why does the foetus need the gas named in part (b)?
(d) Name a gas that passes in the direction of the arrow Z.
(e) From what organ does the gas named in part (d) pass out of the mother's body?
(f) Why can a foetus in the uterus not breathe through its mouth?

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11.20 What is the importance of the placenta during human development in the womb?
11.21 From what tissues is the placenta formed?

Contraception

Medical issues

Contraception is the deliberate use of artificial methods to prevent pregnancy.

Some couples want to control the number of children they have or to control how soon after each other their children are born. Others wish to have sexual intercourse without the female becoming pregnant.

These couples may use contraception as a method of birth control, or family planning, in order to prevent unwanted pregnancies.

There are two main types of contraception:

- Preventing fertilisation
- Preventing implantation.

Preventing fertilisation

Natural methods Natural methods of preventing the sperm from reaching the egg are based around avoiding intercourse during the female's fertile period. These methods aim to predict or detect the time of ovulation.

Artificial methods Artificial methods of contraception include stopping the female from producing eggs. This can be achieved by the female taking the contraceptive pill.

Other artificial methods involve preventing the sperm from reaching the egg. These methods include:

- The use of a condom, which covers the top of the penis
- A cap, which covers the cervix
- Chemical creams or foams, which kill sperm
- Medical operations in which the sperm ducts or fallopian tubes are cut and sealed.

Preventing implantation

- Some pills prevent pregnancy by stopping the embryo from attaching (or implanting) in the uterus.
- A T-shaped device inserted by a doctor in the uterus also acts in this way.

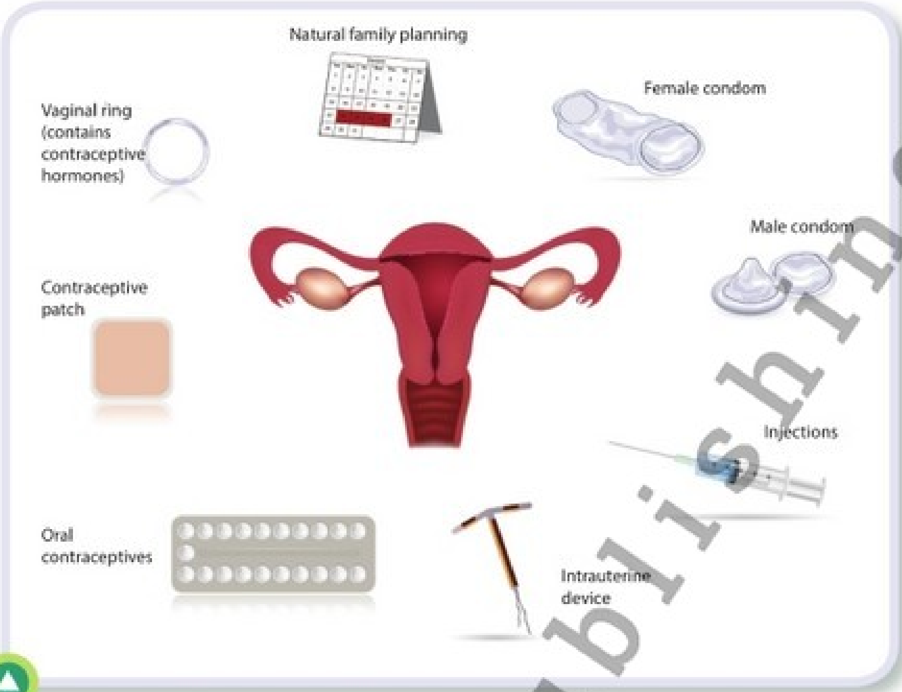

Figure 11.24 *Contraceptive methods*

Q U2 Understanding

11.22 What are two of the main purposes of contraception?

11.23 Contraception can aim to prevent one of two things? Name them.

Sexually Transmitted Infections

Sexually Transmitted Infections [STIs] are infections passed from person to person through having sexual intercourse or from oral sex.

It is not usual for such infections to be transmitted through mouth to mouth kissing, sitting on a toilet seat or sharing a drinking cup. Both men and women can be affected by STIs and in some cases there may be no obvious symptoms.

General signs of STI's, however, include:

- Rashes, sores and itchiness around the genital area
- Unusual discharge from the genital area
- A burning sensation when urinating or having intercourse.

STI's can be avoided by not having sex or using a condom. The pill and many other methods of contraception do not protect against STIs.

Gonorrhea

Around half of women and one in ten men infected with Gonorrhea will show no obvious signs or symptoms.

Common symptoms

- Unusual watery vaginal discharge – yellow or green in appearance
- Pain when urinating
- Pain in the lower abdominal area
- Bleeding between periods
- Pain in the testicles

Long-term effects if untreated

- Pain in the pelvic area
- Can lead to blocked fallopian tubes or ectopic pregnancy.

Syphilis

The symptoms of syphilis vary according to the stage [primary or secondary] the infection has reached.

Common symptoms

Primary stage:

- sores appear where the bacteria entered the body
- other sores can appear on other areas body, most commonly for women in the genital area and on the cervix and for men in the genital area and on the penis

Secondary stage:

- an infectious rash which appears all over the body or in patches, mostly on the palms of hands and soles of feet
- symptoms resembling flu: tiredness, loss of appetite and swollen glands

Long-term effects if untreated

May cause serious damage to the heart, brain, eyes and other internal organs.

AIDS

Cause

AIDS is a disorder in which the person cannot make antibodies. This is due to infection with HIV.

Transmission

HIV enters the body in fluids such as blood and semen. The most common methods of transmission are sexual intercourse, infected blood products and shared needles. It can also be passed from mother to child across the placenta or in breast milk.

Figure 11.25 *HIV (pink) emerging from the membrane of an infected white blood cell*

HIV is not contracted by touching, embracing, kissing where saliva is not exchanged, sharing utensils such as cups or from toilet seats.

Effects

Once the virus enters the body, it may enter a white blood cell and either remain dormant and produce no effects, or disable the white blood cell.

Control and Prevention

At present there is no cure or vaccine for AIDS. However, recent discoveries in medication can reduce the complications and prolong life for those with AIDS.

Prevention is vital in controlling the spread of AIDS. The main methods of prevention are:

- Avoid sexual intercourse
- Confine sexual intercourse to one faithful partner
- Use a condom during intercourse
- Do not use shared needles, toothbrushes or razors
- Avoid contact with blood and body fluids (i.e. wear gloves when treating another person's wounds)
- Those with AIDS or who have tested positive for HIV antibodies should not donate blood, semen or body organs.

Q Understanding U2

11.24 The chances of catching a sexually transmitted infection are greatly reduced if ... .
Put a tick (✓) or cross (✗).

(a) the man uses a condom ________
(b) the couple keep themselves clean ________
(c) the woman is on 'the pill' ________
(d) the partners are 'faithful' to each other ________

11.25 True or False?

(a) Obvious symptoms of gonorrhoea are less common in men. ________
(b) Gonorrhoea can prevent successful pregnancy. ________
(c) You might not know you had an STI unless the doctor or partner told you. ________
(d) Sometimes the symptoms of STIs go away, but the person can still be infected. ________
(e) The symptoms of primary and secondary stage syphilis are very different. ________
(f) Once you've had an STI you cannot catch it again. ________
(g) STIs are not normally transmitted mouth to mouth. ________

11.26 (a) What does HIV attack in the blood?
(b) What is the effect of HIV attacking this part of the blood?

11.27 Apart from sexual intercourse, name two other ways HIV can be transmitted.

11.28 Which method of contraception is effective in preventing the spread of HIV?

Activity 11.1

Question

How can STI's spread harmful microbes without either partner knowing?

Equipment needed

A test tube filled with water for every member of the class except one

A test tube filled with dilute sodium hydroxide for one (unknowing) member of class

An indicator solution for teacher e.g. phenolphthalein

Pipette for each student

Safety

- Care should be taken not to spill water to avoid someone slipping.

Conducting the activity

1. The solution in the test tubes represents bodily fluid. One test tube is different [infected].
2. Each student should mix the solution in their test tube with the solution in the test tubes of five other students.
3. Use the pipette to transfer solution and stir with the pipette.
4. Return to your seat when done.
5. The teacher will now add an indicator solution to each test tube.

Figure 11.26 *Testing samples*

11.29 What percentage of the test tubes were 'infected' [turned pink]?

11.30 What conclusions can be drawn about the spread of STIs from this?

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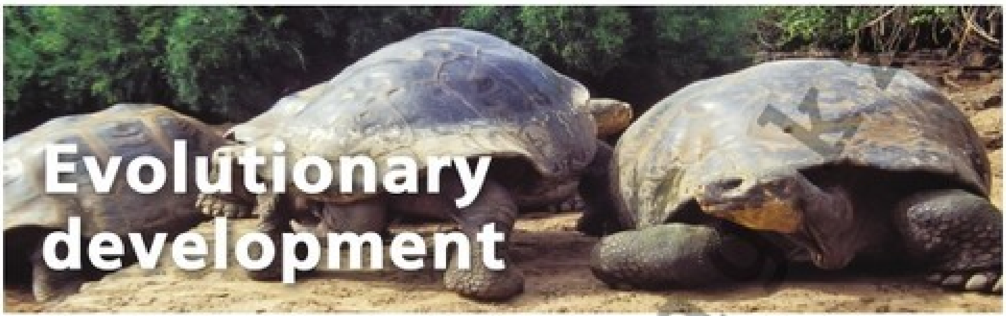
MODULE 12



Evolutionary development

Learning outcomes

At the end of this module you will be able to:

- Understand the works of C. Linnaeus and J.B Lamarck 9.2.5.1
- Explain the role of Darwin's theories in the teaching of evolution 9.2.5.2
- Describe the driving forces of evolution 9.2.5.3
- Describe the role of natural selection in the adaptation of organisms 9.2.5.4
- Understand the definition and nature of species 9.2.5.5
- Explain the causes of speciation 9.2.5.7

Keywords

✔ biodiversity ✔ fossil ✔ extinct ✔ species ✔ natural selection ✔ mutation ✔ evolution ✔ adaptation ✔ taxonomy ✔ classification ✔ speciation

Introduction

There is a rich **biodiversity** on Earth. This means there are many different types of living things. Humans have often wondered where all these types of life came from. Were they always present on Earth? Will they always be here?

Figure 12.1 *A fossil*

Evidence from **fossils** (which are the remains of very ancient living things) tells us that some types of living things have been wiped out.

But there are no very old remains of some modern living things.

This suggests that some living things disappear (become **extinct**) and new types of living things emerge, i.e. that life on Earth changes.

Communicating C2

12.1 Name two types of living things that were on Earth but are no longer present (i.e. they are now extinct).

12.2 Name two extinct animal species from Kazakhstan.

12.3 Research how long ago modern humans are thought to have arisen.

Evolutionary scientists before Darwin

Carl Linnaeus

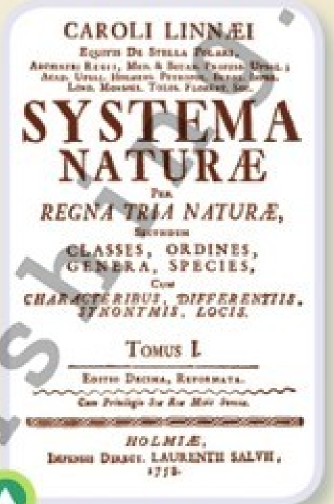

CAROLI LINNÆI
SYSTEMA NATURÆ
PER
REGNA TRIA NATURÆ,
SECUNDUM
CLASSES, ORDINES, GENERA, SPECIES,
CUM
CHARACTERIBUS, DIFFERENTIIS, SYNONYMIS, LOCIS.
TOMUS I.
EDITIO DECIMA, REFORMATA.
HOLMIÆ,
IMPENSIS DIRECT. LAURENTII SALVII,
1758.

Figure 12.2 *Carl Linnaeus*

Carl Linnaeus, born in 1707, was a Swedish lecturer in botany who is best known for creating the system of naming animals and plants that is still used today. He is known as the 'father of taxonomy' because of his classification system which divides animals and plants into hierarchies and gives each an individual name. The *binomial system* is a system in which each animal or plant is identified first by its genus name and then by its specific species name – both names are given in Latin. Thus, humans are identified by *Homo* our genus name, which modern humans share with closely related species like Neanderthals, and our species name: *sapiens*. Thus, in the binomial system we are called *Homo sapiens*, whereas Neanderthals are identified as *Homo neanderthalenis*. In his lifetime, Linnaeus identified and classified over 12,000 species in this way and his work is recorded in his publications such as *Species plantarum* (1753) and *Systema naturae* (1758) which are still referred to today.

Scientists continue to identify new species each year and estimate that many species will disappear before they are discovered. To-date, only around 2 million of the estimated 8 million species on earth have been identified.

Jean Baptiste Lamarck

Figure 12.3 *Jean Baptiste Lamarck*

Although Charles Darwin was the most well-known scientist working on theories of evolution in the nineteenth century, there were others working on related ideas before him. Jean Baptiste Lamarck, who was born in 1744, based some of his ideas on similar evidence for evolution used by Darwin: fossil records and the identification of vestigial structures. He was one of the first scientists to investigate the idea that organisms adapted to changes in environment.

There were four main ideas in Lamarck's theory of the development of organisms over time that Darwin's theories would eventually explain differently.

- Lamarck argued that organisms evolved as they were required to make greater or lesser use of an organ in their environment. So, for example, giraffes that were required to stretch for higher leaves would develop longer necks in their lifetime. Similarly, if an environment required less use of an organ it would shrink through disuse. (Compare this to Darwin's notion of variation in the next section.)

- He also argued that organisms would transmit these acquired characteristics to their offspring. (Compare this to Darwin's idea of inheritance in the next section.)
- Lamarck, based on the two ideas above, further argued that all life was involved in a process of developing from a simpler to a more complex form, which set him against those who held strong religious views on creation at the time. (Compare this idea to Darwin's notion of differential survival.)
- Finally, given the above, his theory did not embrace the idea of extinction. (Compare this to Darwin's ideas of survival of the fittest and extinction.)

Understanding U2

12.4 Use the internet to research and find the binomial classification of these animals and plants native to Kazakhstan.

Figure 12.4

12.5 What percentage of the species on earth have been identified according to current estimates?

12.6 Identify three ways in which Lamarck's and Darwin's ideas of variation are different.

12.7 Give two examples in animals of vestigial structures.

Charles Darwin

There are a number of suggestions as to how the variety of living things may have arisen However, the most widely accepted explanation based on evidence is the theory of evolution **by natural selection**. This theory was first put forward by Charles Darwin (in association with Alfred Russel Wallace) in 1859.

Understanding U2 Society S1

12.8 Write a short biography of Charles Darwin. Include a couple of sentences on each of the following:

- His childhood
- His studies
- The famous ship journey he took
- The islands off South America that he visited
- His health.

Figure 12.5 *Charles Darwin, aged 40*

Animated Scientist Biography

Watch an *Exploring Science* animation to find out more about Darwin and his theories.

Evolution by natural selection

Evolution is the process by which different kinds of living things develop from earlier forms during the history of Earth. Before we look at Darwin's theory of evolution, we need to look at a couple of important terms: species and mutation.

Species

A species is a group of living things that can reproduce together to produce offspring which themselves can reproduce. For example, humans are a species; dogs are a species; so are daffodils, cabbages, cats and rabbits.

A cat and a rabbit cannot reproduce together and so you know they are different species.

The members of a species have similar genes and so they have many characteristics in common. However, the members of a species may show variations that are inherited because they are caused by changed genes.

Variation and Mutation

We know that characteristics of an organism are controlled by genes and that genes are passed from parents to their offspring during reproduction.

Changes in genes are called **mutations**. The genes in the members of a species are different due to mutations and due to events that occur in sexual reproduction.

Figure 12.6 *Most humans have five toes: if the gene is altered the person may have extra toes*

For example, while humans are similar in having two eyes, they show variations in eye shape and eye colour. These variations are passed on to the next generation because they are inherited or gene-controlled variations.

Q U2 C2 Understanding Communicating

12.9 A cocker spaniel and a poodle can breed together to produce a cockapoo (a 'designer' dog). A poodle and a cat cannot breed together. What does this tell you about:

(a) Cocker spaniels and poodles?

(b) Poodles and cats?

12.10 Name two other 'designer' dogs that humans have developed.

Theory of evolution

Darwin's theory of evolution is based on three things he noticed (called **observations**) and from these he made two predictions (called conclusions).

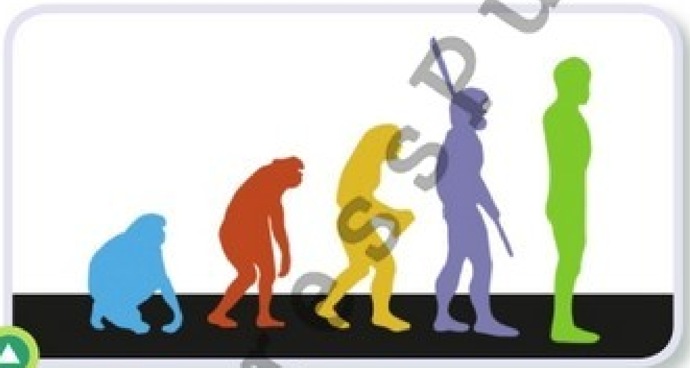


Figure 12.7 *The ascent of mankind*

Darwin's theory of evolution

Observation 1

Living things produce huge numbers of offspring.

For example, a tree may produce thousands of seeds, or a fly may lay thousands of eggs.

Figure 12.8 *A tree can produce thousands of seeds*

Observation 2

The environment (or surroundings) can support only a limited number of living things.

For example, there is not enough space for all the seeds to grow or there may not be enough food for all the flies to live. Observations 1 and 2 lead to conclusion 1 below.

Conclusion 1

If more living things are produced than can survive, they will struggle to get scarce resources. Darwin called this the **struggle for existence**. It is now often called **competition for scarce resources**.

For example, seeds may struggle to get enough space and light to grow; the flies may struggle for food and water.

Observation 3

Darwin studied animals such as pet pigeons and cows on farms. Also, on his voyage around the world he noticed that species showed **inherited variations**. He realised that species could have differences that they would pass on to their offspring. Observation 3 leads to conclusion 2 below.

Figure 12.9 *Variations in pet pigeons*

Conclusion 2

Suitable variations

Darwin realised that some of the variations would help the living thing to survive better.

For example, if some seeds produced longer or bigger roots, those seeds would grow better; if the wings of some flies developed more quickly, they could fly away to get more food.

An **adaptation** is a characteristic that helps an organism to survive and reproduce. Living things that are best suited or adapted to their environment survive more easily. If they survive, they have a better chance of reproducing and so passing on their genes (and their suitable variations) to the following generations.

Unsuitable variations

However, some variations do not help living things to survive better. These living things are not adapted to their environment and so may die. This means they do not pass their genes (and unsuited variations) on to the next generations.

Natural selection

The way in which organisms whose variations are suited to their environment survive and reproduce is called **natural selection**. Nature selects those organisms that are best suited (or adapted) to their environment.

Table 12.1 Summary of the theory of evolution by natural selection

Observation	Conclusion
1. Living things produce large numbers of offspring.	1. Living things struggle to survive.
2. The environment can support only a limited number of living things.	
3. The members of a species have inherited (genetic) variations.	2. Nature selects the organisms with variations that help them to live in the environment. These organisms survive and reproduce to pass on their genes and their variations.

Communicating C1

12.11 Use the Internet to research three major adaptations that have allowed humans to survive in their environment.

Did you know?

Some people believe that Darwin's theory of evolution was the greatest single idea that any human ever had.

Understanding U2 Communicating C1

12.12 Read about the changes in peppered moths and then answer the questions that follow.

> Before the Industrial Revolution (which began around 1780) most of the peppered moths in the north of England were light-coloured. This meant they were hard to see on the light-coloured barks of the lichen (a fungus combined with an algae) covered trees. During the Industrial Revolution, for the first time a huge amount of pollution was emitted. This killed off most of the lichens. The barks of the bare trees were now dark-coloured. By the 1860s most of the moths were dark-coloured.
>
> After more recent pollution control measures were put in place, the lichens grew back on the barks of the trees.

In summary:

Timescale	Moth colour
Before 1780	Light
1780 to 1860	Some light, some dark
After 1860	Mostly dark
Now	?

Figure 12.10 *The light-coloured moth is hard to see on the lichen-covered tree*

Figure 12.11 *The light-coloured moth is very visible on the tree with no lichens*

Now answer questions (a-e), based on the information above.

(a) What was the evolutionary change that took place in the moths between 1780 and 1860?

(b) What was the cause of this change?

(c) What might have happened to any light-coloured moths in the late 1800s?

(d) Predict the colour of the moths in recent years. Give a reason for your answer.

(e) Explain how the changes in the moths provide evidence for the theory of evolution by natural selection.

Evolution and the diversity of life

Evolution by natural selection has given rise to all of the different types of living things on Earth today. This happens when a single species evolves to form two (or more) different species. These two species then evolve to form even more species. In time huge numbers of species develop from the original species.

Species and Speciation

Species is a group of organisms which share a genetic heritage and can interbreed to create offspring that are also fertile.

There are a number of common features that represent defining criteria for a species. None of the criteria is absolute but taken together they provide evidence for a species. The criteria are presented in Table 12.2.

Table 12.2

Criteria	Meaning
Morphological	relating to features of external and internal structures
Genetic	specificity of the number and structure of chromosomes
Physiological	similarity of life processes and ability to interbreed to give fertile offspring
Biochemical	ability to synthesize specific proteins, the chemical composition of cells, etc.
Ecological	relationships with other species and habitat
Geographical	specific area of the species distribution
Ethological	features of behavior

When referring to the structure of a species we typically refer to sub-species and populations within it.

species ⟶ sub-species ⟶ population

A **sub-species** is a subdivision within a species consisting of individuals that share certain distinct traits. It is usually linked to geographical distribution and isolation within a species.

A **population** is a collection of individuals of a given species that occupy a certain area of territory within the range of a species. Members of a population breed among themselves and are partially or completely isolated from other populations. Population is the elementary unit of evolution, because it is at the level of population that evolutionary development occurs through the struggle for existence, natural selection and the emergence of mutations.

Speciation is the evolutionary process by which populations evolve to become distinct species not able to reproduce fertile offspring through interbreeding.

Geographic isolation is considered to be the most common cause of speciation events, where one species divides into two new ones. For various reasons, populations become isolated by physical barriers such as bodies of water or mountain ranges. The new environmental factors prevent the gene flow between the two populations and conditions in their respective environments introduce new selective pressures.

As an example of how new species form, consider the finches on the Galapagos Islands. Darwin studied these birds on his voyage on the Beagle. He noticed that the finches on the different islands were similar in many ways, but they showed differences in many features, especially their beak shapes.

Did you know?

Galapago is the Spanish word for tortoise.

Figure 12.12 *Finches*

Darwin concluded that the original finches must have got to the islands from the mainland of South America. On each island the conditions were different. This meant that:

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- Where hard seeds were available, those birds with short, strong beaks were better-suited to feeding.
- If there were many insects, birds with sharper and more slender beaks were better-suited to feeding.
- On an island with many cactus plants, finches with long, pointed beaks were better-suited to getting cactus seeds.

On each island, those finches that had a beak that was not well-suited to feeding on that island got less food. As a result they died out. Those birds with the beaks that were most suited to getting the available food survived. When they reproduced they passed on their beak shape to the next generation.

Darwin concluded that from a single species of finch that flew (or was blown) in from the mainland, many different types of finch evolved. The new beak shapes arose when genes became altered or mutated.

This type of process has happened all over the world to different living things over very long periods of time to produce the wide range of living things found on Earth today.

Did you know?

Over 99% of all species that ever existed have become extinct.

Communicating C1

12.13 Research the following:

(a) What country is nearest the Galapagos islands?

(b) How far is this country from the Galapagos islands?

(c) Suggest why the finches did not evolve into as many species in their country of origin.

Understanding U2 Communicating C1

12.14 Read this information on the evolution of Galapagos tortoises and then answer the questions that follow.

> On one of the Galapagos Islands Darwin noticed that most of the giant tortoises had shells with low neck collars.
>
> However, he noticed a few tortoises with higher neck collars. All the tortoises fed on plants.
>
> Darwin predicted that in the future (possibly as a result of a long period with no rain) the tortoises with high neck collars would survive better. Over the last hundred or more years the tortoises with low neck collars have become extinct on that island, but many of those with high neck collars have survived.

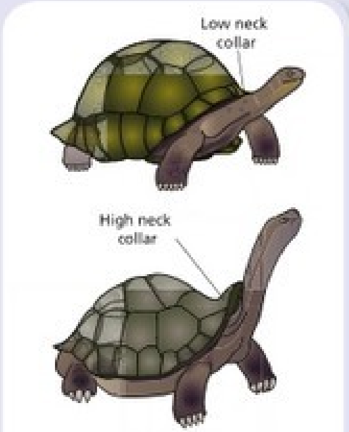

Figure 12.13 *Two tortoises*

(a) How would a lack of rain affect the number of plants on the island?
(b) What advantage might a high neck collar provide for a tortoise in drier conditions?
(c) Apply your knowledge of the theory of evolution to explain why tortoises with high neck collars survived and those with low neck collars died out.

Q C2 Communicating

12.15 'Living things that do not reproduce are an evolutionary dead end.'
Explain why this is the case.

Q C2 Communicating

12.16 Arman and Assel wanted their future children to be big and strong. So they went to the gym every day for a year and developed really big, strong muscles so that their children would inherit big, strong muscles.
Discuss this with your partner. Do you think their children would have big, strong muscles as a result of their parents' working out in the gym? Explain your answer.

Timeline for biodiversity

The planet Earth formed about 4.6 billion years ago. The first forms of life on Earth appeared about 3.8 billion years ago. They were tiny, single-celled bacteria that lived in the sea. For about 90% of Earth's history, living things were found only in the sea or in watery environments.

About 500 million years ago the first plants and fungi grew on land. It is only since then that all the modern life forms have developed. For example, dinosaurs first appeared about 220 million years ago, birds 140 million years ago, and humans only 200 000 years ago. The examples given show that evolution normally takes place over long periods of time.

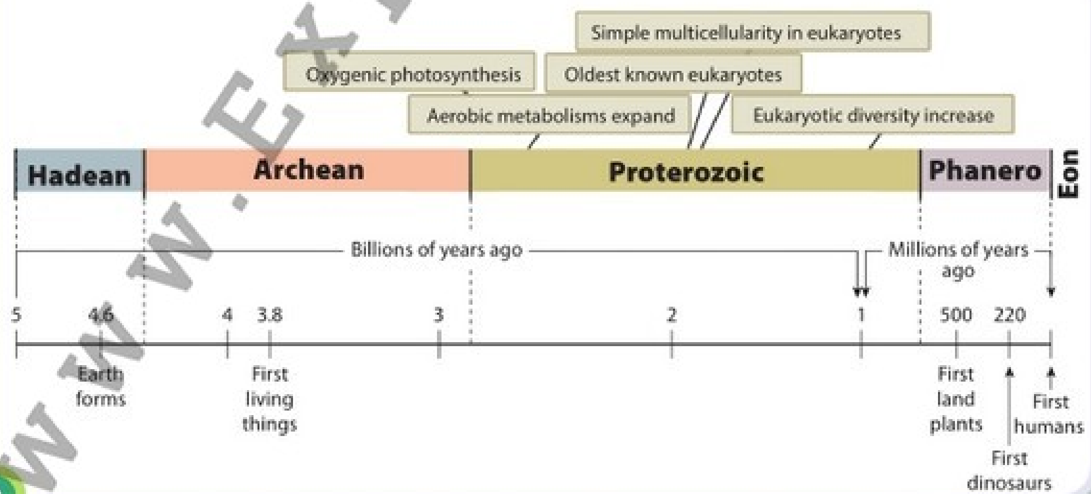

Figure 12.14 *A simple timeline for evolution*

Glossary

A

abiotic factors Non-living factors.

acoustics Relating to sound or the sense of hearing.

acquired variations They are not inherited but are learned or developed during life.

active site The part of an enzyme that combines with the substrate.

active transport Energy (in the form of ATP) is used to move molecules, often against a concentration gradient, i.e. from low concentrations to high concentrations.

adaptation Any alteration that improves an organism's chances of survival and reproduction.

adhesion Occurs when different molecules stick together.

aerobic respiration The controlled release of energy from food using oxygen.

alleles Different (or alternative) forms of the same gene.

alveolus A tiny air sac in the lungs.

amnion A membrane that surrounds the baby in the womb.

amniotic fluid Liquid that surrounds (and protects) the baby in the womb.

anaerobic respiration The controlled release of energy from food without the use of oxygen.

antagonistic pair Two muscles that have opposite effects to each other.

antibiotics Chemicals produced by micro-organisms that stop the growth of, or kill, other micro-organisms without damaging human tissue.

antibody A protein produced by white blood cells (called lymphocytes) in response to a specific antigen.

asexual reproduction Involves only one parent.

autotrophic (organism) One that makes its own food.

axon The long threadlike part of a nerve cell along which impulses are conducted from the cell body to other cells.

B

batch culture The growth of cells in a sealed container (or bioreactor) over a short period of time and under ideal conditions until all the nutrients are used up.

biodiversity All living organisms within an ecosystem; this includes plants, animals and micro-organisms.

biogenesis Living things arise from other living things of the same type. This is also called **continuity of life**.

biomass The total quantity or weight of organisms in a given area or volume.

biomolecules Chemicals that are made inside a living thing.

bioprocessing The use of enzyme-controlled reactions to produce a product.

bioreactor A vessel or container in which living cells or their products are used to make a product.

biosphere That part of the planet containing living organisms.

biotechnology The use of living things or their components (especially cells and enzymes) to manufacture useful products or to carry out useful reactions.

birth When the baby comes out of (emerges from) the uterus of the mother.

birth control Methods taken to limit the number of children that are born.

blood pressure The force exerted by the blood against the walls of the blood vessels (mainly the arteries).

bud A potential growth point that may develop into a shoot, a leaf or a flower.

bulb A modified bud.

C

cancer A group of disorders in which certain cells lose their ability to control both the rate of mitosis and the number of times mitosis takes place.

carnivores Animals that feed mainly on animals. Examples are dogs, cats and ladybirds.

carrying capacity The number of people, animals or crops which a region can support without environmental degradation.

carpels The female parts of the flower.

catabolic reactions Release of energy when a complex molecule is broken down to a simpler form.

catalyst A substance that speeds up a reaction, without itself being used up in the reaction.

cell continuity All cells develop from pre-existing cells.

cell cycle The changes that take place in a cell during the period between one cell division and the next.

cell wall Found outside the cell membrane in plant cells.

cellular energy The energy stored in the bonds of biomolecules.

centromere The point at which the chromosomes are attached in a double-stranded chromosome.

cervix The neck or opening into the uterus (or womb).

characteristics Traits or features that are inherited genetically.

chlorophyll The green pigment found in plants (acts as a catalyst for photosynthesis).

chloroplasts Contain the green pigment called chlorophyll.

chromatin The name given to chromosomes when they are elongated and not dividing.

chromosomes Coiled threads of DNA (which forms genes) and protein that become visible in the nucleus at cell division.

chromosome mutation A large change in the structure or number of one or more chromosomes.

classification Placing objects into groups based on similar characteristics.

climatic factors Weather conditions such as temperature, air pressure and precipitation averaged over a series of years.

cloning The production of identical copies of the bacterium (containing the target gene).

closed circulatory system Blood remains in a continuous system of blood vessels.

codominance Neither allele is dominant or recessive with respect to the other. Both alleles are equally expressed in the heterozygous genotype to produce an intermediate phenotype.

codon (or **triplet**) A sequence of three bases in DNA (or RNA) that act as a code for an amino acid.

cohesion The sticking of similar molecules to each other.

community All the different populations in an area.

competition Occurs when organisms actively struggle for a resource that is in short supply.

complete metamorphosis An insect life cycle where each stage of the cycle is physically different to the previous stage: Egg - Larva - Pupa - Adult.

concentration gradient A gradual change in the concentration of solutes present in a solution between two regions.

conclusion A summary of the results of an experiment.

contraception The use of artificial methods to prevent pregnancy.

consumers Organisms that take in food from another organism.

continuity of life Living things arise from other living things of the same type. This is also called **biogenesis**.

continuous flow (food processing) The growth of cells in an open container (or bioreactor), where nutrients are added and the end products are removed all the time at a rate that maintains the volume of liquid and the number of cells.

contraction The process in which a muscle becomes or is made shorter and tighter.

contraception The deliberate prevention of fertilisation or pregnancy.

control Used to provide a comparison (or standard) against which the actual experiment can be judged.

copulation The act of sexual intercourse.

cotyledon A seed leaf.

crossbreeding Mating animals or plants from two different breeds, varieties or species.

cytoplasm The liquid part of the cell that surrounds the nucleus.

D

data The measurements, observations or information gathered from experiments.

decode Convert into a different or usable form.

decomposers Organisms that feed on dead organic matter.

denatured enzyme One that has lost its shape and can no longer carry out its function.

dendrite A short branched extension of a nerve cell along which impulses received from other cells at synapses are transmitted to the cell body.

denitrification The conversion of nitrates to nitrogen gas.

depolarisation To reduce or remove the polarisation of (the membrane).

detritus feeders Organisms that feed on small pieces of dead organic matter.

diffusion The spreading out of molecules from a region of high concentration to a region of low concentration.

digestion The breakdown of food.

dihybrid cross A cross between two different genes that differ in two observed traits.

diploid cell One that has two sets of chromosomes, i.e. it has two of each type of chromosome in the nucleus.

dispersal The transfer of a seed or fruit away from the parent plant.

diuretic (chiefly of drugs) Causing increased passing of urine.

diversity A variety or range.

DNA profile (also called a **DNA** or **genetic fingerprint**) A method of making a unique pattern of bands from the DNA of a person, which can then be used to compare with the DNA profile of another person.

dominant The allele that prevents the recessive allele from being expressed.

dormancy A resting period when seeds undergo no growth and have reduced cell activity or metabolism.

E

echo A sound or sounds caused by the reflection of sound waves from a surface back to the listener.

ecological niche (of an organism) The functional role it plays in the community.

ecology The study of the interactions between living things (organisms) and between organisms and their environment.

ecosystem A group of clearly distinguished organisms that interact with their environment as a unit.

ectotherms Gain or lose heat from or to their external environment.

ectoparasite An external parasitic organism that lives on the skin or exterior of the body.

ejaculation The release of semen from the penis.

endocrine gland A ductless gland that produces hormones, which are released directly into the bloodstream.

endoparasite A parasitic organism that lives in the internal organs of an animal.

endospermic seed Contains some endosperm when fully formed.

endotherms Generate their own heat from metabolic reactions.

enzymes Proteins that speed up a reaction without being used up in the reaction.

enzyme specificity Each enzyme will react with only one particular substrate.

eukaryotic cells Have a nucleus and cell organelles, all of which are enclosed by membranes.

evolution The way in which living things change genetically to produce new forms of life over long periods of time.

excretion The removal of waste products of metabolism from the body.

exocrine glands Produce and secrete substances by way of a duct (examples include sweat, salivary, mammary and sebaceous).

experiment A test for a hypothesis.

expression The formation of the product by the organism with the recombinant DNA.

extensor A muscle whose contraction extends or straightens a limb or other part of the body.

extinct (of a species, family or other larger group) Having no living members.

exponential Growth whose rate becomes ever more rapid in proportion to the growing total number or size.

F

fallopian tube A structure linking the ovary to the uterus in females.

fauna All the animals in an ecosystem.

fermentation Another name for anaerobic respiration.

fertile period The time in the menstrual cycle when fertilisation is most likely to occur.

fertilisation The union of the male and female gametes to form a diploid zygote.

filtrate A liquid which has passed through a filter.

filtration Water and small molecules pass (under high pressure) from the blood into the nephron.

flexor A muscle whose contraction bends a limb or other part of the body.

flora All the plants in an ecosystem.

food chain (grazing food chain) A sequence of organisms in which each one is eaten by the next member in the chain.

food web Two or more interlinked food chains.

forensic medicine The way in which medical knowledge is used in legal situations.

fossil The remains of something that lived a long time ago (or some indication of something that lived a long time ago).

fossil fuel A natural fuel, coal, oil, peat and gas, that was formed over millions of years from the remains of dead plants and animals.

frequency The chance of finding a named species with any one throw of a quadrat.

fruit A developed ovary.

G

gametes Haploid cells capable of fusion.

ganglion (plural: ganglia) A group of cell bodies located outside the CNS.

gene A section of DNA that contains the instructions for the formation of a protein.

gene expression The way in which the genetic information in a gene is decoded in the cell and used to make a protein.

gene (or **point**) **mutation** A change in a single gene.

genetic code The sequence of bases in DNA that provide the instruction for a cell (using RNA) to form a protein.

genetic engineering The artificial manipulation or alteration of genes.

genetic screening Testing DNA for the presence or absence of a particular gene or an altered gene.

genotype The genetic make-up of an organism, i.e. the genes that are present.

genus A principal taxonomic category that ranks above species and below family, and is denoted by a capitalised Latin name.

geotropism (or **gravitropism**) The change in growth of a plant in response to gravity.

germination The regrowth of the embryo, after a period of dormancy, if the environmental conditions are suitable.

gestation The length of time spent in the uterus from fertilisation to birth.

glycolysis The conversion of glucose into two molecules of pyruvic acid.

gonad An organ that produces sex cells in animals.

growth promoter A chemical that causes increased growth in plants.

growth regulator A chemical that controls the growth of a plant.

H

habitat The place where a plant or an animal lives (and is also the local area of study).

haploid cell One that has one set of chromosomes, i.e. it has only one of each type of chromosome in the nucleus.

harvesting The collection of a product to be used or analysed.

herbaceous plants Do not contain wood (or lignin).

herbivores Animals that feed mainly on plants. Examples are sheep, cattle and rabbits.

heredity The passing on of features from parents to offspring by means of genes.

heterotrophic (organism) One that takes in food made by other organisms.

heterozygous The alleles are different.

homeostasis The ability of an organism to maintain a constant internal environment.

homologous pair Two chromosomes of similar size with the same sequence of genes.

homozygous Two alleles that are identical.

hormone A chemical messenger produced by an endocrine gland and carried by the bloodstream to another part of the body, where it has a specific effect.

hydrotropism A change in growth of a plant in response to water.

hypothesis An educated guess based on observations.

humidity Atmospheric moisture.

I

immobilised enzymes Are attached or fixed to each other, or to an inert material.

immunisation Occurs when we produce or are injected with antibodies against a pathogen.

immunity The ability to resist infection.

implantation The embedding of the fertilised egg into the lining of the uterus.

intercourse The act of sexual union (i.e. the placing of the penis in the vagina).

inbreeding The mating of closely related animals that increases the chances of the offspring being affected by undesirable recessive traits.

infertility The inability to produce offspring.

inflorescence The fixed arrangement of spikelets on the stem.

infrasound Sound waves with frequencies below the lower limit of human audibility.

inhalation Breathing in.

inherited variations Are controlled by genes.

insemination The release of semen into the vagina, just outside the cervix.

interdependence Living things depend on each other for survival.

interneuron (also called an **intermediate, relay** or **association neuron**) Carries information between sensory and motor neurons.

internode The region on a stem between two nodes.

interphase The phase in the cell cycle when the cell is not dividing.

isolation The removal of the chromosome (containing the target gene) from the human cell and the plasmid DNA from the bacterium.

J

joint Where two or more bones meet.

K

kidney stone A hard mass formed in the kidneys, typically consisting of insoluble calcium compounds.

kilocalorie A unit of energy of one thousand calories (equal to one large calorie).

L

lactation The secretion of milk by the mammary glands (breasts) of the female.

lactic acid The product formed due to anaerobic respiration in humans (causing muscles to cramp).

larynx The voice box.

law or **principle** Arises from a theory that has been shown to be valid when fully tested over a long period of time.

law of independent assortment States that: when gametes are formed either of a pair of alleles is equally likely to combine with either of another pair of alleles.

law of segregation (Mendel's first law) States that:

- Inherited characteristics are controlled by pairs of alleles.
- These alleles segregate (or separate) from each other at gamete formation, with only one member of the pair being found in each gamete.

life The possession of all the following characteristics: organised, requiring nutrition and excretion, capable of responding and reproducing.

ligaments Strong, fibrous, slightly elastic tissues that connect bone to bone.

ligation The joining of two sections of DNA to form a single strand.

lignin A strengthening material found in some plant cell walls.

linkage Genes are located on the same chromosome.

longitudinal wave A wave vibrating in the direction of propagation.

M

magnification The degree to which something is or can be magnified.

meiosis A form of nuclear division in which the four daughter nuclei contain half the chromosome number of the parent nucleus.

menopause When ovulation and menstruation stop happening in a female.

menstrual cycle A series of events that occurs every 28 days on average in the female if fertilisation has not taken place.

menstruation The discharge of the lining of the uterus (the endometrium) and the unfertilised egg.

metabolism The sum of all the chemical reactions in an organism.

micro-organisms Small living things.

millivolts One thousandth of a volt.

mitochondrion A structure in a cell in which respiration takes place.

mitosis A form of nuclear division in which one nucleus divides to form two nuclei, each containing the same number of chromosomes with identical genes.

molars Larger teeth that are used for chewing, crushing and grinding food.

monohybrid cross Involves the study of a single characteristic.

morula A solid ball of cells formed from a zygote by mitosis.

motor (or **efferent**) **neuron** Takes a message from the CNS to a muscle or a gland.

mutagens Agents that cause mutations.

mutation A spontaneous (or sudden) change in the amount or structure of DNA.

N

natural active immunity Occurs when a pathogen enters the body in the normal way (i.e. when you get an infection).

natural passive immunity Occurs when a child gets antibodies from its mother.

natural selection The process by which those organisms with genetically controlled characteristics that allow them to be well-adapted to their environments will survive and reproduce to pass on their genes to following generations.

natural vegetative propagation Involves forming new plants from a stem, root, leaf or bud.

negative tropism Occurs when the growth is away from the stimulus.

nephron Each of the functional units in the kidney, consisting of a glomerulus and its associated tubule, through which the glomerular filtrate passes before emerging as urine.

neuron (or **neurone**) A nerve cell.

nitrification The conversion of ammonia and ammonium (NH_4^+) compounds to nitrite and then to nitrate.

nitrogen fixation The conversion of nitrogen gas into ammonia (NH_3), ammonium (NH_4^+) or nitrate (NO_3^-).

node The point on a stem at which a leaf is attached.

non-renewable Sources of energy that cannot be replaced once they are used.

nutrient recycling The way in which elements (such as carbon and nitrogen) are exchanged between the living and non-living components of an ecosystem.

nutrition The way organisms obtain and use food.

O

observation When something is noticed.

omnivores Animals that feed on plants and animals. Examples are humans, badgers and hedgehogs.

open circulatory system Blood leaves blood vessels and flows around the cells of the animal's body before re-entering blood vessels again.

optimum pH The pH value at which the enzyme works best.

organ A structure composed of a number of tissues that work together to carry out one or more functions.

organisation Living things are composed of cells, tissues, organs and organ systems.

organism A living thing.

organ system A number of organs working together to carry out one or more functions.

oscilloscope A device for viewing oscillations by a display on the screen of a cathode ray tube.

osmosis The movement of water molecules across a semi-permeable membrane from a region of high water concentration to a region of low water concentration.

ovary The female reproductive organs in which eggs are produced.

ovulation The release of an egg from the ovary.

ozone depletion A reduction in the concentration of ozone in the ozone layer.

P

paralysis The loss of the ability to move (and sometimes to feel anything) in part or most of the body.

parasites Organisms that take in food from a live host and usually cause harm.

parasitism When two organisms of different species live in close association and one organism (the parasite) obtains its food from, and to the disadvantage of, the second organism (the host).

passive immunity Occurs when individuals are given antibodies that were formed by another organism.

passive transport The movement of molecules or ions across a cellular membrane without expenditure of chemical energy, as by diffusion or osmosis.

pathogen An organism that causes disease.

pathogenic bacteria Bacteria that cause disease.

pedigree A diagram showing the genetic history of a group of related individuals.

percentage cover An estimate of the amount of ground in a quadrat covered by each species.

peristalsis A wave of muscular action in the walls of the alimentary canal that moves the contents along.

penis The structure in a male used to pass sperm to a female and to excrete urine.

pesticide A chemical used to kill pests, particularly insects or rodents.

perennial Living for several years (of a plant).

pH A measure of the concentration of the hydrogen ions in a solution.

pharynx The throat.

phenotype The physical make-up, or appearance, of an organism.

phloem The vascular tissue in plants which conducts sugars and other metabolic products downwards from the leaves.

phospholipids Fat-like substances in which one of the fatty acids is replaced by a phosphate group or has a phosphate group added to it.

photolysis The splitting of water by light.

phototropism The change in growth of a plant in response to light, usually from one direction (i.e. unidirectional light).

pitch The quality of a sound governed by the rate of vibrations producing it; the degree of highness or lowness of a tone.

placenta The organ that connects the developing baby to the lining of the womb.

plasma The liquid part of blood.

plasma B cells Produce antibodies.

plumule The part of the plant embryo that develops into the shoot.

pollination The transfer of pollen from an anther to a stigma of a flower from the same species.

pollutants Harmful additions to the environment.

pollution Any harmful addition to the environment.

population All the members of the same species living in an area.

portal system A blood pathway that begins and ends in capillaries.

positive tropism Occurs when the growth is towards the stimulus.

predation The catching, killing and eating of another organism.

predator An organism that catches, kills and eats another organism.

pregnancy The length of time the baby spends developing in the uterus.

prey The organism that is eaten by a predator.

principle (or **law**) Arises from a theory that has been shown to be valid when fully tested over a long period of time.

producers Organisms that carry out photosynthesis.

product The substance(s) formed by an enzyme.

progeny Offspring that are produced.

prokaryotic cells Do not have a nucleus or membrane-enclosed organelles.

premolars Large rounded teeth used for chewing, crushing and grinding food.

prosthetic An artificial body part, such as a limb, a heart or breast implant.

protoplasm All the living parts of a cell.

puberty The beginning of sexual maturity.

pulse The alternate expansion and contraction of the arteries.

pump A mechanical device using suction or pressure to raise or move liquids.

punnett square A grid used to show the ratio of the genotypes of the progeny in a genetic cross.

purines (double-ring molecules) Adenine (A) and Guanine (G).

pyramid of numbers Represents the numbers of organisms at each trophic level (or stage) in a food chain.

pyrimidines (single-ring molecules) Thymine (T) and Cytosine (C).

Q

quadrat A frame used to estimate the number of plants in a habitat.

R

radicle The part of the plant embryo that develops into a root.

reabsorption Molecules pass from the nephron back into the blood.

recessive The allele is prevented from being expressed by a dominant allele.

recombinant Relating to or denoting an organism, cell or genetic material formed by recombination.

reflex action An automatic, involuntary, unthinking response to a stimulus.

reflex arc The pathway taken by a nerve impulse in a reflex action.

reproduction The production of new individuals.

renewable A source of energy that can be reused.

resonance The reinforcement of sound by reflection from or by the synchronous vibration of a neighbouring object.

response The activity of a cell or organism as a result of a stimulus.

respiration The process in living organisms involving the production of energy, typically with the intake of oxygen and the release of carbon dioxide.

root tuber A swollen, underground root that remains dormant during winter and from which new plants may grow.

S

scale bar A measure used to ascertain size.

scientific method A process of investigation in which problems are identified and their suggested explanations are tested by carrying out experiments.

scrotum The sac that contains the testes.

secondary sexual characteristics Those features that distinguish males from females, apart from the sex organs themselves.

secretion Some substances pass from the blood into the nephron.

selectively permeable membrane Allows some but not all molecules to pass through.

self-pollination The transfer of pollen from an anther to a stigma on the same plant.

semen A fluid containing sperm and seminal fluid.

sensory (or **afferent**) **neuron** Takes a message from a sense organ to the CNS.

serum Plasma from which the clotting proteins have been removed.

sex linkage A characteristic is controlled by a gene on a sex (or X) chromosome.

sexual reproduction The union of two sex cells or gametes.

sink A body or process which acts to absorb or remove energy or a particular component from a system.

solar energy Energy from the Sun.

source A body or process through which energy or a particular component enters a system.

speciation The production of new species as a result of evolution.

species A group of similar organisms that are capable of naturally interbreeding with each other to produce fertile offspring.

specific defence system Attacks particular (or specific) pathogens.

sperm The male sex cell or gamete.

sporulation The process of making spores.

STI A sexually transmitted disease.

stamens The male parts of the flower.

sterile All micro-organisms are destroyed, i.e. there is nothing living.

stimulus (plural: stimuli) Anything that causes a reaction in an organism or in any of its parts.

substrate The substance with which an enzyme reacts.

symbiosis Occurs when two organisms of different species live (and have to live) in close association and at least one of them benefits.

synapse A region where two neurons come into close contact.

synaptic cleft The tiny gap between the two neurons at a synapse.

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Express Publishing

ISBN 978-1-4715-7525-9